Diverse Design Features of EU-APR1400 for Residual Heat Removal Function with Open RCS

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1. Introduction

Diversity is the fundamental principle in safety system design of new nuclear power plants, which uses different mitigation measures to provide diverse ways of responding to a significant event. Regarding the diversity principle, EU-APR1400 (European APR1400) safety system should be in accordance with European design requirements [1, 2, 3].

This paper provides how the core residual heat can be removed with open RCS (Reactor Coolant System) closure head condition using diverse cooling systems assuming a loss of SCS (Shutdown Cooling System). The loss of SCS results from a common cause failure of SCS or a loss of UHS (Ultimate Heat Sink). One of the postulated common cause failures which lead to the loss of SCS can be a manufacturing deficiency of shutdown cooling pumps, component cooling water pumps or essential service water pumps. The limiting event of the loss of SCS is the loss of UHS since the loss of UHS causes losses of safety systems including SCS, CCWS and ESWS.

NO operator action inside the MCR (Main Control Room) during the first 30 minutes and outside the MCR during the first 60 minutes can be credited to recover the failed SCS.

2. Description of SCS

The SCS is used to reduce the temperature of the reactor coolant to a refueling temperature and to maintain the proper reactor coolant temperature during refueling. This system utilizes the shutdown cooling pumps to circulate the reactor coolant through the shutdown heat exchangers, returning it to the RCS. The shutdown cooling pumps do not share functions with SIS (Safety Injection System). The SCS, by itself and in conjunction with containment spray system performs safety functions of decay heat removal of the reactor core and containment heat removal respectively.

Residual heat is generated even after reactor shutdown. Therefore it needs to be removed with adequate measures. The SCS shall be available to remove residual heat during the cooldown operation. This SCS operation for core residual heat removal continues to refueling operation after a reactor pressure vessel closure head opened. If shutdown cooling function is lost and an operator does not take proper action, reactor coolant boils and eventually causes core damage.

3. Diverse Design Features

Diversity design features for the loss of SCS with RCS open condition are described in this paper. If the SCS with RCS open condition is lost, in such situation, the refueling pool boil is considered to achieve diversity. The pool structures and the reactor building are designed taking pool boil into account.

The makeup water supply is needed to compensate for the boil. The refueling pool makeup is provided using SFPMP (Spent Fuel Pool Makeup Pump) from AFWST (Auxiliary Feed Water Storage Tank). Two identical makeup pumps are installed in spent fuel pool cooling system. Each pump is sized to deliver water of the AFWST into the refueling pool to makeup the evaporated water in the pool. The pumps are controlled automatically from the MCR.

Chilled water for HVAC (Heating, Ventilation and Air Conditioning) system for SFPMP room and safety injection pump room cooling is supplied from the water cooled type chiller. If water cooled type chiller is not available because of the loss of CCWS, ESWS or UHS, the air cooled type chiller can be used.

CFVS (Containment Filtered Vent System) is used as one possible approach to ensure the containment overpressure protection. The CFVS is also capable of venting filtered air to the environment against the uncontrolled release of the fission products inside the containment.

4. Preliminary Assessment of Diverse Design

If shutdown cooling function is lost with RCS open condition, the diverse removal of residual heat by boiling and vaporizing the pool water is applied. If refueling pool is not filled up, makeup water supply from IRWST (In-containment Refueling Water Storage Tank) to the refueling pool by an automatic start of the safety injection pump is considered.

Figure 1 shows refueling pool configuration of the EU-APR1400. Initially, the refueling pool water level maintains within the maximum water level with the shutdown cooling pump or the safety injection pump. Boiling without makeup gradually lowers the refueling pool water level. During refueling, the SFPMP is interlocked with the pool level gauge. If the pool level is lowered below the limit value, the pump is operated automatically.

