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CANADA-INDIA REACTOR

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INTRODUCTION

About the time of the First Geneva Conference in 1955, India was considering the construction of a high flux research reactor with facilities for materials testing and engineering loop experiments. Different reactor types were being considered for this purpose, when Canada generously offered assistance under the Colombo Plan in the design and construction of a reactor of the NRX type. A team of Indian scientists visited Chalk River after the Geneva Conference to finalize the technical details, and construction work started at the site in December of that year. It is expected that the reactor will go into operation by the end of 1959.

The Canada-India Reactor is located at the Atomic Energy Establishment at Trombay, the Government of India's centre for research in atomic energy. This reactor provides a high thermal neutron flux for experiments in physics and chemistry and will also enable large quantities of radioisotopes to be produced for use in industry, agriculture and medicine. It will also be suitable for conducting engineering test experiments for studies of different types of fuel elements and reactor components for diverse reactor systems. The reactor and other associated research facilities will also be available to scientists from other countries of South and Southeast India.

The Canada-India Reactor is the first major atomic energy project to be undertaken in the field of international assistance. This project is a joint India-Canada enterprise, in which the costs are being shared in approximately equal proportions by the two countries. Under the agreement, Canada is responsible for the design and construction of the reactor, while India has assumed responsibility for the execution of certain civil works and all the necessary auxiliary services and facilities. India is also supplying the fuel elements, which will be fabricated at Trombay from locally produced uranium metal. The heavy water required for this reactor has been purchased from the United States Atomic Energy Commission under a bilateral agreement.

This presentation is also a co-operative work in which Canada has outlined some of the interesting CIR design features, while India has presented information on some of the construction aspects of the work as it is proceeding.

The Canada-India Reactor design is basically similar to that of NRX but has been modified to provide improved experimental facilities, particularly for engineering loop experiments. The reactor building and certain reactor auxiliaries such as the cooling, ventilation and air-conditioning systems were designed to suit local conditions.

Consequently, a brief outline of the NRX is presented prior to the description of the CIR. It is not intended that this should be a detailed description, since it has been already given by Hurst and Ward(1). Attention is drawn, however, to recent modifications to the NRX and, in particular, to the various experimental facilities which have proved useful.

THE NRX REACTOR

GENERAL

When it is recalled that the NRX reactor was designed in 1944-45, and put into operation in July 1947, it becomes apparent that great foresight was used by the physicists and engineers responsible for the program. The fact that NRX has proved to be such an increasingly useful research tool is indicative of the adaptability provided for in the original design. NRX has not only provided excellent facilities for Canadian research and development, but also has been used to the limit of its capacity by joint programs between Canada and countries such as Great Britain and the United States.

As originally planned the NRX reactor was intended to be used for several purposes:

(a) High thermal neutron fluxes for research experiments in physics and chemistry. These facilities included beam ports for experiments external to the outer shielding of the reactor.

(b) The production of radioisotopes for use in research, agriculture and industry.

(c) The production of plutonium in the spent uranium fuel. A solvent extraction plant was constructed and operated for the purpose of recovering this by-product.

(d) The providing of operational experience which would permit eventual design of larger reactors.

This program was continued until about 1950 at which time a rapidly growing interest developed in the application of natural uranium, heavy water moderated reactors for the production of electrical power. Since the NRX reactor provided high neutron fluxes over large volumes it was adapted to provide facilities for "loop" experiments, or large scale engineering studies. These studies involved the operation of closed "loops" in the reactor under conditions of temperature, pressure and flow which approximate those expected in a power reactor. It is then possible to study such design aspects as fuel geometry, radiation stability and heat transfer. Other important items as sheathing, integrity, corrosion effects and coolant properties can also be observed.

Since about 1950 this part of the program has been the most important one at Chalk River, and the NRX reactor has proved very well suited for such studies. For some time now the reactor core has been physically "saturated" with loop experiments. Since high flux positions are essential to these tests, to produce the designed heat ratings, it is necessary to substitute the experimental pressure systems for normal fuel rods. With six such "loops" in the NRX core it has been found that the external piping and equipment in the upper and lower header or service rooms becomes limiting. To achieve a reasonable operational efficiency the number of loops in NRX has therefore been limited to six.

2. FEATURES OF THE NRX REACTOR

2.1 Building

When the NRX reactor was designed it was felt that containment was not required, so a pressure shell was not used. This decision was partly due to the remoteness of the site, hence the large distances to centres of population. A similar philosophy applies today, and in fact the experiences of a major accident in December, 1952, confirmed this opinion.

NRX is housed in a conventional steel structure with brick walls. The reactor is centrally located in a hall 100 feet by 144 feet (30 meters by 44 meters), with a height from main floor to the crane bridge of 85 feet (26 meters). A large portion of three walls is used for window space. The fourth wall separates the main reactor hall from an annex which contains the control room as well as office and laboratory space.

A bridge connects the top of the reactor to the top of a concrete storage block. A 30 ton (27,000 kg) flask mounted on rails is used to move irradiated fuel elements and experimental assemblies to the storage block. From this point full length fuel rods can be lowered into a trench containing 12 feet (3.7 meters) of water and leading to an adjacent building containing facilities for storage, cutting, inspection and other remote work.

A partial basement was provided beneath the main operating floor of NRX. This basement leads to the header room below the reactor and contains one or two other rooms which are used for various instrumentation. The full basement provided in CIR offers many advantages not possessed by NRX.

The crane which services the main reactor hall has two lifting hooks. One has a 25 ton (23, 000 kg) capacity and the other, which has a much faster lift, has a 3 ton (2700 kg) capacity.

2.2 Reactor Structure

Figure 1 is a simplified vertical section through the reactor. Figure 2 is a plan of view, similarly simplified.

It is interesting to note that originally NRX was designed to operate at a maximum output of 20 MW. This was increased to 30 MW by the addition of further cooling capacity for the heavy water. During the rebuilding following the 1952 accident, two important changes were made. Firstly, a 2 inch thick water-cooled stainless steel shield was installed between the bottom of the heavy water vessel (calandria) and the top of the steel thermal shield directly below. This made operation at 40 MW possible. Secondly, the water-filled steel shield directly above the heavy water vessel was replaced with an aluminum shield of similar dimensions. This provided for easier replacement of subsequent calandrias.

2.3 Fuel Rods

Although there are 199 lattice positions in the NRX heavy water vessel, a large number of these are filled with other than normal fuel rods. Table 1 shows an approximate distribution for these positions. Descriptions of the special assemblies are given in a following section.

The present NRX fuel rod design is indicated in Figures 3 and 4. Several modifications have been made over the years to improve the performance of these elements. The overall dimensions of the finished uranium fuel element have remained unchanged but the treatments received during fabrication have varied. As a result, some fuel is now being irradiated to nearly 6000 MWD/tonne. This represents an average irradiation of 3800 MWD/tonne for the 10 feet (3.05 meters) long fuel element.

TABLE I.

	No. of Positions occupied
Normal Natural Uranium Fuel Rods	143
Enriched Alloy Rods to compensate for Experimental Load	22
Tray Rods - Isotope Production	12
Shut-off Safety Rods	6
Loop Experiments	6
Fast Neutron Transformer Rods	4
Adjuster Rods - Isotope Production	4
Control Rod	1
Pneumatic Carrier Rod	1
TOTAL	199

To conserve reactivity it has been possible to reduce the thickness of the aluminum cladding on the fuel from 0.080 inches (0.20 cm) to 0.040 (0.10 cm) and also to reduce the thickness of the cooling water annulus from 0.100 inches (0.25 cm) to 0.070 inches (0.18 cm). As a result of numerous modifications to various NRX components, the present limitations on NRX power outputs now rest with the fuel rods themselves. The temperature distribution across the fuel section is not known precisely, but calculation indicates that the alpha-beta transition temperature is not reached, even for a rod producing the maximum allowable output of 400 kW. Although Haddow (2) has calculated that the thermal expansion in the central region of the rod raises the stress in the surrounding metal beyond the elastic limit, there has been no evidence to date of such a condition presenting serious operational problems. However, the rod failures or sheath ruptures that do occur are generally in the central portion of the calandria in high flux regions.

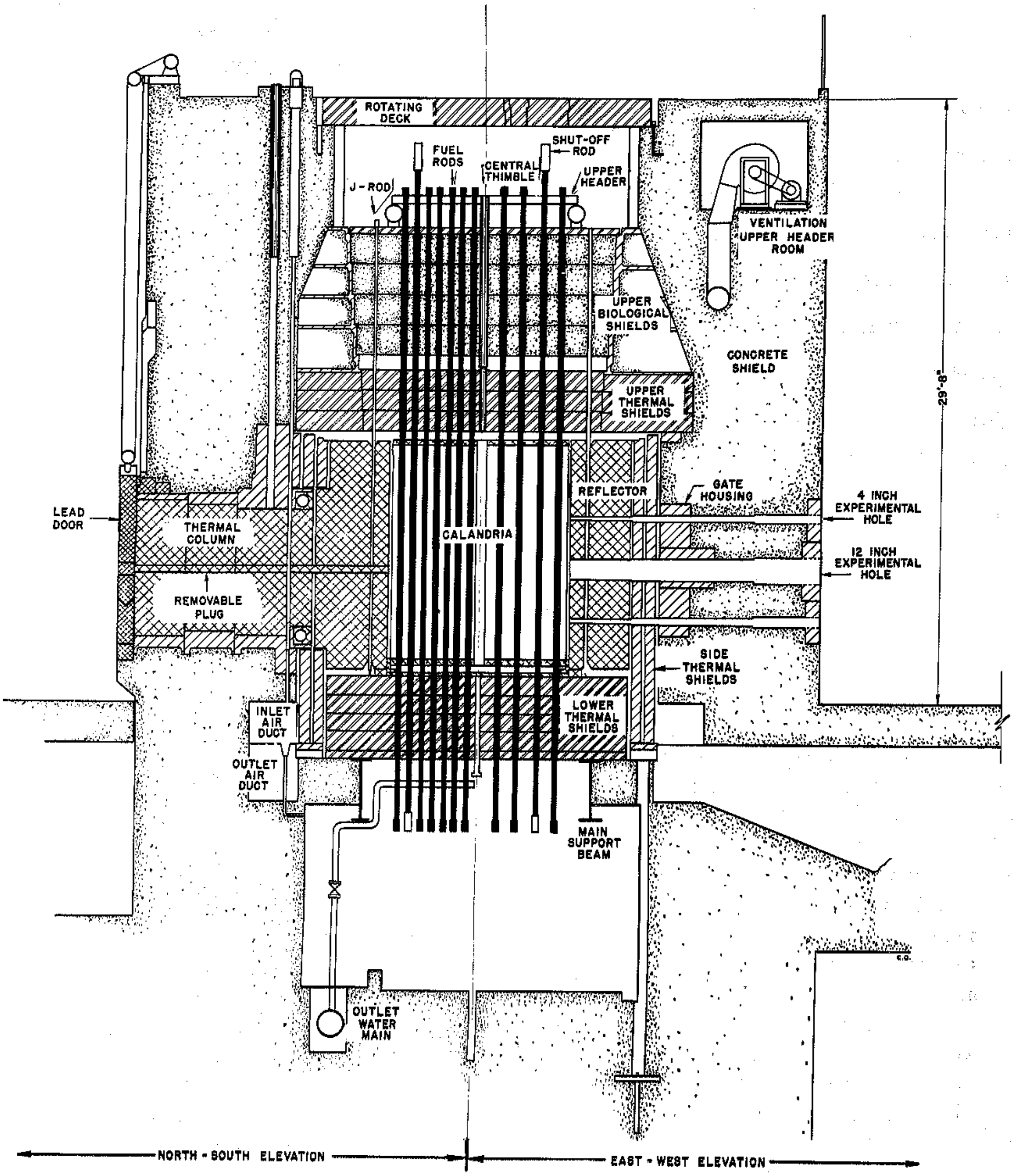


Figure 1.

Schematic vertical section of the NRX reactor. The actual locations of 4-inch and 12-inch holes and thermal columns are shown in Fig. 2.

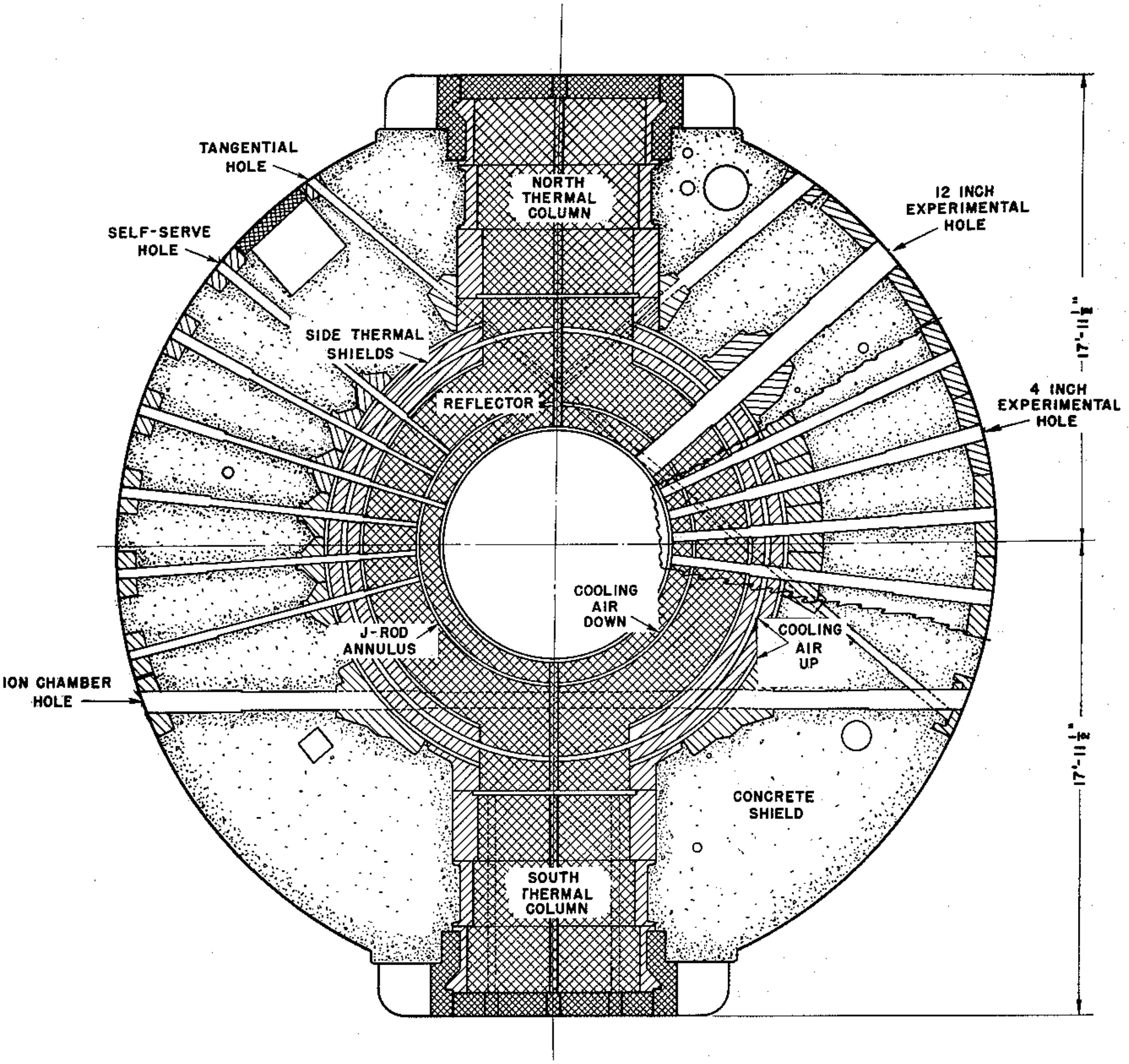


Figure 2.

