

Innovative CVCS Design for SMRs

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1. Introduction

The Chemical and Volume Control System (CVCS) treats a portion of the reactor's primary coolant to maintain coolant cleanliness and water chemistry for reactivity and corrosion control reasons. Since the CVCS performs various functions, the system consists of many components and structures, and has many interfacing systems.

Most of light water Small Modular Reactors (SMR) have the CVCS to maintain the required primary water inventory and quality, and also provide pressurizer spray and boric acid concentration control in the reactor coolant. In order for an SMR to compete with large commercial reactors, its design should be more safe and economical. The CVCS has a significant influence on the SMR design and a room for various improvement. The SMR CVCS shall be designed more compact and economical.

In this paper, several conventional CVCS designs are reviewed, and some innovative options are introduced for a Soluble Boron Free (SBF) CVCS design.

2. CVCS Designs of NPPs

2.1 CVCS of a Large PWR

The CVCS of conventional large NPPs is very complicated with many components, structures and interfacing systems. In most cases, the CVCS letdown systems are operated at low pressures and low temperatures to protect resins from thermal damages. Many components, such as valves, orifices and heat exchangers are necessary to reduce pressure and temperature of the letdown flow, and high head pumps are used to pressurize the charging flow. The boron recovery system and borated water source are also needed for reactivity control. APR1400 CVCS system is shown as a typical example in Fig.1.

2.2 CVCS of a BWR

Fig. 2 shows the Reactor Water Cleanup/Shutdown Cooling(RWCU/SDC) System Schematic of ESBWR. The RWCU system purifies the reactor coolant and assists in the control of reactor water level, and also provides the functions of shutdown and cooldown. The RWCU/SDC system is operating at high pressure and low temperature. The impurities of reactor coolant are

removed by the demineralizer downstream of non-regenerative heat exchanger and RWCU/SDC pumps. The RWCU/SDC system does not have a boron recovery and a boron addition system since the ESBWR is soluble boron free.

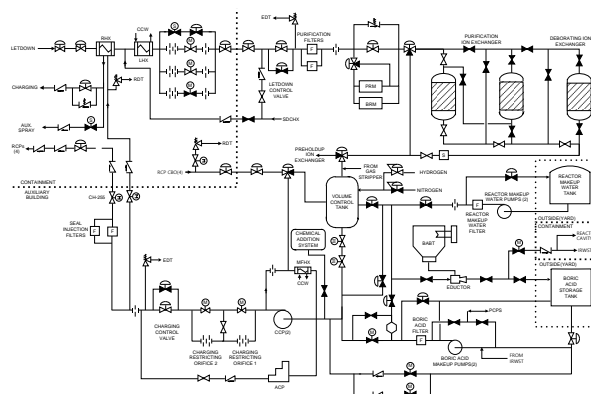


Fig. 1 CVCS Schematic of APR1400 (SKN 3&4)

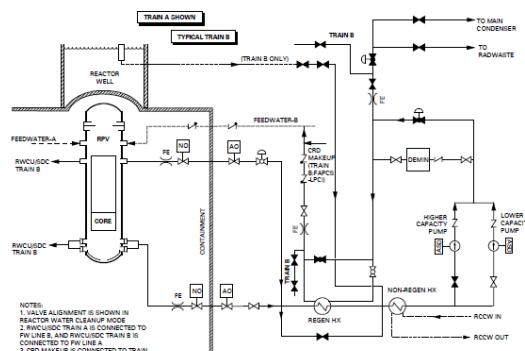


Fig. 2 Reactor Water Cleanup/Shutdown Cooling System Schematic of ESBWR [1]

2.3 CVCS of KLT-40S

Fig. 3 shows the composition of reactor system of KLT-40S for a floating NPP. The purification and cooldown cooling system is denoted '2' in the figure, which is operating at high pressure and high temperature. The system includes a primary-third circuit heat exchanger and a primary circuit ion-exchanging filter, and controls boric acid concentration.

