APSARA

50

अप्सरा के 50 गौरवपुर्ण वर्ष

50 GLORIOS YEARS OF APSARA

भारत सरकार
Government of India

भाभा परमाणु अनुसंधान केंद्र
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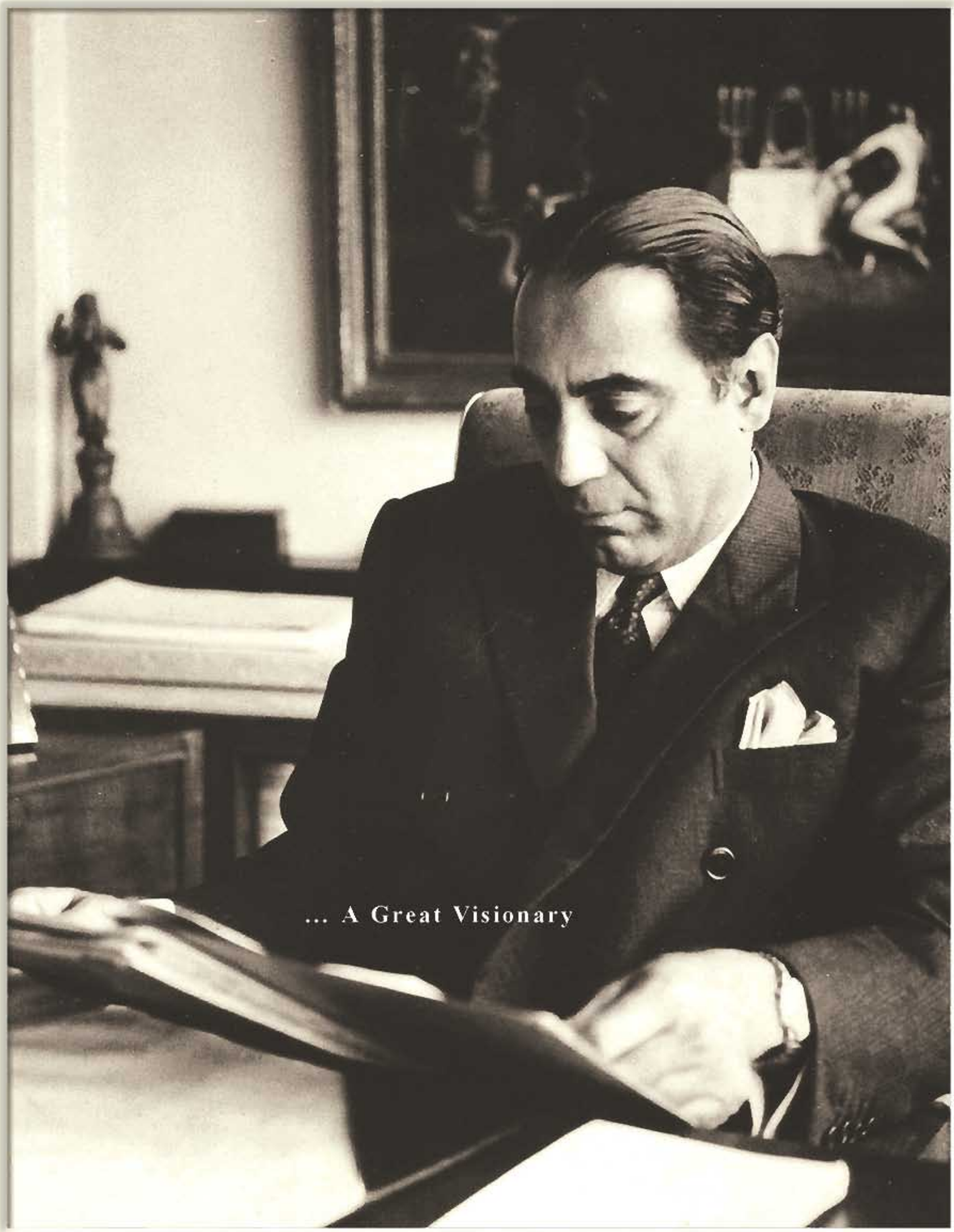
स्वर्ण जयंती वर्ष
GOLDEN JUBILEE YEAR
50
2006 - 2007



Dr. Homi J.Bhabha (1909 – 1966) Founder of Indian atomic energy programme

FORMER PRIME MINISTER PT. NEHRU IN APSARA

FROM DIRECTOR, REACTOR GROUP ....

The first Indian Nuclear Reactor went critical at 15.45 Hrs on Saturday, August 4, 1956 and this event marked the beginning of what is today acclaimed internationally as the success story of Indian Nuclear Programme. Later, on January 20, 1957, the reactor was dedicated to the nation and was named *"APSARA"* by then Prime Minister of India Pandit Jawaharlal Nehru.

The reactor was designed and built in record time entirely by Indian scientists and engineers. Apsara reactor has been a well-utilized facility and continues to support the education and research needs of the nation. It also laid the necessary infrastructure for nuclear research in basic & applied sciences and isotope production. Thus, Apsara truly served as the cradle for the development of nuclear technology in the country.

This brochure on APSARA is brought out to commemorate the golden jubilee year of Apsara, on August 4, 2006. The brochure contains a brief description of the reactor; its utilization and future plan for its up-gradation and life extension.

We also acknowledge with thanks contributions made in the form reminiscences from some of those who were closely associated with Apsara.

(A.C. Tikku)

SALIENT FEATURES OF APSARA

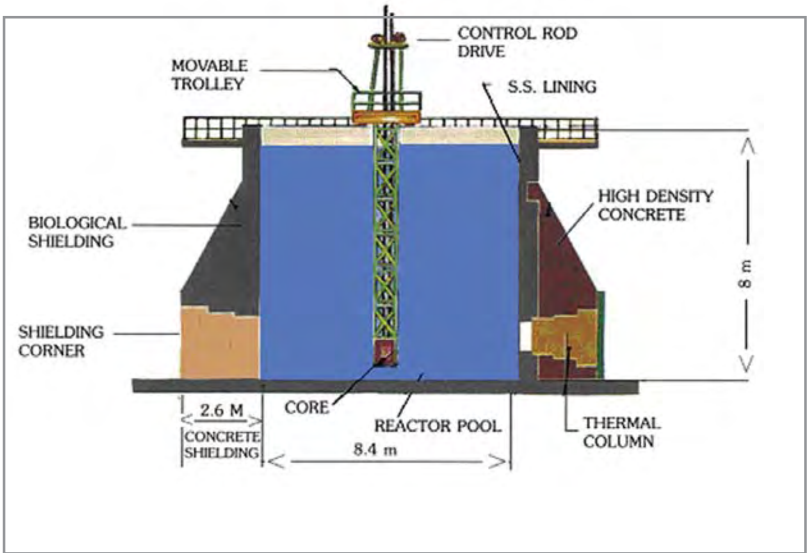
REACTOR TYPE	SWIMMING POOL
RATED POWER	1 MWth.
FUEL	HIGHLY ENRICHED URANIUM – ALUMINIUM ALLOY
FUEL ELEMENT TYPE	STRAIGHT PLATES
FUEL CLADDING	ALUMINIUM ALLOY
MODERATOR	LIGHT WATER
COOLANT	LIGHT WATER
REFLECTOR	GRAPHITE, BERYLLIUM OXIDE, LIGHT WATER
CORE SIZE	560 x 560 x 615 mm
MAXIMUM THERMAL NEUTRON FLUX	10^{13} $ncm^{-2}sec^{-1}$
CONTROL CUM SHUT-DOWN DEVICES	CADMIUM SHUT-OFF RODS
UTILISATION	➢ RADIOISOTOPES PRODUCTION ➢ NEUTRON ACTIVATION ANALYSIS ➢ NEUTRON INDUCED FISSION STUDIES ➢ FORENSIC RESEARCH ➢ BEAM TUBE RESEARCH ➢ SHIELDING EXPERIMENTS ➢ NEUTRON RADIOGRAPHY ➢ NEUTRON DETECTORS TESTING ➢ SEED IRRADIATION, ➢ RADIO-BIOLOGY RESEARCH ➢ HUMAN RESOURCE DEVELOPMENT

IMPORTANT MILESTONES

Decision to build the first nuclear research reactor in India	March 15, 1955
Ground breaking	May, 1955
Finalization of the design	July, 1955
Loading of the first fuel charge	July 30, 1956
First criticality	August 4, 1956
Reactor dedicated to the nation by The Prime Minister of India, Pandit Jawaharlal Nehru	January 20, 1957
Loading of second fuel charge	May 4, 1965
First charge of spent fuel shipment to UK	March 23, 1966
Reactor pool lined with Stainless Steel	June, 1970
Creation of central water hole in the core for neutron flux enhancement	July 1, 1982
Loading of third fuel charge	August 1983
Up-gradation of reactor control system	August 27, 1984
Second charge of spent fuel shipment to UK	December 29, 1990
PFBR shielding experiment (Phase I, II, III)	Dec. 1997 – Mar. 2003
AHWR shielding experiment	Apr. 2003 – Mar. 2004
AHWR two phase flow experiment	Oct. 2001 – Jun. 2003
PFBR shielding experiment (Phase IV)	Apr. 2004 – Aug. 2005
Five decades of successful reactor operation	August 4, 2006

THE REACTOR

Apsara is a swimming pool type of reactor loaded with enriched Uranium fuel. The core is suspended from a movable trolley in a pool 8.4 M long, 2.9 M wide and 8 M deep filled with de-mineralized light water. The pool walls are made of reinforced concrete 2.6 M thick up to 3 M height and thereafter tapering to 0.7 M thickness.



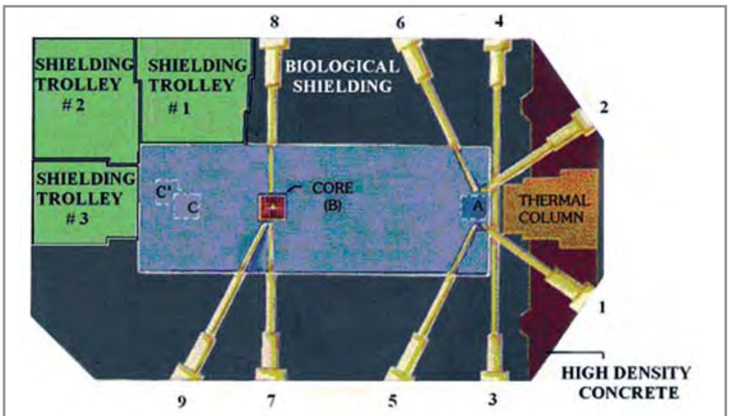
Sectional elevation of Apsara Reactor

The pool water serves as coolant, moderator and reflector besides providing shielding

As the core is mounted on a trolley, it can be moved to four different positions, 'A', 'B', 'C' and 'C-dash' (a newly created position). In position 'A' there are six beam holes and a thermal column, with five experimental channels [3]. In position 'B' there are three beam holes and a Standard Neutron Irradiation Facility (SNIF). In position 'C' facilities are provided for conducting shielding experiment. In this position on outside the pool there are three movable trolleys provided within the cavity of concrete wall, which facilitate installation and removal of experimental shielding assemblies. In the newly created 'C-dash' position, the reactor core can be brought nearer to the SS liner on the shielding corner side, thus reducing the water gap between the liner and core edge resulting in enhancement of neutron flux inside the shielding corner.

The reactor core is supported by an aluminum grid plate of 56 x 56 x 15 cm size with 49 holes on a 7 x 7 lattice containing fuel elements, control elements, reflectors, irradiation holes, neutron source and fission counter in the grid hole.