Schematic horizontal cross section of the NRX reactor.

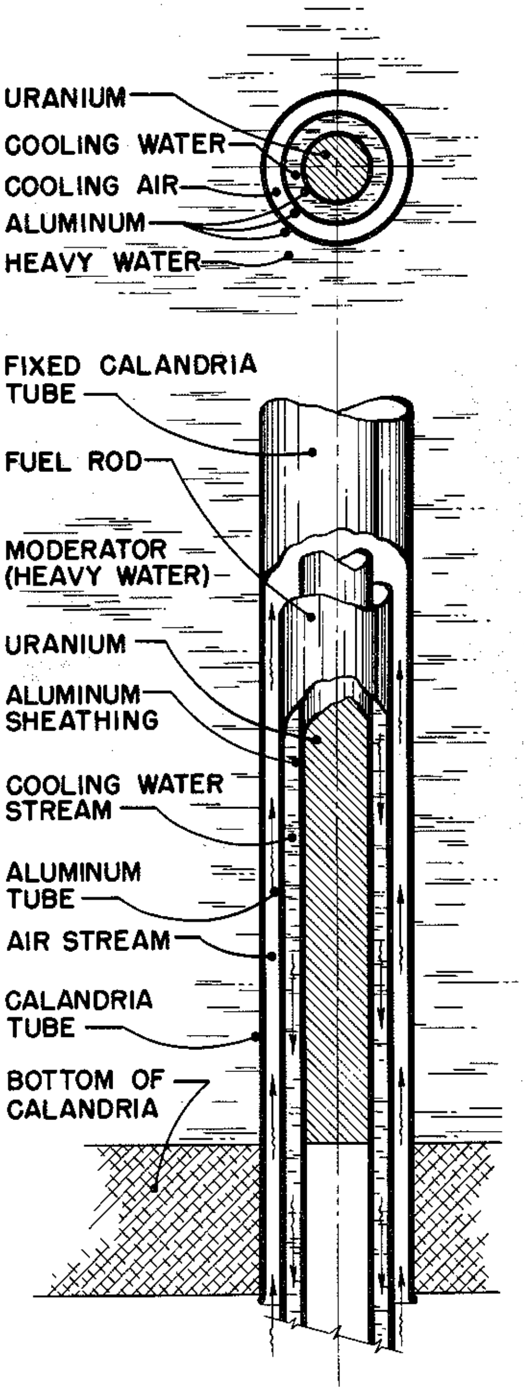


Figure 3.

Schematic vertical section of NRX fuel rod in calandria tube.

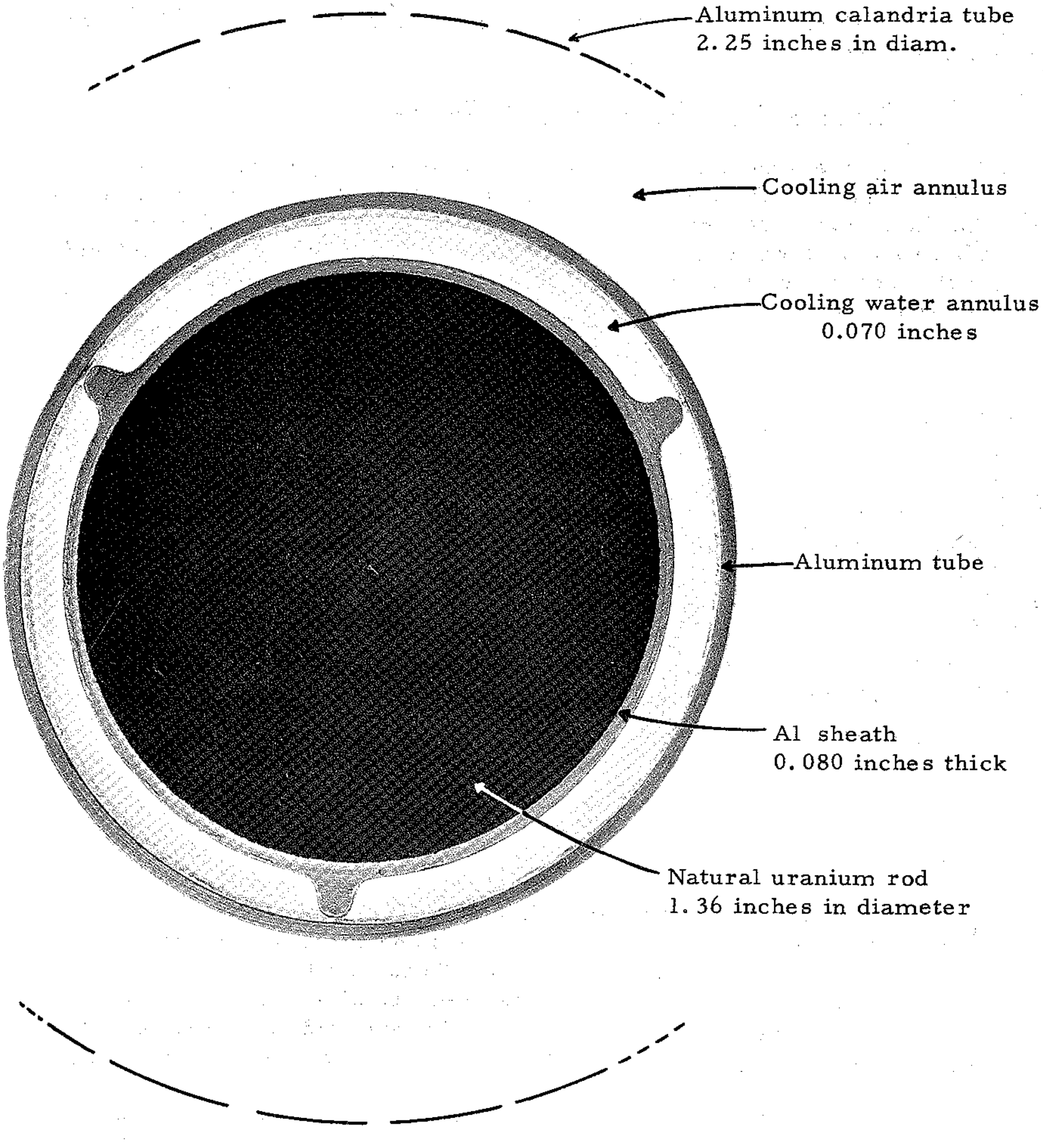


Figure 4.

Horizontal cross section of NRX fuel element.

3. EXPERIMENTAL FACILITIES OF THE NRX REACTOR

In general these facilities can be grouped into two classifications as indicated:

3.1 Facilities Involving the Reactor Vessel

Where high neutron fluxes are required, it is necessary to use the central thimble or a fuel rod position. Table 2 indicates some of the fluxes for 40 MW operation. These flux values are actually nv where n = neutron density in n/cm^3 and $v = 2.2 \times 10^5$ cm/sec (2200 m/sec). The basis for these values is discussed by Hone, Hurst and Westcott (3).

TABLE 2.

FLUX, (nv 2200) FOR 40 MW OPERATION

Location	Remarks	Maximum Flux (neutrons/cm^2/sec.)
Empty Calandria Tube	Based on 98 barns for gold	6.8×10^{13}
Average across uranium rod at position of maximum flux	Based on f(U) = 4.18 barns and 198 MeV per fission	2.7×10^{13}
Moderator	Maximum in normal lattice cell	5.6×10^{13}

3.1.1 Loops

To provide the data required for the design of power reactor fuels it is necessary to irradiate test fuels under conditions approximating those expected for the reactors. These conditions can be approached by replacing a normal fuel element with a closed circuit in which the desired coolant can be kept at the required temperature and pressure. In NRX six loop circuits have been operating for some time.

Due to the radioactivity of the coolant it is necessary to provide shielded room space adjacent to the reactor core for the fixed equipment such as circulating pumps, surge tanks, heaters and coolers. When NRX was designed and built no provision was made for loop tests. It has, therefore, been necessary to use whatever shielded space was available. To this end the helium gasholder was relocated from a room beneath the main floor near the base of the reactor, and a large concrete "tank" was built on supporting columns, so that the room inside the rectangular tank would be close to the header room at the top of the reactor. In the case of CIR the full basement provides for more suitably located shielded rooms for loop installations.

In most cases the experimental fuels placed in the "in-pile" loop sections do contain enrichment so as to obtain the required heat fluxes. Such enrichment is not sufficient, however, to compensate for the reactivity loss resulting from the absence of the normal fuel as well as from the presence of a heavy walled pressure vessel. These and other "loads" are, therefore, balanced by the installation of enriched fuel rods containing U-235 or Pu-239 alloyed with aluminum. NRX normally contains 20 to 24 of these alloy rods carefully located so as to level out the flux distribution across the reactor core.

3.1.2 Tray rods

Twelve such rods are normal in the NRX loading. The rods are essentially aluminum tubes 10 feet (3.05 meters) long with attached shielding end-pieces. Cylindrical aluminum capsules containing isotope target materials are loaded into the tube and held in position by spring clips. Approximately 30 capsules can be accommodated over the length of one tube. The tray rods are air cooled and are removed from the reactor with the 30-ton (27,200 kg) fuel flask. Facilities are built into the flask for clamping and indexing the tray rod so that individual capsules can be replaced. To date cobalt-60 has been one of the more important isotopes produced in the tray rods. As in the case of loop experiments, reactivity compensation is provided by the aluminum alloy rods.

3.1.3 Pneumatic carrier rods

One rod is located in the core and one in the J-rod annulus. These units provide for the rapid insertion and removal of short-lived material. Small capsules containing the target material can be transferred pneumatically from the nearby chemistry building directly into the reactor position, and similarly returned for counting at the end of the irradiation.

3.1.4 Neutron convertors

Four units are normally located in the NRX core, and are water cooled similarly to normal fuel rods. The section inside the heavy water vessel contains a tubular uranium element, sheathed inside and out with aluminum and cooled with water. The interior of this tube provides a space where the fast neutron flux has been increased and into which samples can be inserted without moving the semi-permanent converter assembly. Similar converters are also used in the J-rod annulus and in the horizontal experimental holes, although the fluxes are necessarily lower in these positions.

3.1.5 Adjuster rods

Four units are used in the NRX core. They are basically tray rods loaded with cobalt for the production of cobalt-60. However, these four rods are fitted with head-gears containing a drum and cable attachment to the top of the tray rod section. The motor drives which raise and lower these rods are operated from the control room console.

The adjuster rods are withdrawn as required after a shutdown to provide extra reactivity to compensate for xenon growth. A shutdown period of seventy-five minutes is allowable under these conditions. Following a long shutdown, insertion of the adjuster rods increases the required depth of heavy water for 40 MW operation. This increases the maximum heat flux since the full length of the fuel element is contributing. With lower heavy water levels it is necessary to reduce the power output so that the maximum allowable heat rating per unit length of fuel rod is not exceeded.

3.2 Facilities Outside the Reactor Core

3.2.1 J-Rod annulus

In the original NRX design provision was made for a 2.5 inch (6.35 cm) annular ring in the graphite reflector. Ninety holes were provided through the upper shielding to permit thorium rods (J-rods) to be suspended in the annular space for the production of uranium-233. In the reactor design provision was made for a flow of air up the annular space between the side thermal shields and the graphite reflector, and down the J-rod annulus. This permitted a maximum output per rod of approximately 1 kW without exceeding reasonable temperatures in the thorium.

At the present time the principle material loaded into this space is cobalt although a wide variety of irradiations have been made. The space is useful for bulk irradiations requiring lower fluxes. The maximum flux in the J-rod annulus is $1.0 \times 10^{12} n/cm^2/sec$ at 40 MW operation.

3.2.2 "Self-serve" holes

Eighteen such units were originally provided on the west side of the reactor. Aluminum capsules, similar to those used for tray rod irradiation, are fitted into aluminum balls which are rolled through the concrete biological shield, dropping into "saddles" in an aluminum tube at the inner end of a plug which can be manually driven inward toward the sidewall of the heavy water vessel. On removal the plug is withdrawn and inverted, the ball dropping from the saddle and rolling into a lead flask attached to the face of the reactor. Of the eighteen units, three extend to the calandria wall and have positions for five aluminum balls. The remainder extend only to the J-rod annulus and have positions for three balls. The maximum flux in the "inner-most" saddle position is somewhat greater than in the J-rod annulus being approximately 1.7×10^{13} n/cm^2/sec.

