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Severe Accident Management Strategy for EU-APR1400

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1. Introduction

Severe accidents in a nuclear power plant are defined as certain unlikely event sequences involving significant core damage with the potential to lead to significant releases according to EUR [1] 2.1.4.4. Even though the probability of severe accidents is extremely low, the radiation release may cause serious effect on people as well as environment.

Severe Accident Management (SAM) encompasses those actions which could be considered in recovering from a severe accident and preventing or mitigating the release of fission products to the environment. Whether those actions are successful or not, depending on a progression status of a severe accident to mitigate the consequences of severe accident phenomena to limit the release of radioactive materials keeping the leak tightness of the Primary Containment, and finally to restore transient severe accident progression into a controlled and safe states.

In EU-APR1400, the dedicated instrumentation and mitigation features for SAM are being developed to keep the integrity of containment and to prevent the uncontrolled release of fission products.

2. SAM Conceptual Strategy

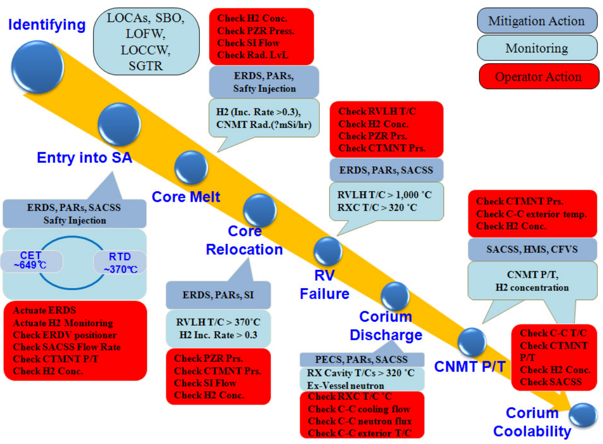

Fig.1 Diagram of SAM Strategy for EU-APR1400

2.1 Entry Condition of Severe Accident

Even though the engineering safety features (ESFs) automatically operate to play their functions as designed after the accident initiated, various causes including unexpected or very low probability of successive failures and human errors can lead a design base accident to a severe accident resulting in core damage. In EU-APR1400, the entry condition of a severe accident is when the Core Exit Temperature (CET) reaches 648.9 °C. At the higher temperature than 648.9 °C, it is expected that core uncovery and oxidization of fuel clad would accelerate and these phenomena would lead core temperature to increase fast until core meltdown occurs. Therefore, it is reasonable that CET higher than 648.9 °C is regarded as a threshold temperature for determining whether an accident enters into severe accident condition or not.

2.2 Rapid Depressurization

In case of a postulated high pressure sequence without a depressurization process, at the timing of vessel failure, RCS has very high temperature and pressure due to the amount of hot steam and hydrogen generated from the uncovered core and the relocated corium pool into the reactor vessel lower head. If the reactor vessel breach occurs in this condition, a large fraction of melt core can be transported up to the upper containment atmosphere and then fragmented particles of small size during a transport process can abruptly enhance heat transfer between corium particles and containment atmosphere, so called a Direct Containment Heating (DCH), by which the containment pressure would be sharply increased and finally the integrity of containment is jeopardized. To reduce the risk of the early containment failure, EU-APR1400 provides the dedicated Emergency Reactor Depressurization System (ERDS).

2.3 Hydrogen Mitigation

In a Nuclear Power Plant, hydrogen is generated from several interactions such as the fuel clad oxidization, fuel-coolant interaction and molten core–concrete interaction. The conditions of severe accident accelerate these interactions that generate hydrogen. The containment atmosphere containing hydrogen concentration of over a certain level can bring about Flame Acceleration (FA) and Deflagration-to-Detonation Transition (DDT) phenomena from which dynamic loads can sufficiently threaten the integrity of containment. Therefore, the EU-APR1400 containment has 46 Passive Autocatalytic Recombiners (PARs) to eliminate the risk of occurrence of FA and DDT.

