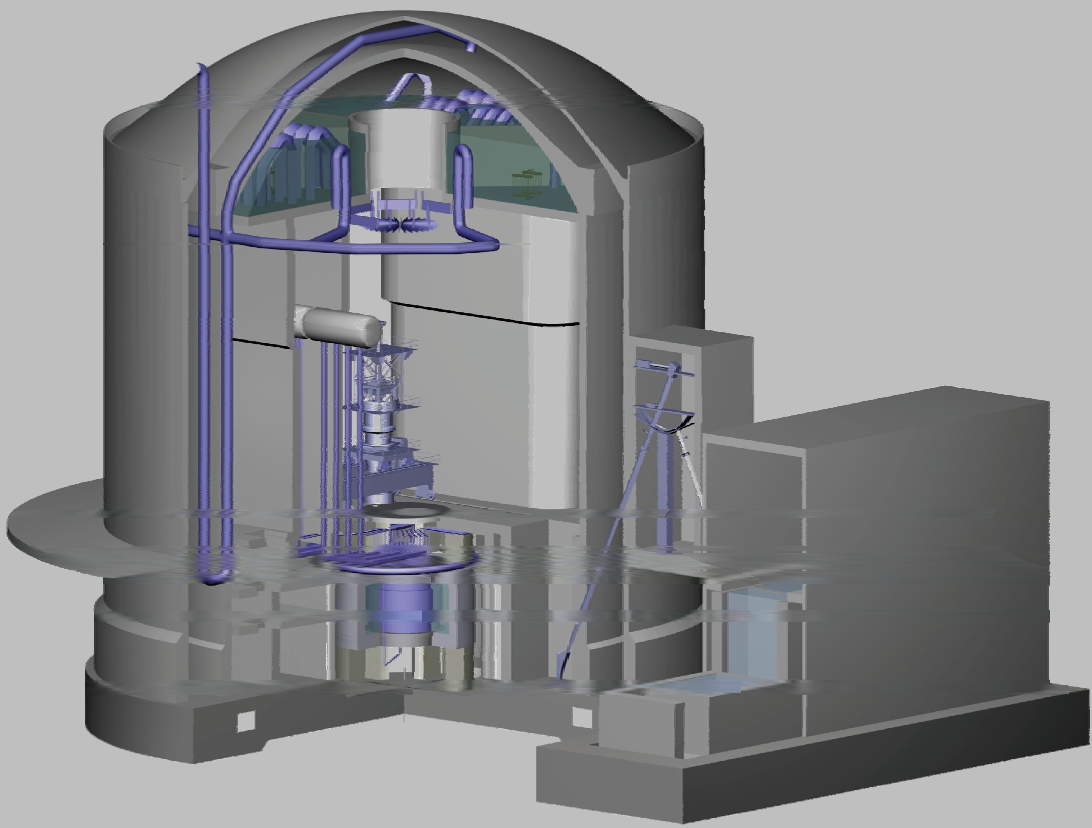
Advanced Heavy Water Reactor



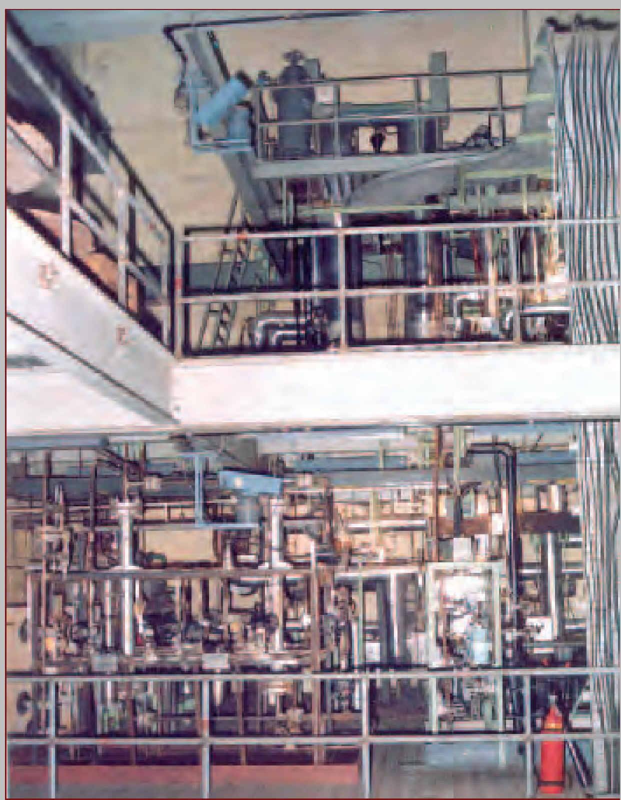
Bhabha Atomic Research Centre
Department of Atomic Energy
Mumbai, INDIA