The facility is useful in that installations and removals may be carried on without affecting reactor operation in any way. To provide additional space for experimental equipment three of the self-serve positions were recently eliminated in NRX.

3.2.3 Experimental holes

These holes extend to the east side of the reactor and are of two diameters. Three 12-inch holes are located at mid-calandria level, with six 4-inch holes on a level 2.5 feet above, and six more 4-inch holes on a level 2.5 feet below.

NRX experience has proved that the experimental equipment used in conjunction with these holes for various physics studies is bulky and hence only a limited number of the holes can be used. Other adjacent holes are blocked by the various neutron spectrometers, beam catchers and similar equipment.

3.2.4 Thermal columns

Two thermal columns were provided in NRX, each consisting of a graphite assembly, approximately 6 feet (1.8 meters) square extending from the reflector to the outside of the biological shielding, where it is closed by a lead filled door 9 inches (23 cm) thick. The outer part of the column consists of three sections, each of which can be moved as a unit, being built up from graphite blocks about 6 inches (15 cm) square and 2.5 feet (0.76 meters) long. Various sizes of holes may be made in the column by removing these blocks, either individually or in groups.

The ionization chambers for reactor control are located in one thermal column, the other being available for experimental purposes. The thermal neutron flux in the thermal column is little affected by small variations in heavy water level or by experimental assemblies in the calandria. This location is, therefore, suitable for control ionization chambers.

4. CONTROL AND INSTRUMENTATION

A number of alterations have been made to the NRX control system since it was first operated in 1947. At the time of writing a reactor shutdown is planned for the month of March, 1958, during which time further modifications will be made. When the new system is completed, it will be normal practice to control reactor power by adjustment of the heavy water level.

A duplicate system will be installed in CIR and a detailed desription is given under the CIR section of this report. It is expected that the NRX system will have operated for over a year before the CIR operation begins.

5. HEAVY WATER - HELIUM SYSTEM

The calandria is constructed of aluminum and the remainder of the piping and equipment is either stainless steel or aluminum. The system contains approximately 38,000 lbs of heavy water. During reactor operation the heavy water is circulated from the calandria through heat exchangers at a rate of 230 Igpm to remove about 5% of the total heat produced. A small stream of heavy water is circulated continuously through mixed-bed ion exchange resins to maintain a pH of about 5.0 and a conductivity of about 1×10^{-6} mho cm^{-1}. Conventional centrifugal pumps with mechanical seals are used for circulation. Valves are either diaphragm type or globe type with bellows seals on the spindles.

The helium atmosphere above the heavy water is maintained at a pressure of 12 inches (30 cm) of water. The gas is circulated periodically through a carbon sorber to remove impurities such as nitrogen, and continously over a catalyst to recombine the decomposition products, deuterium and oxygen.

6. PRIMARY COOLING SYSTEM

6.1 Liquid cooling system

Water from the Ottawa River is pumped through sand filters to the top of the reactor where it enters the fuel rod channels at a pressure of about 165 psi (11.5 atm). The average temperature differential across the reactor is 40°C for a flow of 3000 Igpm, (680 cu meters/hr). The effluent flows through a tank system which delays the water for one and one-half hours before it is returned to the river. This permits the decay of the short-lived, induced activities.

At the present time a system of individual rod monitors is being installed, using the gaseous fission products as indication of cladding failure. A similar system will be used in CIR.

Separate closed circuits are provided for the cooling of the water-filled thermal shields in order that corrosion control can be maintained.

6.2 Air cooling and ventilation

The graphite reflector and thermal columns are air cooled. Dehumidified, temperature-controlled air is supplied to the main reactor hall from where it is drawn through the reactor by the exhaust fans. The interior of the reactor is thus maintained at a negative pressure with respect to the main hall. Approximately 76,000 lbs/hr of air are exhausted through roughing filters and through absolute paper filters before being discharged from a stack located one half a mile from the reactor. The top of the stack is 370 feet above the main floor of the reactor building.

7. INDIAN TRAINING IN CANADA

An important phase of the joint program has been the training of a group of Indian engineers, physicists and chemists at the Chalk River establishment.

Approximately thirty Indians were involved, the main group arriving in Chalk River in September 1956, and departing in November 1957. During this period an intensive training program was scheduled to familiarize these people with the details of NRX operation. Approximately twenty men trained on the operational aspects and to this end spent a large part of the time working on a shift basis with the senior supervisors in charge of NRX operation. Five engineers worked directly with the Maintenance groups to become familiar with the problem of electrical, electronic and mechanical maintenance. Two reactor physicists, in addition to receiving some shift operating experience, spent much of their time working in the office of the NRX reactor physicist. Two chemists were trained in the Control Laboratories on the techniques used for such work as heavy water analysis.

During this training period the Indian engineers became familiar with CIR design as drawings were issued. From these drawings a good start was made on a series of design and operating manuals which will be completed in India. Lecture series were given to the group by various members of the Chalk River staff, as sponsored by the Operations group.

During their stay in Canada the Indian trainees were supported financially by the Colombo Plan. They lived in Pembroke and Deep River and quickly became integrated with their Canadian associates both on and off the job. It is felt that this training program was a most successful one and will greatly assist the operating efficiency of the CIR program.

REFERENCES

(1) Hurst, D.G. and Ward, A.G. (1956) Canadian Research Reactors Progress in Nuclear Energy, Series II, Volume I, Pergamon Press, pp. 1 to 48.

(2) Haddow, J.B. (1955) A.E.C.L. Report No. ED-28.

(3) Hone, D.W., Hurst, D.G. and Westcott, C.H. (1955) A.E.C.L. Report No. NDC-2.

THE CANADA-INDIA REACTOR

1. INTRODUCTION

The Canada-India Reactor design is based on the NRX. The latest modifications, both proposed and installed in the NRX, have been incorporated in this reactor. A number of minor changes have also been made in the reactor to improve and extend the research facilities.

Although the reactor aspects are similar in both cases, there are major differences in the housing, cooling system and service facilities due to site conditions. The reactor is located close to the metropolitan area of Bombay city and is only a few hundred feet from the sea. In view of its proximity to an urban area, the reactor is housed in a steel pressure shell and use has been made of sea water as a secondary coolant.

2. REACTOR BUILDING

The reactor building (Figure 5) is a hemispherical cylindrical structure 120 feet in diameter and 134 feet high with a basement and sub-basement and is referred to as the rotunda. This is surrounded by a one storey building with a single basement, called the annulus.

The design concept of the building is based on the United Kingdom DIDO and PLUTO reactors. This concept was followed because the Canada-India Reactor site is situated adjacent to a heavily populated area. It provides complete containment of radioactive materials if an excursion occurs.

The design pressure is 5 psi but working stresses have been selected to withstand a pressure rise of 30 psi without producing serious deformation of the structure. The shell and dome are fabricated from welded steel plate, 7/8" and 1/2" respectively.

The rotunda houses the reactor and the storage block (Figure 6). Eight shielded rooms (Figure 7) for housing experimental equipment are located in the main basement.

The rotunda is serviced by a revolving crane having a 30 ton main hoist and a 5 ton auxiliary hoist. The crane design has a free turning bridge without the usual king post.

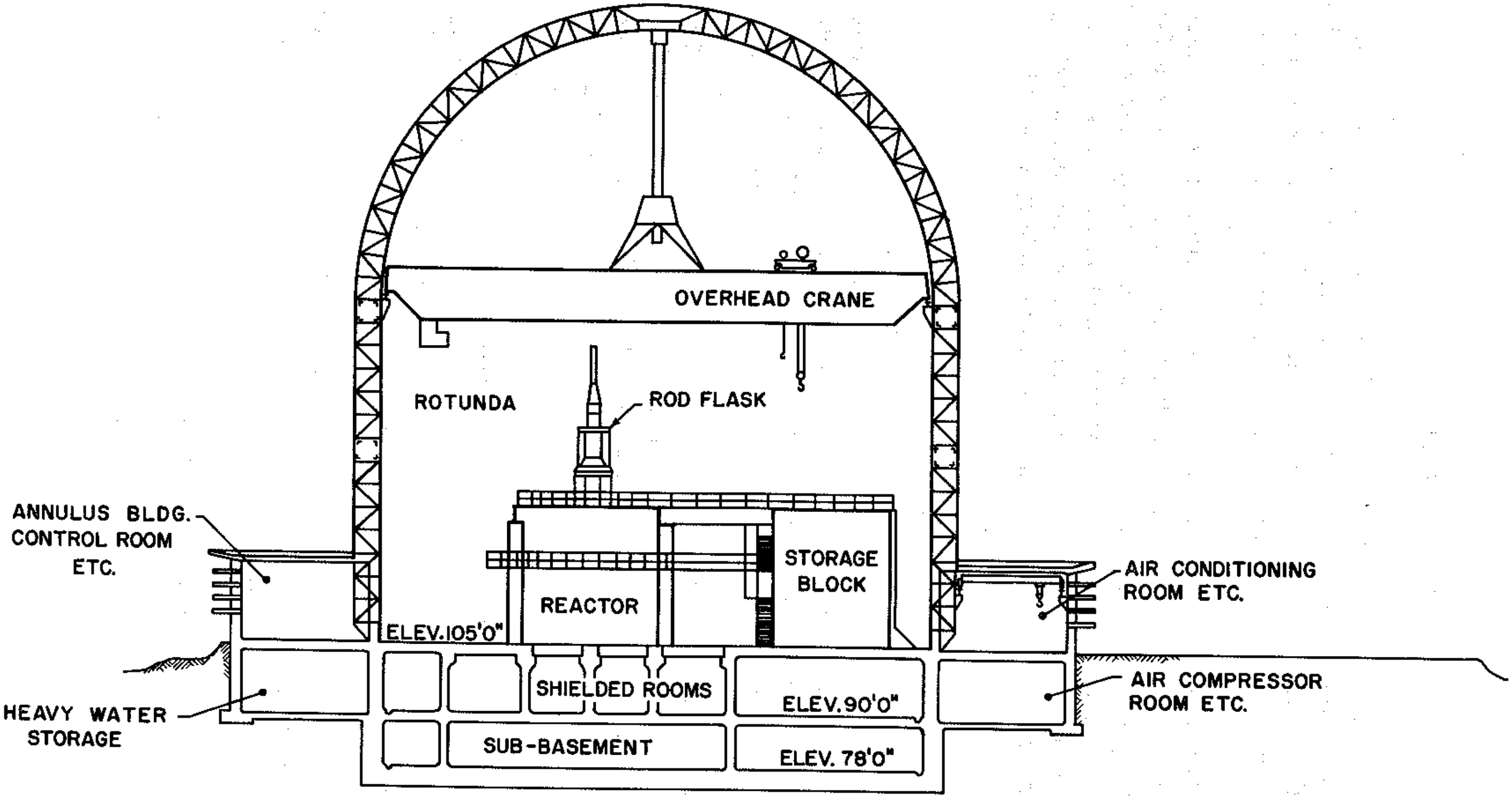


Figure 5.

CIR Reactor

Access to the rotunda is through air locks in the personnel and vehicle entrances.

The annulus structure is built of reinforced concrete. It houses the reactor control room, personnel offices and auxiliary process equipment.

3. REACTOR STRUCTURE AND EXPERIMENTAL FACILITIES

The basic reactor structure (Figure 8) for the CIR is the same as the NRX. Additional experimental facilities have been added and minor alterations have been made based on NRX experience.

Thus six fuel rod positions have been enlarged to permit experimental assemblies up to four inches in diameter to be irradiated in the reactor core. The six inch central thimble has been provided with a passage through the lower shields to permit irradiation of full length assemblies. The thorium fuel positions have been extended to the lower header room. This will allow water-cooled thorium metal rods to be irradiated.

Further, nine of the self-serve positions have been replaced with eight four inch and two twelve inch horizontal holes (Figure 9). Removable biological shielding has been provided on two of these positions.

4. STORAGE BLOCK FACILITIES

The storage block is located in the rotunda (Figure 10). Full length, irradiated fuel rods and experimental assemblies are stored in this block in a vertical position. Provision is also made to allow an NRX type canal system to be added at a later date.

The fuel rods and experimental assemblies are transferred from the reactor to the storage block in a single vertical travelling flask. This flask is designed to combine the features of the two flasks required for this operation in the NRX.

5. HEAVY WATER - HELIUM SYSTEM

The heavy water and helium systems (Figure 11) in the CIR are a replica of the new NRX installation. The basic circuit contains a storage tank, heat exchanger and pump in series with the calandria.

