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Upgradation of Apsara Reactor

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ABSTRACT

Refurbishment of the 1 MW Indian swimming pool research reactor Apsara has been taken up after completion of 53 years of its successful operation. It has been decided to replace the HEU fuel with LEU fuel as per the current international practice. Further it is planned to upgrade the reactor by raising its power level from 1 MW to 2 MW to improve its utilization. Reactor systems, structures and components will be upgraded in line with current safety standards. Towards this, detailed investigations were carried out on the civil structures to assess their healthiness as per present codal requirements. It has been decided to demolish and reconstruct the existing reactor building and pool structure. The reactor has been shut down and decommissioned and preparations are in progress for reconstruction of the reactor. This paper gives a brief account of the design features and safety aspects of the upgraded Apsara reactor.

1. Introduction

Apsara reactor was commissioned in the year 1956. It was a 1 MW swimming pool type reactor using high enriched uranium (HEU) as fuel, demineralised water as coolant & moderator and graphite, BeO & water as reflector. The maximum thermal neutron flux at the rated power of the reactor was about $1x10^{13}$n/cm^2/sec. The reactor core was suspended from a movable trolley and could be parked at three different locations inside the pool to facilitate wide range of experiments at beam tubes, thermal column and shielding corner in addition to the in-core irradiations [1]. These facilities have been used extensively to carry out research in a number of areas in basic sciences, production of radioisotopes, neutron radiography, detector testing, shielding experiments, material characterization etc. Apsara reactor has contributed enormously towards training young scientists and engineers. Considering the long service period extending over fifty three years, the reactor has been shut down in June, 2009 and decommissioned for upgradation of its systems, structures and components in line with the current safety standards to extend its useful life.

2. Upgradation programme

Under the upgradation programme, the reactor power will be increased to 2 MW and reactor core will be replaced with low enriched uranium (LEU) in the form of U_3Si_2 dispersed in aluminum matrix as fuel. The core is surrounded by beryllium oxide (BeO) reflectors. The maximum thermal neutron flux is enhanced to 6.1×10^{13} n/cm^2/sec. The higher neutron flux will facilitate production of isotopes for applications in the field of medicine, industry and agriculture. The other major utilization of Apsara reactor is to provide enhanced facilities for beam tube research, neutron activation analysis, neutron radiography, neutron detector development & testing and shielding experiments. Salient features of the upgraded Apsara reactor are given in Table-1.

Table - 1 : Salient Features of Upgraded Apsara reactor

Reactor type	Pool type
Thermal Power	2 MW
Maximum Thermal Neutron Flux	6.1×10^{13} n/cm^2/sec
Maximum Fast Neutron Flux	1.3×10^{13} n/cm^2/sec
Maximum Thermal Neutron Flux in reflector region	4.4×10^{13} n/cm^2/sec
Fuel	Plate type U_3Si_2 dispersed in aluminium matrix Loading density of Uranium -: 4.3 gm/cc
Reflector	Beryllium Oxide
Coolant / Moderator	Demineralised water
Shutdown system	Fast acting Hafnium shut-off-rods
Normal core cooling	Forced convective, downward
Shutdown core cooling	Natural convection
Secondary cooling	Cooling tower system

During the refurbishment & Upgradation programme, new pool block and reactor building with annex building will be constructed, meeting seismic requirements and shielding adequacy as per current standard. All the systems and components of various nuclear and process systems of upgraded Apsara reactor will be designed, manufactured and installed according to the requirements of latest safety codes and standards.

The primary coolant flow from top to bottom across the core coupled with provision of a hot water layer on the top of the pool water limits the radiation field at the pool top to acceptably low values. A delay tank is provided at the core outlet to limit the radiation field in the process equipment room and on pool water within permissible values. Single channel ON / OFF type reactor power regulating system is being upgraded to a triplicated channel proportional control system using both neutron power and reactor period signals. Two shut down systems consisting of i) two control cum-shut off rods and ii) two shut-off rods are provided to shut down the reactor. The reactor will be equipped with emergency power supply for safety related equipment.

3. Core and Reflector

Upgraded Apsara reactor core is mounted on a 140 mm thick aluminium grid plate having 64 lattice positions arranged in 8 x 8 square array with a lattice pitch of 79.7 mm. The central 4 x 4 lattice positions of the core are loaded with fuel assemblies and are surrounded by two layers of reflector assemblies on all the four sides as shown in Fig. 1. The central 4 x 4 lattice positions of the core consist of eleven standard fuel assemblies (SFA), two control fuel assemblies (CFA-

CSR), two shut off rod fuel assemblies (CFA-SOR) and one hollow beryllium oxide plug (HBP). This in-core HBP will be used for high neutron flux experiments/irradiations [2].