Some Experimental Facilities for AHWR Thermal Hydraulic Studies

Facility at Apsara reactor for Flow Pattern Transition Studies by Neutron Radiography

Natural Circulation Loop (NCL) for Stability and Start-up Studies

Transparent Set up for Natural Circulation Flow Distribution Studies



3 MW Boiling Water Loop

Advanced Heavy Water Reactor

It is generally agreed that in the long term, nuclear power employing closed fuel cycle is the only sustainable option for meeting a major part of the world energy demand. World resources of thorium are larger than those of uranium. Thorium, therefore, is widely viewed as the 'fuel of the future'. Thorium based nuclear fuel cycle possesses several well-known characteristics indicated below.

Advantages of Thorium Fuel Cycle

- Using external fissile material uranium-235, plutonium or an accelerator driven neutron source, thorium can sustain a thermal breeding cycle.
- The cycle produces virtually no plutonium.
- The waste products contain low amount of long-lived alpha-emitters

The Indian **Advanced Heavy Water Reactor (AHWR)** is designed and developed to achieve large-scale use of thorium for the generation of commercial nuclear power. This reactor will produce most of its power from thorium, avoiding any external input of uranium-233, in the equilibrium cycle.

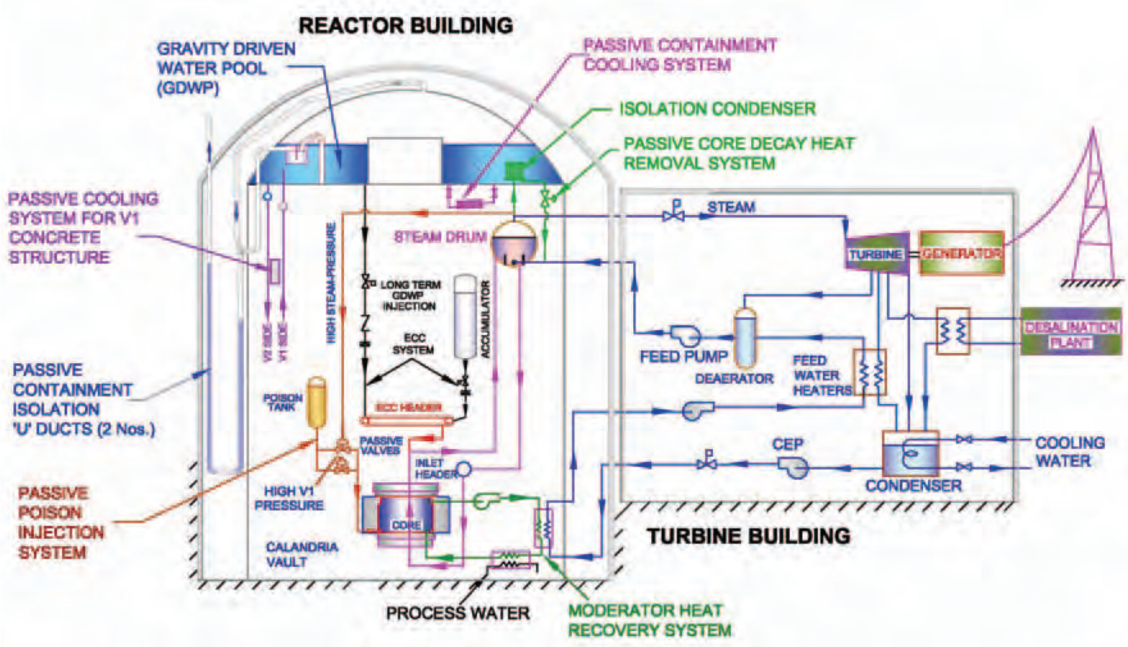
AHWR is a 300 MWe, vertical, pressure tube type, boiling light water cooled, and heavy water moderated reactor. The reactor incorporates a number of passive safety features and is associated with a fuel cycle having reduced environmental impact. At the same time, the reactor possesses several features, which are likely to reduce its capital and operating costs.