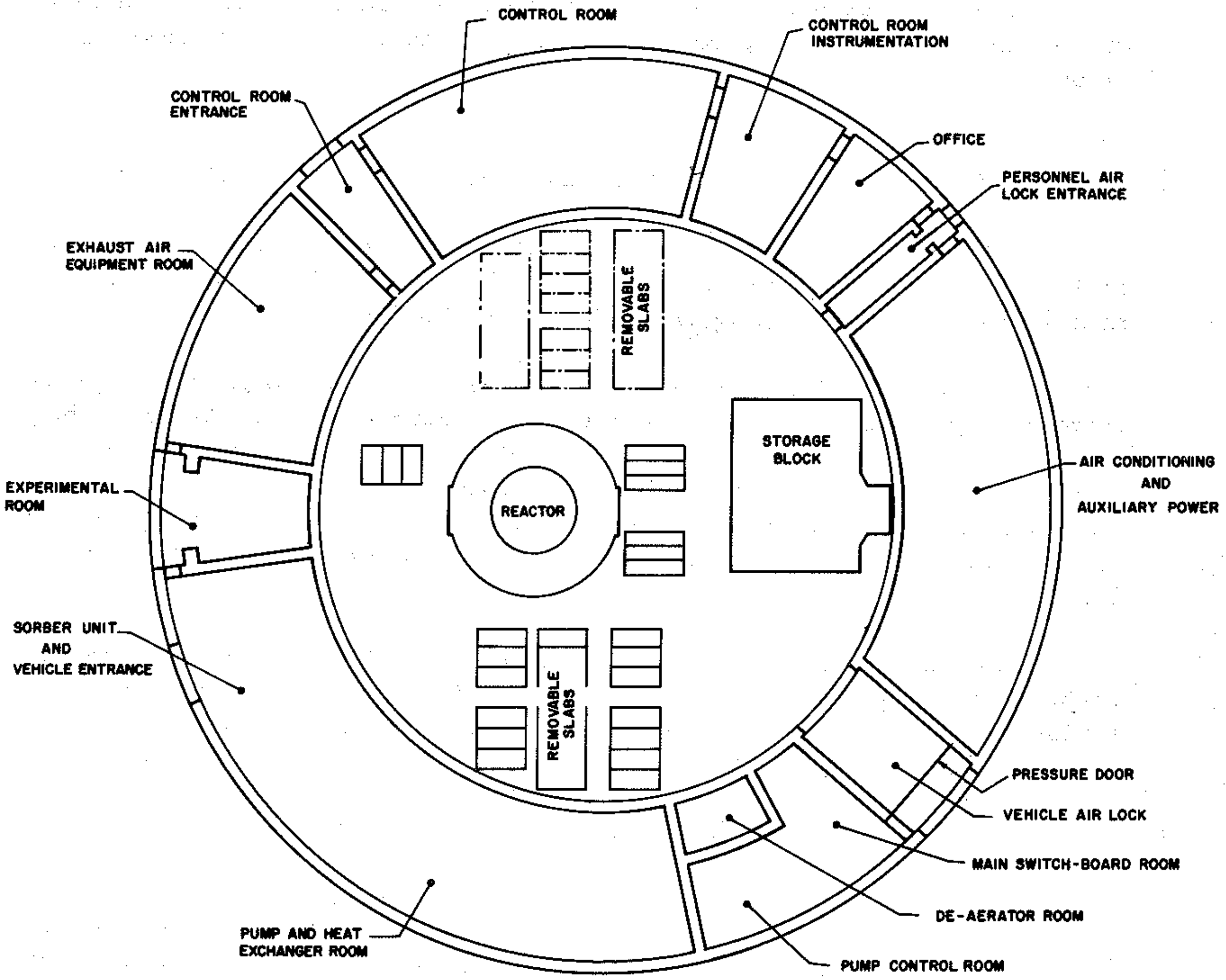
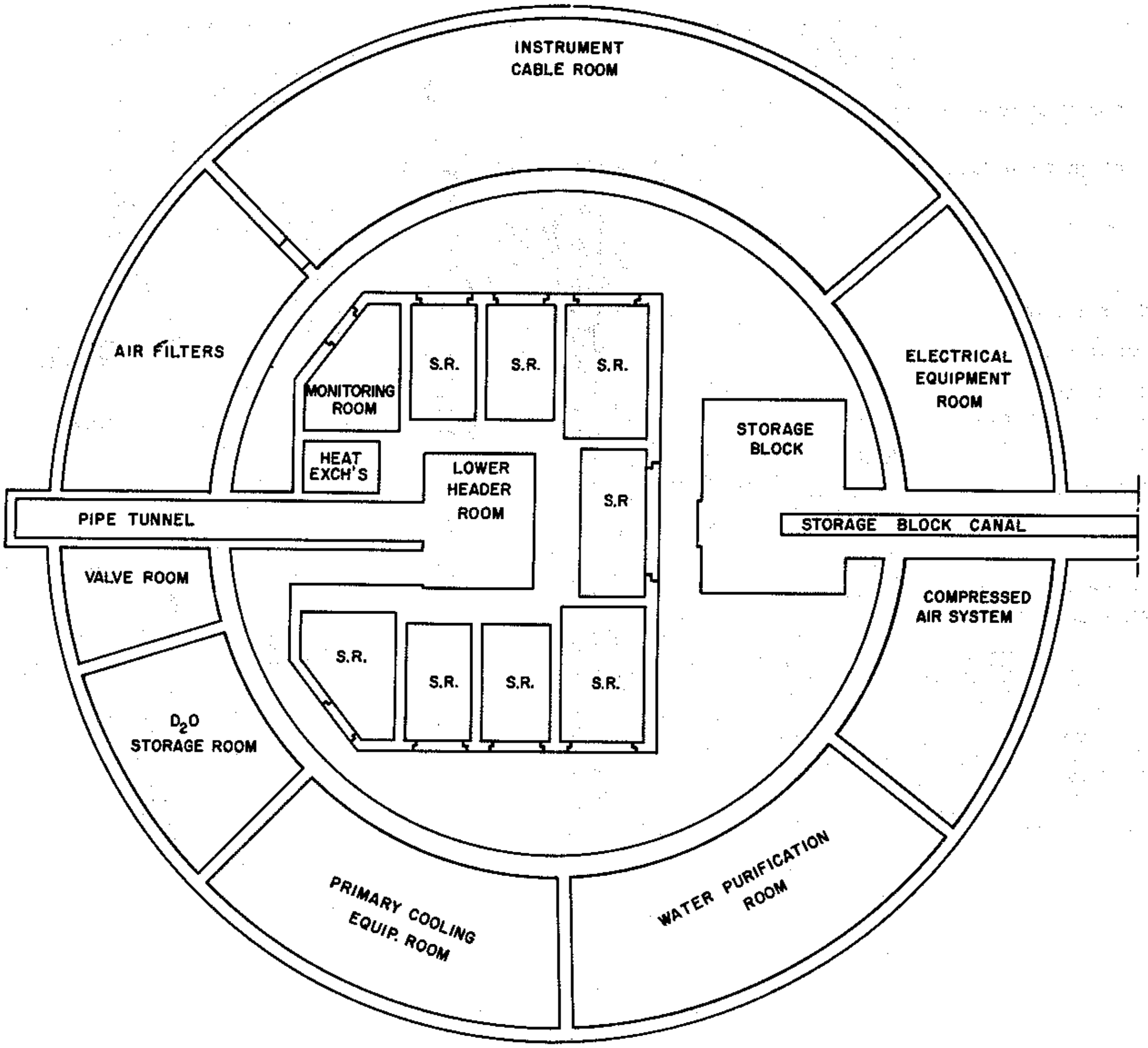


Figure 6.

Layout of ground floor - elev. 105'0"
(Scale 1/16" : 1'0")



LEGEND

S.R. = SHIELDED ROOM

Figure 7.

Layout of basement - elev. 90' 0"
(Scale 1/16" : 1' 0")

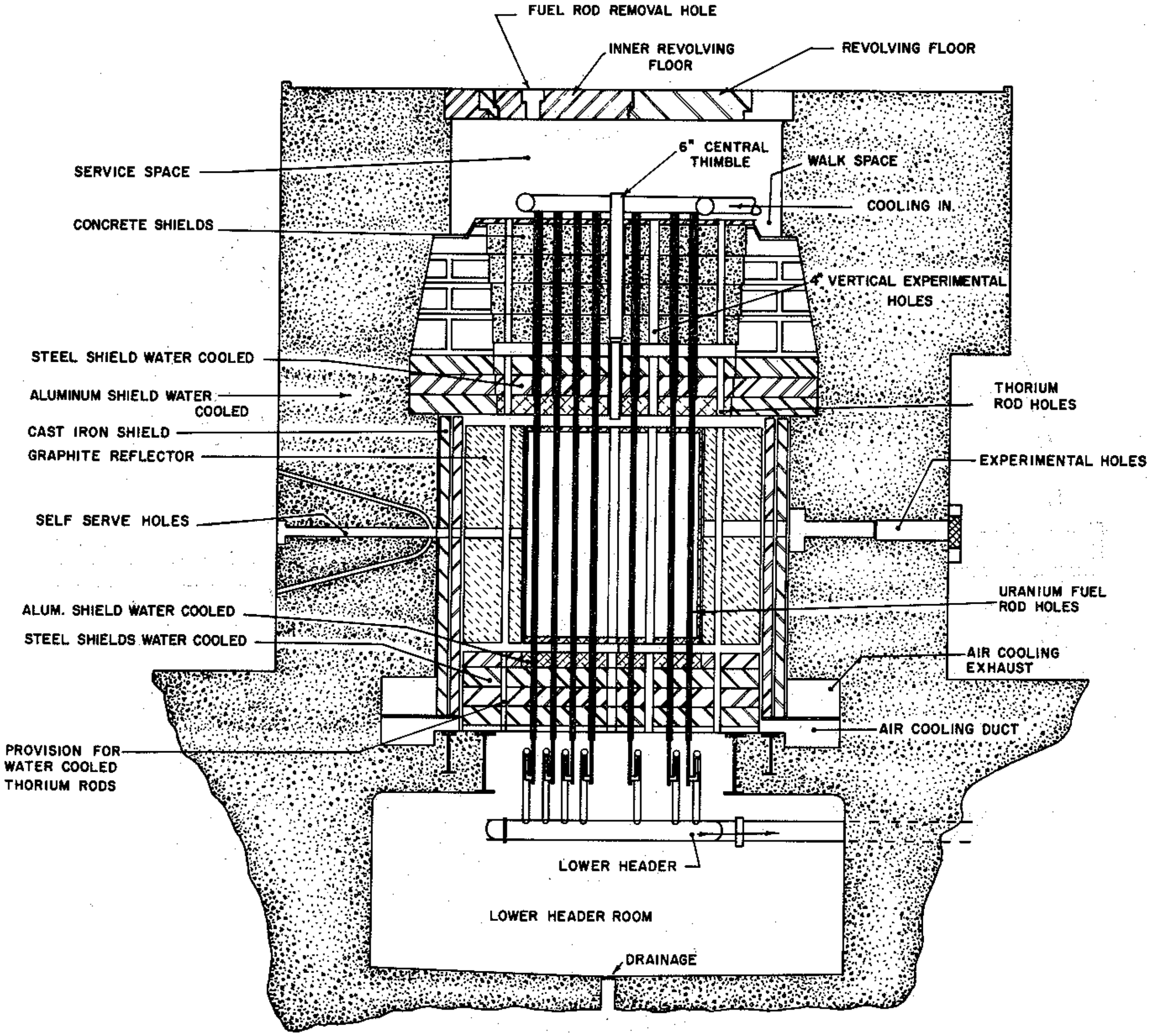


Figure 8.

