Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 29-30, 2014

Passive Decay Heat Removal System Options for S-CO2 Cooled Micro Modular Reactor

Jangsik Moon, Yong Hoon Jeong*, Jeong Ik Lee
Dept. of Nuclear & Quantum Engineering, KAIST,
291 Daehak-ro, Yuseong-gu, Daejeon, 305-701, Republic of Korea
**Corresponding author: jeongyh@kaist.ac.kr*

1. Introduction

In the world, there are many researches on Small Modular Reactor (SMR), such as SMART in Korea. However in many cases, reduction of reactor power is conducted, but modularization of whole reactor system is not. Especially, the most of SMRs take Rankine cycle that is difficult to be modularized due to large required space for steam cycle [1].

To achieve modularization of whole reactor system, Micro Modular Reactor (MMR) which has been being developed in KAIST took S-CO2 Brayton power cycle. The S-CO2 power cycle is suitable for SMR due to high cycle efficiency, simple layout, small turbine and small heat exchanger. These characteristics of S-CO2 power cycle enable modular reactor system and make reduced system size [2].

The reduced size and modular system motived MMR to have mobility by large trailer. Due to minimized on-site construction by modular system, MMR can be deployed in any electricity demand, even in isolated area. To achieve the objective, fully passive safety systems of MMR were designed to have high reliability when any offsite power is unavailable.

In this research, the basic concept about MMR and Passive Decay Heat Removal (PDHR) system options for MMR are presented.

2. PDHR system options

2.1. Design Basis Accidents (DBAs) for MMR

Configuration of MMR is shown in Fig. 1. MMR is a kind of fast reactor, nominal thermal power is 36 MWth and electric output is 10 MWe. Reactor coolant system is consist of single S-CO2 loop and pressure in the loop is 20 MPa. S-CO2 flows into core, and transfer energy directly to turbine Flow of S-CO2 follows sequence of the numbers in Fig. 1. The whole reactor system is contained in one pressure vessel and one containment. There is only two penetrations between outside and inside due to pre-cooler, therefore integrity of the pressure vessel and the containment is reliable.

In MMR, one of DBAs that require PDHR system is Loss of Coolant Accident (LOCA). LOCA happens due to leakage on the S-CO2 loop and it causes loss of power cycle, and reactor shuts down. However, the leakage is mitigated due to the pressure vessel. The vessel is pressurized and has similar pressure with S-CO2 loop. Therefore, the leakage stops since pressure in the vessel and S-CO2 loop is same.

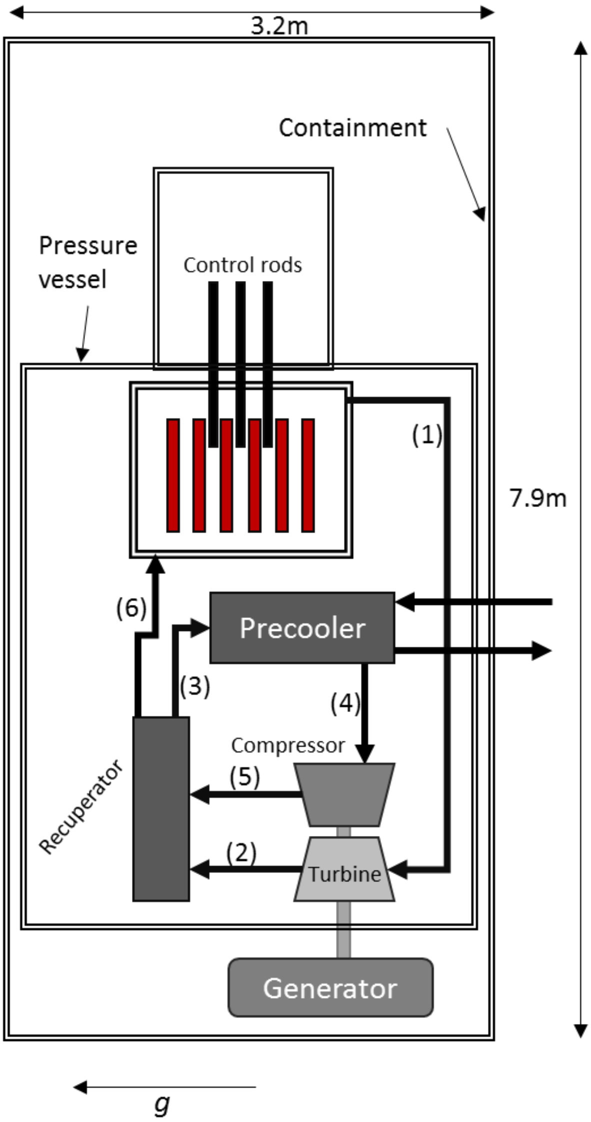

Fig. 1. Schematic of MMR reactor system

Other accidents, non-LOCA, which make shutdown are Loss of Flow Accident (LOFA) and Loss of Heat Sink (LOHS). When flow in the S-CO2 loop stops, released fission energy from core does not transfer to turbine, and reactor shuts down. The LOFA is caused by failure of the compressor. When sufficient waste heat is not able to be removed, the reactor shuts down. The LOHS is caused by failure of pre-cooler system.

Failures of compressor and pre-cooler that make non-LOCA happen due to not only damages on themselves but also loss of power in the systems. Therefore, Station Blackout (SBO) is considered as one of DBA.