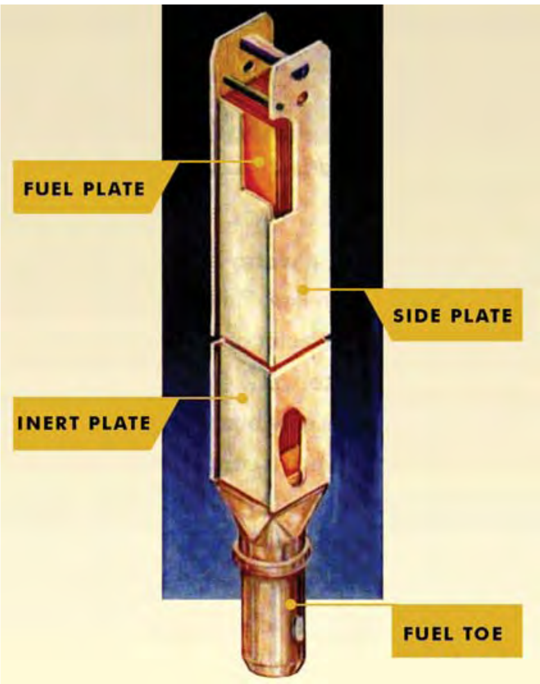
The fuel is in the form of alloy with ^{235}U enrichment limited to 93% w/w. Overall dimensions of fuel elements are 73 x 73 x 905 mm and a standard fuel element has 12 fuel plates. Each fuel plate consists of 0.5 mm thick Uranium Aluminum alloy meat clad with 0.5 mm thick Aluminum. Fuel inventory also consists of partial fuel elements having 10, 8 and 4 numbers of fuel bearing



Apsara Reactor Sectional Plan

Apsara Reactor Core

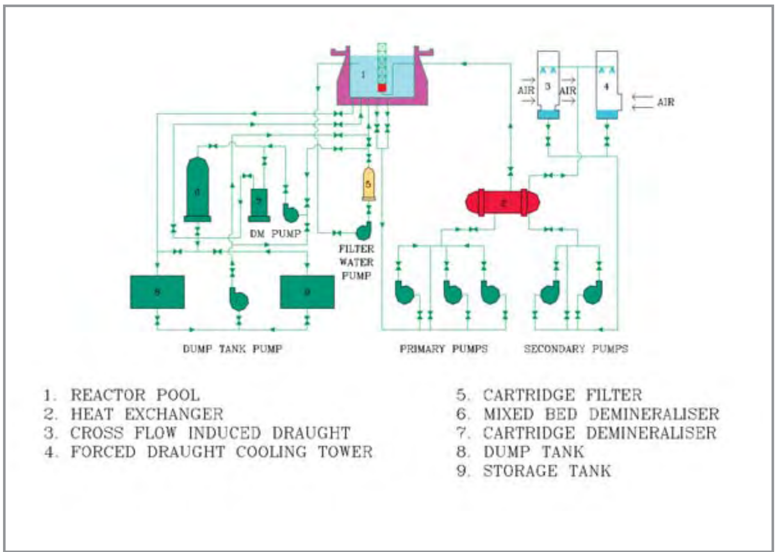
standard and control fuel assemblies to ensure adequate cooling. 10 plate partial fuel elements are provided with long Aluminum guide channels to accommodate control rods. Four Cadmium blades are used as control rods, of which three are for coarse control and are also used as accommodate control rods. Four Cadmium blades are used as shutdown devices. Fourth rod is used for fine power regulation. Drive mechanisms for control rods are located at the top of a movable trolley. The reactor has a primary and a secondary coolant system for the removal of heat from the core and subsequent release to atmosphere through cooling towers. The main function of primary coolant system is to provide adequate and un-interrupted cooling to fuel elements and other assemblies within the core. Thus the fission heat generated in core is transported and transferred to secondary system.



Apsara Fuel element

The chemical purity as well as clarity of the pool water, which comes continuously in contact with atmosphere and various structural materials, is maintained satisfactorily by online purification of pool water through filter and mixed bed ion exchanger.

The reactor is designed for a maximum power level of 1 MW_t operation and is normally operated up to 400 KW_t since most of the user needs are fulfilled at this power level. The average neutron flux available in the



Reactor Coolant System

core is of the order of 10[illegible] n/cm²/sec.

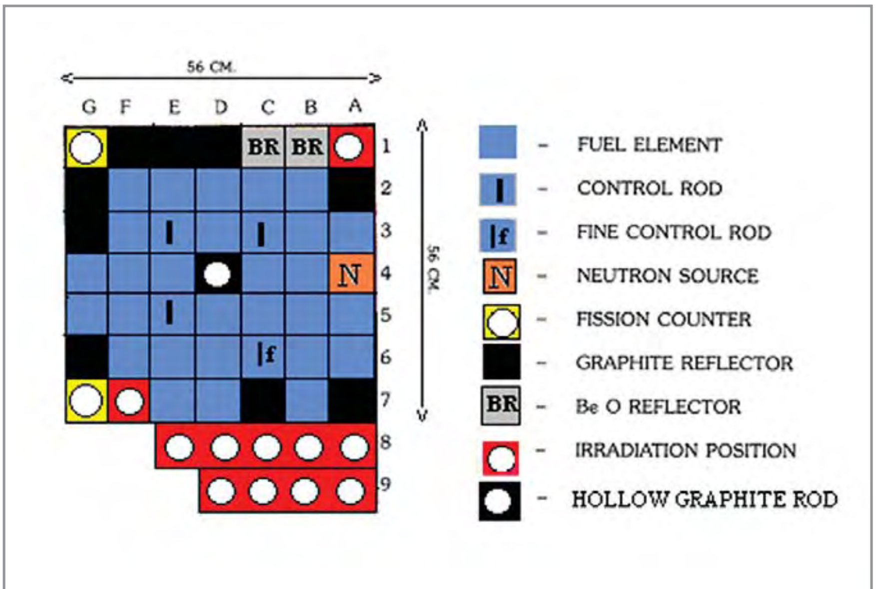
REACTOR CORE

Apsara reactor employs highly enriched ^{235}U as fuel with light water as moderator, coolant, reflector and partial shield. The existing core has 49 holes, arranged in a 7 x 7 square lattice pitch of 77 mm. The present fuel charge (reload-II) consisted of 34 fuel elements including control, partial and standard fuel elements with ~ 4.5 Kg of U of 93% w/w enrichment, 8-12 solid reflectors and a few isotope production tubes. A standard fuel element consists of 12 fuel plates with each fuel plate containing 12 gm of ^{235}U in the form of U-Al alloy. Two peripheral core positions are utilized to house fission counters. One position is used for housing an antimony beryllium neutron source for reactor start-up.

The average fuel burn-up till date is about 22-23% of the initial fissile content.

CORE MANAGEMENT & REACTIVITY CONTROL DEVICES

Reactivity control is provided by a bank of three shim control rods (RA, RB and RC) and a fine control rod (FCR). These rods are blade-type with 1.5 mm thick cadmium strips sandwiched in between aluminum plates and are moved up and down in the central water gaps (12 mm) of 10-plate control elements. All the three shim rods are normally moved manually as a bank; whereas the movement of fine control rod can be done on either manual mode or auto mode. Progressive core loading from center to outward positions (i.e, from more reactive positions to less



Typical Core Configuration

reactive positions) is adopted to

achieve the requisite core excess reactivity to cater to operational and burn-up reactivity loads for sustaining reactor operation for a reasonable period. The operational reactivity loads consist of xenon, temperature, isotopes & experimental assemblies. The fuel burn up load is caused due to fuel depletion and accumulation of fission products in the fuel. The maximum core excess reactivity for core configuration should not be more than 15 mk.

As an operational requirement, core sub-criticality, reactivity worth of control rods, operational reactivity loads, etc are often measured using standard methods after core loading changes. The reactivity control capability is designed to meet reactivity safety criteria for all operational and shut down states of any designated core configuration under most reactive core condition.

When sub-critical, the reactor will be either in Complete Shut Down (CSD) state or at Partial Shut Down (PSD) state. At CSD state, the three shim rods and fine control rod are fully inserted in the core. At PSD state, all the three shim control rods are withdrawn to 25 cm and fine control rod is at bottom limit. The difference in reactivity of theses two states of the reactor is normally more than 15 mk. Core loading changes are always carried out at PSD state. This ensures that during reconstitution of the core, adequate shut down margin is available.

REACTIVITY MEASUREMENTS

Two categories of reactivity measurements are done. In the first category, reactivity experiments to assess the worth of fuel elements, reflector elements, core sub-criticality, core excess reactivity, shutting down capability of control rods etc are carried out. Depending on the nature and magnitude of reactivity involved, the reactivity measurements are performed at one of the following three states of the reactor, viz., sub-critical state, critical state and super-critical state.

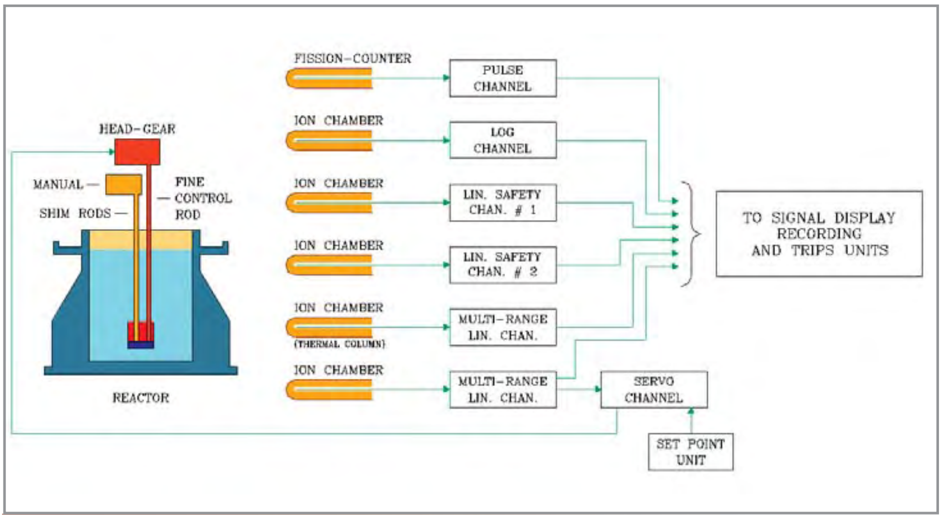
The second category of reactivity experiments dealing with core physics parameters includes measurements of void and temperature coefficients, xenon poisoning and fuel burn up rate.

Apsara Reactor Control Room

REACTOR REGULATION AND PROTECTION SYSTEM

The existing reactor regulation and protection system, is a single channel On/Off control system, and makes use of only Linear Power feedback. The regulating system comprises of the linear channel, servo channel and the fine control rod with drive mechanism. The reactor power output from the linear channel is compared with the demand power setting in the error amplifier in servo channel. When the error signal exceeds 1% of the demand power, depending on the error signal polarity, the servo amplifier actuates the rod drive mechanism to raise or lower the fine control rod. When the error reduces below 0.5%, the corrective action is stopped.

For reactor start-up and power monitoring from



Reactor Regulation and Protecion System

source range, fission counter based pulse counting channel is used, with the detector located inside the core. For power measurement in the operating region, a seven range linear DC channel and a six-decade Log channel are used.

Detectors for all the four neutronic channels are Boron coated Ion-chambers, which are located just outside the core on one side.

FUEL CHARGES

Apsara reactor has been loaded with three charges of MTR type fuel with varying uranium enrichment, the basic design of fuel remaining unaltered.

Based on operating experience with the earlier fuel charges an improved flat-plate fuel design was worked out for the third fuel charge. The structural and fuel cladding material chosen was an Aluminum alloy with small amounts of Mg, Mn & Cr for better irradiation stability, mechanical strength and corrosion resistance. Two outer inert plates were provided to protect the fuel plates from external physical damages during handling. The overall dimensions were kept unchanged to enable mixed loading with previous charge. The number of fuel plates and content of 235U in the fuel box were so chosen to have an optimum balance between reactivity gain and negative temperature coefficient of reactivity.

The third fuel charge consisted of thirty-four fuel elements with 4.5 Kg of 235U having 93 % enrichment. A standard fuel element consists of twelve fuel plates with each fuel plate containing 12 gm of 235U in the form of U-Al alloy.

Fuel Charges

	1ST Charge	2ND Charge	3RD Charge
No. Of fuel plates	13	14	12
^{235}U enrichment %	46	80	93
Fuel plate shape	Curved	Curved	Flat
Period of utilization	8.5 years	18.5 years	Since 1983
Burn-up	13 %	40 %	22.5 %
Fissile charge	4.7 kg	4.38 kg	4.5 kg.

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REACTOR UTILISATION

Apsara has been in operation for nearly five decades and used extensively for production of radioisotopes, neutron activation analysis, neutron radiography, fission physics studies, neutron beam research, neutron detectors testing, biological irradiations, shielding experiments and training of young scientists and engineers entering the field of nuclear science and technology.

Apsara is a versatile facility with flexibility of operating the reactor at four different positions facilitating different experiments with minimum radiation exposure. Horizontal beam holes, a thermal column facility and in-core and out-of-core irradiation positions and a Standard Neutron Irradiation Facility with fast neutrons are some of the research and irradiation facilities provided at Apsara.

Isotope Production

Production of radioisotopes started in the country with the commissioning of Apsara and appropriate isotope handling and processing facilities were designed and set-up in the Isotope laboratories. The experience gained at Apsara enabled in setting up a full-fledged Isotope production laboratory at Trombay. Prior to commissioning of Apsara these isotopes were imported mostly from U.K. and U.S.A.

Radiopharmaceuticals Laboratory at Trombay

Irradiation Facilities

Apsara core has 3 to 4 in-core positions for long term and short-term irradiation of target materials. In addition, nine positions are available just outside the core on one face for short-term irradiations. The availability of high fast flux component in Apsara reactor enables production of isotopes such as 32P by threshold reactions.

The irradiation container used in Apsara is made of 1S aluminum and is designed to enable sample loading and unloading operation in an easy manner. Each container can hold nine screw cap aluminum cans, each of which contains the actual target for isotope production. These small cans are arranged vertically by hooking them to an aluminum holder, which in turn, is fitted into the bigger container. The outer container containing the cans is made leak proof by a rubber O-ring seal. After irradiation, the samples are handled in a lead shielded isotope handling station located in the reactor hall.

