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Technical feasibility study for coupling a desalination plant to an Advanced Heavy Water Reactor

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HIGHLIGHTS

- Various options of using thermal energy of AHWR for desalination plant have been studied.
- Integration of LTE and MED desalination plants with AHWR has been proposed.
- Safety precaution towards radioactivity ingress to desalinated product water is highlighted.
- Feasibility of nuclear desalination using AHWR is presented.

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ABSTRACT

Advanced Heavy Water Reactor (AHWR) is the latest Indian design for a next generation nuclear reactor. It is 300 MWe, vertical, pressure tube type, boiling light water cooled natural circulation and heavy water moderated reactor. It burns thorium in its fuel core to meet the objectives of using thorium fuel cycles for commercial power generation. Desalination systems are included in the reactor circuit to produce high quality water from seawater utilizing thermal energy of AHWR to meet the reactor make-up and other process water requirements. Studies have been carried out for various options of using thermal energy of AHWR for desalination. LTE and MED-TVC desalination plants are planned to be coupled with the reactor using Main Heat Transport purification circuit waste heat and using steam from a tapping between the cross-over line of HP and LP turbine respectively. Metallic barriers, intermediate loops and pressure reversal concepts are applied to prevent radioactive ingress to product water of desalination plant. This paper describes the technical feasibility studies of coupling 250 m^3/day LTE and 2400 m^3/day MED-TVC seawater desalination plants coupled to AHWR. Coupling of desalination plants, methodologies, loss of reactor power and various safety considerations are discussed in details.

1. Introduction

Fresh water plays an important role in sustainable development of a country. Demand for fresh water increases dramatically for rapid industrial and economical growth. Lack of supply of potable water is set to become a constraint on development in some areas. In several regions of the world, safe drinking water is also not readily available. There are various methods to produce fresh water. Desalination of seawater is an alternative and viable option to meet these demands in coastal areas. However, desalination process needs energy. Compared to membrane desalination, thermal desalination technologies are very energy intensive. Energy costs are rising while environmental pressure on reducing greenhouse emissions requires alternative and sustainable energy sources. Use of clean and green nuclear energy has potential that will help to produce clean drinking water and help reduce carbon emissions as well. When a nuclear reactor is used to supply steam for a desalination plant, the method of coupling has a significant technical and economic impact. The exact method of coupling depends on the type of reactor and the type of desalination plant. A desalination plant coupled to nuclear reactor of pressurized heavy water reactor type is a good example of dual-purpose nuclear desalination plant. Utilization of nuclear energy for seawater desalination provides a safe, feasible and economic solution for the production of very good quality water. In recent years detailed coupling aspects of desalination plant with nuclear reactor has been studied worldwide. India has set up a 30 m^3/day capacity Low Temperature Evaporation (LTE) based nuclear desalination plant using waste heat from the nuclear research reactor (Cirus) at BARC, Trombay and is operated since 2004 to supply make-up water in the reactor [1,2]. India has also set up a Nuclear Desalination Demonstration Plant (NDDP) of 6300 m^3/day capacity, coupled to Madras Atomic Power Station (MAPS) having Pressurized Heavy Water Reactor (PHWR) at Kalpakkam in south-east part of India. NDDP comprises of a Multi-Stage Flash (MSF) desalination unit of 4500 m^3/day capacity and a reverse osmosis (RO) unit of 1800 m^3/day capacity [3]. This is the largest nuclear desalination plant based on hybrid MSF-RO technology using low-pressure steam and seawater from a

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nuclear power station [4]. These nuclear desalination plants have given enough data to design large scale desalination plants connected to nuclear reactor.

The latest Indian design for a next generation heavy water moderated nuclear power reactors is AHWR. It is 300 MWe vertical, pressure tube type, boiling light water under natural circulation cooled, and heavy water moderated reactor. It burns thorium in its fuel core to meet the objectives of using thorium fuel cycles for power generation [5]. Details of AHWR development is given elsewhere [6]. Desalination system is included in the reactor circuit to produce high quality water from seawater utilizing thermal energy of AHWR to meet the reactor make-up and other process water requirements. Fig. 1 gives a schematic diagram of overall AHWR reactor system and a connecting desalination system.

Estimated make-up requirement of demineralized (DM) water of the reactor is about 360 m^3/day. In addition to this, there is need of additional process water for various process demands. Considering the present and future requirement of fresh water of AHWR system, various options have been explored. The conventional demineralization (DM) system gives desired quality water but at an exorbitant cost. It also leads to environmental pollution by discharging lot of acid and alkali during regeneration. Seawater desalination using heat energy from the reactor is one of the options that can be used to meet the various requirements of the reactor. AHWR uses steam for power production and seawater for condenser cooling. A small fraction of this seawater and steam is used for desalination plant to produce distilled quality water from seawater.

