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Transient analysis of AP1000 NPP under the similar Fukushima accident conditions

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ABSTRACT

Stress tests are conducted on AP1000 NPP to investigate the effectiveness of Passive Core Cooling System (PXS) in mitigating the similar Fukushima accident conditions, using thermal hydraulic analysis code RELAP.

Key transient parameters, including the Reactor Coolant System (RCS) pressure, core coolant temperature and passive safety system flow, were obtained and the results were analyzed. The calculation results show that the AP1000 NPP can reach hot shutdown status when the Passive Residual Heat Removal System (PRHR) is available. However, the transient would develop to severe accident within five hours if double-ended rupture of one PRHR-HX tube occurred.

Several suggestions are given based on the analysis results. Additional protections resulted from the earthquake are necessary for PRHR, especially for the tubes of the heat exchanger. Furthermore, reliability of the battery sets is of great importance, such special attentions should be paid to improve the availability of the battery sets under accident conditions.

1. Introduction

AP1000 NPP technology employs series of passive safety systems, which just rely upon passive driven forces such as gravity, compressed gas and natural circulation, to improve its inherent safety. The passive safety systems of APP1000 include the Passive Safety Injection System (PSIS), the Passive Residual Heat Removal System (PRHR), the Passive Containment Cooling System (PCCS) and the Passive Main Control Habitability System. Employment of these passive safety systems reduces interventions of the operators, accordingly decreases the possibility of human errors.

The passive systems are defined as those totally consisted of passive components without any active components or those consisted of passive components activated by limited active components (IAEA, 1996a,b) in the IAEA technology reports .According to the reports, the PSIS and PRHR are ranged as the level-4 passive systems, the lowest level, which are activated by active components supplied by the storage batteries (IAEA, 1996a).

After the similar Fukushima accident conditions, stress tests were conducted on those Nuclear Power Plants (NPP) under operation and construction all around the world (ENSREG, 2011) to reevaluate the safety margins of the NPP, assess the impact of extreme natural disasters on the safety of the NPP and the possibility that could lead to severe accidents. In this paper, stress tests are conducted on AP1000 NPP, with the purpose to investigate the effectiveness of PXS in mitigating the similar Fukushima accident conditions.

2. Basic assumptions

The responses of AP1000 under similar Fukushima accident conditions are analyzed, with the basic assumptions described below:

1. Large seism with ground acceleration above 0.5 g, causing the reactor scram.
2. Flooding induced by tsunami, causing total loss of DC power supply, including the on-site and off-site DC powers.
3. Total loss of AC power supply. The class-1E battery sets of AP1000, supplied to the safety related power supply systems, are located in the underground rooms of auxiliary building, which cannot resist external flooding. Two sets of auxiliary diesel generators are installed as the backup of the class-1E battery sets. However, under similar Fukushima accident conditions, all

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Nomenclature

g	gravitational acceleration (9.8 m/s^2)
P	pressure (MPa)
T	temperature (K)
ACC	accumulator
ADS	Automatic Depressurization System
CMT	Core Makeup Tank
NPP	Nuclear Power Plant
PBL	Pressure Balance Line
PCCS	Passive Containment Cooling System
PCCSWST	Passive Containment Cooling System Water Storage Tank
PRHR	Passive Residual Heat Removal System
PRHR-HX	Passive Residual Heat Removal System Heat Exchanger
PSIS	Passive Safety Injection System
PXS	Passive Core Cooling System
RCS	Reactor Coolant System
RCP	Reactor Coolant Pump
SBLOCA	Small Break Loss of Coolant Accident
IRWST	In-containment Refueling Water Storage Tank

these AC power supplies will become unavailable. And even worse, no AC power supply can be recovered during the transient progress (IAEA, 2011).

4. The I&C systems are out of operation due to the total loss of AC power, causing monitor and actuation signals unavailable.
5. Electrically operated valves cannot be actuated due to the unavailable actuation signals.
6. The fail-open valves are opened automatically as the AC & DC power are totally lost. The PXS system and the corresponding fail-open valves are shown in Figs. 1 and 2 (Westinghouse, 2010).

Based on the assumptions above, calculations are carried out using RELAP code. The accident progress can be subdivided into two phases that could be called short-term and long-term phase according to the system responses and the accident results. Main phenomena and system responses are different in the two phases. In short-term phase, the main focuses are on whether the Passive Core Cooling Systems (PXS) could mitigate the accident consequences and whether the safety criteria could be met. In long-term phase, which belong to the severe accident category, focuses are on the phenomena such as core melting, containment damage and radioactivity release. In this paper, analyses are focused on the short-term phase of the accident.

3. Description of the accident

Brief descriptions of the transient responses of AP1000 under similar Fukushima accident conditions will be given in this section. Two accident conditions are considered, one with no primary broken and the other with primary broken.

3.1. Short-term phase

3.1.1. Accident with no primary broken

Total loss of AC & DC power supplies causes the dropping of control rods, the trip of steam turbines, the trip of RCPs, thus coolant mass flowrate starts to decrease. Atmospheric relief valves of the SG secondary side become unavailable because of the loss of the driven power. The fail-open valves on the outlet line of RRHR, the outlet line of Core Makeup Tanks (CMTs) and the Passive Containment Cooling System (PCCS) open automatically.

At the beginning of the transient, the residual heat is mainly removed to the In-containment Refueling Water Storage Tank (IRWST) by PRHR, then removed to the outside of the containment by PCCS.

The spray lines of the PCCS operate automatically, providing the cooling water to the outside of the steel containment. The water in

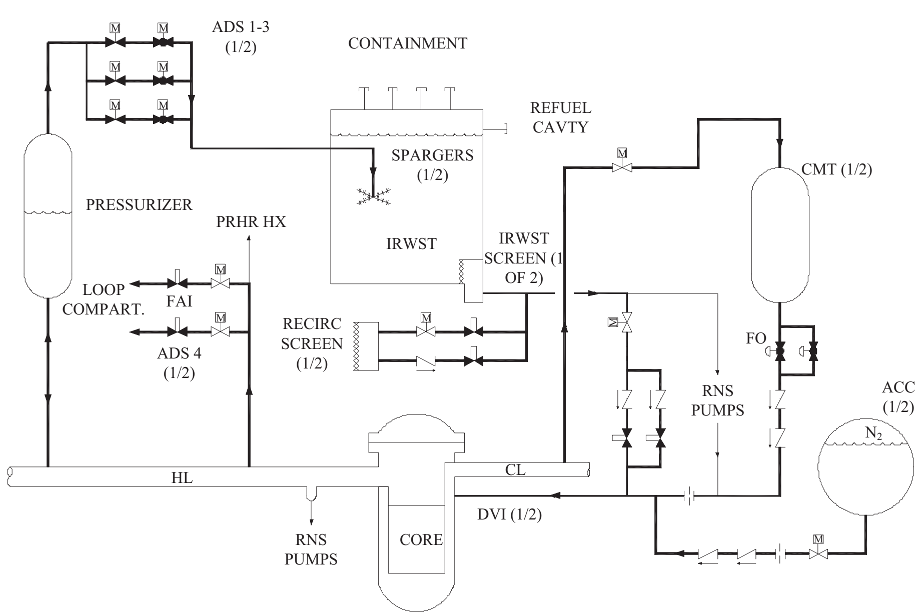

Fig. 1. Passive safety injection system.