Application of Radioisotopes

Apsara was extensively used for the production of 192Ir, 59Fe, 60Co etc. for industrial use, 32P, 45Ca, 35S etc. for agriculture use and 46Sc, 198Au for use in silt movement studies in harbours. In the early studies of silt movement in Indian harbours, 46Sc produced by the irradiation of large quantities of scandium glass mixture was used. Even in the sixties, APSARA was utilized as a source for sterilization of bandages, surgical instruments, sutures, etc. In addition, the reactor has been utilized for carrying out irradiation of biological samples, seeds, fungal spores, etc. for research studies.

Presently the reactor is mainly used for service irradiation of specific samples for universities and research institutions.

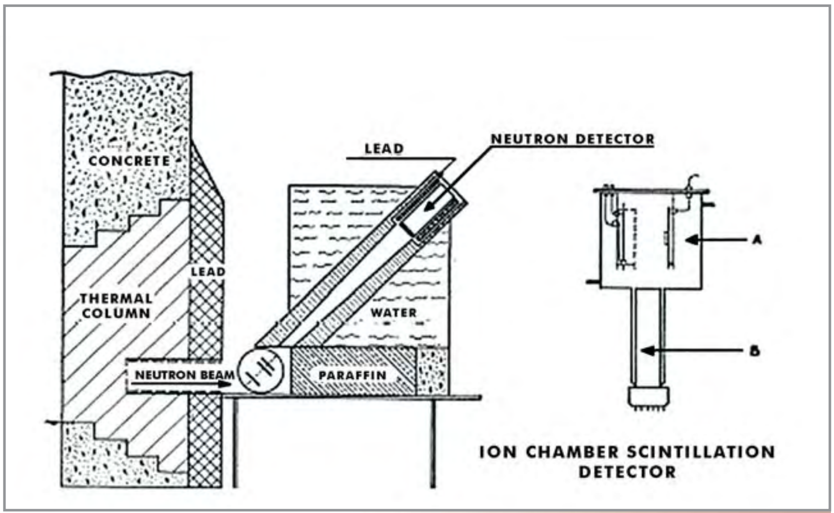
Fission Studies

In the area of basic research, studies on mass distribution in the neutron induced fission of actinides using radiochemical and gamma spectrometric techniques.

Neutron and Gamma Ray Emission Studies

Nuclear fission, which involves a complex dynamics of division of the nucleus into two parts, still continues to be one of the most interesting processes of collective flow of nuclear matter. This subject was extensively investigated utilizing the neutron beams from Apsara reactor. The reactor was utilized over the years to the studies of radiations emitted in thermal neutron induced fission reaction, such as prompt neutrons, gamma rays and long range alpha particles, mass and kinetic energy distribution of fission fragments and their correlations which have provided valuable information on mechanism and dynamics of the fission process. Among the first studies to be carried out was the energy and angular distribution of prompt neutrons emitted in the thermal neutron induced fission of 235U using Time-of-Flight (TOF) method.

In this study a gridded ionization chamber was used to measure kinetic energy and the angle of the fission fragments. The prompt neutrons were detected with plastic scintillators on a photo multiplier tube and kept at a distance from the chamber along the direction of electric field in the ion chamber. From the energy distributions in the laboratory system, the emission spectra of prompt neutrons from selected light and heavy fragments were obtained. It was shown that emission spectra from each fragment group are a superposition of the various evaporation spectra corresponding to a distribution of nuclear temperature. The angular distributions of the prompt neutrons of four different average energy with respect to light fragments have been determined. Analysis of these angular distributions showed that about 10% of the prompt neutrons were not emitted from the moving fragments. It was suggested that these neutrons are evaporated from excited fissioning nucleus during the saddle to scission transition in the fission process.



Experimental setup for fission studies

Emission of prompt gamma rays in the thermal neutron induced fission of 235U was also investigated utilizing the thermal beam of Apsara reactor.

In these studies the angular distribution of prompt gamma rays with respect to direction of selected light fission fragment was studied for two different gamma energy groups.

The measured value of anisotropy [N(0?)-N(90?)]/N(0?) for gamma ray energies greater than 180 and 510 KeV was found to be 14.9% and 12.2% respectively. The observed anisotropy indicated the presence of significant angular momentum of the fragments correlated with fission axis.

The prompt neutron emission study in fission has been continued in recent years utilizing better detecting systems, multi-parameter data acquisition system and more intense beams from Cirus reactor. In these later studies the measurements of the neutron emission spectra, neutron fragment angular correlations were carried out which yielded information on the post-scission, pre-scission neutron multiplicities; effective temperature and level densities as a function of fragment mass and total kinetic energy. The value of the pre-scission neutron multiplicity averaged over all fragment masses is found to be 0.25 ± 0.05 (about 10% of the total neutron multiplicity) again confirming the results of earlier studies.

The early studies utilizing Apsara reactor formed a base that was subsequently expanded to carry out exhaustive and comprehensive studies using better facilities in the form of more efficient detector setup and high intensity charged particle beams from Cirus.

Neutron Induced Fission

Radiochemistry Division, carried out exhaustive work on mass & charge distributions and fragment angular momentum studies in the neutron induced fission of actinides using reactor Apsara. Cumulative yields, independent yields and independent isomeric yield ratios (IYR) of a large number of fission products (with the half lives ranging from a few minutes to hundreds of days) have been determined in the neutron induced fission of 229,232Th, 232,233,235,238U, 237Np, 238,239,240,241Pu, 241,243Am and 244,245Cm using radiochemical and gamma ray spectrometric technique. These data were used to understand the nuclear fission mechanism vis-à-vis effect of shell closure proximity, odd-even effect and role of descent dynamics. The fission yield data in the fast neutron induced fission of 238U, 237Np, 238,240Pu, 243Am and 244Cm [6] are useful in the fast reactor calculations. Nuclear track-etch method was developed, standardized and being used to determine absolute fission yields.

Diffusion Kinetics of Fission Product Gases

The neutron irradiation facilities in the Apsara reactor have been of immense use in the experimental programme on the studies of release behavior of fission gases in irradiated fuel materials carried out in the Chemistry Division in the past few decades. These studies are required in analyzing fuel performance in normal and accidental situations of the nuclear reactor. The transport of inert gases and volatiles occur mainly by their diffusions inside crystal lattice and grain boundaries of the fuel matrix. For the use of any new fuel such as the thoria based ones for the Advanced Heavy Water Reactor (AHWR), which is being developed in India with the aim of thorium utilization in power generation, one needs reliable data on the diffusion coefficients of the fission product species at the reactor operating temperatures.

Among the various fission products the transport data of gaseous xenon and the corrosive volatiles, iodine and tellurium, in the irradiated fuel materials are immensely useful in the fuel-clad compatibility analysis. The measurement of the high temperature diffusion properties was accomplished by using Post Irradiation Annealing (PIA) technique. In analyzing the PIA results with highly sintered polycrystalline specimens, the grains were statistically fitted into spherical model normally used.

These are only a few examples that show the impact of fission studies at Apsara reactor and tremendous impetus given to the nuclear physics and chemistry research in India.

Fuel material	Burn up (fissions/m^3)	Temp.range (K)	Isotopes analysed
ThO_2-$U^{235}O_2$	$<10^{19}$	473-1523	Xe^{133}
ThO_2-$U^{235}O_2$	$2.0x10^{20}$-$2.0x10^{24}$	723-1323	Xe^{133},I^{131}
ThO_2-$U^{235}O_2$-Y_2O_3	$<10^{19}$	1173-1573	Xe^{133}
UO_2,UO_2-Y_2O_3	$5.9x10^{20}$-$2.5x10^{24}$	1273-1823	Xe^{133}
ThO_2-UO_2(AHWR)	$2.0x10^{20}$	1290-1790	I^{131},Te^{132}
AHWR Sim fuel	$5.4x10^{26}$(Simulated Burn up)	1273-1773	I^{131},Te^{132},Xe^{133}

A Brief Summary of Investigations on the Diffusion Kinetics of Fission Products in Different Sintered Fuel Materials

PIA set up for Xe release studies.

PIA set up for I/Te release studies

Neutron Activation Analysis

APSARA was the starting point of the development of this powerful analytical technique in the country. Apsara reactor has proved itself to be very versatile reactor with flexibility to handle odd size real life samples for analytical investigations. Apsara has also been extensively used for Neutron Activation Analysis for the determination of trace elements and for characterization of materials in a wide variety of matrices like geological, archaeological and environmental samples as also for high purity and nuclear pure materials, forensic exhibits and in industrial applications.

The activation analysis programme, in Apsara encompasses material sciences, earth sciences forensic, environmental sciences, life sciences and also archaeology.

Some of the materials are not amenable to direct activation due to the large activation cross-section, resulting in both high induced activity in the matrix and distortion of the flux seen by the elements in the bulk of the sample. This has necessitated pre-irradiation separation to remove the major and minor components with high cross-section. This approach has been used for characterization of Uranium and Thorium Oxide samples. One of the most powerful applications in the material sciences has been the characterization of ultra high purity silicon, with estimation of the elements at ppb and lower levels.

The Neutron Activation Analysis at Trombay has provided valuable information in respect of several elements, particularly rare-earth elements and also some precious metals like gold and platinum group of metals for studies in eartah sciences. Development in application of mathematical methods using multivariate approach have helped established the petrogenesis of samples like Basalt. This technique has also been used in the characterization of lunar samples and also meteorites. NAA has been applied to many types of rock samples ranging from Basalt to Granite, minerals like Zircon, Monozite, Apatite, Ilmenite etc and ore samples for the determination of a number of trace elements which are crucial for the geologists. Geological Survey of India laboratory at Pune regularly utilizes the Apsara reactor for the trace characterization of geological specimens. This NAA service has been made available to large number of researchers in academic institutions across the country.

In the area of forensic sciences, NAA has contributed in three major areas: a) Determination of specific elements in the case of toxicology, b) Determination of known group of elements, such as in case of ballistics, c) To establish the commonness of origin of samples collected from the scene of crime, with those collected from the suspect.

As for the application of NAA to environmental sciences are concerned, NAA of prawn and shrimp samples at Apsara helped establish the low levels of mercury in these precious sea foods obtained along the Indian coast, thereby allaying the unnecessary fears caused by some inaccurate results. The power of ANN of environmental samples is best reflected in providing the validation support to various groups using different analytical techniques.

NAA has contributed significantly in the area if life sciences. NAA has been successfully used in the analysis of tissues and body fluids to help understand the role / effect of trace elements in health and diseases.

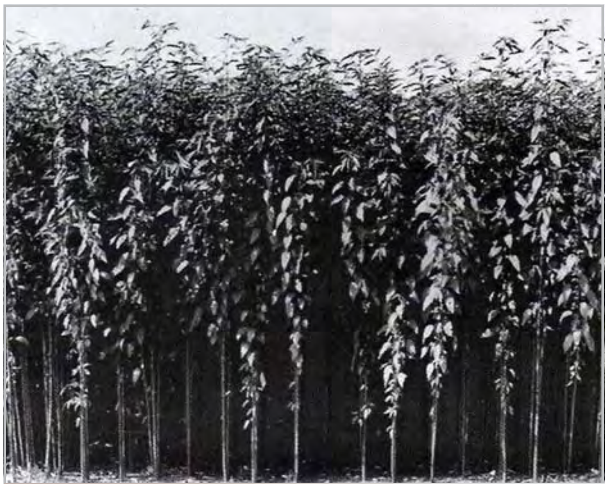
Beam Tube Research

The beam hole facilities at Apsara have been used for carrying out experiments such as thermalisation studies, total cross-section measurements, study of double Bragg effect, magnetic diffraction of simple structures etc. Development of neutron spectrometers, velocity selectors and control units were also initiated at Apsara.

Biological Applications

Irradiations of various biological samples like plants, seeds, etc were carried out in Apsara. The experiments carried out at Apsara in the field of biosciences relate to systematic studies on different biological crop plants and ornamentals. These include induced growth stimulation, relative biological effectiveness of radiation, post irradiation storage effects, role of induced radioactivity, combined effects of chemical mutagens & neutrons and spectrum & frequency of induced mutations. Many of these experiments and the subsequent ones initiated with the aim of inducing genetic variability led to the development of high yielding varieties both in food crops and pigeon pea and in ornamentals like portulaca.

In the early years of Apsara, the neutrons available for biological research were thermal neutrons and pile neutrons. One of the early publications dealt with the relative radio-sensitivities of twenty four agricultural crops to gamma rays and pile neutrons.



An Experimental Jute Field with Day-neutral Mutant Induced with Fast Neutrons

Since pile neutrons had gamma ray contamination and slow neutrons as well and because the neutron dose was expressed in terms of neutrons per sq. cm and gamma ray dose as rads, it was impossible to

Trombay Rice Variety "Hari" a Dwarf Mutant Induced with Fast Neutrons

make meaningful comparison of the effects of gamma rays and neutrons.

To get useful comparative data, it was imperative that the absorbed dose is measured in common unit. This became possible in the Apsara reactor with the installation of the SNIF (Standard Neutron Irradiation Facility) in the sixties. This facility cuts down gamma contamination to about 10% of neutron dose and absorbs slow neutrons. The fast neutron dose in the SNIF could now be measured in rads.