Thermal desalination plants e.g. MED, MSF and LTE produce very high quality distilled water. Choice of particular plant depends upon the site characteristics and utilities available. The water produced by these thermal desalination plants can be used for various utility purposes, namely,

- *Reactor make-up without or with minor polishing by ion exchange depending upon the makeup feed quality requirement*

This provision eliminates conventional cation/anion exchange based DM plant but needs minor polishing mixed bed to suit the actual requirement.

- *Direct process water for various cooling systems make-up and heat exchanger circulations*

For cooling tower, the blow down losses will be minimized.

- *Potable water or drinking water*

After suitable post-treatment by addition of relevant minerals with the distilled water, it gives potable or drinking water as per WHO or IS 10500 standard quality

- *Augmentation of total water availability by mixing this distilled water with the existing brackish water*

2. Source of thermal energy from AHWR for desalination

Availability of requisite quality and quantity of thermal energy in AHWR as energy source for sea water desalination was explored. There are various sources of thermal energy available in different circuits of AHWR. But all of them are not suitable for desalination plant due to restriction imposed by reactor system. Moderator cooling circuit waste heat is one of them. Following are the main thermal energy considered to be utilized for desalination, namely:

(i) *Main Heat Transport (MHT) purification circuit waste heat*: In AHWR, the primary function of the MHT purification system is to remove chemical impurities and suspended solids from the reactor coolant so as to maintain the coolant chemistry within the prescribed limits of the parameters and to protect MHT system piping and equipment against corrosion [6]. The purification flow at system pressure and temperature (259 °C) from primary system is passed through the regenerative coolers and cooled up to 100 °C and by nonregenerative coolers is cooled up to 42 °C. The pressure is reduced by pressure reducing valves before it passes to the filters and ion exchanger columns. The purified water is pumped to the shell side of the regenerative coolers and returned to MHT. Main Heat Transport (MHT) purification system process water @ 33.3 kg/s at 259 °C and at 70 bar is

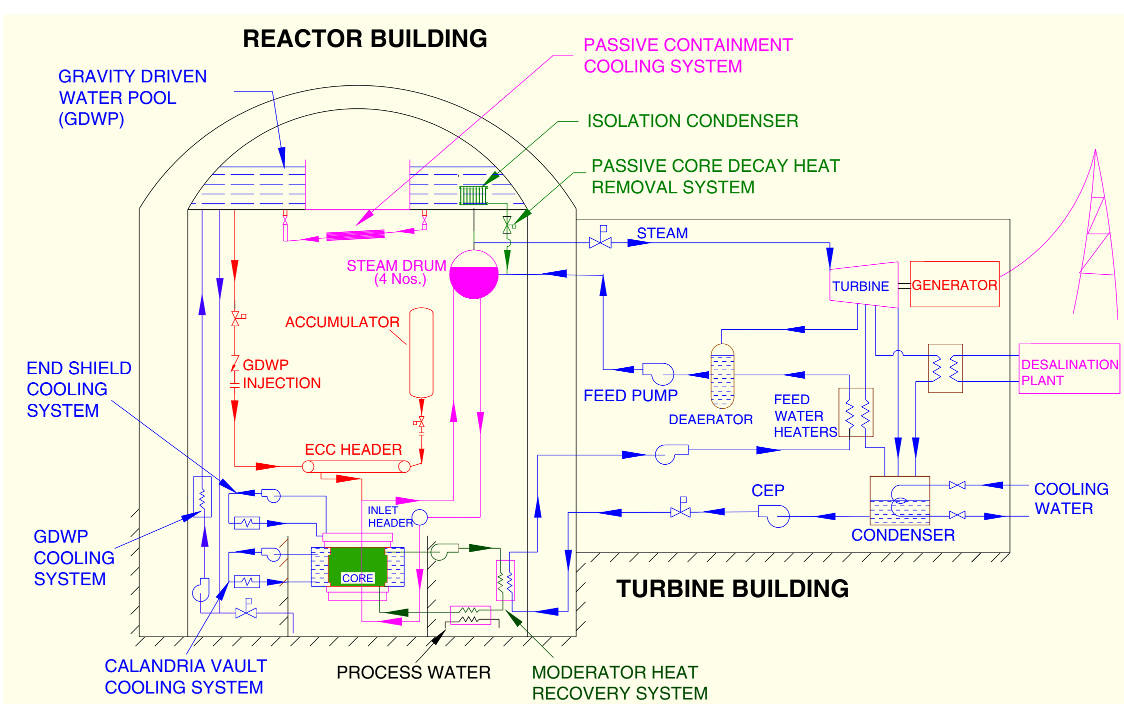

Fig. 1. Schematic diagram of overall AHWR system.