Vertical section CIR reactor

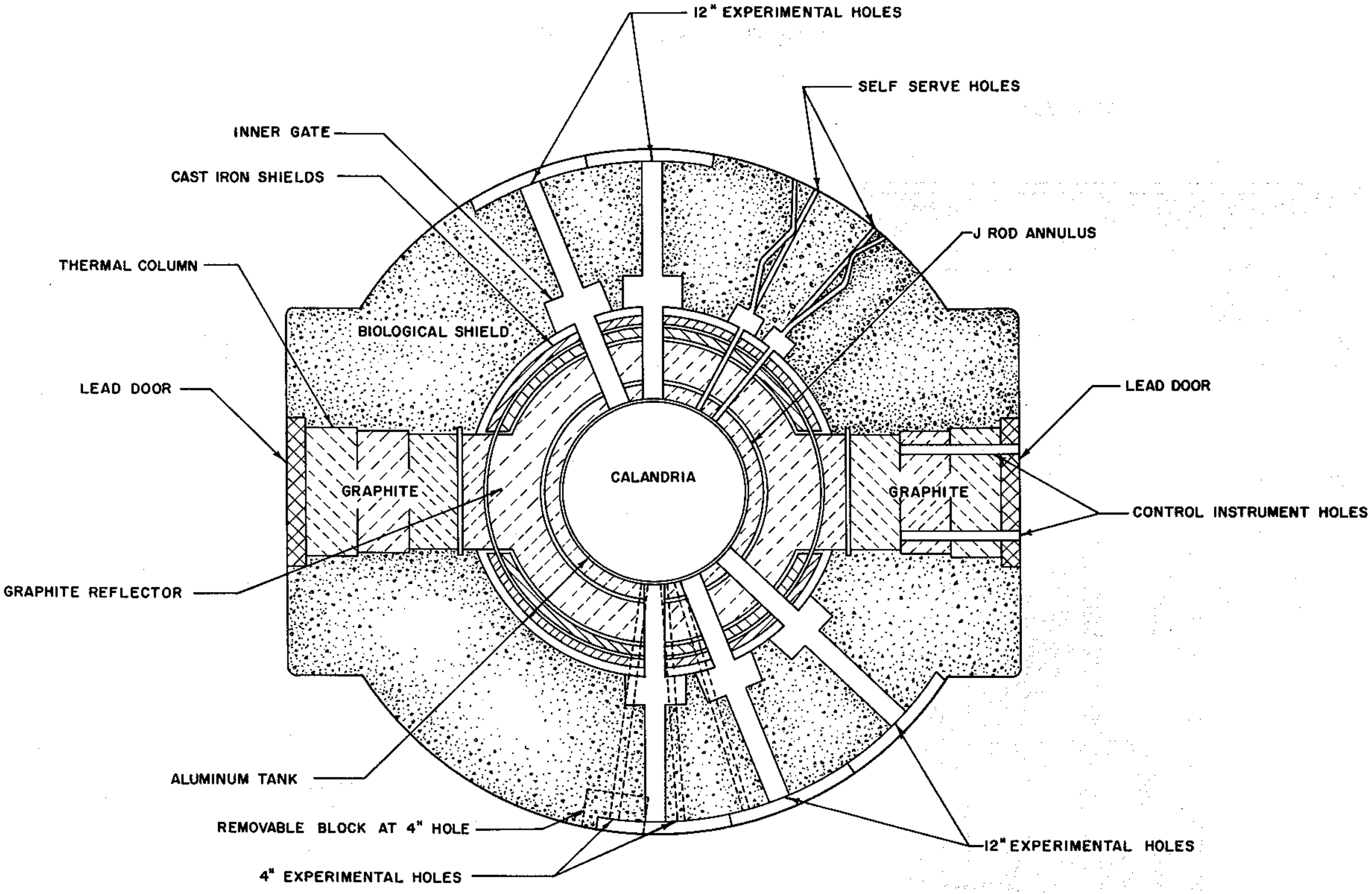
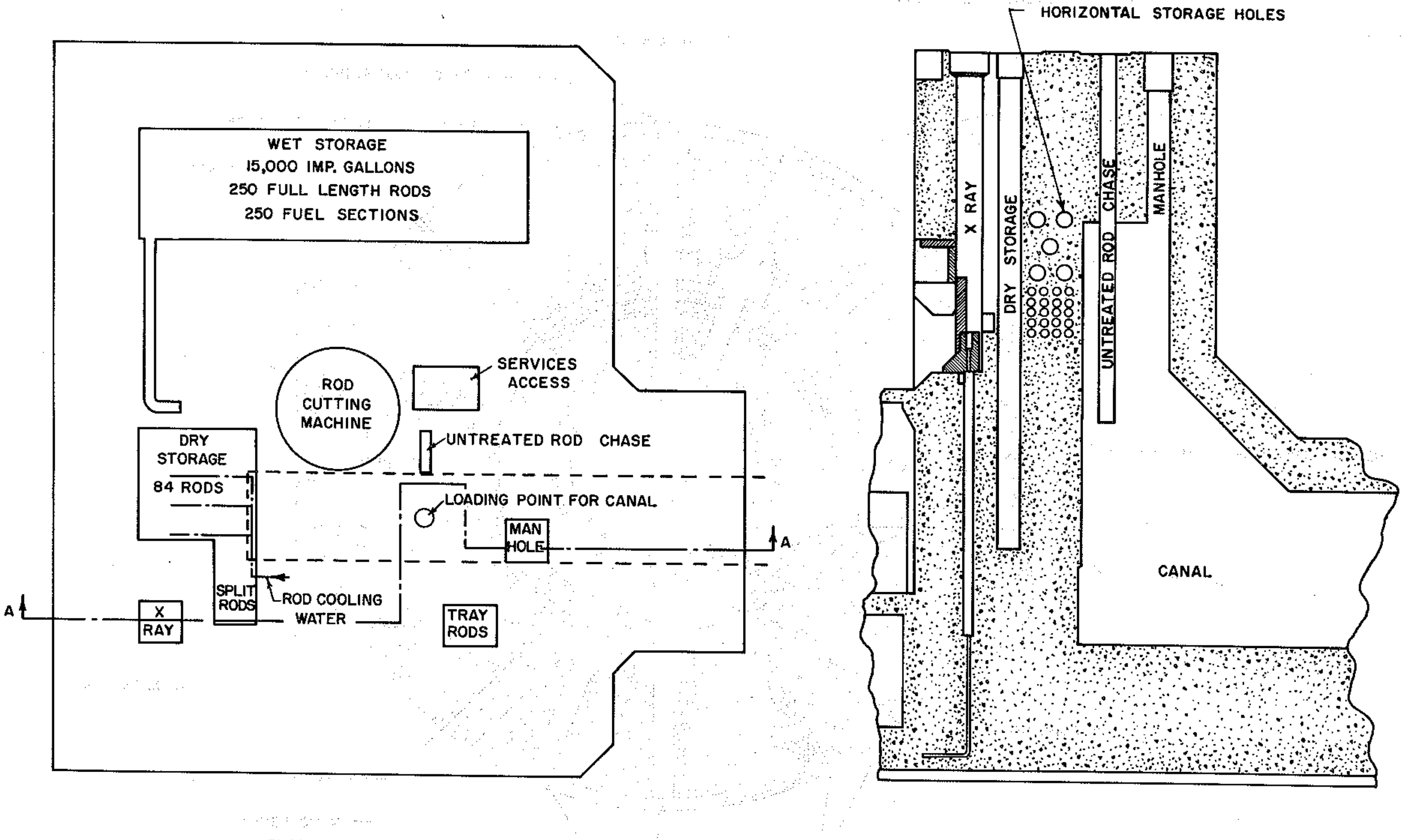


Figure 9.

Horizontal section through reactor showing experimental holes



PLAN VIEW

SECTION AA

Figure 10.

CIR reactor storage block

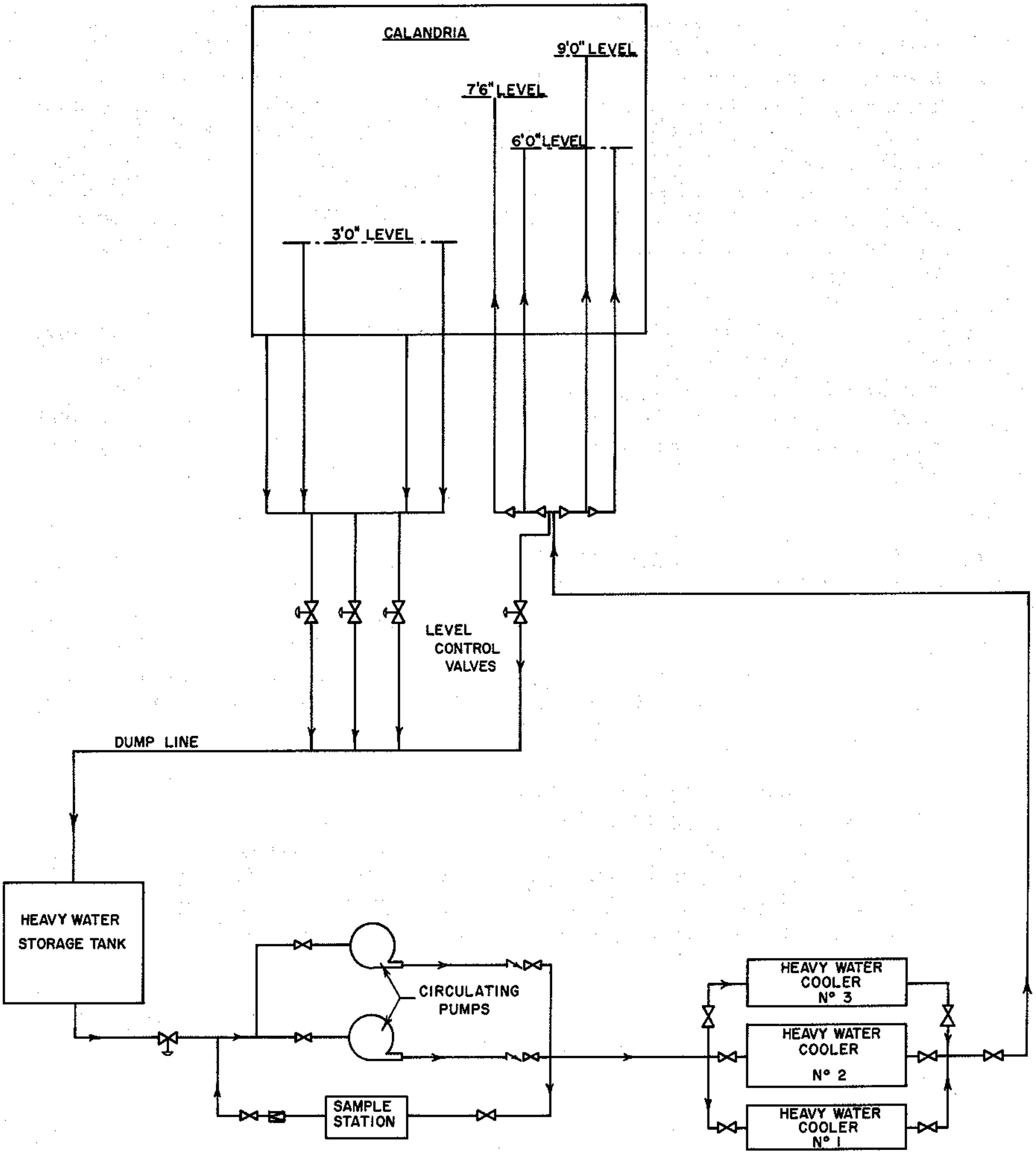


Figure 11.

Heavy water circulation

In normal operation heavy water is pumped from the storage tank, through the heat exchanger, to the calandria at 250 Igpm to the storage tank. Three control valves regulate the rate of heavy water discharge from the calandria. These valves are controlled from signals received from the reactor control system. On a reactor trip the circulating pump is shut down and the dump and control valves open. The storage tank is sized so that when it is full the level in the calandria is approximately 150 cm. Dumping to this level effectively shuts down the reactor and at the same time limits thermal stresses in the calandria tubes.

Three heat exchangers are supplied, two of which will be in use, the other acting as a standby. Duplex tubes and tube sheets are incorporated in the design to guard against corrosion. Surfaces in contact with heavy water are fabricated from stainless steel. Surfaces in contact with the sea water coolant are fabricated from 70:30 copper-nickel alloy.

6. REACTOR POWER CONTROL

The reactor is designed to operate at a maximum thermal power of 40 MW. The thermal power is calculated from the sum of the heat removed by the primary cooling water circuit, the heavy water cooling circuit, the thermal shields cooling circuits and the reactor air cooling exhaust system.

Ionization chambers are placed in the graphite reflector and thermal column (Figure 12) to measure the thermal neutron flux. Since the thermal power varies directly as the thermal neutron flux, the ionization chambers can be calibrated to indicate the thermal power of the reactor. The current induced in the ionization chambers by the neutron flux is amplified and used to control the reactor power.

The reactor power is four to six decades below operating power when the reactor is shut down. A logarithmic amplifier is used with a second ionization chamber to detect and control the reactor power at low levels.

Since the rate at which the reactor power increases is exponential, additional control is provided to prevent overshooting the set power during start-up. Differentiators are added to the linear and logarithmic amplifiers to obtain signals proportional to the rate of change of power and the rate of change of logarithmic power respectively. The rate of rise of reactor power is controlled by setting maximum values on these rates.

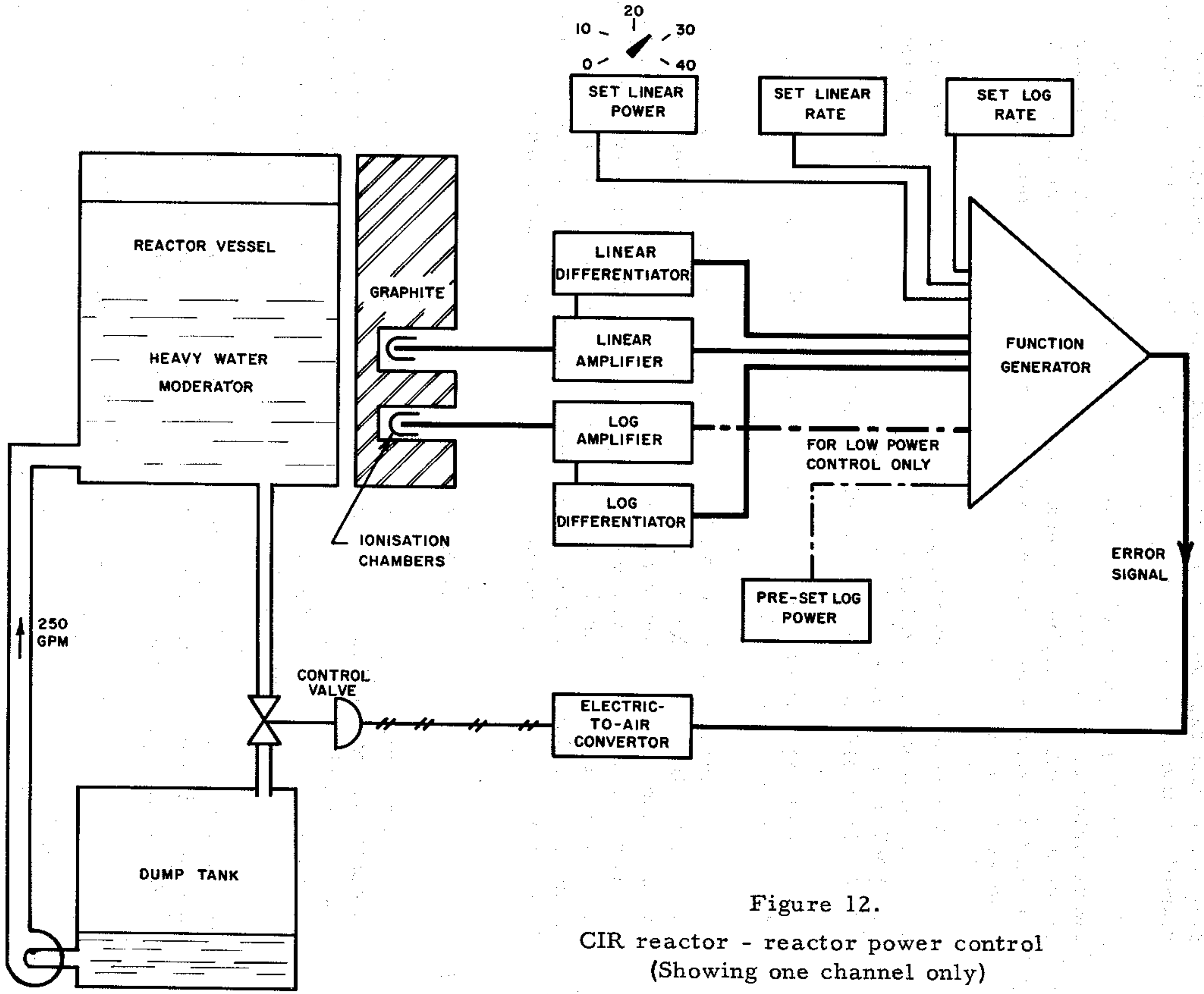


Figure 12.

CIR reactor - reactor power control
(Showing one channel only)

A "function generator" compares the measured values of power, power rate and log power rate with the set values. A resultant "error signal" is produced when the measured values differ from the set values.