The core is surrounded by BeO reflector assemblies to achieve the desired core reactivity and sustain high thermal neutron flux levels over a large radial distance around the reactor core for material irradiation studies and isotopes production. BeO reflectors consist of 72.5 mm × 72.5 mm × 70 mm BeO blocks stacked over each other. These reflector assemblies are clad with aluminium. They are located in 8 × 8 matrix in grid plate around the central 4 × 4 fuel matrix as shown in Fig. 1. Seven experimental/ irradiation positions are provided in reflector region.

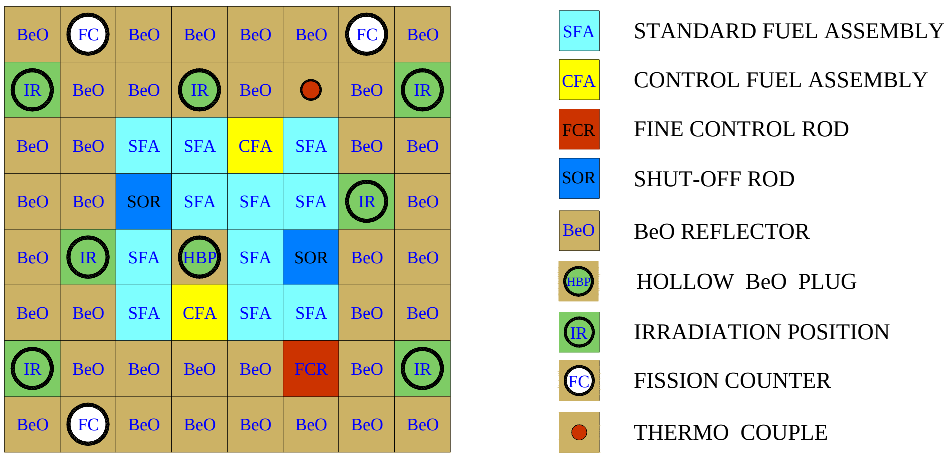

Figure -1 : Core configuration of upgraded Apsara reactor

The reactor power is controlled by means of two control cum shut-off rods (CFA-CSRs) and one fine control rod (FCR). The shutdown of the reactor is also achieved by the CSRs. In addition, two Shut-off rods (SORs) are also provided to shut down the reactor. The CSRs and SORs are located inside control fuel assemblies. The FCR is located in the BeO reflector region adjacent to the core. Each CSR/SOR contains two fork type hafnium blades and FCR contains a single hafnium blade. The reactivity worth of CSRs and SORs in the equilibrium core is about 81 and 83 mk, respectively.

The reactor core design ensures negative coefficient of reactivity from zero power to full power operation. The estimated fuel temperature coefficient of reactivity is about (-) 0.014 mk/ ^{o}C. The coolant temperature coefficient of reactivity is about (-) 0.06 mk/ ^{o}C. The coolant void reactivity coefficient is about (-)1.6 mk/% void. The estimated average burn-up coefficient for the equilibrium core is about (-) 0.08 mk/MWD.

Maximum thermal neutron fluxes at the in-core irradiation position and at the reflector region are estimated to be about 6.1×10^{13} and 4.4×10^{13}n/cm^2/sec respectively. The fast neutron flux (>821 KeV) in the in-core water hole is estimated to be about 1.3 x10^{13} n/cm^2/sec.

4. Fuel

Dispersion type LEU fuel (U_3Si_2 dispersed in Aluminium matrix) is chosen for the reactor considering high uranium loading density in fuel meat, good compatibility with aluminium matrix, good thermal conductivity, excellent blister resistance threshold, stable swelling behaviour under irradiation, high fission gas retaining capability and good fabricability. U_3Si_2 is synthesized by using powder processing route [3] with uranium metal powder and silicon powder as the starting materials. Aluminium alloy of nuclear grade is chosen as cladding material considering its high thermal conductivity, small cross section for neutron absorption and good compatibility with U_3 Si_2 –Al dispersion matrix. The core is loaded with two types of fuel assemblies namely standard fuel assemblies and control fuel assemblies. The general arrangement drawing of the standard and control fuel assemblies is shown in Fig. 2.