2.4 Core Melt

In this accident progress status, core components may be partially covered by a water pool. Steam generated in covered nodes boils up the pool. During boil-down of the core water, heat generated in the covered part of the core is transferred into the water pool as sensible and latent heat. Hence, the temperature of this part of the core is close to the pool saturation temperature. In the uncovered part of the core, on the other hand, heat can be removed by convection to the gas stream and by pin-to-pin radiation across the core. This heat removal rate is generally less than the decay heat generation and thus the temperature in the uncovered region increases.

2.5 Core Relocation

As the core heats up and collapses, the material may eventually reach conditions in which one or more nodes begin to melt and, depending on the capability to flow downward or sideways, may eventually reach a fully molten state. If this occurs, energy and mass could be transferred between molten nodes more efficiently due to the pool natural circulation. Also, the crust surrounding the pool can prevent the coolant flow from interacting with these molten nodes. Due to the continuous generation of decay heat in the pool, the crust will eventually break and molten core poured into the lower plenum or lower core region.

2.6 Reactor Vessel Failure

The corium pool relocated in the lower head has a high temperature of about 2,800 K. On the other hand, the melting temperature of reactor vessel made of carbon steel is less than 1,800 K. Nevertheless, the mass of corium relocated into the lower head before reactor vessel failure has been expected to be about 100 tones when looking at the typical analysis results. When considering such lower head conditions, the reactor vessel lower head could be comparatively deformed.

2.7 Corium Discharge

Upon initial delivery, the molten corium melts through the In-Core Instrument (ICI) tubes and enters the penetration channels. Once inside, the melt may refreeze and thereby plug the channel, or it can travel through the penetration line thereby increasing the wall temperature and potentially causing failure of the penetration outside the vessel

Sustained heating from accumulated debris may lead to weakening of the penetration support weld and subsequent ejection of the penetration.

The combination of internal pressure and weight of the debris combined with high temperatures may result in creep rupture of the lower head.

Coherent jet of debris impinging directly onto the lower head may cause localized ablation of the lower head. And, a molten metal layer on top of the debris in the lower plenum may thermally attack and weaken the vessel wall.

2.8 Ex-Vessel Corium Retaining and Cooling

Once a reactor vessel fail happens, approximately corium mass of 100 to 200 ton is released into the reactor cavity. The corium with high temperature makes containment to be high pressure and temperature by interaction with concrete, water and other materials, and finally threaten the integrity of containment. For the reason, the dedicated ex-vessel corium cooling system is designed in EU-APR1400. The Passive Ex-vessel corium retaining and Cooling System (PECS) is designed as a debris retention device in the containment for those core melt accident sequences that could progress to failure of Reactor Pressure Vessel and discharge of molten core debris from a reactor vessel.

2.9 Containment Temperature and Pressure Control

During the progress of a severe accident, containment might be highly pressurized by a huge amount of steam and non-condensable gases including hydrogen. The EU-APR1400 containment could be kept leak tightness during, at least, the first 12 hours from the beginning of the severe accident conditions without any heat removal actions. Nonetheless, containment temperature and pressure control system is designed in EU-APR1400 as severe accident mitigation feature.

2.10 SAM Exit Condition

Even though the exit conditions of SAM have been met, the plant might be under the conditions that long term actions for ensuring the integrity of containment and the restriction of release of radioactive materials to the environment should be required. The exit conditions of SAM could be accomplished after confirming that there are no more any threats against the fission product boundary of the containment and the core and containment conditions are under a safe state.

3. Conclusions

In this paper, SAM strategy for EU-APR1400 was introduced in stages. It is still under development and finally the Severe Accident Management Guidance will be completed based on this SAM Strategy.

Acknowledgement

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REFERENCES

[1] "European Utility Requirements (EUR) for LWR Nuclear Power Plants", Vol. 2, Rev. D, October 2012.