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Compact Design of BANDI CVCS by KEPCO E&C

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1. Introduction

Recently, KEPCO E&C unveiled an evolved version of BANDI designed specifically for marine applications. The ongoing design enhancements of BANDI prioritize simplification and optimization, drawing insights from safety and performance analyses. Key modifications resulting from these evaluations involve transitioning the system from a two-loop to a one-loop configuration as Fig. 1 and the type of steam generator (SG) from saturated steam and U-tubes to superheated steam with a helical configuration. [1]

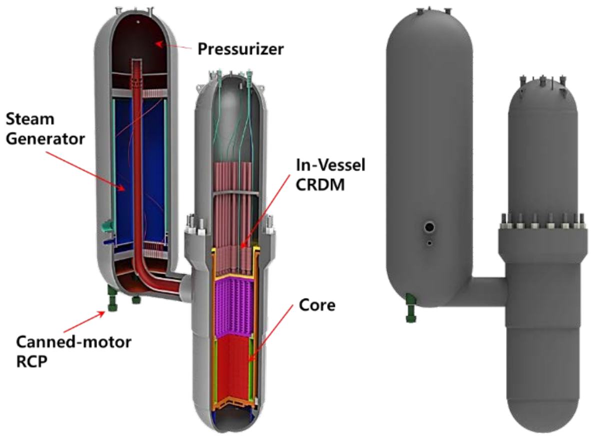

Fig. 1. RCS Configuration of BANDI. [1]

Additionally, there have been several other design changes. The reactor vessel block and the SG block are connected nozzle-to-nozzle, and a soluble boron-free core is employed. In terms of engineering safety systems, BANDI includes an in-vessel CRDM and a top-mounted ICI, along with fully passive safety features. Moreover, the system incorporates canned-motor Reactor Coolant Pumps (RCP) and a pressurizer integrated into the SG block, all housed within a compact steel containment vessel. Furthermore, it is equipped with automatic load following and designed to withstand ocean motions with six degrees of freedom. [1]

The Chemical and Volume Control System (CVCS) is an auxiliary system directly connected to the Reactor Coolant System (RCS), responsible for maintaining the water chemistry conditions and purity of the reactor coolant during normal and shutdown operations. It also compensates for changes in coolant volume due to temperature variations, ensuring optimal volume through various components such as pumps, tanks, valves, and even gas strippers. Regardless of reactor types, these functions are essential for the RCS and are performed by the CVCS in almost all reactors. [2]

The CVCS of large-scale commercial nuclear power plants, both domestically and internationally, typically comprises numerous components for the above functions, making operation and maintenance complex. These facts highlight the need for an optimized compact design for the CVCS, especially for Small Modular Reactors (SMRs) including the BANDI CVCS.

2. CVCS of International SMR

2.1. KLT-40S

The KLT-40S CVCS is referred to as the "Purification and Cooldown System," responsible for maintaining the required water quality of the primary system and removing residual heat from the core. Fig. 2 depicts the overall schematic diagram of the KLT-40S, including the Purification and Cooldown System. [2]

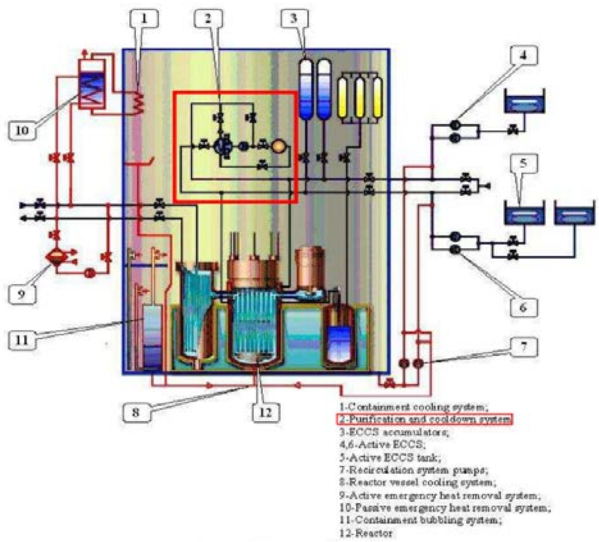

Fig. 2. The overall schematic diagram of the KLT-40S includes the Purification and Cooldown System. [2]