Destructive analysis of some elements in tissue samples by irradiation at the Apsara reactor were carried out employing thermal neutron activation analysis. A rapid and selective method has been developed and applied for determining elements present in normal, benign and cancerous tissues of human brain by destructive activation analysis. Elements are determined by irradiating the samples in Apsara reactor core at the required neutron flux and radio-chemically separating the isotopes of interest using sub-stoichiometric extraction and precipitation technique. The statistical evaluation of the method with respect to accuracy and precision of the method and its sensitivity were studied. The purity of the isotopes was verified by determining the gamma energy, beta energy and half-life of the separated isotopes, wherever possible and found to be pure.

Neutron Radiography

Neutrons are efficiently attenuated by only a few specific elements such as hydrogen, boron, cadmium, samarium and gadolinium. For example, organic materials, water, etc. attenuate neutrons because of their high hydrogen content, while many structural materials such as aluminum, steel are nearly transparent. Neutron Radiography (NR) is a non-destructive imaging technique for material testing. It is similar to X-ray and gamma ray radiography. NR can be effectively employed for imaging irradiated material where conventional gamma and X-ray radiography cannot be employed. Hence, NR has some special advantages in Nuclear, Aerospace, Ordnance, Rubber and Plastic industries. Information is obtained on the structure and inner processes of the object under investigation by means of transmission. In Apsara, the thermal neutrons from the reactor are collimated by divergent, cadmium lined aluminum collimator with a length/inner diameter (L/D) ratio of 90. A cadmium shutter facilitates the opening and closing of the beam. The specimen can be mounted about 60 cm from the collimator followed by a cassette containing neutron converter and X-ray film. The whole setup is properly shielded to avoid any radiation exposure to the operator.

The NR facility of Apsara has been used for variety of applications in nuclear, aerospace, defense and metallurgical industries. The facility has been extensively used for recording neutron radiographs of:

- Experimental fuel elements,
- Water contamination in marker shell loaded with phosphorous,
- Electric detonators,
- Satellite cable cutters and pyro valves
- Boron-aluminum composites,
- Hydride blisters in irradiated zircaloy pressure tubes,

Neutron Radiographs of various objects taken with Apsara NR Facility

- Variety of hydrogenous and non hydrogenous materials and
- Two-phase flows in metallic pipes.

Neutron Detector Testing

From the very inception, thermal column and the core dry tubes were extensively used for testing various types of neutron and gamma detectors as a part of research and development programme in that area. The type of control instrumentation tested in Apsara facilities included fission counters, linear power range monitors, intermediate range monitors, self powered neutron detectors, ion chambers and reactor regulation instrumentation for our research and power reactors.

Detector Type	Sensitivity
High sensitivity B-10 lined proportional counter	17 cps/nv
In-core Boron lined proportional counters	0.15cps/nv & 1 cps/nv
B-10 lined proportional counters - Seven cathode assembly	5.5cps/nv
B-10 lined proportional counters - Three cathode assembly	10 cps/nv
B-10 lined proportional counters - Baffle structure	0.8 cps/nv

Detectors Tested by Electronics Division in Apsara

Gas filled neutron proportional counters are extensively used over a wide range of application such as flux and area monitoring, fuel activity measurement, study of nuclear reactions, residual activity measurement of nuclear waste, measurement of cosmic radiations and material studies using neutron scattering techniques. SSPD, BARC, is involved in indigenous development of gas filled signal detectors and position sensitive detectors (PSDs) for X-rays and neutrons. Continuous efforts are made towards improvement of detection techniques to carry out the experiments efficiently. Various types of detectors developed are 3He and BF3 filled signal detectors, linear 1D single anode PSD, 1D and 2D multiwire PSDs, curvilinear PSD and a microstrip based PSD.

High Sensitivity B-10 lined counter and In-core Boron Counter

Detector Type	Meant for	Use	Testing Location
Un-compensated Neutron Ion Chambers	235 MWe& 540 MWe reactors	For reactor control and safety in the range of 10^4 to 10^{10} nv	Thermal column hole No. 5
Compensated Neutron Ion Chambers	TAPS # 1 & # 2 (PRM)	For reactor control and safety in the range of 10^4 to 10^{10} nv	Thermal column hole No. 5
Source Range Monitors	TAPS 1 & 2	For the measurement of in-core neutron flux in the range of 10^3 to 10^8 nv	Thermal column hole No. 5
Intermediate Range Monitors	TAPS 1 & 2	For the measurement of in-core neutron flux in range of 10^6 to 10^{10} nv by using Campbell technique	Thermal column hole No. 5
Miniature Fission Chamber	TAPS 1, 2 & TAPP-4	For the measurement of in-core neutron flux	Thermal column hole No. 5 & Dry tube
Traveling In-core probe - Miniature Fission Chambers	TAPS 1, 2 & TAPP-4	Measurement of in-core neutron flux for calibration of LIQHs and SPNDs, etc.	Thermal column hole No. 5 & Dry tube
Self Powered Neutron Detectors (SPNDs)	500 MWe PHWR	In-core neutron flux mapping	Dry tube
Source Range Monitors – Miniature Fission detectors	AHWR critical facility	Reduced neutron sensitivities (10^{-4} cps)	Thermal column hole No. 5

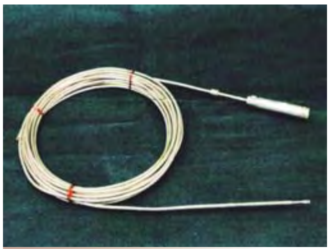
Testing of ECIL Detectors in Apsara


Un-compensated Neutron Ion Chamber


Compensated Neutron Ion Chamber

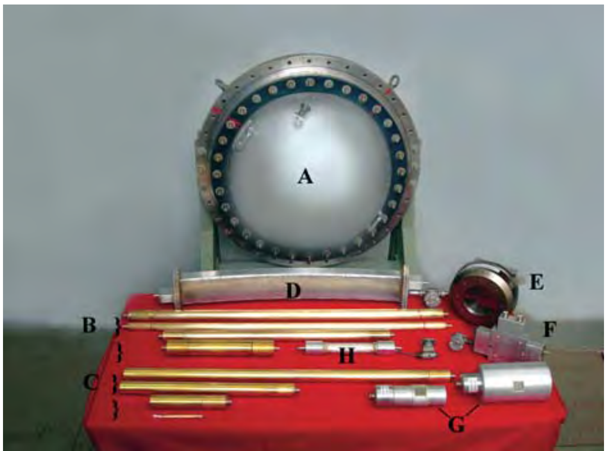

Miniature Fission Chamber


Source Range Monitor


Intermediate Range Monitor


Self Powered Neutron Detector

Such detectors mounted on spectrometers and other counting instruments show excellent operational characteristics and stability over long periods. Various types of neutron detectors developed by Solid State Physics Division and tested at Apsara are shown in figure. The linear PSDs used in neutron experiments are high-pressure 3He filled chambers, having an efficiency of 60% to 93%. Suitable stopping gases are mixed with the 3He gas for reducing intrinsic position resolution.



Various types of neutron and X-ray detectors developed by Solid State Physics Division at Apsara

A : 2-D Position Sensitive Neutron Detector,
B : 1-D Position Sensitive Neutron Detectors,
C : Neutron Proportional Counters,
D : 1-D Curvilinear Position Sensitive Neutron Detector,
E : 2-D Position Sensitive X-ray detector
F : Microstrip Detector for X-rays and Neutrons,
G : X-ray Proportional counters,
H : 1-D Position Sensitive X-ray Detector.

Shielding Experiments

Evaluation of radiation shielding in any reactor project is a difficult exercise because it involves large attenuation, flux anisotropy, complicated geometry and wide energy range for both neutrons and gammas. Theoretical estimates are generally carried out using codes based on neutron transport theory or Monte-Carlo methods.

In transport calculations, errors may occur due to modeling and numerical methods used for solving transport equation. The transport calculations are sensitive to uncertainties in cross section data.

In any shielding calculation scheme, the uncertainties due to modeling approximations and nuclear data are taken care of by using suitable bias factors (BF) obtained from experimental measurements. The ratios of measured to calculated reaction rates corresponding to parameters of interest are called bias factors. The BFs are used as multipliers in the exit flux from a shielding set up. Over-conservatism of BF leads to cost penalties and under estimation may result in serious radiological problems.

Analysis of large number of benchmark problems is carried out to assess the uncertainties due to cross section data and numerical methods. Apart from these, mock-up experiments are carried out prior to detailed shield design for the proposed shield configuration, to obtain bias factors and to optimise the shield.

A Typical Arrangement of PFBR Shielding Experiments at Apsara

Experiments were carried out in Apsara shielding corner facility to study the shielding adequacy of Dhruva beam hole gate, steel ball and water filled model for end shields of Pressurised Heavy Water Reactors.

Bulk shielding and radiation streaming experiments were carried out in Apsara to optimise shield design of Proto Type Fast Breeder Reactor (PFBR) being built at Kalpakkam and Advanced Heave Water Reactor (AHWR) being developed at BARC.

The shielding corner at Apsara was extensively used for these experiments, which were carried out during the year 2000 to 2005. Apsara reactor was operated at various power levels of 4 Kwth, 40 Kwth and 400 Kwth for a total of about 1500 hours amounting to about 13 MWD reactor operations. In all about 3000 activation detectors were irradiated and measured data analyzed to get various reaction rates of interest and neutron spectrum.

Shielding Corner Facility with AHWR Shield Model on Trolley

Advanced Heavy Water Reactor (AHWR) end shield design has penetration of various sizes and shapes in the form of cylindrical ducts, angular ducts, and spiral and stepped ducts. Experiments were also carried out using various shield models to optimize end shield design of AHWR. were helpful to solve problem of resin-ingress in the tube sheet region of Dhruva reactor.

Studies on Radiation Stability of Reactor Materials

Apsara reactor has been gainfully utilized for studying the physico-chemical behaviour of materials used in the chemical control of nuclear reactors. Solution of Gadolinium Nitrate, which is used as a soluble neutron poison in shutdown systems of reactors, have been irradiated to study its stability to radiation and deposition on Zircaloy surface under reactor conditions. The studies generate useful data for application in the design of our power reactors. In another experiment, irradiation of slurries of ion exchange resins was carried out at high radiation doses to understand the changes in physical and chemical properties of the irradiated resins. Results obtained from irradiation experiments

Studies on Chemical Consequences of Nuclear Transformations in Solids

A detailed investigation of Szilard and Chalmers Process in several cobalt complexes consisting of hexadentate, bidentate, monodentate compounds has been carried out, using 'Apsara' for thermal neutron irradiations. Effects of post irradiation thermal treatment in air, nitrogen, vacuum, and also electron accepting and electron donating ambient gases, as well as the effect of hydration in de-hydrated samples, etc. have been investigated on the re-combination of the recoiled species in the matrix to give the parent compound.

The results of this series of studies were explained on the basis of variable depth electron trapping isotope exchange model and the exciton induced exchange mechanism. These studies were recognized internationally and this group of researchers was referred as "Trombay School of Recoil Chemistry Studies". It may be mentioned that some special irradiations at –78° C for 1-3 minutes were done using dry ice cooled samples to experimentally prove that inherent retention of recoiled species in the parent form could be as low as 4%.

Some studies were also carried out on the chemical effects induced by nuclear isomeric transition of bromine [80m Br(1-T) 80 Br] in hydrocarbon solvent matrix. Liquid bromine sealed in pyrex/quartz ampoules was irradiated in 'Apsara' and used in these studies. These studies were greatly facilitated mainly because of relative ease with which one could get the thermal neutron irradiation of the samples done irrespective of the sample shape and size.

Radiation Damage Studies

Radiation damage studies due to fast neutrons were initiated in seventies. Initially recovery studies of metal like vanadium were undertaken after irradiation with fast neutrons. Both third and fifth stages of defect annealing were studied, using resistivity recovery. These irradiations were carried out initially in special positions so that metal samples were in contact with the water of the core. Some electron microscopy studies of fast neutron irradiated vanadium, (fluence of 1019 ncm2) were also carried out.

Later on recovery studies of tungsten, A-203 steel, zircalloys after fast neutron irradiation were also carried out. In later period, radiation damage studies of dilute alloys of vanadium, with 2% Nb, 1% Al, V + 2% Ca, V + 2 % Zr etc. were completed using fast neutron irradiation in Apsara. These studies showed that radiation damage recovery was affected by the presence of these impurities and depended upon the binding energy of impurity with the vacancies created by fast neutrons. These studies also demonstrated that it was the oxygen impurity, which was migrating at 170° C to radiation-induced defects.

Some diffusion studies of impurities in Al, Zr and Zircalloy-2 were also undertaken. For this purpose, the diffusing material was first irradiated in Apsara, to get some concentration of required isotope of the species. Later on this irradiated impurity was deposited on to the metal in evaporation unit. Useful results have been obtained from these studies.