The "error signal" is converted to an air signal to operate the heavy water control valves. These valves maintain the reactor power at the set value by varying the heavy water level in the reactor vessel. The heavy water level is raised to increase the reactor power and lowered to decrease it.

During normal start-up of the reactor, the power is increased from the shut-down condition of approximately 4 kW of residual power to 20 MW at a log rate of 1% per second. The power is increased from 20 MW to 40 MW at a linear rate of 0.2 MW per second.

The logarithmic power channel can be used to control the reactor at a fixed power below 400 kW.

To increase the reliability of the control system, all the equipment is triplicated in three independent channels. Any channel may be tested without shutting down the reactor. The channels are continuously compared and if one disagrees with the other two it is automatically disconnected. The two remaining channels will continue to control the reactor while the faulty channel is being repaired. A disagreement between the two remaining channels automatically shuts down the reactor.

7. REACTOR SAFETY SYSTEM

The control system ensures that the energy output of the reactor is controlled at all times. It is necessary to be sure that no reaction can take place under certain conditions. These conditions may arise because of failure of equipment, fuel changing, or maintenance. The power output of the reactor is determined by the state of the reactor power control system. The shutdown of the reactor and preparation for the startup of the reactor are determined by the state of the reactor safety system. The design will allow the reactor to produce power quickly and to operate safely at power, with a minimum number of false signals.

The reactor may be shut down by lowering the moderator level or inserting six boron "shut-off" rods into lattice positions. The moderator level is lowered by opening six fast-acting "dump" valves on the heavy water drain lines from the reactor vessel. The valves are closed during startup.

The control circuits (Figure 13) are designed to shut down the reactor if the air or electrical supply fails. The shut-off rods are raised by electrical motors. They are held above the reactor core by magnetic clutches. The dump valves are pneumatically operated and the air supply is controlled by electrical solenoids. Three of these valves are used to control the level of the moderator when the reactor is operating. The flow through these valves is determined by the signals received from the reactor power control system. The signal operates an electro-mechanical positioner which regulates the air supply to them.

The circuits of the shutdown devices are de-energised during reactor shutdown by the trip system. The trip system annunciates collectively the condition of the reactor and its auxiliary systems in the control room. Signals from instruments indicating faults are graded with regard to their effect on the status of the reactor, in the following order of importance: absolute coincidence trips, conditional trips and alarms.

Absolute coincidence trips shut down the reactor or prevent it from starting up. They operate regardless of the reactor power level if a fault is indicated on an instrument which monitors a component affecting the immediate safety of the reactor. Conditional trips will not shut down the reactor when the power level is below 1% of full power. These trips are actuated by less important instruments and allow the reactor power to be raised quickly to 1% of full power. Above 1% of full power these trips shut down the reactor by opening the absolute trip bus if a fault occurs. Alarms indicate when a minor component is not functioning correctly and requires attention. The components actuating an alarm do not affect the safety of the reactor. All the instruments which operate the absolute trips and, as far as practical, instruments which operate the conditional trips are triplicated. The signals are directed into three independent busses. These busses, A, B & C, energise the main trip relays. Contacts from these are arranged in networks which de-energise the shutdown circuits if faults occur in a minimum of two channels at one time. The annunciation of a fault in one channel is indicated by an alarm. This system enables testing and maintenance of a trip channel and its pertinent instrumentation while the reactor is in operation. This system also reduces the number of false trips due to faulty instrumentation.

Special consideration is given to the positive operation of the shutdown devices. The dump valves are divided into two banks, each containing three valves. Each bank is actuated by a separate trip circuit. Two trip circuits are used to de-energise the shut-off rod magnetic clutches. The motors of the shut-off rods are energised by the action of an extra

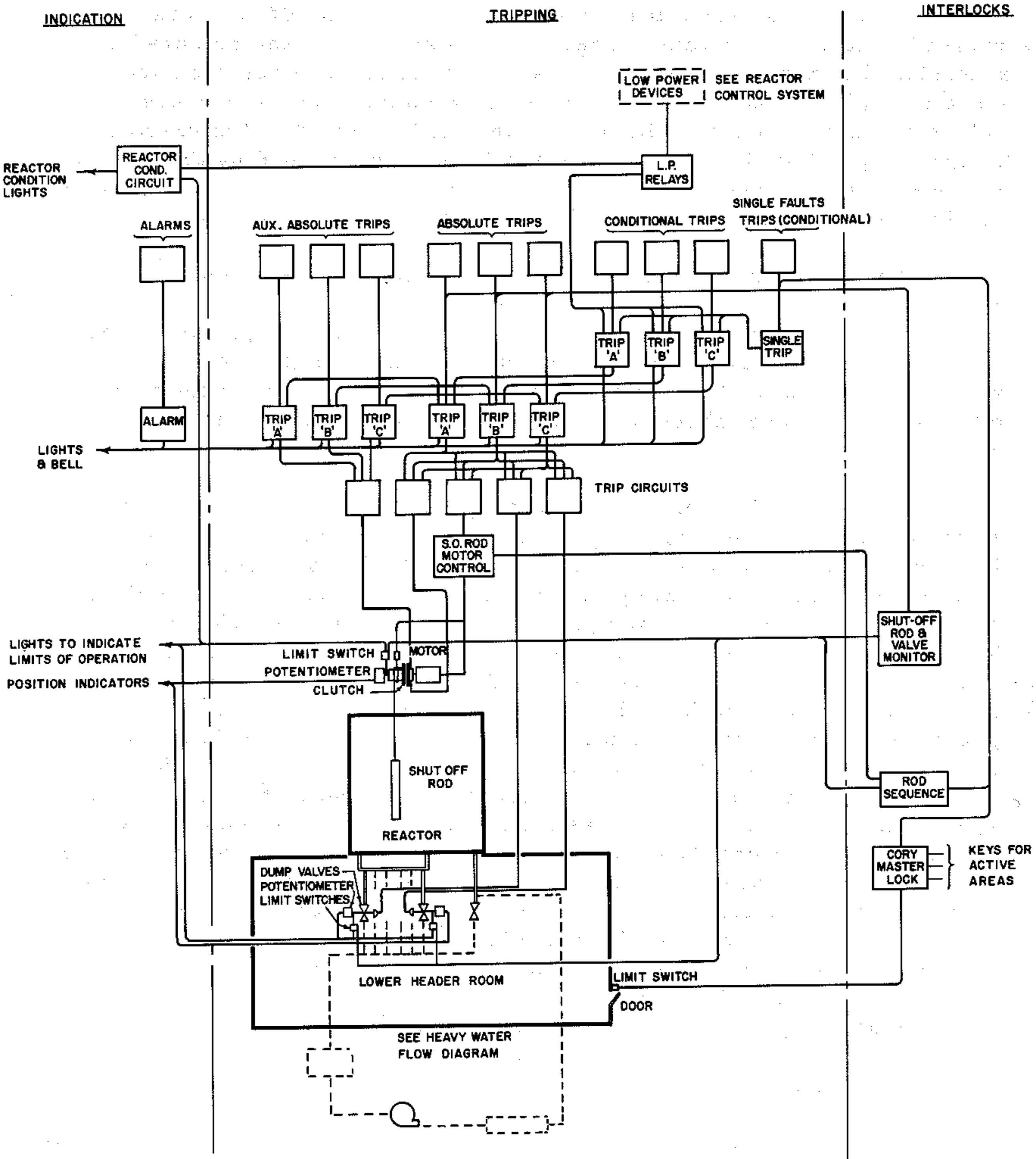


Figure 13.

Reactor safety diagram

trip circuit to ensure that the shut-off rods are lowered if the magnetic clutch fails. The operating time of these shutdown devices is critical. A monitoring circuit is incorporated which will sound an alarm if either a shut-off rod or a dump valve is slow acting. If any two of these devices are slow acting, the trip system will not allow the reactor to be brought to power unless the circuit is re-energised manually.

The shut-off devices and heavy water pumps are interlocked with the trip circuits. A detailed procedure, which includes checking of all auxiliary systems before starting the reactor has been prescribed to allow the reactor to be started quickly and safely. Personnel are also protected by the use of a key interlock system so that all areas that become radioactive when the reactor is operating are locked with a key and these keys must be returned to the control room before the master key can be used to start the reactor.

Indication of faults in the system are given both audibly and visually. The positions of the shut-off devices are shown at all times on indicators. The conditions of auxiliary systems are shown by coloured lights. Reactor condition lights which indicate the operating condition of the reactor are mounted at several vantage points throughout the building.

8. GASEOUS FISSION PRODUCTS MONITOR

Failure of a sheath on any fuel will allow fission products to escape into the cooling water stream. The whole cooling water system can be contaminated if the damaged fuel rod is not isolated and removed quickly.

A gaseous fission products (GFP) monitor is used to detect failure in the fuel rod sheaths at an early stage. Some of the gaseous fission products (e.g. Kr-88 and Xe-138) escape into the cooling water stream when a small hole develops in a sheath. These gases are carried along with the water until they reach the stripping chamber of a GFP monitor unit. A current of air through the stripping chamber separates the fission product gases from the water and carries them past a sensitive Geiger counter. An increase in the signal from this counter indicates a release of radioactive gases into the cooling water stream. This method is used in preference to monitoring the cooling water stream directly, to avoid the high radioactive background normally present. The limit of the sensitivity of the GFP monitor is governed by the uranium contamination present on the outside of the sheath when it is installed in the reactor.

A sample of the cooling water from each rod is divided between two GFP monitors (Figure 14). Each GFP unit monitors the sample stream from 19 rods. Twenty GFP units are required to monitor the 190 rods in the reactor. A rise in activity from a fuel causes two GFP monitors to activate indicating lights and sound an alarm. The indicating lights are arranged in the form of a matrix which allows the faulty rod to be identified.

9. PRIMARY COOLING SYSTEM

Location of the reactor at Trombay, with its limited supply of fresh water, dictated the use of a closed fresh water system cooled by sea water. The sea water reaches a maximum temperature of 90°F. The designed outlet temperature of the fresh water from the heat exchangers is 120°F. This compares to a maximum cooling water temperature in NRX of 74°F.

A much larger cooling water flow through the CIR fuel rods is required to keep the sheath and fuel rod temperatures within safe limits. The initial Canada-India Reactor fuel charge will be the NRX type 5B rod design. This type has a larger cooling water annulus than the type now used in the NRX and hence results in a loss of reactivity. Type 5B rods were chosen because safe sheath and fuel rod temperatures can be obtained at normal rod pressures. Additional pumping capacity is being installed to allow fuel rods with smaller cooling annuli to be installed. Operating experience will dictate the optimum size of the cooling water annulus for CIR flow conditions.

The primary cooling system (Figure 15) is designed to supply 5000 Igpm at a top header pressure which can be varied between 155 and 200 psi. Five pumps will be installed. Only three of these are required at the lower operating pressure.

Six shell-and-tube type exchangers are connected in parallel. Under maximum flow demand five heat exchangers will be in use, the sixth remaining on standby. All tubes and tube sheets are made of 70:30 copper-nickel alloy and shells are of copper bearing, low carbon steel. Other parts of the heat exchangers in contact with sea water are fabricated of silicone bronze.

Hold-up capacity for the primary cooling water has been included in the circuit in the form of a delay loop. This consists of a 5 ft. diameter pipe, 800 ft. in length in the form of a U having a capacity of 100,000 gallons. This loop provides a delay time of 20 minutes with a flow of 5000 Igpm.

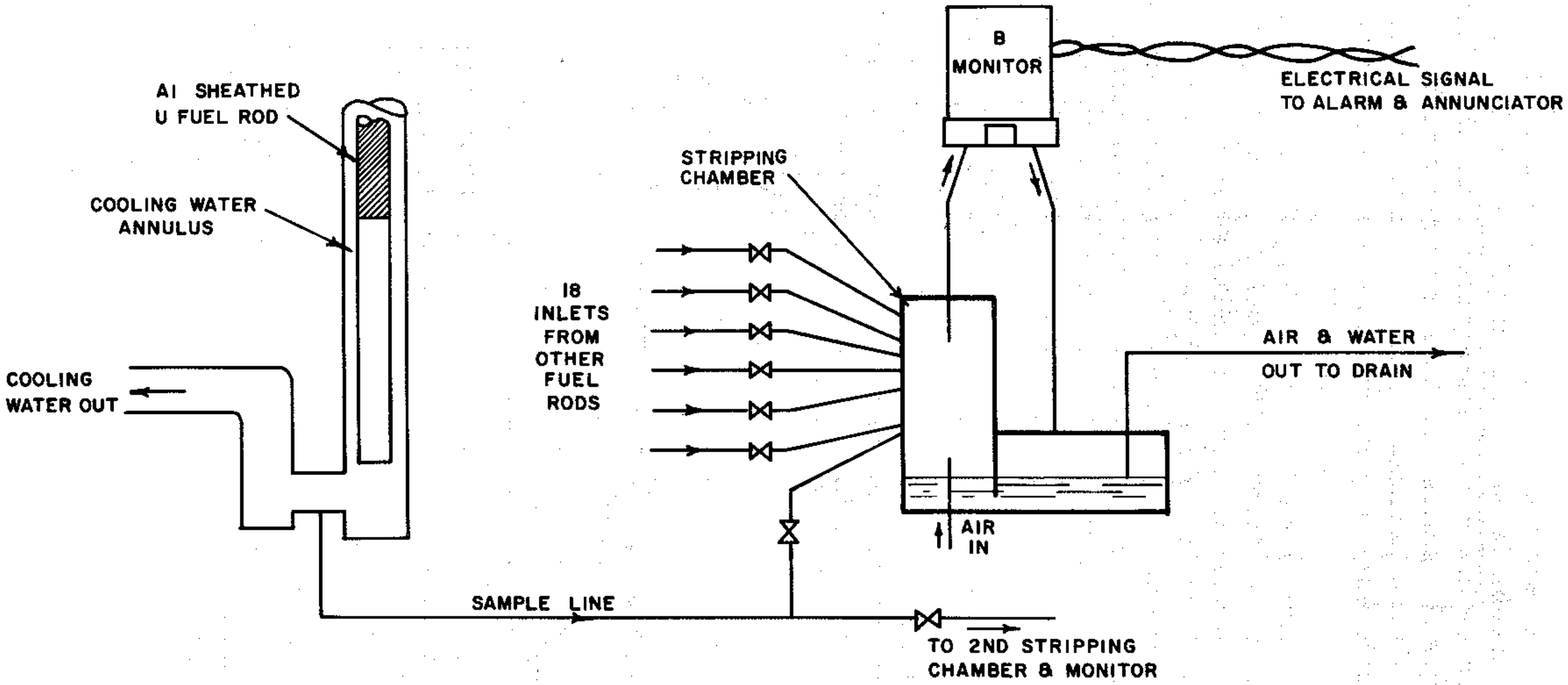


Figure 14.

