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Performances of DHRSs in the KALIMER and the Sodium-cooled DFR

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1. Introduction

The sodium-cooled demonstration fast reactor (DFR) with the reference plant of the KALIMER is under the design by KAERI. One of the most important designs of the DFR is the Decay Heat Removal System (DHRS) for the safe and reliable decay heat removal. The safety grade DHRS of the KALIMER[1] which is operated by natural circulation flow consists of a DHX (Decay Heat eXchanger), an AHX (Air Heat eXchanger), and piping system connecting two heat exchangers.

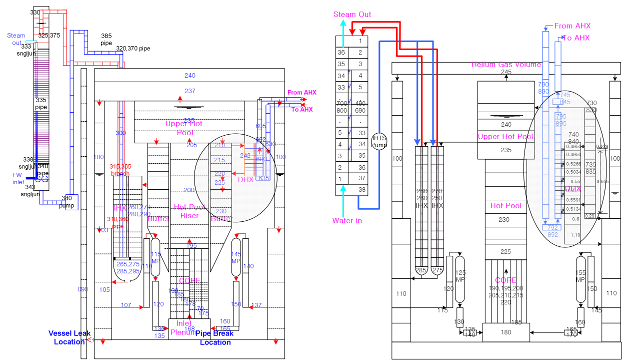
In general, the place of DHX plays an important role in the determination of the size of the AHX because the temperature difference of the hot pool and the cold pool is about 150 ℃ in a fast reactor. So the size of the AHX based on the cold pool temperature has to be much larger than that based on the hot pool temperature to remove the same capacity of heat. The DHRS of KALIMER is similar to the way of cooling by the hot pool because of using the flooded sodium from the hot pool although the DHX is in the cold pool. However, the DHRS is not available in accidents of which the sodium level in cold pool is below the DHX due to the running of pumps or which the overflow from the hot pool to the cold pool is not formed as the sodium level of the hot pool is lower than the location of a reactor barrel path for the overflow.

In this paper, the thermal hydraulic behaviors of the DHRS of KALIMER for two postulated events are compared with the behaviors of the new DHRS which is conceptually designed for the DFR. For the comparison of the long-term cooling capability of both systems, a LOHS (Loss Of Heat Sink) and a reactor vessel leak were analyzed using two types of DHRS's using the MARS-LMR system analysis code [2].

2. Calculation Models and Initial Conditions

Figure 1 shows the MARS-LMR calculation nodal system for two plant designs. The most difference in nodalizations is the modeling of the DHX represented within gray circles. The DHX of DFR is located at the path of down flow in peripheral region of the hot pool. So the main flow is reached IHX (intermediate Heat eXchanger) inlet via annular region of hot pool while the small amount of sodium flows the DHX shell side parallel to main flow. The DHX is above of the IHX to enlarge the natural circulation head in accident situations. On the other hand, the DHX of KALIMER is placed in the cold pool. The barrel in which the DHX shroud is contained inside is connected with the upper hot pool node and the upper shell side of the DHX is linked by the middle node of the barrel. The cold sodium cooled at the DHX is dumped into cold pool through the DHX outlet junction and the bottom part of the barrel is also connected with the cold pool.

The KALIMER core has the breakeven breeding characteristic which consisted of 1 ultimate shutdown assembly, 117 inner fuel assemblies (FAs), 96 middle FAs, 120 outer FAs, 15 control rods, 72 reflector assemblies, and 370 non-fuel assemblies. The core inlet temperature is 390.0 ℃ and the core outlet temperature is 545.0 ℃. The height and diameter of reactor vessel are respectively 11.5 m and 18.5 m and the active core height is 94 cm. The power of the KALIMER is 1523.4 MWt while the DFR power is 1548.2 MWt. The DFR core is composed of 150 inner FAs, 174 outer FAs, 349 non-fuel assemblies. The core inlet/outlet temperatures are reduced to 365.0/ 510.0 ℃ because of the clad material change from the Modified HT-9 to the HT-9. The height and diameter of vessel are 11.9 m and 16.5 m and the active core height is 89 cm. The DHRS of the DFR is composed of passive 2 loops and active 2 loops of the decay heat removal circuit of which the heat removal capacity of each loop is 9 MW while it's of the KALIMER is 8.25 MW.



<DFR> <KALIMER>

Fig. 1 MARS-LMR nodalizations for KALIMER and DFR

3. Analysis of LOHS

An accident of the LOHS is initiated by a loss of feedwater supply to all steam generators. It was assumed that a loss of offsite power was occurred at 5 seconds after the reactor scram as an aggravation failure of the accident. Figure 2 compares the core outlet temperatures of the KALIMER and the DFR for this transient.

The reactor was scrammed by the signal of the high core outlet temperature, which caused to drop the temperature rapidly. All pumps were tripped and experienced a coastdown then, the temperature was raised until the heat removal by the DHRS exceeded the core decay power.

