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Accident Sequence Analysis of Autonomous Micro Modular Reactor in LOCA case

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1. Introduction

Today, The safety goal has become restrictive to reactor types for next generation. To improve the safety and performance, many new reactor designs are adopting gas cooled fast reactor type and passive systems such as VTHR and supercritical CO_2 (S-CO_2) cooled gas cooled reactor (GFR).

One of the future reactors, autonomous micro modular reactor (MMR) is devised and still in developing stage to meet the requirements. [1] MMR is devised to be transported as a module and tried to minimalize the limitations in site selection. Therefore, it adopted ambient air as an ultimate heat sink and introduced passive safety system to operate properly even in the isolated inland area. MMR operation was analyzed, and the result showed that it can maintain the safe condition in a steady state and several design basis accidents (DBAs). [2]

Prior to probabilistic safety analysis of MMR, we need to look at other reactor types with similar characteristics. One of the new reactors types, Very High Temperature Reactor (VHTR) was developed by KAERI. In the previous study, the performance of the reactivity cavity cooling system (RCCS) was analyzed in a low pressure conduction cooling (LPCC) accident. To assess the risk quantitively of the passive system, the authors proposed two methods: exceedance probability (EP) model and stress-strength interference (SSI) model. The failure criterion is provided as an exact value in EP model, while SSI model needs both distribution of the stress and strength. Among the two methods, EP model was recommended to use, because of the uncertainty of the strength model used in SSI model. In the future, this study could provide an insight when performing probabilistic safety assessment (PSA) of passive decay heat removal (PDHR) system in MMR. [3] One of the new reactor types, a large sized S-CO_2 cooled GFR is proposed by MIT research team. The performance of the safety system was analyzed in a few accident scenarios such as loss of external load (LOEL) transient, loss of coolant accident (LOCA), and loss of flow (LOF). MMR is also direct S-CO_2 cooled GFR with smaller size, therefore it would be helpful to understand the characteristics of S-CO_2 cycle. [4]

2. Selection of Initiating events

MMR is a GFR which contains a direct S-CO_2 Brayton cycle and power conversion system in a module with the size 3.7m wide, 7m length, and 3.8m height. There are four safety features: turbine bypass valve, venting valve, feed valve, and PDHR system. Turbine bypass valve makes bypass flow when the turbine rotational speed is over 110% of nominal. Venting valve is located upper and bottom side of the reactor core and operates when the system pressure exceeds the setpoint. Feed valve usually operates in LOCA case to replenish the inventory in the cycle. PDHR system is devised to remove decay heat for long-term recovery after shutdown. It cools down passively in the accidents instead of the air fan which needs power supply. Besides, the system is contained in two containments: inner and outer containment which is pressurized 5MPa and 1MPa respectively. [2]

The design of MMR is quite different from typical LWR, which means that the initiating event lists must be reviewed. MMR is designed as a compact module including the turbomachinery so that it used supercritical CO_2 as a coolant. It also does not have any steam generator and the coolant cool down the core directly. Therefore, several reactor types can be considered in the selection of initiating events such as PWR, BWR, GFR, and so on.

Through this process, several initiating events were identified which have possibility to occur in MMR such as loss of coolant accident (LOCA), loss of load (LOL), loss of ultimate heat sink (LOHS), and so on. For each initiating event, the accident scenarios were analyzed with Gamma+ code and the event trees were developed considering the success and failure of the safety functions.

Therefore, a number of analyses are necessary, and the operation of the passive systems would play an important role in risk assessment. In this paper, as a preliminary safety assessment, LOCA scenario was analyzed and event tree was updated to reflect the module situation depending on the success and failure of each system.

3. Accident Sequence Analysis of Autonomous MMR

In the analysis, GAMMA+ code is used which is developed by KAERI and modified with the S-CO_2 data from National Institute of Standards and Technology (NIST) by KAIST research team. In this paper, LOCA is analyzed with the variation of the break size of the leak and the steam mass reactivity.

3.1 Break size of LOCA

MMR was already analyzed in LOCA case with conservative assumptions: single failure of PDHR and reactor scram failure. The break size was assumed 6.4516e-2m^2, which is scaled size of large break LOCA in PWR. The break is assumed to occur at the compressor outlet 10 seconds after the simulation began. [2] In this paper, it changed the break size between 0.2m^2 and 0.6m^2 which is near the large break size without conservative assumptions as a sensitivity analysis.

When LOCA occurred, the coolant inventory in the cycle rapidly leaked out into the inner containment. After the pressure of the compressor outlet decreased lower than 16.08MPa, a shutdown signal was generated, and negative reactivity is inserted about 1 second after the signal. To prevent the reactor from damage, the passive decay heat removal (PDHR) system was activated simultaneously. Another passive safety feature, the feed valve was opened to replenish the inventory and formed a constant mass flow with the break flow.

In Fig. 1 and 2, the cladding temperature showed that the system could maintain the safe and stable condition under the safety limit 1200℃. In Fig. 1, the cladding temperature started to decrease after the operation of the PDHR system. It means that MMR can maintain the core integrity after the reactor trip, feed valve opening, and PDHR system operation in LOCA case with large break size. Meanwhile, the order of the headings of feed valve and PDHR system is reversed from the actual sequence of the operation starting time. This is because the PDHR system requires long-term operation to keep the system status stable after shutdown.