GFP Monitor

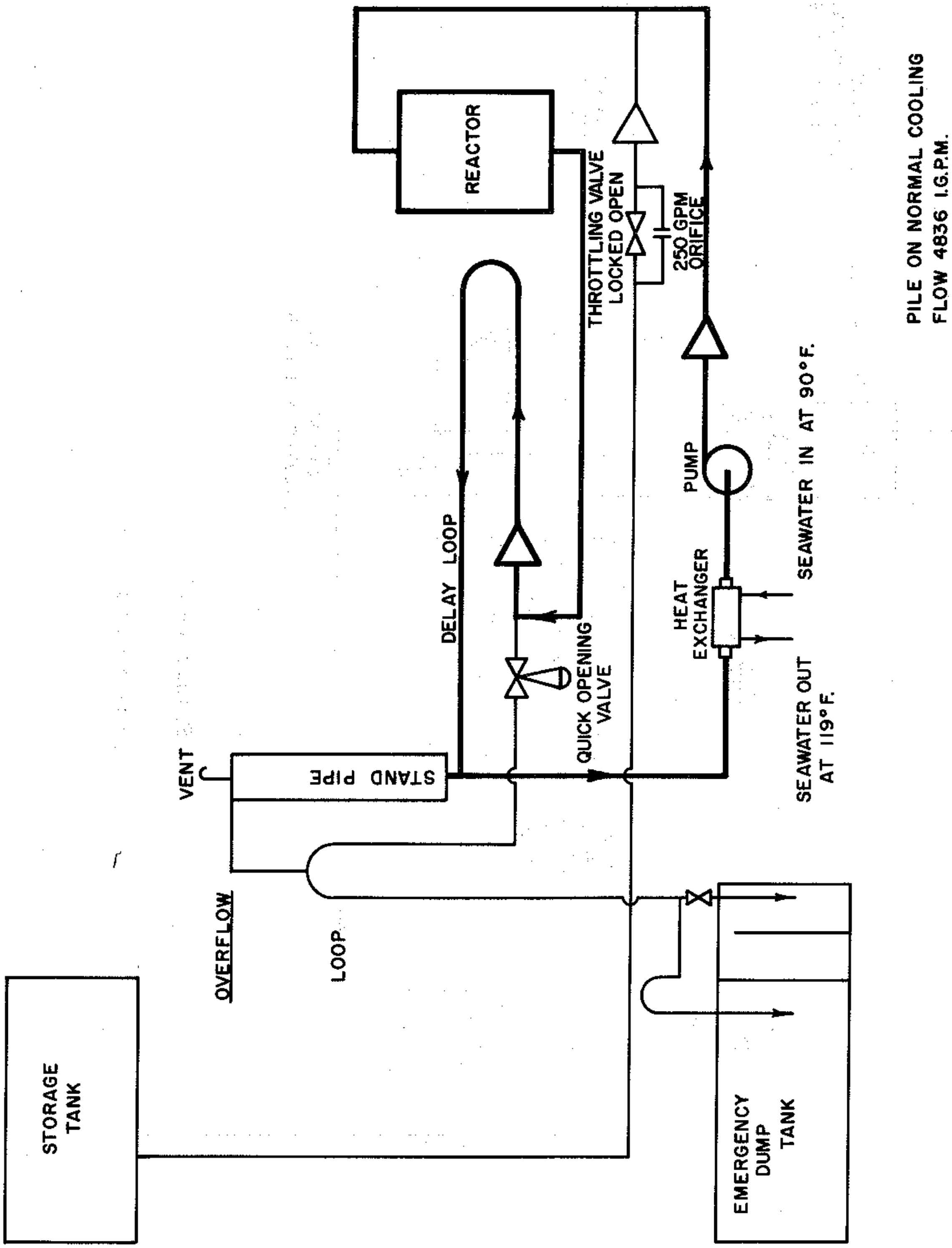


Figure 15.

Primary Cooling System

It provides sufficient time for decay of the 7.35 sec half life N^{16} which is produced in the cooling water by the fast neutron reaction O^{16} (n, p) N^{16}.

Fission product contaminants in the CIR cooling system are removed by an ion exchange purification system. During circulation a side stream of 100 Igpm is bled off the primary circuit through a vacuum deaerator and ion exchange circuit designed to maintain the cooling water at a pH of 6 to 7.

Under emergency conditions, when the pumps fail or a fuel rod ruptures, the flow is automatically switched from the normal recirculating system to a one pass gravity flow through the reactor. Emergency cooling water for this purpose is stored in a 850,000 gallon storage which delivers water at approximately 40 psi.

The emergency storage reservoir rides on the high pressure side of the system. A check valve prevents back flow from the circulating pumps. Should the pressure fall below 50 psi the check valve opens permitting water from the reservoir to flow through the reactor to the dump tank. In the event of a split fuel rod occurring, activity monitors in the system shut down the reactor and the circulating pumps. The resultant loss of system pressure brings the emergency cooling system into operation. The emergency cooling water flows from the reactor to a 1,000,000 gallon capacity dump tank. On return to normal operating conditions this water is purified by ion exchange and returned to the emergency reservoir.

The maximum flow obtainable from the emergency supply is approximately 1400 gpm which provides adequate cooling under reactor shut-down conditions. One second after shutdown of the reactor the required flow is reduced to 30% of the normal operating demand. As the heat load falls off during a long shutdown the flow can be correspondingly reduced. Under shutdown conditions the emergency tank has sufficient capacity to supply cooling water for a four day period.

The emergency dump tank is divided into three compartments, two of 75,000 gallon capacity which receive contaminated water from a split rod. The 850,000 gallon compartment is kept in a relatively clean state and only clean water is diverted to this section during pump failure. Should the two 75,000 gallon compartments be filled, the water overflows to the clean compartment necessitating a major clean up.

Contaminated water in the 75,000 gallon compartments of the dump tank is pumped through the ion exchange system at the rate of 50 gpm. It is returned to the 850,000 gallon clean compartment of the dump tank. From here the purified water is returned to the emergency reservoir.

10. SECONDARY COOLING WATER SYSTEMS

Sea water for cooling the primary cooling system and auxiliary circuits is obtained from the Bombay harbour. The pumping station is located on a concrete caisson at the end of a 3200 ft. jetty. The effluent sea water from the reactor building is discharged into a stilling well located near the mid-point of the jetty.

Four centrifugal pumps, each capable of supplying 2700 gpm against a 120 ft. head will be installed initially. Normal demand is handled by 3 pumps, the fourth being on standby. Provision is being made for the installation of a fifth pump to meet future demands for cooling of loop installations.

The pipeline from the pumping station to shore is 40" welded steel, lined with concrete. Rubber-lined pipe is used in the reactor building. Special radiation monitors will be installed in the sea water effluent lines from the heavy water heat exchangers for the detection of heavy water leakage.

The sea water, particularly during the monsoon period, carries considerable quantities of silt. Careful attention has been given to this problem. The flow velocities have been chosen to limit the amount of settling and to prevent the settling out of silt during periods of shutdown. By-pass connections have been provided which permit the sea-water lines to be continually flushed. To overcome the problem of marine growth in the system, the incoming sea water is chlorinated to a residual of 3 ppm of chlorine.

Two separate and distinct closed-circuit fresh water systems are required for the thermal shields, one for the aluminum shields and one for the steel shields. These two systems remove approximately 254 kW of heat with the reactor operating at 40 MW.

The aluminum thermal shield system consists of a closed fresh-water circuit containing two centrifugal pumps, two heat exchangers, an expansion head tank with automatic make up and an ion exchange purification circuit. Under normal conditions one pump and one heat exchanger will be in service. The pumps are electrically interlocked as a safety measure. The designed flow is 80 gpm at 40 psi, 30 gpm going to the top shield and 50 gpm to the lower shield.

The cooling water is maintained at a pH of between 6 and 7 by passing a side stream of 5 gpm through an ion exchange system. Aluminum was chosen as a construction material due to the short half-life of induced irradiation. This will permit a major dismantling of the reactor without undue radiation from these components.

The steel thermal shield system is essentially the same as the aluminum one. It is provided with a water flow of 200 gpm at 40 psi, this flow being equally divided between the upper and lower shield sections. No ion exchange is required, the water pH being maintained between 9.5 and 10.5 by caustic soda treatment. The dissolved oxygen is held to a minimum by injection of sodium sulphite into the water.

11. VENTILATION AND AIR-CONDITIONING

While the fundamental objectives of the ventilation and air-conditioning are essentially the same for CIR and NRX, the existing differences are caused by different climatic and structural conditions. Fundamentally, these systems must provide: an adequate flow of cooling air to remove the heat generated within the air cooled section of the reactor, adequate pressure differentials throughout the building to minimise the spread of air-borne contamination, and comfortable working conditions for operating personnel.

At an operating level of 40 MW the ventilation system will remove a total of 214 kW of heat from the reactor. This is produced in the J-rod annulus, the graphite reflector and the cast iron thermal shields. Sufficient overcapacity is designed into the system to remove appreciable amounts of heat generated by experimental installations in the shielded rooms and in the rotunda proper. To prevent the spread of radioactive contamination, none of the air in the rotunda is recirculated.

Ventilation is provided in the annulus building primarily for the comfort of the occupants. The control room is provided with a separate air-conditioning plant which has independent control of both temperature and humidity. In the auxiliary equipment areas, ceiling suspended unit coolers are provided, whenever cooling is required.

The central refrigeration plant serves the total cooling and dehumidifying requirements of the rotunda and annulus rooms. It consists of two identical self-contained water chilling machines operating in parallel and delivering water at a temperature of 46°F to the conditioners and unit coolers. The rated capacity of each machine is 130 tons of refrigeration. Fresh air is taken at an average wet bulb temperature of 84°F and is delivered to the building at a dry bulb temperature of 75°F.

A total flow of 24,000 scfm of air is filtered and conditioned in the central air-conditioning plant. 22,000 scfm is discharged to the rotunda and 2000 scfm is diverted to the annulus (Figure 16). The conditioned air is ducted to various areas in the rotunda. The exhaust air from these areas is used as supply air for the reactor proper. The air is exhausted from the reactor, through absolute filters, to the stack.

The ventilation design provides for a minimum of 10 changes per hour in the shielded rooms, 22 changes per hour in the lower header room and 28 changes per hour in the upper header room. A minimum velocity of 100 fpm is provided at the storage block openings.

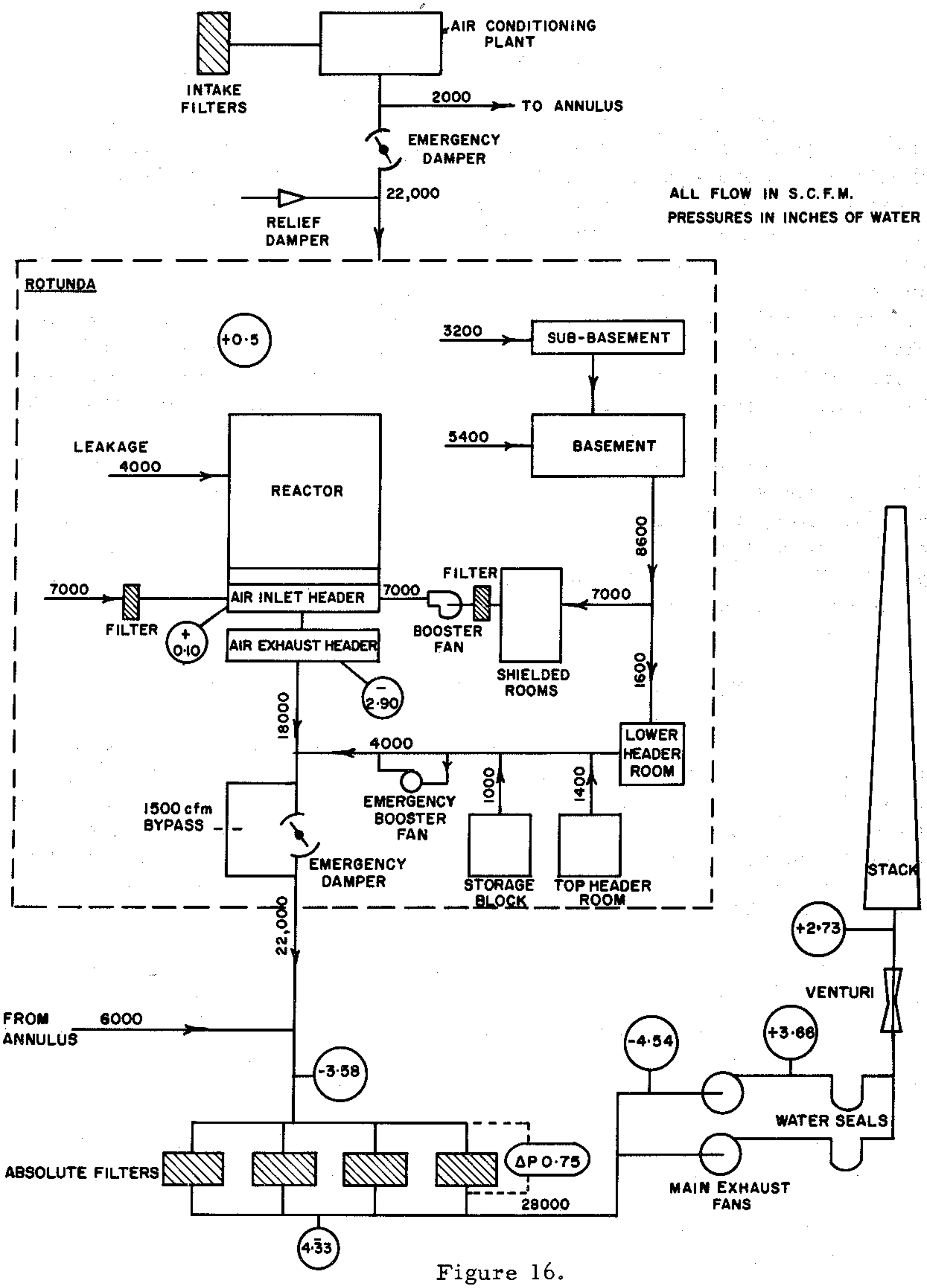
Exhaust air from the rotunda passes through four parallel banks of absolute filters. It is discharged to the stack by one of two identically rated motor driven blowers, each capable of handling the total exhaust air requirements.