Radiation Hardness Studies

A specially designed liquid scintillator test module filled with BICRON liquid BC-517L was exposed to fission energy neutrons at the shielding corner facility of Apsara, to test the radiation hardness of the liquid. The aim was to study possible pressure build up in the closed container due to radiolysis of the liquid. In fact after the irradiation was over, it was observed that an excess pressure of 0.5 atmospheres had built up inside the container. Many inorganic scintillating crystals and glasses like Barium fluoride, Gadolinium silicate, Curium fluoride, lead glass, lead tungstanate etc. were studied. These studies provided valuable information on the behaviour of these crystals in a high radiation environment like a high luminosity collider.

Bio-kinetics of Uranium and Thorium

Materials such as uranium and thorium are extensively used in our nuclear programme. Because of their radio-toxic nature, it is essential to know the harmful effect if they are inhaled or ingested. Towards this, a reliable and sensitive analytical method using neutron activation followed by radio-chemical separation was developed and applied to the determination of the concentration of uranium in human tissues, body fluids, total diet, air and drinking water samples in relation to the population groups from natural back ground areas as well as those occupationally involved with uranium and thorium processing. The data thus generated were employed to determine the bio-kinetic parameters of uranium and thorium such as the gut-absorption factor, retention half-lives in various organs, the excretion ratio etc.

Estimation of Trace Levels

The method for trace level estimation of plutonium in urine involves the separation of trace plutonium from bulk urine sample, electro deposition of plutonium on a suitable backing and estimation of plutonium by alpha spectrometry. This technique has a sensitivity of 0.5-1.0 mBq for estimation of plutonium. In order to comply with the ICRP recommendations, the detection limits has to be 0.34 mBq for class M type plutonium compounds and 0.038 mBq for class S type plutonium compounds. There is a need, therefore, to have a method to estimate plutonium at ultra trace levels. A method has been developed and standardised based on fission track registration in Solid State Track Detectors (SSNTDs) for the estimation of ultra trace levels of plutonium.

Test Facility in Apsara Reactor Hall

Radiotracers in Chemical Separations

Apsara reactor has also been used extensively for preparation of several radioactive tracers. Various radioisotopes are produced for use as tracers in chemical separations. Radiotracers like 131I, and 51Cr were produced, and used in developing separation procedures. Radioactive tracers of several rare earths and uranium have been used to study the solvent extraction behavior using several extracting agents. Radiotracer of Iodine (131I) was used for measuring the ion-exchange sites in membrane samples and uptake of iodine.

Flow Visualization and Void Fraction Measurement in Two Phase Natural Circulation Loops

Void fraction plays an important role in the calculation of two-phase flow parameters like pressure drop, flow pattern, etc. In two-phase natural circulation loops, the driving force for flow is provided by the buoyancy force, which in turn depends on the void fraction. In such loops, since the magnitude of the driving force itself is low, an accurate knowledge of the void fraction is required for the estimation of the flow rate.

Flow pattern transition instability studies were carried out in Apsara by constructing a loop similar to the geometry of Advanced Heavy Water Reactor (AHWR) coolant circuit. The loop was located in Apsara reactor hall and the measurements were carried out at different pressures ranging up to 85 bars and heater section power varying from 1 to 10 kw. The neutron radiography facility available at beam hole No. 6 in 'A' position of the reactor was utilized to visualize the flow pattern and also to measure the void fraction which is an important parameter causing the flow pattern transition. The void fraction measured by the neutron radiography and electrical conductance probe were compared with various correlations. The neutron radiography method is capable of giving cross-sectional average besides axial and radial variation of the void fraction.

Quality Assessment of BPR using Apsara Reactor

Burnable Poison Rods (BPR) consist of material with high absorption cross section. The quality of these rods was tested against their reactivity effectiveness in sub-critical state of Apsara reactor. The reactor was made sub-critical by 1 mk with all control rods at top limit by carrying out required loading changes. The central D-4 location of Apsara core was utilized for inserting the BPRs for measurements. A graphite block along with a housing tube for placing the BPR was specially designed to get accurate results.

Experimental Validation of Reactivity Meter

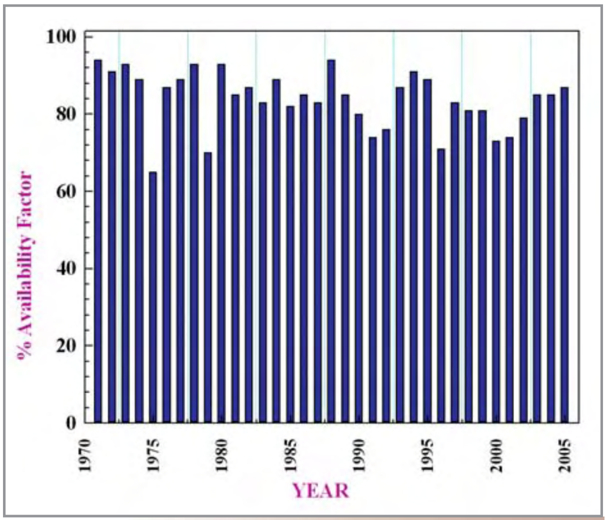
Experimental validation of core reactivity meter based on Kalman filtering technique was carried out with the core reactivity variation at sub critical level, around criticality and power level operation. Reactivity estimated using Kalman filter based reactivity meter compares well with the reference reactivity obtained from the extent of absorber rod position inside the core.

Training

Apsara reactor is suitable for imparting training to fresh scientists because of its' simplicity. Science and engineering graduate trainees of BARC Training School are given basic training in Apsara for reactor start up, operation and shut down. This is done through a well-structured lecture cum hands-on training programme.

OPERATING EXPERIENCE

Apsara reactor has been in operation for 50 years. Initial trial runs at the rated power level of 1 MW had shown high gamma radiation field (140mR/hr) on reactor top with the coolant flow in upward direction through the core. Reversing the direction of flow resulted in high radiation field on coolant pipelines and the heat exchanger. Hence, the reactor power was limited to 400 KWt for research and isotope production. The reactor was operated on round-the-clock basis till 1988. With the operation of Cirus and commissioning of Dhruva resulted in enhancing the facilities for research and isotope production.



Availability factor of Apsara during the operation years [1971-2005]

Subsequently, Apsara rector was operated on single shift basis at 200 KW on working days. Reactor had an excellent record of operation with an average availability factor of over 80%.

Apsara has been refueled twice, apart from the initial fuel charge in its 50 years of operation. First and second charges of fuel were obtained from United Kingdom. Forty-three out of forty eight elements of first charge were shipped back to the supplier in 1966 in two shipping flasks. The second charge fuel elements along with five fuel elements of first charge were shipped in 1990 in a special shipping cask to United Kingdom. The third charge consisting of 34 fuel elements of 93% enrichment supplied by France is presently in use since August 1983. Fuel handling operations are carried out by qualified and trained manpower. Maintaining appropriate chemistry of the reactor pool and underground storage tank water over the last five decades has resulted in no failure of fuel. Some of the important modifications carried out over the years are covered as under:

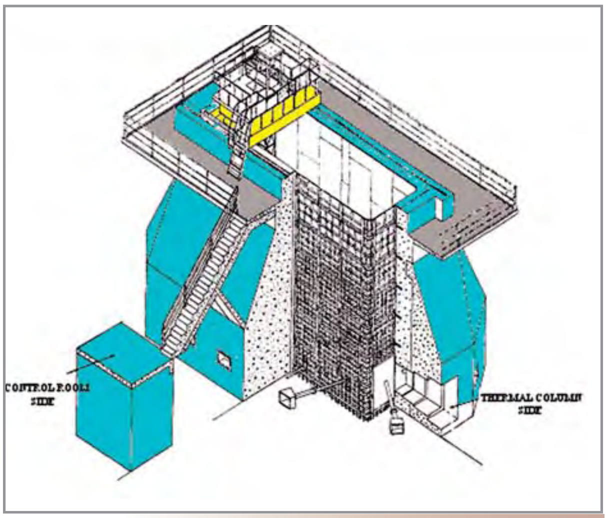
Removal of Delayed Tank

During the initial stages of Apsara operation three delay tanks were provided in primary coolant system to reduce radiation field due to Nitrogen (16N) activity on the coolant pipelines and heat exchanger. The delay tanks were removed from the system to prevent frequent shutdowns for repair work. The primary coolant flow direction was also reversed. This has helped in bringing down radiation field on primary coolant pipeline and equipments and also the manrem consumption.

Metal Lining of Apsara Reactor Pool

Shortly after the commissioning of the reactor in 1956, operation of the reactor was affected on several occasions due to increased leakage of pool water. In June, 1958 the pool was internally painted to reduce the leakage but with little success. In September, 1960 the pool water leakage went up to 2000 gallons per day. Repairs to the pool were carried out by gunniting and plastering. This could arrest the leakage temporarily only since in the later part of 1964 the leakage had increased again to about 900 gallons per day. Pressure grouting and epoxy painting were carried out on the walls of the pool in January 1965. Temporarily the leakage rate came down to 250 gallons per day. However, leakage rate showed an upward tendency in March, 1967 and reached a maximum of 3600 gallons per day by the end of June, 1967. Radiotracer studies and dye penetrant tests were carried out to locate the leakage path. Pressure grouting and epoxy painting were done on the pool floor and walls respectively. This brought down the leakage rate to less than 100 gallon per day. With reactor being operated at 400 kW, the leakage rate started showing an increasing trend. The leakage rate increased from a value of 400 gallons/day in May, 1968 to reach a maximum of 3900 gallons/day in January, 1969.

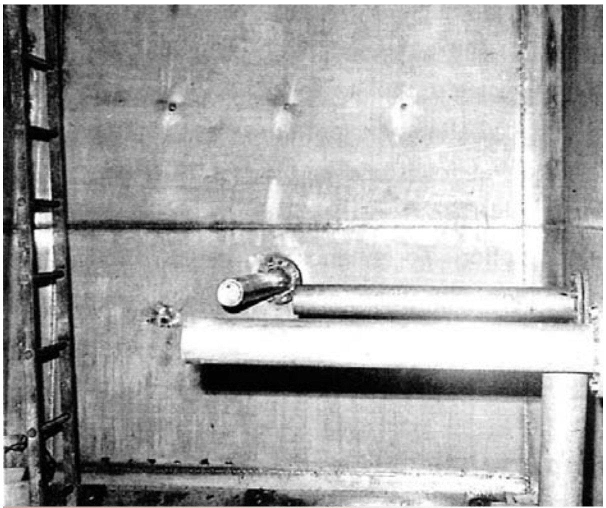
Operation of the reactor at this rate of leakage became extremely difficult and hence the reactor was shutdown for repair work. Since arresting leakage by pressure grouting, gunniting etc. was not successful and could not be guaranteed, it was decided to metal line the pool. Aluminium and Stainless Steel (SS) were



Cross-section of lined pool

The walls of the liner are constructed of 1/8" thick stainless steel sheet and the floor of ¼" thick plate. A mild steel framework with grillwork was developed to hold the metal sheet against the walls and to provide a means of vertical welding of wall sheets.

A view of reactor pool wall during lining work showing the Back-up Carbon Steel framework anchored to concrete



Shielding corner view of the pool SS lining with Beam hole # 10 & 11

The framework was separated from the wall by about 2" to enable to fill the space between the liner and the existing pool wall with concrete. Stainless steel penetrations were welded to the liner using gusset plate beam hole penetrations. This method enabled installation of the liner over existing penetrations. A system of drain channels was provided on the concrete floor beneath the liner to collect any leakage, should it occur. Water collects in these channels, drains out of the pool to the main liquid waste disposal system.

At the shielding corner end, it was decided to run the stainless steel lining over the aluminium panel since the termination of the stainless steel lining at the shielding corner aluminium panel end was difficult to carry out with assurance of leak proof ness because of dissimilar materials. Two additional beam holes (Beam hole # 10 & 11) were provided at this end as shown in Fig 2.3 and were subsequently removed for the creation of [C-dash] position.

Wall expansion joints were not provided for the liner as the calculations indicated that it was not necessary. The strain gauge measurements after lining confirmed this view

At the thermal column side, Stainless Steel was unacceptable because of attenuation of neutrons. Hence Stainless Steel liner was terminated at the thermal column opening with suitable provision for bolting an aluminium plate through a neoprene gasket.

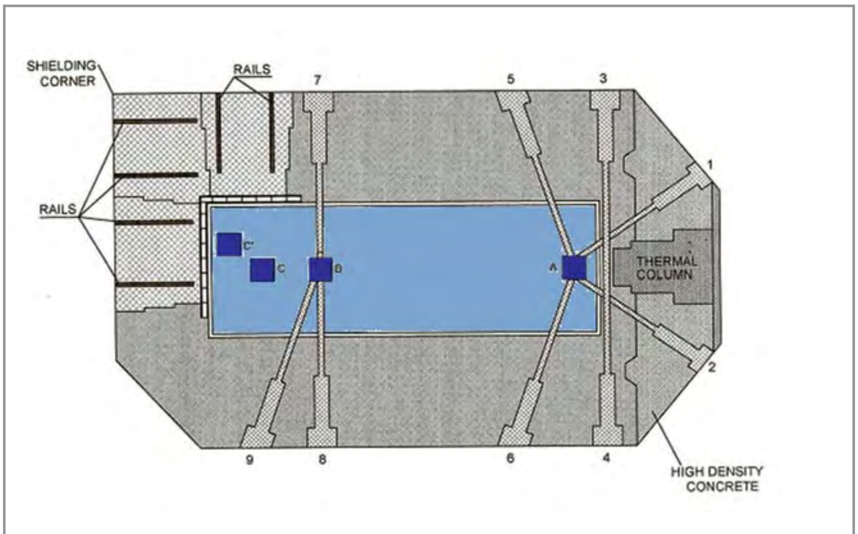
After evolving an accurate method of determining changes in pool water inventory, the pool has remained leak tight and no corrosion in the pool has been noticed.