In KALIMER system, the overflow was started around 1,000 seconds by sodium expansion. The flow was getting increased and formed enough to operate as its design purpose around 10,000 seconds. A momentary temperature drop was occurred at the time because of the inflow into the core of cold sodium accumulated at the cold pool below the DHX. The temperature was at long last decreased because the heat removal outran the core power from about 29,000 seconds.

As the decay heat was reduced and the sodium was cooled, the coolant level in the hot pool was descended which made to decrease the overflow rate. Around 90,000 seconds, the level reached the overflow elevation and then the decay heat was removed by the intermittent overflow. This means that the core outlet temperature is determined by the overflow elevation. The temperature was maintained as 575 ℃ higher than the 545 ℃ at the 100 % power condition because of the higher elevation of the overflow path than the normal operation level.

In the analysis of the DFR, it is conservatively assumed that two loops of DHRS are available and the damper is open in 30 minute after the accident initiation by an operator action. The core outlet temperature in initial phase was calculated about 150 ℃ less than the case of the KALIMER due to the difference of the heat removal in steam generators. But, the decay power bigger than the heat removal led to rise the temperature. The temperature reached the peak of 475 ℃ at around 12,000 seconds thereafter, continued to decrease by the greater heat removal than the decay power. At 60,000 seconds after beginning of the accident, the temperature reached 400 ℃ and the plant could be maintained as hot shutdown state.

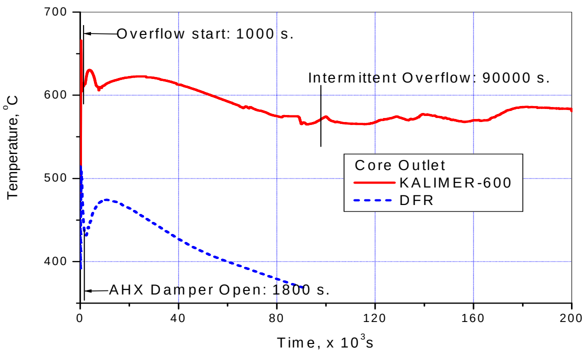


Figure 2. Core I/O temperatures behaviors

4. Analysis of Reactor Vessel Leak

As a hypothetical design basis accident like a large break loss of coolant accident in a water reactor, the rupture of the size of 10 cm^2 in the bottom of a reactor vessel was considered.

It is important to be ensured that the flow path of topmost component in the sodium pool isn't uncovered due to this accident. In the KALIMER, the IHX inlet windows are located at 2.9 m below of the normal hot pool level and the overflow paths are 0.3 m higher than the normal level. As shown in Figure 3, the hot pool level was decreased by 0.85 m because of the sodium discharge to inter-space. The reactor scram was occurred at 70 seconds by the signal of the low pool level. The loss of feedwater to a steam generator and all pumps trip was also triggered 5 seconds after the reactor scram.

The reduced sodium level again rose due to the sodium expansion, which was invoked by the deterioration of the DHRS heat removal. But it was not sufficient to come into force the overflow. The lack of the heat removal of the DHRS of the KALIMER brought the clad temperature to violate the safety limit of 690 ℃ about 17,500 seconds.

On the other hand, in the calculation for the DFR the hot pool sodium level was reduced by 0.67 m but, the level was so 1.57 m above the DHX inlet windows that the DHX was always immersed in the hot pool. Thus the heat transfer from the hot pool sodium to the sodium in the DHX tube worked well as the design purpose and the clad temperature was well fallen off to below of the safe shutdown condition.

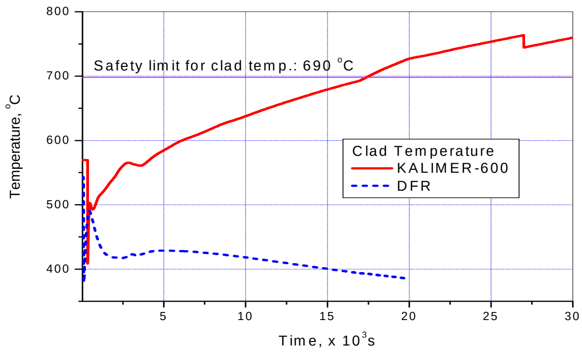


Figure 3. Clad temperature behaviors

5. Conclusion

The performances of the DHRS's of the KALIMER and the DFR were evaluated by simulation of the LOHS and the reactor vessel leak using the MARS-LMR. Through the study, the DHRS of the KALIMER couldn't be operated as design purpose in the accidents conditions due to the elevation of the overflow path. However, the DHRS of the DFR was well operated and all calculated results were proved out to be satisfied the safety criteria.

ACKNOWLEDGMENTS

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