Important Safety Features of AHWR

- Slightly negative void coefficient of reactivity.
- Passive safety systems working on natural laws.
- Large heat sink in the form of Gravity Driven Water Pool with an inventory of 6000 m^3 of water, located near the top of Reactor Building.
- Removal of heat from core by natural circulation.
- Emergency Core Cooling System injection directly inside the fuel.
- Two independent shutdown systems.
- Passive poison injection in moderator in the event of non-availability of both the primary as well as secondary shut down system due to failure or malevolent insider action.

AHWR employs natural circulation for cooling the reactor core under operating and shutdown conditions. All event scenarios initiating from non-availability of main pumps are, therefore, excluded. The Main Heat Transport (MHT) System transports heat from fuel pins to steam drum using boiling light water as the coolant. The MHT system consists of a common circular inlet header from which feeders branch out to the coolant channels in the core. The outlets from the coolant channels are connected to tail pipes carrying steam-water mixture from the individual coolant channels to four steam drums. Steam is separated from the steam-water

mixture in steam drums, and is supplied to the turbine. The condensate is heated in moderator heat exchangers and feed heaters and is returned to steam drums by feed pumps. Four downcomers connect each steam drum to the inlet header.



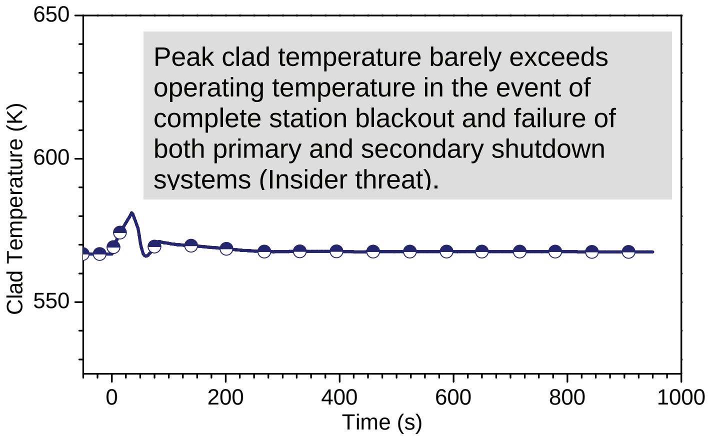
Schematic of AHWR main systems

Emergency Core Cooling System (ECCS) is designed to remove the core heat by passive means in case of a postulated Loss of Coolant Accident (LOCA). In the event of a rupture in the primary coolant pressure boundary, the cooling is initially achieved by a large flow of borated water from accumulators. Later, cooling of the core is achieved by the injection of cold water from a large Gravity Driven Water Pool (GDWP) located near the top of the reactor building.