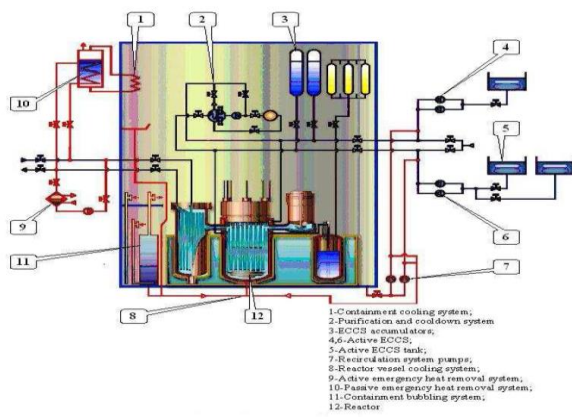


Fig. 3 Reactor plant principal flow diagram of KLT-40S [2]

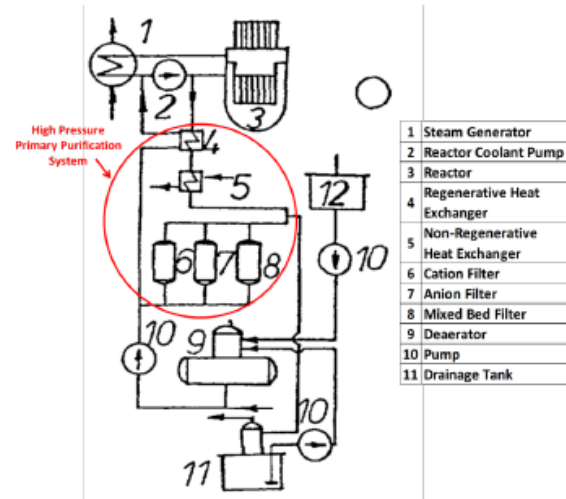


Fig. 5 Schematic Flow Diagram of Primary Circuit of VVER-440 of Russia [4]

2.4 CVCS of NuScale

Fig. 4 shows the CVCS purification and make-up system of NuScale. It maintains the required water inventory and quality in the reactor coolant system, and provides pressurizer spray. It also controls the boric acid concentration and water chemistry in the reactor coolant and reduces coolant radioactivity level. This system is operating at low temperature and high pressure and quite complicated in design.

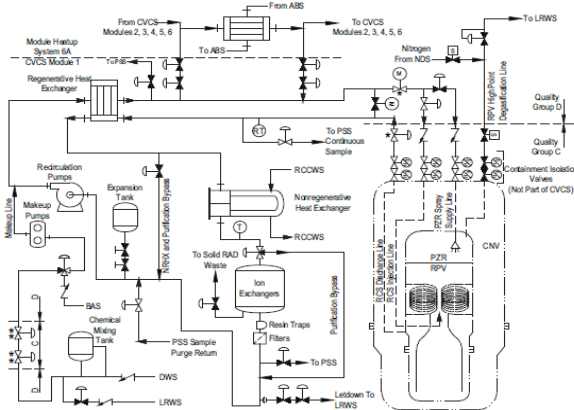


Fig.4. CVCS (Purification and Makeup System) of NuScale [3]

2.5 CVCS of VVER-440

Fig. 5 shows the primary circuit and the coolant purification, letdown, and make-up systems of VVER-440. This system operates at high pressure and low temperature. Mixed bed filter, cation filter and anion filter are used to remove radioactive impurities.

3. CVCS Design Options for an Innovative SMR

3.1 Soluble Boron Free(SBF) CVCS Design

The soluble boron has significant disadvantages such as boron induced corrosion of structural materials and nuclear fuel, large amount of liquid waste generated during boration and dilution process, and increased chance of positive moderator temperature coefficient (MTC) with a high boron concentration [5].

The benefits of no soluble boron are to simplify the design, operation and maintenance of nuclear reactor and CVCS, and to reduce the radioactive waste by removing of the boric acid process, and to prevent the boric acid induced corrosion.

The SBF design is more effective in SMRs where the core power density is much lower and core power distribution stability is higher than large reactors.

3.2 CVCS Design Options for a SMR

The simplicity and compactness of SMR CVCS design is highly dependent on letdown pressure and temperature for operating conditions of purification ion exchanger, and whether boron is used or not for reactivity control. Here, some design options for a boron free SMR are proposed and reviewed based on several combinations of letdown pressures and temperatures.

A Case for High Pressure and High Temperature

Fig. 6 illustrates a CVCS design with high pressure and high temperature of letdown flow. It is the simplest CVCS design since components for reducing of pressure and temperature of letdown flow are removed. However, conventional ion exchanger is not applicable to such a high temperature and CVCS components

should be designed for high pressure. To overcome these drawbacks, innovative components such as Electro Magnetic Filter (EMF) could be considered to remove magnetic impurities instead of conventional ion exchanger. This design requires further works in the future.