2.2. NuScale

The NuScale CVCS performs functions similar to those of conventional large-scale nuclear power plants, including purification of reactor coolant, control of water chemistry, and regulation of boron concentration; provision of reactor coolant makeup water to the RCS; and supply of pressurizer makeup flow for RCS pressure reduction. [3]

However, during startup, this system provides motive flow for RCS natural circulation and Module Heatup System (MHS) is employed to increase temperature. The MHS can be shared among 6 NuScale Power Modules (NPM) and used one at a time. Additionally, NuScale incorporates a Boron Addition System (BAS) as it employs boron as a neutron absorber, with 12 NPMs sharing one BAS. [3]

The inert gases contained in the reactor coolant are removed through a degasser connected to the Liquid Radioactive Waste System (LRWS) in the CVCS letdown system. [3]

Fig. 3 is the schematic diagrams of the NuScale CVCS system.

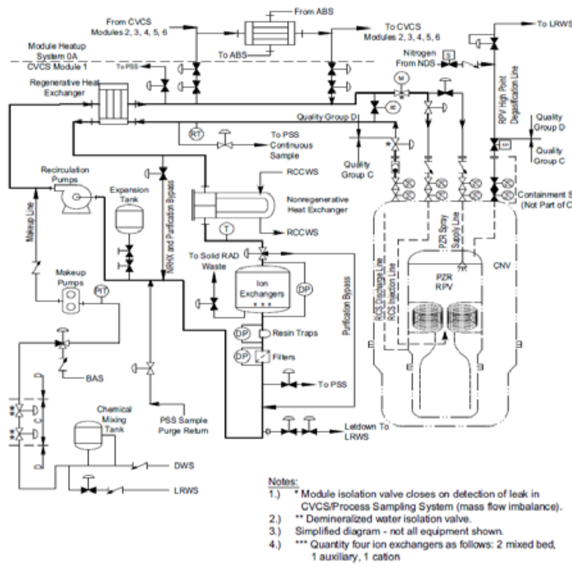

Fig. 3. Schematic of NuScale CVCS. [3]

3. Design Concept for BANDI CVCS

The CVCS is essential for BANDI for several reasons, such as purifying the coolant and maintaining inventory of RCS coolants. With the adoption of a boron-free design, all components and equipment related to boron solution in conventional nuclear power plants could be removed. However, the conventional CVCS of various reactors is still too large to be used in remote sites or marine-based application. Therefore, the CVCS for BANDI was optimized and adapted innovative technology for a compact design.

The CVCS of traditional large-scale power plants and SMRs typically incorporate two shell-and-tube type heat exchangers, a regenerative heat exchanger, and a letdown heat exchanger. The regenerative heat exchanger transfers heat from the letdown coolant to the charging coolant to minimize thermal shock at nozzles between the CVCS and RCS. The letdown heat exchanger cools down the coolant to the temperature at which purification components such as ion exchangers can operate. However, in the BANDI CVCS, the functions of these two heat exchangers are consolidated into a single unit by employing a printed circuit heat exchanger (PCHE), named the regenerative letdown heat exchanger as shown in Fig.4. This integrated heat exchanger serves the roles of both heat exchangers in the traditional CVCS. Like traditional heat exchangers, the regenerative letdown heat exchanger transfers heat from the letdown to charging to minimize thermal shock and cool the discharge water to temperatures suitable for the operation of the purification system.