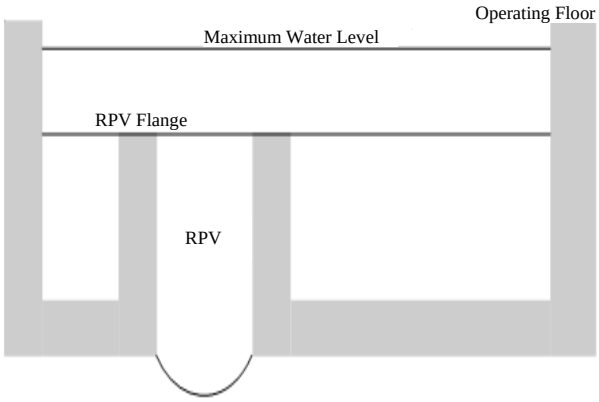

Figure 1 Refueling Pool Configuration

It is assumed that the RCS is opened in 24 hours after the shutdown and the loss of SCS occurs at the same time. At 24 hours after the shutdown, the decay heat power is about 20 MW. Figure 2 shows mass and energy release data in this situation. The refueling pool water volume covered by boiling is about 1633 m^3, which is not enough to compensate for boil and vaporization for 72 hours. If shutdown cooling function is lost with RCS open condition, the pool starts boiling in about 5 hours after event initiation. In about 56 hours after the start of the boil, the top of the RPV flange may be uncovered. Because no operator action is required during 61 hours, the acceptance of the 30/60 minutes autonomy rule is met.

Additional water during 11 hour-time left for 72 hour-diverse cooling is supplied into the refueling pool from the AFWST using the SFPMP.

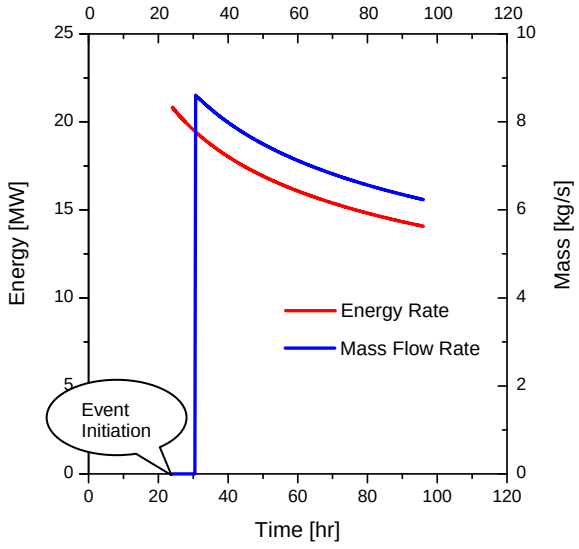

Figure 2 Mass and Energy Release Data after RCS opened during 72 hrs

Figure 3 shows containment pressure and temperature for 72 hours when the shutdown cooling function is lost with RCS open condition. The containment pressure exceeds design value (4.1 x 10^5 Pa) in about 35 hour after event initiation.

According to the level of residual heat generated from the reactor core and released to the containment atmosphere, depressurizing and cooling of containment atmosphere is necessary. The CFVS has been adopted to remove the energy in the containment, which is under design and evaluation. The CFVS should be actuated automatically before the containment design pressure exceeds. The release of radioactive substances should not lead to environmental doses exceeding 20 mSv.

As a result, the plant is expected to be maintained the safe state for 72 hours at least by boiling and vaporizing the refueling pool water and venting the containment atmosphere through the CFVS.

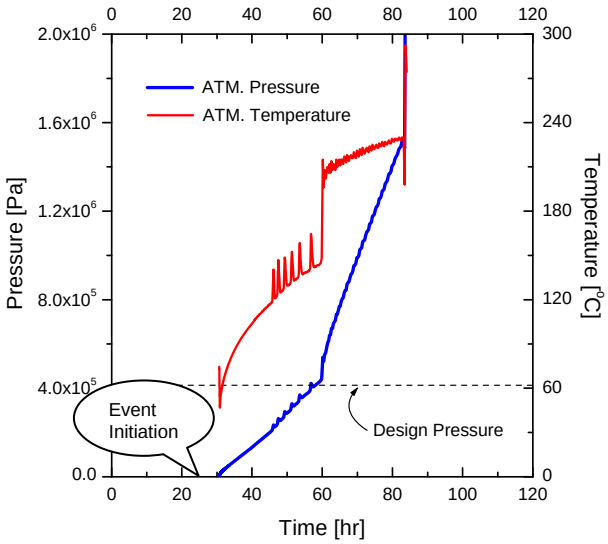

Figure 3 Containment Pressure and Temperature after RCS opened RCS during 72 hrs

5. Conclusions

The diverse means of the EU-APR1400 for the residual heat removal function with RCS open condition have been developed to comply with the diversity principle of the European design requirements of new nuclear power plants. The results of the preliminary assessment show that the diverse design features are expected to satisfy the design criteria.

In the future, more detailed design and assessment for this means will be performed considering interface requirements with completing the design of relevant systems and components.

REFERENCES

[1] IAEA (International Atomic Energy Agency), Safety of Nuclear Power Plants: Design, IAEA Safety Standards Series No. SSR-2/1, 2012

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[3] EUR Organization, European Utility Requirements for LWR Nuclear Power Plants, Revision D, Chapter 2.1, 2012