Thermal Column Gasket Replacement

Thermal column facility provides thermal neutrons for testing of source range monitors and irradiation of specimen samples. To minimize the loss of neutrons through the S.S. liner at thermal column area, a 3.2 cms thick aluminium plate is bolted to the carbon steel frame embedded in the concrete with a elastomer gasket for leak tightness. Due to radiation damage to gasket material, periodic replacement of the gasket is done. Till date the thermal column gasket has been replaced four times. During replacement of TC gasket in 1985, the gasket material was changed from neoprene to ethylene propylene considering radiation stability and longevity.

Modifications in Apsara Shielding Corner

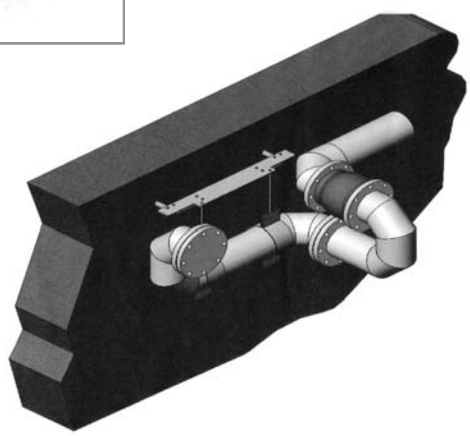
In the beginning, Apsara reactor core could be operated at three different positions in the pool namely 'A', 'B' and 'C' as per the requirement of the type of experiments.



Sectional plan of Apsara Reactor

At the 'C' position, located at the farther end of the pool, an experimental facility known as the shielding corner is provided. In this position an aluminium panel replaces the concrete wall, which is a composite structure of 25.4 mm thick aluminium plates and channel spaces. An SS liner plate of 3 mm thickness welded over MS channels is provided over the aluminium liner plates. Framework along with Al and SS liner plates has an overall thickness of 232 mm. The panel is shielded by cement concrete blocks mounted on three trolley structures, which run on rails embedded in the reactor hall floor. The above said facility is used to study the shielding properties of different materials and also for other nuclear physics experiments. When this facility is not in use, the concrete blocks on three trolleys are moved up to the panel for shielding this side of the pool.

As the distance of the liner from the core in 'C' position was around 4 feet, it resulted in reduction in thermal flux availability in the shielding corner due to absorption of neutrons by the water column. To enhance the neutron flux in the shielding corner, in December 1976 it was decided to establish a new core position called [C-dash]. Towards this, the core was moved closer to the liner and shifted off center. Due to the presence of 6" coolant pipeline by the side of the core assembly, the core could not be moved to the maximum (nearer to the liner). Because of this the water gap between the liner and core was maintained at 400 mm and the core was moved off center by 215 mm with coolant water connection.



Modified coolant pipe at C-dash position

The above arrangement resulted in enhancement of thermal neutron flux in shielding corner to the order of 107 n/cm2/sec. Reactor Physics Section (ERPS), BARC, carried out testing of R-5 gate assembly and NAPP shielding experiments in [C-dash] position.

In late 1990, a proposal to mock up the in-vessel radial shield configuration for Prototype Fast Breeder Reactor (PFBR) in Apsara shielding corner was approved. The thermal flux needed for this experiment at the shielding corner was 1010 n/cm2/sec-1, while maximum thermal flux at shielding corner with reactor in [C-dash] position was 107 n/cm2/s-1. In order to enhance the thermal flux, the water gap (40 cm) between the core and the liner was to be reduced. As this could not be done by moving the core nearer to liner because of the presence of coolant pipe line, it was decided to place a hollow aluminium box of 36.5 mm thickness with lead counter weight between the core and liner. The box was suitably designed and fabricated to take care of beam hole projection on the liner and also to ensure smooth movement of the flapper operating mechanism.

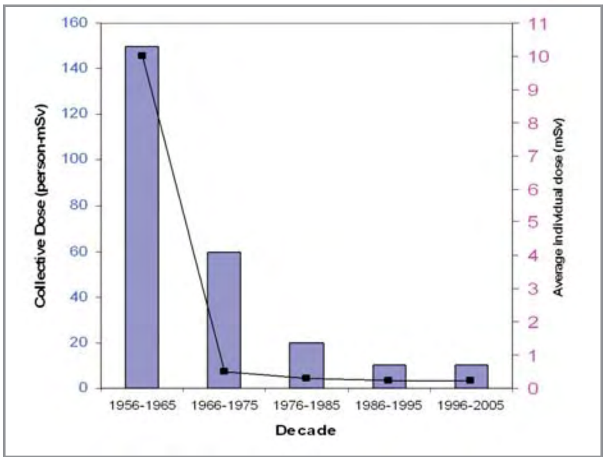
As the core had to be frequently moved to and from [C-dash] position, the spool piece had to be manually handled for connecting it to coolant header. This resulted in consumption of more time and manpower. After ensuring that the cross trolley of the reactor core can be suitably moved in both the directions to and from [C-dash] position, the spool piece was permanently fixed and connected to the coolant header. This resulted in considerable saving of manpower and time.

Creation of a Water Hole Position in the Core Center

In 1982, for enhancing the thermal and fast neutron flux for an irradiation position, a water hole in the core center was created in D-4 position. The thermal neutron flux could be increased by a factor of about 4 and the epithermal neutron flux by a factor of about 2 as compared to the corresponding values at core boundary. This facility was though well utilized, is presently occupied by a hollow graphite rod (with hole of 20 mm inner diameter in center) thus providing the flexibility of operating the reactor for different research experiments without frequent core configuration changes.

Replacement of the Core Grid Plate

First core grid plate of Apsara was of dimension 560 x 560 x 55 mm made of 1S aluminium. Replacement of first grid plate, which has seen a neutron fluence of 1020 nvt, was done during the long outage during 1970 along with the metal lining of the pool. Swelling of aluminium at this low fluence is much less. Tendency of saturation in tensile property of 1S Aluminium beyond a total fluence of 1021 nvt was noticed in Cirus. Since Apsara grid plate has seen a much less fluence, deterioration of mechanical property of grid plate was not anticipated. However, replacement of grid plate was necessitated due to mechanical damage during fuel element handlings in reactor core. Replaced grid plate has seen about 25 years of operation and subjected to twice



Collective and Average Dose for the Period from 1956 to 2005

the neutron flux seen by the old grid plate till now. During the proposed core refurbishment jobs, the grid plate will be replaced with modified core design features.

Radiation Hazards Control unit was set up by Health Physics Division, BARC right from the commissioning of the Apsara reactor for radiation protection of the personnel in and around the reactor building as its major responsibility. Trained health physicists are attached to the plant to implement the radiological protection measures.

Reactor Type	Pool type
Reactor Power	2 MWth
Maximum Thermal Neutron Flux	6.0×10^{13} n/cm^2/sec
Fuel	LEU (19.75 % w/w U^{235}) U_3Si_2 dispersed in Al
Fuel Element	Plate type
Loading Density of U in Meat	3.67 gm/cc
Coolant	Light Water
Moderator	Light Water
Reflector	BeO
Control Element Material	Hafnium
Experimental / Irradiation Facilities	Beam tubes Irradiation positions (In-core and reflector region) Thermal column Shielding corner

Salient Design Features of the Reactor

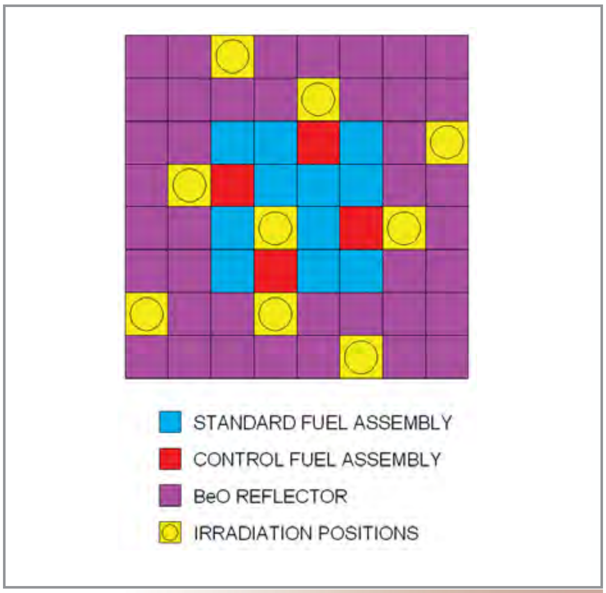
APSARA UPGRADATION

Since the reactor has been in operation for 50 years, it is planned to carry out extensive refurbishment of the reactor so as to extend its useful life and to upgrade the systems in line with the current safety standards.

As a part of up-gradation, it is also planned to replace the existing HEU fuelled core by a LEU fuelled core designed to operate at a higher power of 2.0 MW(th) so as to enhance the maximum available thermal neutron flux to 6 x 1013 n/cm2/s. With enhanced neutron flux, the radio-isotopes that are currently produced in Cirus reactor can be produced at Apsara as and when needed. The refurbished reactor will thus provide enhanced facilities for studies related to material irradiation, shielding studies, neutron detector testing etc. and also facilitate production of isotopes for applications in medicine, industry and agriculture.

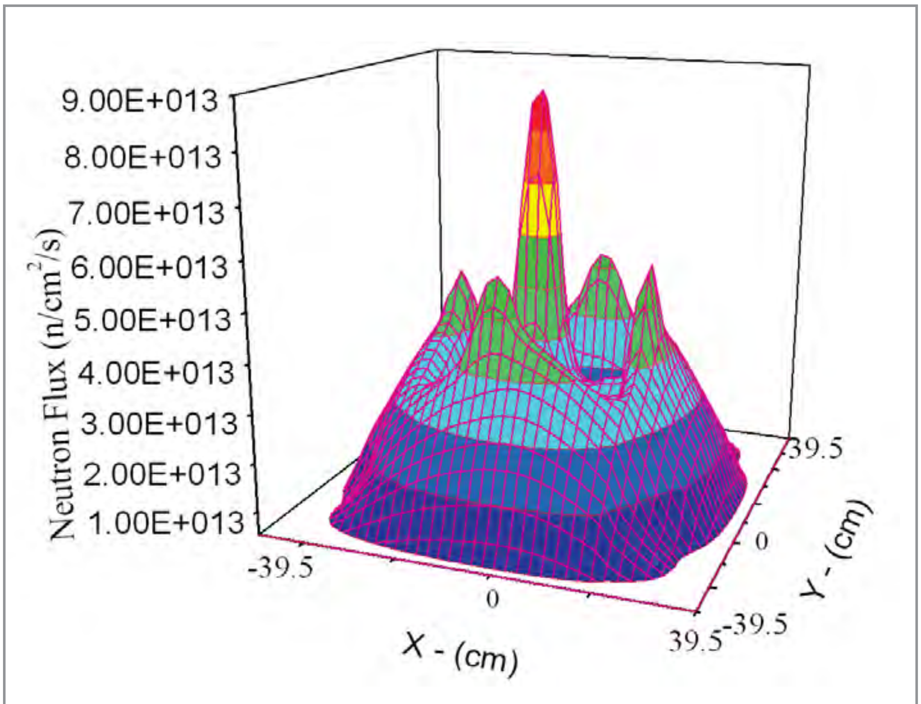
Reactor Core

The core of the upgraded reactor will be mounted on a grid plate having 64 positions arranged in 8 x 8 square array at a lattice pitch of 78.5 mm. The reactor core consists of 11 standard fuel assemblies, 4 control fuel assemblies and one water hole for irradiation/experiments. The core is surrounded by BeO assemblies which act as the reflector. 8 irradiation positions are located in the reflector region. The core configuration is as shown below.



Upgraded APSARA Core

The upgraded Apsara reactor will have improved thermal neutron flux of 1.0 x 10 13 n/cm2/s at beam tubes, 6 x 10 13 n/cm2/s in-core irradiation position and 3 x 10 13 n/cm2/s at irradiation positions in the reflector region. The upgraded reactor will have 10 times higher fast neutron flux as compared to Cirus & Dhruva. The flux distribution is shown below.