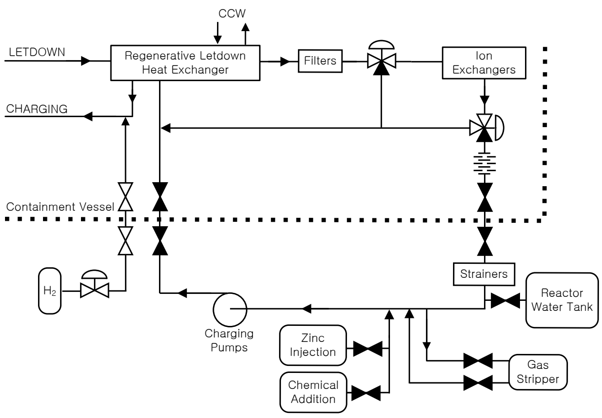

Fig. 4. Schematic of BANDI CVCS operating under high pressure with an integrated regenerative letdown heat exchanger.

Purification filters are designed to remove insoluble particles from the letdown coolant. Reflecting the operating experiences of RCP seal injection filters under high-pressure conditions in commercial large-scale power plants, the purification filters in the BANDI CVCS are intended to operate under high-pressure conditions. Purification ion exchangers are installed to remove ionized impurities from the reactor coolant and operate under high-pressure conditions. Also, the purification flow will be formed by reactor coolant pump rather than the charging pump in Fig.4. So, in order to use the developed head of the RCP, the letdown nozzle and charging nozzle connected to just behind and ahead of the pump, respectively. These simplify and downsize the CVCS system because it eliminates the need for equipment such as orifices and pressure relief valves to "depressurize" and then "pressurize" the reactor coolant.

Thus, it is possible that under normal conditions, the CVCS forms a closed purification loop within the containment vessel. This is because the size of the heat exchanger is drastically reduced, and the components that decrease and increase pressure, such as orifices and pumps, are not needed in normal operation. This makes the CVCS more reliable in safety and performance analysis considering the fact that no flow penetrates the containment vessel under normal steady state power operating conditions.

In typical nuclear power plants, volume control tank provides makeup water to the charging pumps and offer buffering functions within a relatively small range against temperature and pressure variations in the RCS during normal operation. However, unlike in the commercial power plants, the charging pumps in the BANDI CVCS will be intermittently operated under limited conditions such as shutdown or unexpected transient conditions. During these conditions, the pumps deliver purified reactor coolant or chemicals if needed. In shutdown condition, the charging pumps provide coolant for RCS pressure control. Considering this intermittent behavior, volume control tanks are not incorporated into the BANDI system; instead, the reactor water tank (RWT) serves as the suction source for the charging pumps. This operation should be feasible for the charging pump, as the similar operation has been in commercial large reactors.

The design parameters for the BANDI CVCS are as follows:

Table I: Design Parameters of BANDI CVCS

Parameters [Unit]	Values
Normal / Minimum / Maximum Makeup and Discharge Flow Rates [L/min]	70.0 / 35.0 / 100.0
Operating Pressure [MPa]	15.5
Temperature at Letdown Nozzle [℃]	310
Temperature at Ion Exchangers [℃]	50

4. Conclusion

To enhance the compactness of the system, the BANDI CVCS incorporates a printed circuit heat exchanger to combine two shell-and-tube heat exchangers into a single unit. The purification devices operate at the normal operating pressure of the RCS, eliminating the need for components required to decrease pressure, such as orifices and valves, and the need to increase pressure again after depressurization.

During power operation, a closed loop is formed in the containment vessel, passing through the heat exchanger and purification equipment, to purify the reactor coolant and maintain water chemistry conditions. It is certain that the BANDI CVCS will be quantitatively evaluated as a more reliable system through safety and performance analysis considering the purification loop of the CVCS during normal power operation within the containment vessel.

Therefore, by adopting innovative technologies, the BANDI CVCS will be drastically minimized in size, which facilitate the factory fabrication of its components. Also, the system will be estimated to more reliable as the coolant in the system do not pass the containment vessel in normal conditions.

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