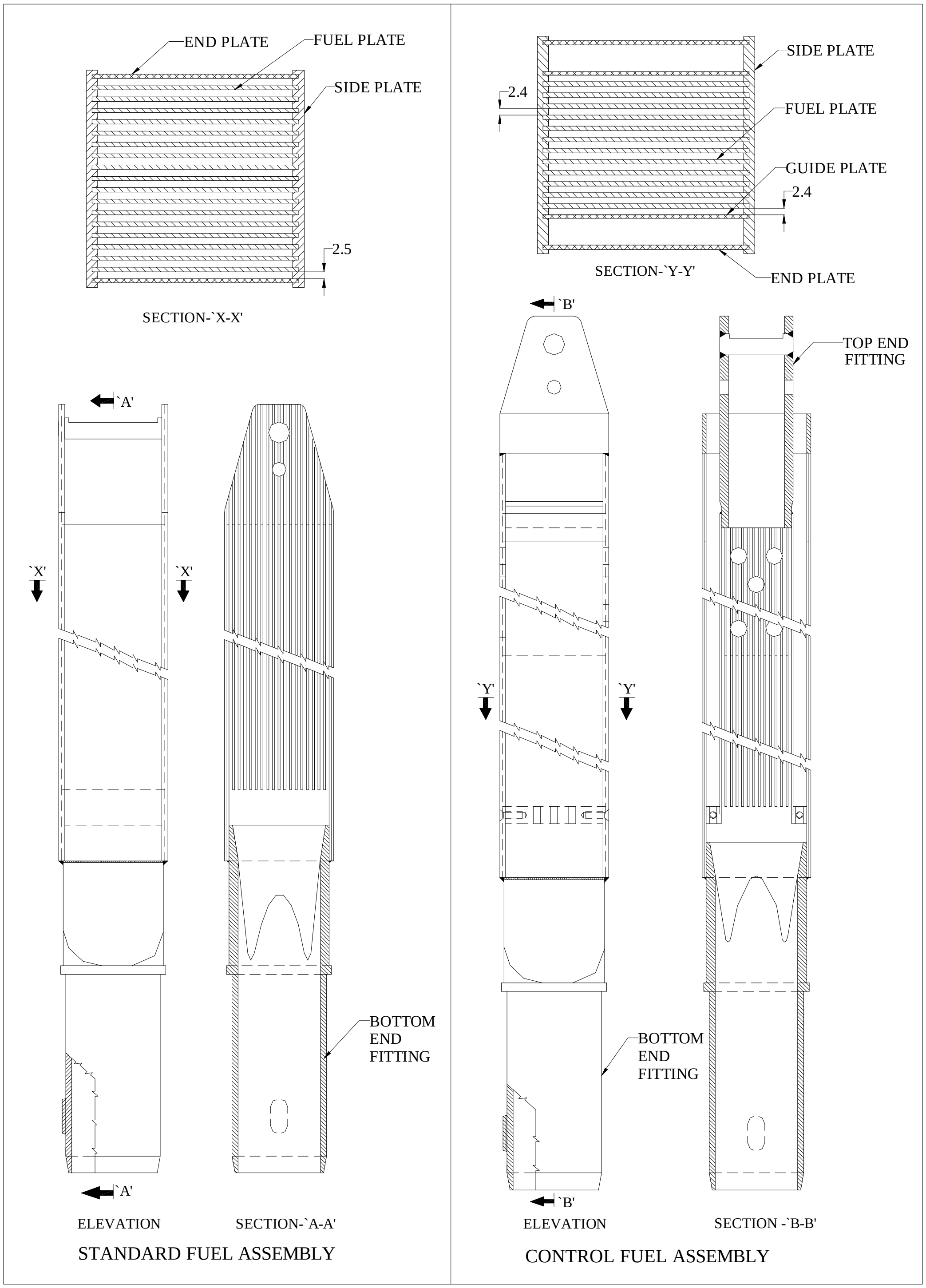

Figure -2 : General arrangement details of standard fuel assembly and control fuel assembly

Each standard fuel assembly (SFA) consists of 17 fuel bearing plates. The fuel meat is clad with aluminium-6061. Two side plates with grooves made in the internal faces are provided for positioning the fuel plates. All these plates are swaged into these grooves to maintain a uniform water gap of 2.5 mm between them. Two end plates are also swaged into the grooves of side plates at both the ends to make a fuel box with a confined boundary from all sides using non-fuel bearing plates. The fuel box is connected at the bottom to a lower end fitting which provides a smooth transition from square cross-section of the fuel box to a cylindrical toe for supporting the fuel assembly on the grid plate.