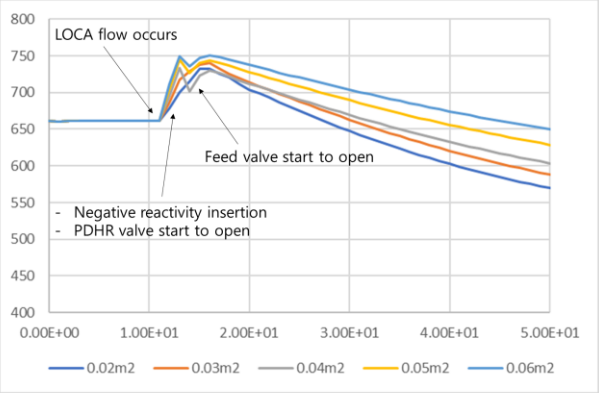

Fig. 1. Cladding temperature in LOCA with the break size from 0.02m^2 to 0.06m^2 at the beginning of the accident.

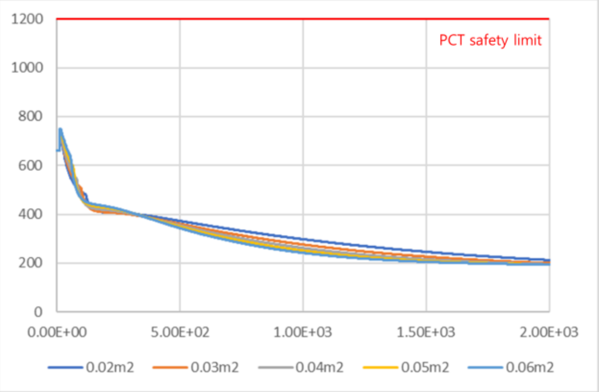

Fig. 1. Cladding temperature in LOCA with the break size from 0.02m^2 to 0.06m^2 in long term operation.

3.2 Steam mass coefficient

In case of the failure of reactor scram, MMR adjusts the reactivity through reactivity feedback. In PWR, there is an unfavorable exposure time, which means the fuel cycle that the reactivity might not have a negative value in anticipated transient without scram (ATWS).

In this paper, it changed the range of steam mass coefficient and analyzed the peak cladding temperature can keep the value below the safety limit. In Fig. 3, the cladding temperature increases above the safety limit when the steam mass coefficient becomes less than 0.063e-5. It means that there is a possibility that the core would be damaged if the inherent reactivity feedback does not work properly after the failure of reactor scram. However, the reactor power keeps decreasing in Fig. 4. Therefore, it should be analyzed not only if the reactivity is not able to maintain a negative value, but also whether the steam mass coefficient can change in the range presented. Thus, further analysis is required for ATWS in the future studies. Through this process, a preliminary event tree for large break LOCA (LLOCA) is developed for MMR in LOCA case in Fig. 5.

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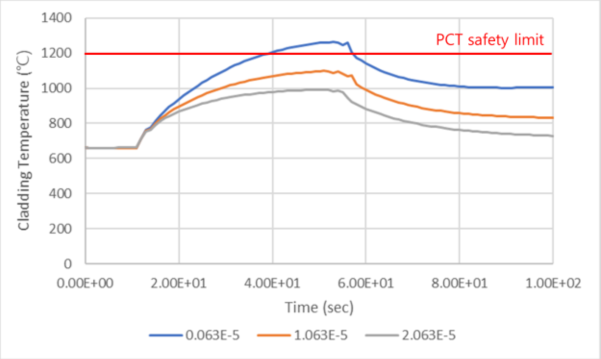

Fig. 3. Cladding temperature for reactivity from 0.063e-5 to 2.063e-5 at the beginning of the accident.

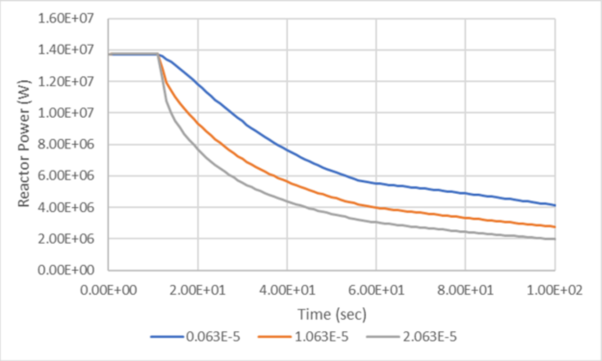

Fig. 4. Reactor power for reactivity from 0.063e-5 to 2.063e-5 at the beginning of the accident.

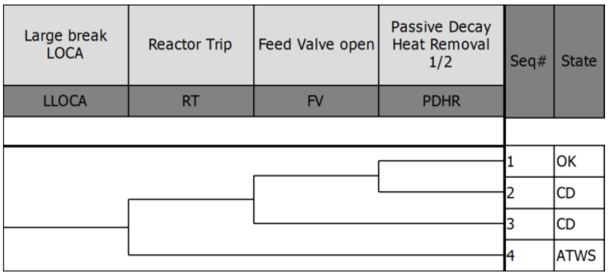

Fig. 5. Preliminary event tree for LLOCA.

4. Conclusions

In this paper, a preliminary event tree is developed for MMR in LLOCA case with several transient analyses. It showed that MMR can remain safe in LLOCA in the range of the break size from 0.02m^2 to 0.06m^2. However, the result showed that the core might fail to remain the safe condition if the reactivity feedback does not work properly. Therefore, the ATWS situation is required to be analyzed in LLOCA case. There are still other initiating events remained which need to be analyzed such as loss of load (LOL) and loss of ultimate heat sink (LOHS). However, the most critical thing in the analysis, safety analysis of passive system should be performed considering its characteristics. The analysis in this paper would be a good stepping stone to the next study.

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