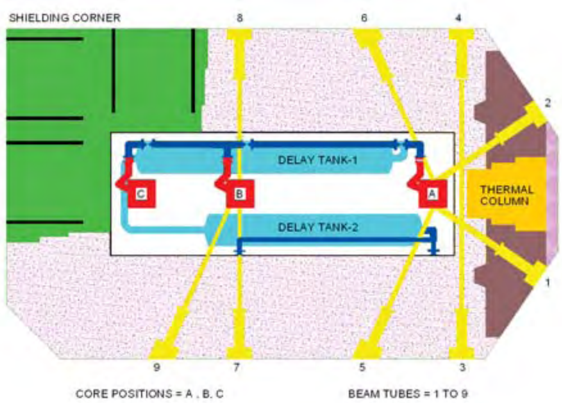


Thermal Neutron Flux Mapping for 2 MWth Apsara Core

The upgraded reactor will be fuelled with U3Si2-Al dispersion fuel with enrichment limited to 19.75 % w/w U235. The standard fuel assembly has 16 fuel bearing plates. The control fuel assembly is similar to the standard fuel assembly except that the central three plates are removed for locating the absorber blade made of Hafnium. The fuel meat is 0.70 mm thick and is clad with 0.45 mm thick aluminum. The water gap between the fuel plates is 2.5 mm.

Core Structure and Pool Block

The reactor core structure of the upgraded Apsara will be housed in the existing pool block. The reactor core structure consists of a grid plate and coolant outlet plenum connected at the bottom of the grid plate. The grid plate locates and supports the fuel and control assemblies, the BeO & Graphite reflector and irradiation assemblies. The core structure will be suspended from the movable trolley located at the pool top. An access opening provided in the movable platform facilitates fuel loading & unloading and handling of irradiation/experimentation assemblies. An auxiliary platform mounted above this platform supports the control rod drive mechanisms. The movable platform also supports actuating mechanism for natural circulation valves.



Reactor block plan view

Primary Coolant System

The reactor core is cooled by pool water drawn through the core from top to bottom. The coolant from the core outlet is led to delay tanks before joining the pump suction header in the process equipment room. The delay tanks are sized to provide adequate delay to permit N-16 activity to decay sufficiently to reduce the radiation field in the process equipment room. The delay tank is located within the reactor pool such that it is adequately shielded on all sides. The heat picked by the primary coolant from the reactor core is transferred to the secondary coolant using a plate type heat exchanger provided at the pump discharge. The cold water from the heat exchanger outlet is returned to the pool.

Control & Instrumentation

Control and Instrumentation For reliable neutronic power measurement and protection from source range to power range, neutron detectors and associated electronics, working on diverse principles and having sufficient redundancy, have been used.

For reactor start up, pulse channel with Fission Counter detector is used. For power measurement and protection in the normal power range, Log-Linear channels and a Multi Range DC channel are used. There are two independent safety channels for the protection system. All these channels use Boron coated Ion Chamber detectors.

Four plate type Hafnium assemblies with higher worth, called shim control assemblies, are used for reactor protection as well as for coarse control of the reactor power. On a reactor trip signal, electro-magnetic clutches de-energize to drop these rods by gravity. For power regulation, they are driven up or down under manual control. Fine Control Rod, having lower worth, located in the reflector region of the core is used for the fine control of the reactor power.

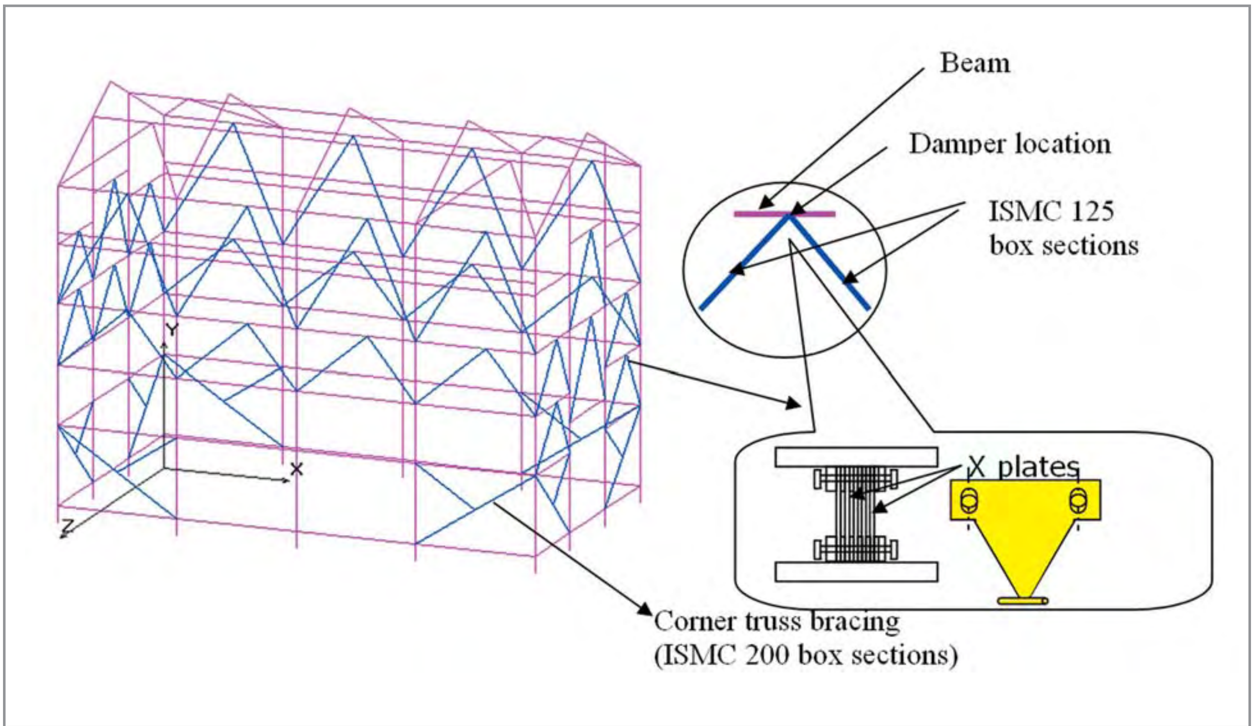
The Reactor Regulating System is a computer based system, which receives the neutronic power and the demand power signals and generates a signal to move the Fine Control Rod up or down, through a stepper motor drive. Proportional control is employed in the upgraded reactor, instead of the ON-OFF control used in the existing Apsara reactor.

LIFE EXTENSION OF APSARA REACTOR BUILDING

Apsara reactor building was constructed in 1955, using the codes that were in place at that time. The building is a reinforced concrete frame structure with un-reinforced brick masonry and glass in filled panels. The brick in-filled panels are not designed to carry any load. However, in the event of an earthquake they attract forces due to their own mass. To ensure safe and continued availability of the existing structure while meeting the current codes and guides it was felt necessary to re-evaluate the structure as per the guidelines laid out in IAEA-TECDOC-1347. A detailed seismic analysis of the structures along with a retrofit scheme using elasto-plastic dampers was carried out to demonstrate that the building frame along with the foundation meets the present seismic design requirements.

The structure was modeled and analyzed for dead load, live load and earthquake load. Soil structure interaction was considered by incorporating soil springs at the base of the structure.

The seismic analysis of Apsara reactor building revealed that it was necessary to strengthen the structure, especially the footings. Since the structural strengthening of the footings is not feasible due to site constraints, structural retrofitting using a combination of elasto-plastic dampers and corner truss bracings of ISMC 200 box sections has been proposed. The truss members will be provided at the four corners as braces, in order to reduce the



Finite Element Model of Apsara Building and Arrangement for Dampers

moments in the corner columns. Elasto-plastic dampers will be provided in the frames and the connections of the dampers with the beams and columns of the structure will be made using ISMC 125 box sections. The beams on the north wall (Truck Entry side) will be retrofitted by carbon fiber wrapping with epoxy bonding. The retrofitting of masonry walls is suggested using any one of the three different materials namely, Carbon Fiber Reinforced Polymers, Stainless Steel Strips or Welded Wire Mesh.

Non-destructive examination of the concrete of Apsara building is planned for generating the material data. The tests to be performed include Impact Hammer tests, Corrosion Rate tests, Core Sample tests, Ultrasonic Pulse Velocity tests, etc. Shake table tests on Apsara reactor building model are planned with and without dampers at Central Power Research Institute (CPRI), Bangalore. Static and cyclic testing is also planned on the dampers in order to obtain the force displacement characteristics. Testing on walls with different strengthening schemes is also planned. The retrofit scheme for the building will be implemented after successful completion of the planned tests.

Reminiscences

DR. P.K.Iyengar
Former Chairman, AEC

In the early years of atomic energy, almost all countries built natural-uranium, graphite moderated, gas-cooled, reactors, to start with. However, in the early 50s, enriched uranium was available in plenty and the technology was freely available to build the pool-type, enriched uranium, light-water reactor for research purposes.

Thanks to Dr. Homi Jehangir Bhabha's friendship with Sir John Cockcroft of the UK Atomic Energy Authority, he was able to obtain the fuel for the swimming-pool reactor, since Harwell was also building a similar reactor. Since the amount of enriched uranium required was small, there were no restraints on its supply. Bhabha decided that the civil works, the shielded pool, and the control system must be designed and built in India. No regulatory authority existed at that time for the approval of the design. In fact, it was rumoured that the approach to criticality of the Apsara reactor was indeed unconventional. It went critical on 4th August 1956. But soon, a leak of light water from the pool was detected, and hence some repairs had to be done before the power could be raised to 100 kW. Subsequently, SS cladding was provided to the pool, to contain the leaks in the concrete shield.

Mr. A.S. Rao, then an electronics expert who helped Bhabha in his cosmic ray balloon flights, was asked to take charge of the design and fabrication of electronic systems. I recall how a handful of electronics engineers designed and built the control system, including the detectors, for the Apsara reactor. Looking back, the control system of Apsara went through several cycles of improvement, keeping up with the progress in electronics, from vacuum tubes to transistors and computers. The fact that we are celebrating fifty years of Apsara is a testimony to the continuing development in our infrastructure, to design and engineer the basic requirements for the nuclear programme.

Apsara provided a neutron flux in the range of 1012 neutrons/cm2/s, a relatively large flux compared to any small accelerator or radioactive neutron source, though small compared to other reactor sources. This provided to us physicists an excellent opportunity to plan a series of experiments in neutron physics and nuclear physics. Scientists from the Physics Group, BARC, and TIFR, were engaged in building equipment and in carrying out many experiments using the neutrons. At this flux, isotope production became feasible, and hence both, the Radiochemistry Group and Isotope Group, produced a number of radioisotopes by neutron capture, and developed practical applications using them. The reactor provided an excellent opportunity to train engineers in the operation and maintenance of the reactor, which was the beginning for our expanded nuclear energy programme. My interest was in using neutrons for neutron diffraction and inelastic scattering. Since 1958 we *were engaged in developing neutron diffractometers and triple-axis spectrometers, and used them to obtain valuable data in condensed-matter physics, even at that low flux of 1012 n/cm2/sec. It however helped to plan the instrumentation for the CIRUS reactor, which was commissioned in 1960, and produced a neutron flux of 1013 n/cm2/sec. By 1964 we were able to build a series of neutron equipment around the CIRUS reactor, and this enabled us to establish an internationally competitive research group in neutron scattering.*

Thus, Apsara laid the foundation for training of scientists, engineers and the infrastructure for reactor technology. The fact that we have continued to use this reactor for fifty years, with considerable innovations in its technology and use, shows what a developing country can achieve in a short time.

Those who participated from the initial criticality, through the developments, feel grateful for the bold decision of Dr. Homi Bhabha to design, build and operate a nuclear reactor for the first time in Asia, east of the Suez Canal. I also remember that this reactor was an attraction for many of the VIPs from many countries around the globe. Visits of people like Chou en Lai, Marshal Tito, Abdul Nasser, come to my mind. It was Pandit Nehru, along with the Commission Member, Dr. K.S. Krishnan, who named this reactor Apsara, seeing the beautiful Cherenkov radiation that could be seen in the pool.

Shri. S. D. Soman

Former Chairman, AERB

During 1955 and early1956, it was decided that our first research reactor to be built at Trombay would be swimming pool type. Design was proceeding in various aspects, control system was being done by Electronics Division (Mr. A.W. Periera) & Civil Engineering Division (Mr. V.T.Krishnan) was looking after construction. Shielding being safety related was assigned to health physics, headed by Mr.A.S.Rao. I took up the work & calculations were done by slide rule. Dr.Vishwanathan of Theoratical Physics Division was to oversee my calculations. The work was completed in a month's time. Then in May1956, I proceeded to Kerala for the study of high background radiation in that area.

Then in July 3rd week, I got a message to rush back. On returning, I was asked to proceed to Trombay and from 1st August, the health physics work related to source handling, fuel handling etc. was being attended to. The pool was not in finished form; hence water was not clear, posing difficulty in fuel loading. Some of us were there for whole day, Col. Menon of IRE made excellent arrangements for food and sleeping etc. Dr.Bhabha used to come every day and personally oversee the experiments leading to criticality, which was achieved on 4 th August, 1956 at about 3.45 PM. It was operated for about 15 minutes, during which radiation surveys were carried out. In the control room, all those present were asked to sign.

The shielding and other design were for a maximum power of 1 MW. Within one month it was operated up to 400 kW.