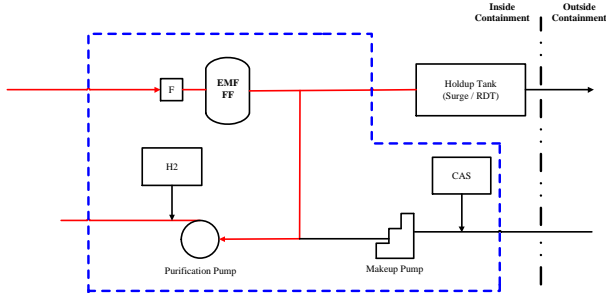


Fig. 6 CVCS design at high pressure and high temperature.

Cases for High Pressure and Low Temperature

Fig. 7 illustrates a CVCS design with high pressure and low temperature of letdown flow without Volume Control Tank (VCT). It requires regenerative and non-regenerative heat exchangers to reduce the letdown flow temperature. Thus, the system would be pretty complicated and shall be designed for high pressure.

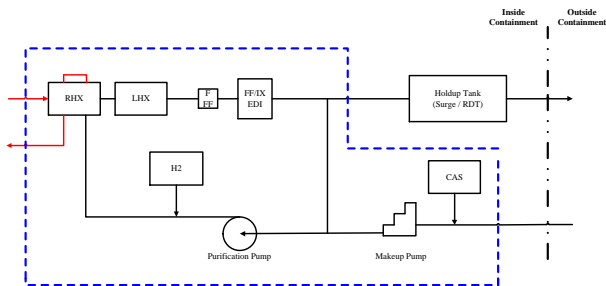


Fig. 7 CVCS design at high pressure and low temperature without VCT

Fig. 8 illustrates CVCS design with high pressure and low temperature of letdown flow with VCT. It is a supplement of the design in Fig. 7, and provides a more feasible option for the charging system.

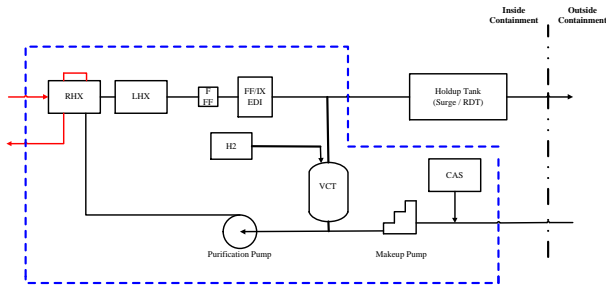


Fig. 8 CVCS design at high pressure and low temperature with VCT

A Case for Low Pressure and Low Temperature

Fig. 9 illustrates a CVCS design with low pressure and low temperature of letdown flow. It looks similar with those of conventional NPPs, except that it doesn't have the boron treatment system.

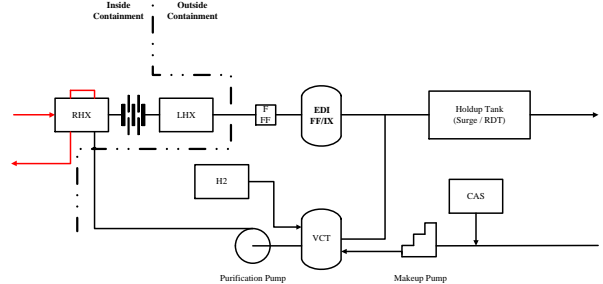


Fig. 9 CVCS design at low pressure and low temperature of letdown flow

4. Conclusion and Future works

To improve the inherent safety and economy of a SMR, the CVCS design should be developed simpler and more compact than those of conventional NPPs. This has reviewed and evaluated several CVCS design options for a boron free SMR assuming a few combinations of letdown pressures and temperatures. If proven technologies are utilized and certain innovative technologies should be applied, the innovative CVCS design would be at high pressure and low temperature (with or without VCT, Fig. 7 and Fig. 8) with Fine Filter (FF) and Electrodeionizer (EDI) for a SBF CVCS design. However, the CVCS design with high pressure and high temperature is worth more study for an innovative SMR since it will surely make the SMR simpler and more economical due to reductions of components.

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