2.2. Water cooled PDHR system

Configuration of water cooled PDHR system is shown in Fig. 2. The water cooled system utilizes pre-cooler that is only penetration between outside and inside. The water cooled system purpose to remove decay heat fast at initial state after shutdown. Auxiliary water tank is deployed higher than reactor system and water in tank flows into the pre-cooler passively by gravity. The water evaporates in the pre-cooler and the steam is released to outside. Water of 5 tons are required to remove decay heat from shutdown to 6 hrs after shutdown.

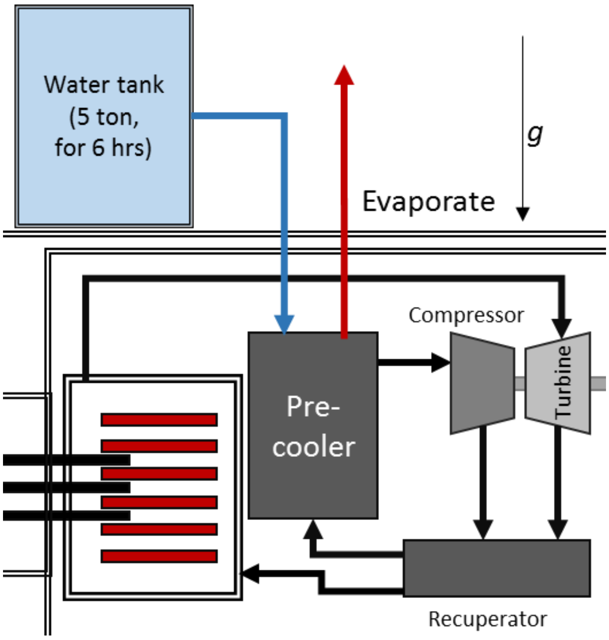

Fig. 2. Schematic of water cooled PDHR system

The water cooled PDHR system shows very simple layout and is estimated to have small cost. The system can cope with SBO, LOFA and LOHS but LOCA. Moreover, the system depends on the pre-cooler system, so it has Common Cause Failure (CCF) with pre-cooler.

2.3. Air cooled PDHR system

Configuration of air cooled PDHR system is shown in Fig. 3. The air cooled system uses natural circulation of air to cool containment outer wall and fins are equipped on the containment wall to increase surface. The air flow on the wall of containment is prevented during normal operation to reduce heat loss. Two-phase closed thermosyphons, which is vertical heat pipe and has high heat transfer efficiency, are equipped between reactor vessel and pressure vessel, and between pressure vessel and containment wall. Released decay heat from fuel rods is transferred to reactor vessel by natural convection of S-CO2. Then, the decay heat is transferred to containment by the thermosyphon.

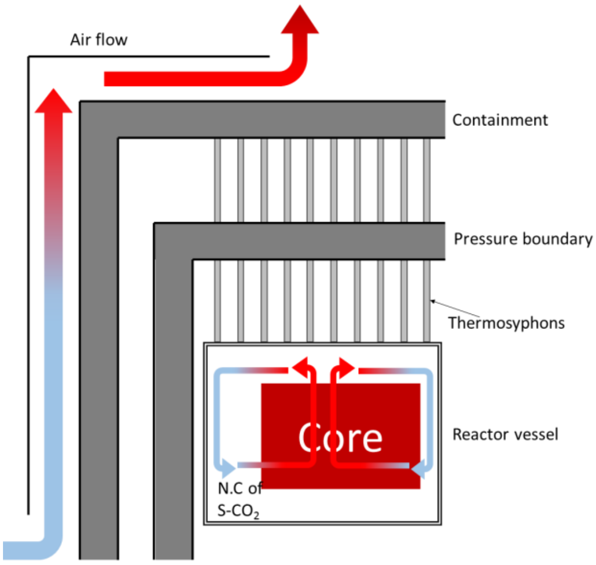

Fig. 3. Schematic of air cooled PDHR system

The air cooled PDHR system is individual cooling system and does not depend on any reactor system, therefore CCF is minimized and reliability of the system is high. The air cooled system can cope with all DBAs, on the other hand the water cooled PDHR system cannot cover LOCA and has CCF with existing reactor system.

3. Conclusion

LOCA, LOFA, LOHS and SBO are considered as DBAs of MMR. To cope with the DBAs, passive decay heat removal system is designed. Water cooled PDHR system shows simple layout, but has CCF with reactor systems and cannot cover all DBAs. On the other hand, air cooled PDHR system with two-phase closed thermosyphon shows high reliability due to minimized CCF and is able to cope with all DBAs. Therefore, the PDHR system of MMR will follows the air-cooled PDHR system and the air cooled system will be explored.

REFERENCES

[1] Min-Gil Kim, Jeong Ik Lee, Donny Hartanto, and Yong Hee Kim, Conceptual Design of S-CO2 Cooled Micro Modular Reactor, Korean Nuclear Society Spring Meeting, May 30-31, 2013, Gwangju, Korea
[2] Seong Gu Kim, Min Gil Kim, Seong Jun Bae, and Jeong Ik Lee, Preliminary Design of S-CO2 Brayton Cycle for KAIST Micro Modular Reactor, Korean Nuclear Society Autumn Meeting, Oct. 24-25, 2013, Gyeongju, Korea