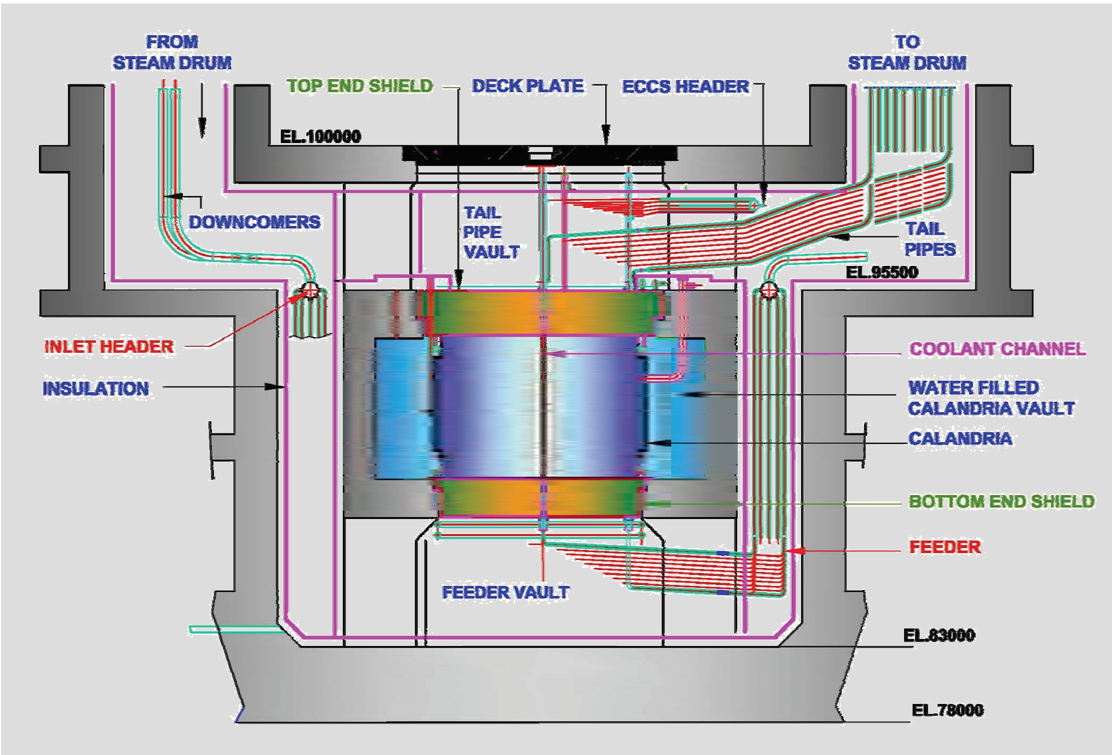
In AHWR, subsequent to energy absorption in GDWP in vapour suppression mode, the Passive Containment Cooling System (PCCS) provides long term containment cooling following a postulated LOCA. GDWP serves as a passive heat sink yielding a grace period of three days. The core gets submerged in water long before the end of this period.

Consistent with the approach used in standardised Indian PHWRs, AHWR is provided with a double containment. For containment isolation, a passive system has been provided in AHWR. The reactor building air supply and exhaust ducts are shaped in the form of U-bends of sufficient height. In the event of LOCA, the containment pressure acts on the water pool surface and drives water, by swift establishment of syphon, into the U-bends of the ventilation ducts. Water in the U-bends acts as a seal between the containment and the external environment, providing necessary isolation between the two.

The safety of AHWR in enhanced by incorporation of a Passive Poison Injection System to shut down the reactor in case of a low probability event of failure of wired primary and secondary shut down systems or their incapacitation due to malevolent actions. The increase in steam pressure in the above scenario opens a passive valve to inject liquid poison in the moderator to shut down the reactor. Subsequently, due to decay heat removal in passive mode by Isolation Condensers (ICs) immersed in GDWP, clad temperature is maintained well within acceptable limits.