Reminiscences

Shri. M. S. R. Sarma

Former Chairman, SARCOP, AERB

Apsara Reactor, when critical just a few days after a group of us (19 persons) joined DAE on July 16, 1956. This was the first reactor in this part of the world and it was certainly a matter of great pride for the nation, with newspapers beaming headlines "India enters nuclear age". We have certainly come a long way. Although it was a small reactor, it has contributed its mite towards initiation and further progress into the nuclear programme. It was an exciting site to see Cherenkov Glow. It was from this reactor that the general safety programme of DAE had evolved. The first safety diktat from Dr. Bhabha was on handling radioactive source "That the practices should not cause harm to any worker or anyone else, but the practices should be such that the other organizations in the country would be asked to emulate". Similarly, with regard to keeping the reactor in a shutdown state, the practice used to be to take out one fuel element out of the core and place it in the pool as an abundant caution. The occasion of criticality was in the presence of all the stalwarts starting from Dr. Bhabha, Shri N.B.Prasad, Dr. A.S.Rao and others. Shri P.N.Arumugam, (who is no more) was the first Reactor Superintendent. He was a committed worker, spending days and nights at the reactor site and on one occasion Mr. Allardice, who was the Controller, visited the site and made a remark about Shri Arumugam's attire. Shri Arumugam's reply was, "I am here to do the job which I am doing, all other matters at the moment are inconsequential". He became the Planning Engineer of PPED and contributed immensely towards indigenization programme spending days and nights in the manufacturer's shop. Subsequently he joined BHEL and instilled the concept of quality into that organization.

Shri S.K.Chatterjee was the next Reactor Superintendent and he retired as MD, NPCIL. Dr. A.S.Rao, (subsequently taken over by Dr. A.K.Ganguly), headed the first Safety Committee. These were pioneers in Safety. At that time the safety reports used to be called as Hazard's Evaluation Report. This is how the nuclear industry was its own "Devil's Advocate". It is this kind of terminology like "Criticality"; "Maximum permissible concentration" and such other phrases that created a scare in the minds of the general public.

I was involved more closely when I took over as Planning Engineer. There used to be weekly meetings for scheduling irradiations as well as for clearing the proposed experiments. These were in a small way for the production of isotopes as also to conduct experiments in relation to Nuetronics.

It is most gratifying that APSARA has served for 5 decades, which is far more than what was envisaged at that time. It has been a steppingstone to the frontier technology.

I am very happy that the Golden Jubilee Celebrations are planned and I also feel proud of my association during the initial stages with Apsara.

Reminiscences

Shri. T. K. Rao

Former Director, NPCIL

My association with Apsara was from the year 1965 to 1987, while in ROD, BARC. 1987 to 2002, till my retirement on super annuation, I was working in NPCIL and retired as Director (Corporate Planning). I use this opportunity to share with you some of the interesting memories of Apsara.

1. Moon rock Sample Irradiation in Apsara:

All samples for irradiation are needed to be cleared by Apsara Programme committee, considering several aspects like safety of the reactor, the chemical composition, the mechanical integrity of the samples etc. as per set procedures. Apex committee consisted of S/Shri N. Veeraraghavan (NVR), H.Ranganathan (HR), and Reactor Superintendent etc among others. Shri S.Sankaranarayanan and I used to substitute NVR & HR respectively at a times. As the moon rock sample chemical composition was not known, we could not clear this sample for irradiation. The main aim of irradiation of moon rock was precisely to know the chemical composition of the moon rock. The committee could not resolve this CATCH-22 situation. As per the procedures, this was referred to the main committee. But they could not decide the matter and took this case to Head, ROD; Shri S.M.Sundaram (SMS). Since he also could not come to a conclusion, it was decided to irradiate the moon rock sample in presence of SMS, NVR & HR among all of us on top of Apsara pool. The irradiation took place successfully, like any other sample. A nice experience indeed!

2. Apsara Pool Lining:

Originally, Apsara pool was of concrete construction, and had developed cracks and the pool used to leak. Several attempts were made to arrest the leakage by pressure grouting and other means but without any success. It was decided to line the pool with metal sheets. Initially, it was decided to line it with Aluminium sheets and the sheets were even procured. Soon after, literature survey of other pool linings in the World revealed that Stainless Steel (SS) is preferred to aluminium as liner material. Hence, it was decided to line the pool with Stainless Steel Plates. SS Plates were procured on war footing and the lining of the pool was carried out. At that time, it was the practice that all jobs like design, preparation of drawings, procedures, and execution were done purely as divisional activity. It was an involved job with the co-ordination of various sections of the then ROD and other divisions as well. There were many interesting events, which are lengthy to narrate here, but I cherish to remember.

Reminiscences

Dr. M. R. Iyer

Former Head, RSSD, BARC

My memories of Apsara reactor go back to early 1958, when BARC was known as AEET. After successful operation for more than an year, round-the-clock shift operation and production of radioisotopes were commenced in Apsara during 1958.

During the initial period of reactor operations, various important areas of experiments were carried out using Apsara facilities such as solid state physics investings by Dr. P.K.Iyengar, Shri G.Venkataramani, Smt. Usha Iyengar and Shri V.P.Duggal, angular co-relation studies on fission fragments by Dr. R.Ramanna, Shri P.N.Rama Rao, Shri B.R.Ballal, fission studies by Dr. S.S.Kapoor and Dr. N.Sharma, engineering loop experiments by Shri Krishnaswamy and Nageswar Rao, Dr. A.K.Ganguly, Dr. D.V.Gopinath and myself also various experiments for gathering Health Physics data. Thus Apsara was a cradle of all experimental activities in those days. Several other investigations and studies were also carried out during my stay at Apsara like initial experiments on plutonium reprocessing, fission product activity studies, Sodium24 leaching to reactor coolant, development of chemical dosimeter and studies on organic coolants.

Shri. Ram Sarup

Former Senior Shift Engineer, TAPS, NPCIL

Being one of the early batch of Supervisors recruited to get trained and operate the first research reactor, Apsara I had the opportunity to get involve in various well defined operational procedures, adherence to safety procedures and monitoring & maintaining important parameters within stipulated values. Some of the important events which come to my mind includes production of radioisotopes for the first time and mutation studies carried out on several varieties of rice during 1958, transportation of first charge of used fuel to UKAEA during 1964 and the first criticality with the second charge of fuel during 1965. The name 'Apsara' a water nymph, given to the reactor by Pandit Jawaharlal Nehru seemed to be appropriate and my wish to see the Apsara was realised in one night shift way back in 1958. May be a dream or hallucination, I could see her in the bright Zerenkov glow of Apsara reactor, all alone at 3 AM, thus vindicating the name given by the first Prime Minister.

Shri. K. P. Mani

Former Operation Engineer, Apsara

When I look back to the years that I have spent in Apsara, some of the important activities and aspects that come to my mind include the modification of control system during 1988, design and fabrication of new reactor trolley in 1959, the non destructive neutron activation analysis experiments carried out by Dr. Sankar Das at Apsara shielding corner, the exemplary dediction to the job shown by Dr. Taylor, from U.K. who was In-charge of isotope production, and the leadership quality and the discpline shown by Dr. Bhabha, Mr. E.C.Allardice, then Controller and also the guidance provided by researchers like Dr. A.K.Ganguly. The experience gained and the lessons learnt from such persons will always be remembered.

During the early commissioning and operation of the Apsara Reactor, as a shift in charge of the Reactor, we had two identity cards. One for the general entry to Atomic Energy Establishment Trombay (AEET) and the other special Blue coloured identity card exclusively for the operation and maintenance staff that permits entry inside the control room and the top platform of the Reactor. The importance of security concept was well understood and strictly adhered to from the very beginning.

The Reactor Trolley was redesigned and a new one was fabricated in the Apsara Reactor hall in the year 1959. The drawings were made by Mr. S.H.Divekar and were approved by Mr.Meckoni. The fabrication of the Trolley was carried out under my supervision and along with me were Mr. Sadiq Ali, welders and fitters.

Shri. A. V. Pandit

Former Operation Engineer, Apsara

I had the unique distinction of serving Apsara for 3½ decades of entire service in BARC. During those eventful years, I had the opportunity to participate in many important operations including a number of difficult situations and their appropriate solutions. Some of the important issues which I recall includes water leakage from Apsara pool during the initial period with various attempts to stop the leakage, lining of Apsara pool with stainless steel 304L, popping up of a control fuel element by 10 cms in 1967 leading to the installation of locking device for the control rods and retrieval of the entrapped aluminium handling hook and the core cleaning device with fully indegeniously developed tools. Stainless steel lining of the pool ensured the leak tightness of the structure for 3½ decades. The reactor has excellent record of operation with an efficiency of 80% over the past 50 years.

The expertise developed by the Apsara operation staff greatly helped in resolving many tricky underwater handling problems peculiar to a swimming pool type reactor like Apsara.

Shri. S. F. A. Bauksh
Former Operation Engineer, Zerlina

On the occasion of the 50th anniversary of Apsara reactor, I would like to mention the an incident, that is still fresh in my memory.

It was a Sunday, at about 11 A.M., Dr. Bhabha along with Mr. M.F.Hussain, the famous painter and a reputed architect of the time visited Apsara. Dr. Bhabha explained to them about the reactor. Then he requested them to sign in the visitor's book, and asked me to give the book for signing. As I could not locate the book after repeated search and saw the people waiting for the book, I handed over another readily available book and obtained their signatures.

Thereafter, Dr. Bhabha proudly took the book and while searching for the other pages of the book told them that the book had the signatures of people like President Nasser of Egypt, Marshel Tito, President of Yugoslavia etc. But he was not able to find those signatures on the pages of the given book. He was very angry, asked for my identity and went out with the visitors.

Within half an hour, the then Reactor Superintendnet, Mr. Banerjee informed me that the book had been sent for binding and asked me how I did not know about it! Then he told that Dr. Bhabha wanted that the page on which the dignitories have singed to be removed and pasted on the original book.

In the original book those signatures can be seen to have been pasted over.

Shri. M. George John
Former Shift-In-Charge, Apsara

My association with Apsara was for the period from 1958 to 1961 as part of the first operation group formed to operate this first atomic reactor independently. When I look back to the eventful years in Apsara; I recall many events out of which two of them are quoted here as under –

(i) I still have vivid memories of the first major maintenance of the reactor in 1960, which was mainly to reduce the leakage of pool water. All the fuel assemblies were transferred in special lead flasks to the R.C. bay in Cirus. During the transport of one of the control elements, the top attachment of the flask broke while the transporting truck was near the Cirus end. I was at the Cirus end looking after the fuel transfer and decided to transfer the fuel flask back to the Apsara pool for inspection of damages for which I was initially criticised (and appreciated later). The strange incident was that the radiation level at the driver's seat was less than tolerance limits and I sat along with the driver during the drive back. But due to the high alerts and caution made during the incident, the truck driver fell unconscious after bringing the truck back to the Apsara reactor hall. He recovered later only at the Sion Hospital!

(ii) During the early period of reactor operation, Dr. Bhabha who was a frequent visitor to Apsara, wanted the reactor tank, hall and building to be painted as perceived by his artistic mind. The colour combination for the whole job was changed six times before Dr. Bhabha approved.

Shri. T. Balasubramaniam
Former Shift-In-Charge, Apsara

We were the first few to start round the clock shift operation of the Apsara reactor in the Atomic Energy Establishment Trombay.

I vividly recall one of the initial visits in which Pandit Jawaharlal Nehru walked down the distance from Fuel fabrication shop, Faggots (AFD) to Apsara whereas for the then Home Minister Mr. G.B. Pant, overhead crane was utilised to lift him to reactor top platform for showing the glow of the reactor and getting his signature in the Visitor's book.

The interest that Dr. Bhabha was taking in the smooth and uninterrupted running of this reactor was such that he used to go through all the design changes like modification in design of trolley carrying the core and evinced interest in isotope production schedule, etc.

It gave me the satisfaction that, when I retired from NPCIL, I could take leave of Mr. S.K.Chatterjee, Managing Director, NPCIL to whom I reported when I joined Apsara in 1958.

Shri. Y. H. Prabhu

Former Shift-In-Charge, Apsara

During my long tenure in Apsara, I was witness to several interesting events, which I cherish to remember even after many years of my retirement. I had the opportunity to interact with the legends like Dr. H.J.Bhabha, Dr. R.Ramanna, Mr. A.S.Rao, Mr. N.B.Prasad, Dr. H.N.Sethna and others.

Being the first reactor at that time, Apsara was the centre of attraction. I vividly remember visits of Pandit Nehru, Mr. Lal Bahadur Shastri, Queen Elizabeth, Dr. Neils Bohr and many others. The interest Dr. Bhabha used to take in upkeep of the plant and the surroundings in BARC and the discpline enforced by Mr. Allerdice, the then Controller are some of the good qualities which should be emulated by others of present generation. It was appropriate that Mrs. Indira Gandhi, renamed the organisation as Bhabha Atomic Research Centre in memory of Dr. Homi J. Bhabha a great son of India and a close friend of Nehru family. Of several major jobs carried out at Apsara, I recall various investigations carried out to identify the locations of pool leakage and the subsequent lining of pool with stainless steel, thus arriving at a long lasting solution.

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(S. K. Agarwal)
Head, Reactor Operations Division
BARC