Control fuel assemblies (CFA) have provision to accommodate absorber elements (hafnium blades) inside them. There are two types of control fuel assemblies. In one type, the control rods are used to control the reactor power as well as for fast shutdown of the reactor. They are called "Control cum Shutoff rods (CFA-CSR) fuel assembly'. In the other type, shut off rods are normally parked above the core and they are called "Shut-off rod (CFA-SOR) fuel assembly". On a reactor trip signal, the absorber elements drop inside the recess of control fuel assemblies.

The CFA-SOR fuel assemblies and CFA-CSR fuel assemblies are identical. The Control fuel assembly is similar to standard fuel assembly with five fuel plates removed to create the space required to accommodate the twin blade fork type absorber element. The twin blades are placed symmetrically with respect to central axis of the fuel element. Each assembly has an attachment at the top and recess right through for movement of each absorber blade. The recess has been created between the end plate and an aluminium guide plate. The movement of the absorber blade of the control fuel assembly is controlled by the drive unit provided on the platform at the pool top.

In order to ensure the fuel safety, the coolant velocity has been so chosen that for the hottest standard & control fuel assembly and shut-off rod assembly, the fuel meat and clad temperatures do not exceed the prescribed limits. Maximum fuel centre temperature is about 94 ºC and clad surface temperature is about 92 ºC.

4. Reactor pool block

The reactor pool block is a concrete structure whose inner face is lined with stainless steel plates to act as the reactor pool. The reactor pool is 8.5 m × 3.4 m × 9.6 m deep and is filled with demineralized water. The pool block is located inside the reactor building. Provisions of Thermal column and Shielding experiment facility are made in the pool block. The reactor pool block provides structural support for the reactor trolley from which the reactor core & its support structure and ion chamber support structure are suspended. The pool accommodates process piping, electrical and instrumentation cables and equipment and spent fuel storage cages. Eight numbers of beam tubes are provided to facilitate beam tube related research. The reactor core can be located at three specific locations namely A, B & C positions inside the reactor pool (Fig. 3). Underwater pipe couplings (core position coupler) are provided to connect the core outlet pipe coming from the outlet plenum to the pool outlet header at any one of the core positions. At position 'A' graphite thermal column is provided to carry out studies connected with the thermal neutrons. Four experimental beam tubes of 100 mm diameter are provided at position 'A'. At position 'B' two beam tubes of 100 mm diameter and two beam tubes of 150 mm diameter are provided. The beam holes are provided with motorised inner gates (IG) and outer gates.