Annulus areas, not air-conditioned, are ventilated with filtered air. This air is also exhausted through the absolute filters to the stack. This also includes the contaminated exhaust air from the auxiliary equipment rooms.

Various proposals for the location of the stack are now under consideration. It had been proposed earlier to locate the stack in the immediate vicinityof the reactor building. However, as the possibility of inversion exists (and this would spoil the area for low counting work) alternative proposals are being investigated. One of these consists of running the exhaust duct up to the crest of a low hill which is at an elevation of nearly 500 ft. and providing a low stack of 50 ft. height. The other consists of running the exhaust duct on the jetty into the sea and locating a 400 ft. stack about 1500 ft. into the sea. Final decision on location will be taken at an early date.

In the unlikely event of a major reactor accident involving complete melting of the core, large quantities of steam may be generated and cause rupture of the absolute filter elements. Consequently, temperature sensing devices set at 150°F are provided to close both the dampers automatically. To minimise chances of accidental operation of this circuit and consequent damage to it, a two-out-of-three coincidence system is provided.

The ventilation system is designed to provide absolute filtration of all exhaust air from the reactor and the rotunda, even during a reactor excursion. It also provides sufficient cooling for the reactor components during shutdown conditions, when the exhaust damper is accidentally closed.



ALL FLOW IN S.C.F.M.
PRESSURES IN INCHES OF WATER

Figure 16.

CIR Ventilation Flow

12. ROD HANDLING AND CUTTING FACILITIES

A canal system, similar to the one existing in the NRX, connects the storage block to a separate building with facilities for cutting, de-sheathing and storage of spent fuel elements. Full length rods are transported from the storage block by means of a trolley in the water trench to this building. Provision is made for trisecting the rods under water into three pieces, namely, the two aluminum-stainless steel end pieces and the central uranium part. Equipment is also provided for de-sheathing of the central uranium part. The de-sheathed rods are stored vertically under water in a storage bay. Facilities are also available in a special "isolation bay" for cutting these rods into smaller pieces either for experimental purposes or for feeding to the plutonium separation plant.

In addition, facilities are planned for experimental work on irradiation of food stuffs and other materials using these irradiated rods. Refrigeration facilities will be provided in this block so that materials can be irradiated at different temperatures. It is estimated that the gamma flux will be enough to provide a total irradiation of one million roentgens in a few hours.

13. ATTACHED LABORATORY AND WORKSHOP

Entrance to the reactor hall is through an attached laboratory building in which wash and change room facilities are provided on the ground floor. Personnel entering the reactor hall pass through a health physics "security" and then through these change rooms. A film badge area is provided at the entrance to the reactor hall. Personnel coming from the reactor hall follow the same procedure in reverse. Decontamination facilities are also provided adjacent to the health physics area.

Laboratory space is provided in these attached buildings for assembly of experimental apparatus, counting, etc. Offices for the operating staff and control laboratories, mainly consisting of mass spectrometers, infra-red spectrometers and other equipment for analysis of heavy water, helium, etc. are provided on the first floor (Figure 17).

Although, a large central workshop is provided in the Establishment where all heavy fabrication and maintenance work will be done, a workshop building is attached to the reactor hall to cater to the daily maintenance requirements of the reactor and also the handling of active items of equipment. The total floor area provided in these blocks exceeds 20,000 ft^2.

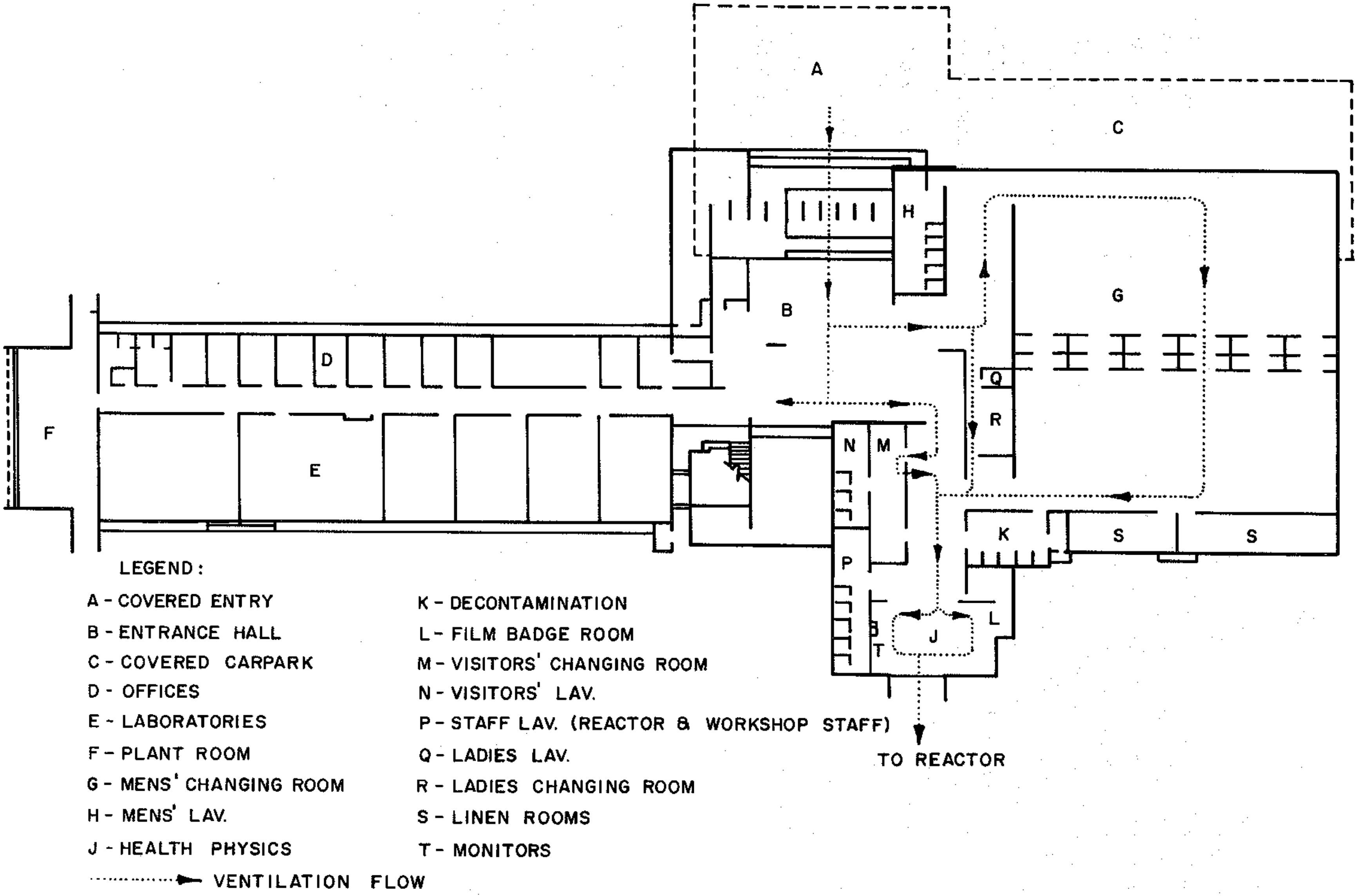


Figure 17.
Plan: CIR Attached Laboratory, Trombay

14. CONSTRUCTION ASPECTS

As the monsoon rains are very heavy in the Bombay area, for a period of three months from the end of June, outdoor construction work has to be scheduled taking this into consideration. Site construction work started in December, 1955, with exploratory bore holes for determining rock depth and foundations. Before the start of the monsoon in 1956, excavation to hard rock, raft foundation, and the 4 ft. thick and 120 ft. radius reinforced concrete ring wall forming part of the basement and sub-basement were completed. Work on the erection of the steel shell to house the reactor and the pouring of reinforced concrete slabs over the basement and sub-basement areas inside the hall could be started only in September, 1956. The erection of the steel shell and concrete work inside the reactor hall is now complete. It is proposed to test the shell to a pressure of 5 psi for structural purposes. At a later stage, another test will be performed to detect leaks in the shell and the air locks. The erection of the 30 ton revolving crane in the rotunda is also complete and work on pile erection will commence as soon as air-conditioning of the reactor hall is complete as otherwise daytime temperature within the shell may exceed 130°F. It is proposed to treat the outside of the shell with insulating material and an outer cladding of anodised aluminum.

The annulus building to house the reactor auxiliaries such as heat exchangers, pumps, etc. is also nearing completion and erection of equipment in this area is also under way.

Work is progressing rapidly on the sea water jetty and it is proposed to start work on the intake caisson shortly. The million gallon dump tank has also been completed and is undergoing tests (Figures 18 and 19).

Pile erection is scheduled to commence in September, 1958, and will be complete in fifteen months. Erection, testing and commissioning of associated equipment will be done simultaneously and completed by September, 1959.

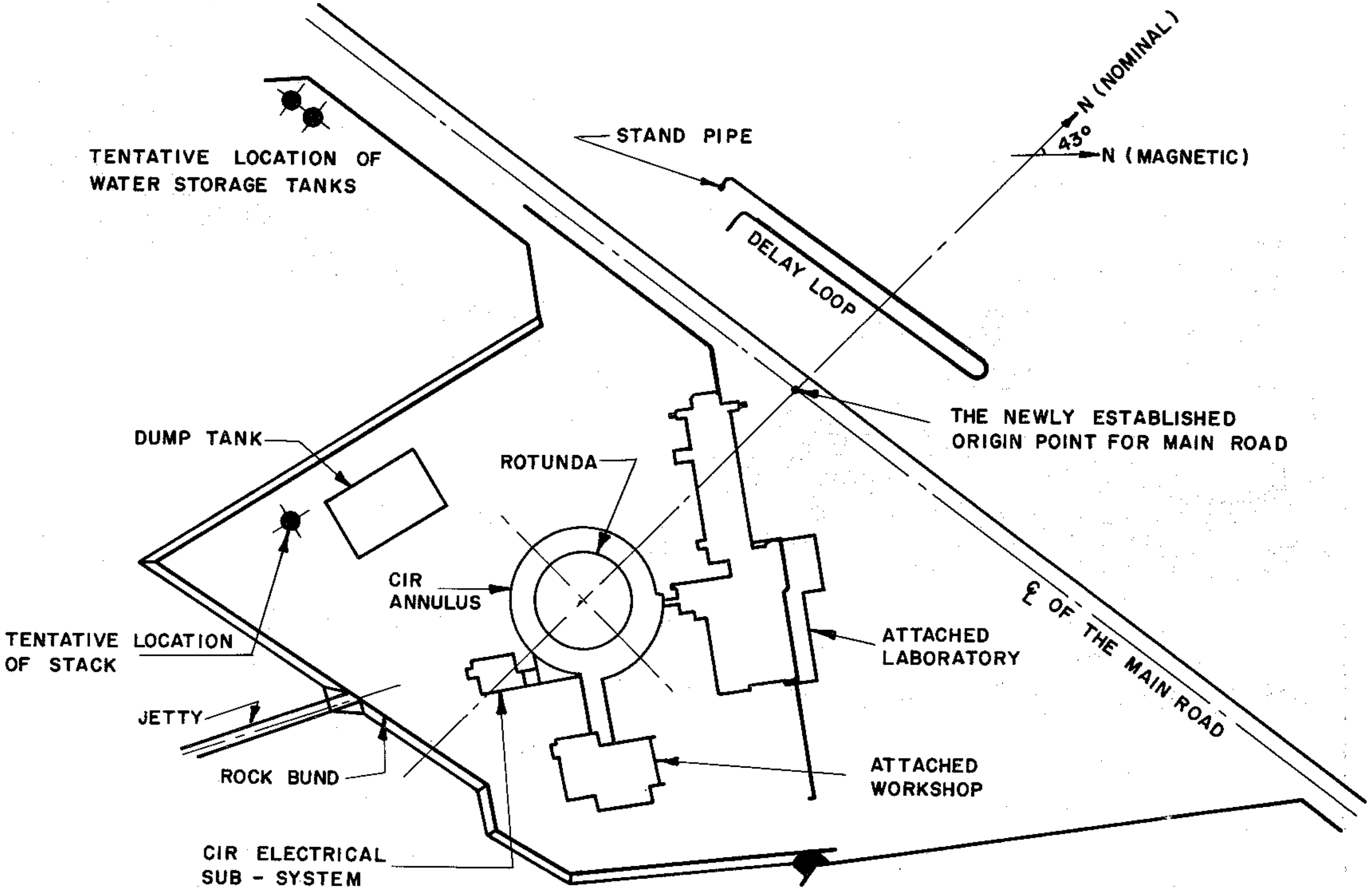


Figure 18.
Canada-India Reactor Site Layout

Figure 19.
Artist's Sketch - Canada-India Reactor - Site Layout