A case study for passive poison injection

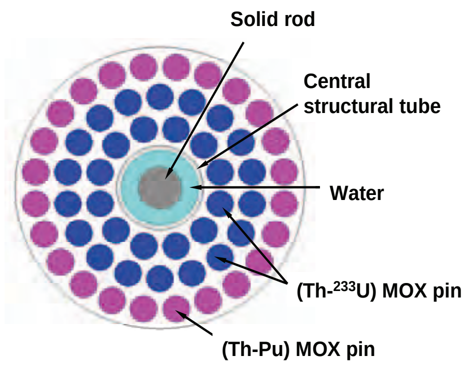


Reactor Block Components

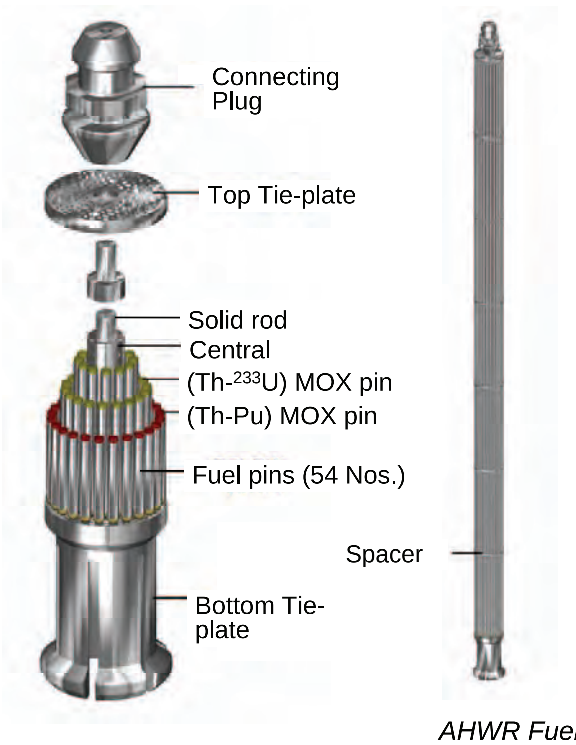
The AHWR fuel contains 54 fuel pins arranged in three concentric circles surrounding a central displacer rod. The inner two circles contain thirty $(Th\text{-}^{233}U)O_2$ fuel pins and the outer circle contains twenty four $(Th\text{-}Pu)O_2$ fuel pins. The fuel also incorporates a water tube for the spraying of ECCS water directly on fuel pins during a postulated LOCA. AHWR fuel is currently designed for an average burn-up of 38 GWd/Te. Its design makes it amenable for reconstitution, if desired to facilitate a further extension of burn-up in the $(Th\text{-}^{233}U)O_2$ fuel pins in future.

The AHWR fuel cycle will be self-sufficient in ^{233}U after initial loading. The spent fuel streams will be reprocessed and thorium and ^{233}U will then be recycled and reused. The AHWR fuel cycle has enough flexibility to accommodate a large variety of fuelling options.

Incidentally, the thorium fuel cycle also presents low proliferation risks, a factor considered significant by several nations for export of nuclear technology. A quantitative analysis of the AHWR fuel cycle substantiates this feature.



Fuel Cluster Cross Section



AHWR Fuel Cluster

Some Distinctive Features of AHWR

- Elimination of high-pressure heavy water coolant resulting in reduction of heavy water leakage losses, and eliminating heavy water recovery system.
- Recovery of heat generated in the moderator for feed water heating.
- Elimination of major components and equipment such as primary coolant pumps and drive motors, associated control and power supply equipment and corresponding saving of electrical power required to run these pumps.
- Shop assembled coolant channels, with features to enable quick replacement of pressure tube alone, without affecting other installed channel components.
- Replacement of steam generators by simpler steam drums.
- Higher steam pressure than in PHWRs.
- Production of 500 m^3/day of demineralised water in Multi Effect Desalination Plant by using steam from LP Turbine.
- Hundred year design life of the reactor.
- A design objective of requiring no exclusion zone on account of its advanced safety features.

Important Design Parameters of AHWR

Reactor power	:	920 MW_{th}, 300 MW_e
Core configuration	:	Vertical, pressure tube type design
Coolant	:	Boiling light water
Number of coolant channels	:	452
Pressure tube ID	:	120 mm
Lattice pitch	:	225 mm (square pitch)
No. of pins in fuel cluster	:	54 $(Th\text{-}Pu)O_2$ - 24 pins $(Th\text{-}^{233}U)O_2$ - 30 pins
Active fuel length	:	3.5 m
Total core flow rate	:	2141 kg/s
Coolant inlet temperature	:	259 °C (nominal)
Feed water temperature	:	130 °C
Average steam quality	:	19.1 %
Steam generation rate	:	408 kg/s
Steam drum pressure	:	70 bar
MHT loop height	:	39 m
Primary shut down system	:	37 shut off rods
Secondary shut down system	:	Liquid poison injection in moderator
No. of control rods	:	24
Passive Poison Injection		Poison injection through a passive valve due to increase in steam pressure

An Acrylic Model of AHWR to Scale 1:50

For further details contact:

Director,
Reactor Design & Development Group,
Bhabha Atomic Research Centre,
Trombay, Mumbai - 400 085. India

Tel. No.: + 91 22 2559 3710 Fax: + 91 22 2550 5303
E-mail: rksinha@barc.gov.in

Published by S. K. Malhotra, Head, Public Awareness Division, DAE & printed by him at Rush Art, Mumbai, India

Printed in September 2008