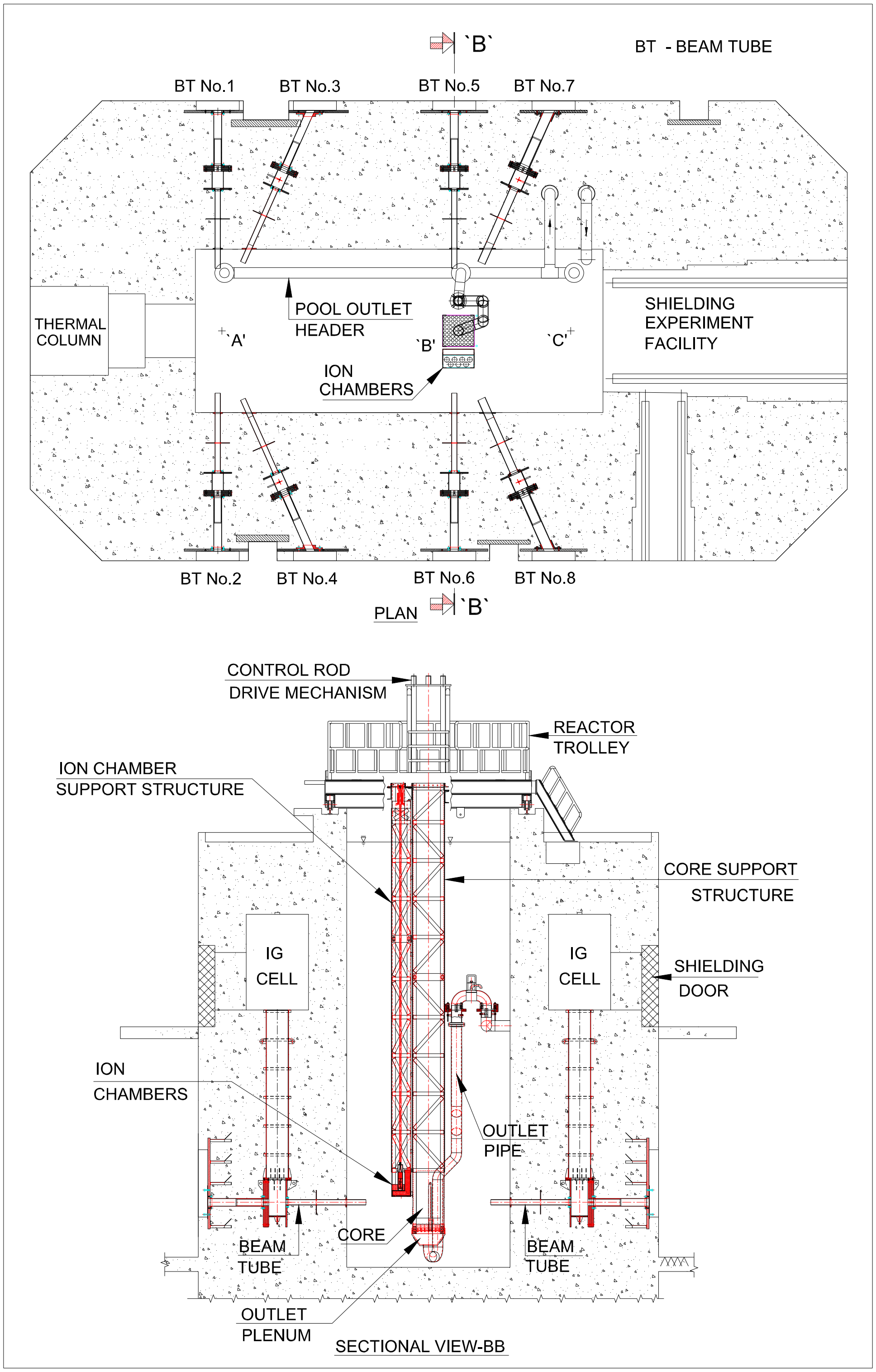

Fig.-3 : Plan and sectional view of reactor pool block

5. Primary cooling water system

Primary cooling water (PCW) system is designed to remove the heat generated in the reactor core as well as the decay heat from the spent fuel stored in the pool. The reactor core cooling takes place by forced downward flow through the core (Fig. 4). A delay tank is located at the core outlet line to provide adequate delay for decay of radioactivity in the primary cooling water mainly due to N^{16} and O^{19}. Three PCW pumps (two operating and one standby), each of 2500 lpm capacity, are provided to draw water through the core and send hot water to the heat exchanger, where the heat is transferred to the secondary coolant. Cold water from heat exchanger outlet is fed back to reactor pool. A part of the coolant flow from the heat exchanger outlet passes through purification system consisting of a filter and ion exchanger to maintain the water chemistry. An underground dump tank having two compartments is provided to collect the complete inventory of water from the reactor pool in case it is to be drained to facilitate maintenance work in the pool. Two make-up pumps are provided to fill the pool by transferring water from the dump tank. Provision is also made to circulate and polish the water stored in the dump tank through a filter and a mixed bed ion exchanger connected in series. An emergency water storage tank (EWST) is kept at a higher elevation to cater to the reactor pool make-up requirement. Normally, EWST water is recirculated in a closed loop through a filter using a EWST pump. The EWST can be made up from underground storage tank using make-up pumps.

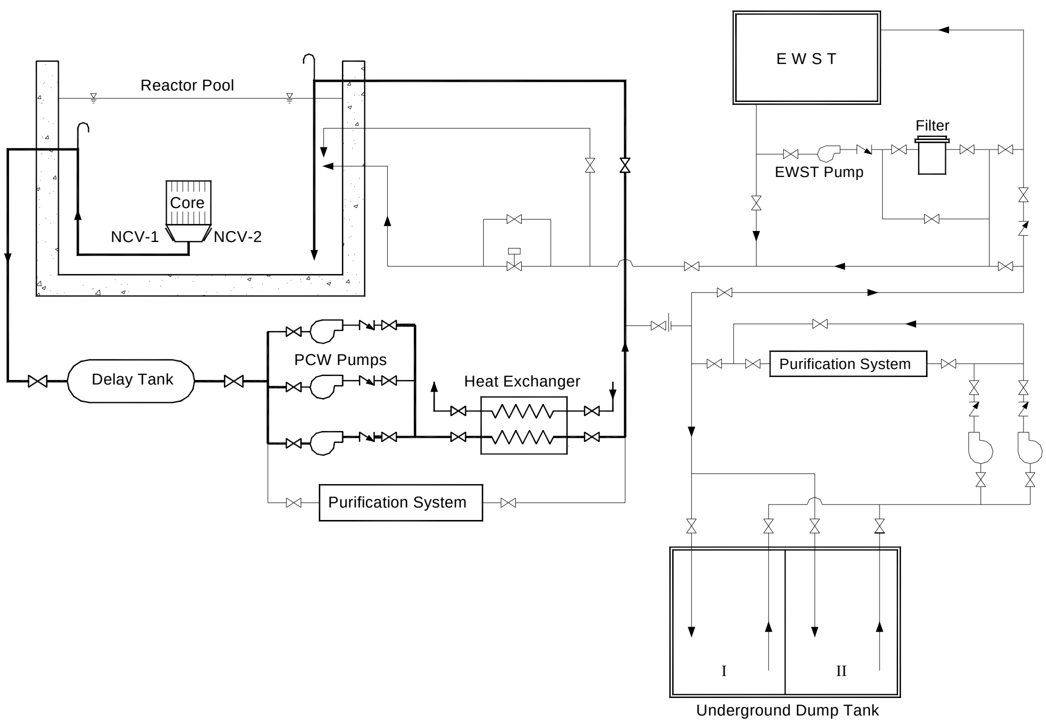

Fig.-4: Primary cooling water system

In the event of non-availability of PCW pumps, reactor will trip automatically and two hydraulically operated fail safe flapper type natural circulation valves (NCVs located on the core outlet plenum) will open automatically when the pump discharge pressure falls below a preset value to establish natural convection cooling flow through the core. Each PCW pump is provided with a suitably sized fly-wheel to ensure adequate coasting down of flow to cool the core during the pump trip transient from forced downward flow to natural circulation upward flow through two NCVs.

A hot water layer system is provided to maintain a water layer of higher temperature at the pool top compared to the bulk pool water to reduce the radiation field at the pool top.

6. Reactor regulation and protection system

The reactor regulating system (RRS) is a dual redundant computer based system which controls the reactor power by precise positioning of fine control rod (FCR). The system receives linear power, log power and log rate signals from the triplicated regulating channels and uses an appropriate control algorithm to generate signal for control of the reactor power by movement of the FCR. Coarse regulation of reactor power is achieved by manual control of two CSRs in a bank.

For reactor start-up, triplicated fission counter based pulse channels consisting of three fission counters located in the reflector region are used. In power range, B-10 coated uncompensated ion-chambers connected to log–linear DC channels operating in current mode are used. There are six log-linear channels with independent ion chambers. Three channels are used for reactor protection system (RPS), the other three channels are fed to the computer based RRS.

A multi range linear DC (MRDC) channel which uses a gamma compensated neutronic ion chamber and a Linear DC amplifier is also used for monitoring the reactor power. This channel covers seven ranges of reactor power from 0-2.5 Watts to 0-2.5 MW.

The reactor protection system makes use of various signals generated from neutronic as well as process system parameters to provide reliable protection action by automatic fast insertion of gravity assisted two banks of control rods into the reactor core.

7. Reactor hall ventilation system

Apsara reactor building is provided with closed loop ventilation system and maintains a temperature of 24 ± 1°C and a relative humidity of 50± 5% in the Reactor building. The system is provided for proper functioning of electronic equipment, personnel comfort and also to ensure more than one air change per hour in the reactor building. A clean up system with iodine & HEPA filters has also been provided.

8. Conclusion

The upgraded Apsara reactor with its higher neutron flux will provide enhanced facilities for various needs of researchers in the areas of beam tube research, production of radioisotopes, neutron activation analysis (NAA), neutron radiography, shielding studies, material irradiation and development & testing of neutron detectors. The upgradation of the Apsara reactor with LEU fuel and as per current safety standards will give a new lease of life to the reactor and improve its utilization in addition to enhancement of the safety of the reactor.

9. References

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