Annals of Nuclear Energy 123 (2019) 110–118

Contents lists available at ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene

Integral effect test on cooling performance of hybrid safety injection tank

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ARTICLE INFO

Article history:
Received 7 June 2018
Received in revised form 6 August 2018
Accepted 15 September 2018

Keywords:
Passive emergency core cooling system
Hybrid safety injection tank
Small break loss of coolant accident
Integral effect test

ABSTRACT

This paper reports an experimental research on the performance of the passive emergency core cooling system (PECCS) using an integral effect test facility in Korea Atomic Energy Research Institute (KAERI). The PECCS consists of two hybrid safety injection tanks (H-SIT), two medium pressure safety injection tanks (MP-SITs) and an automatic depressurization system consisting of four stages. In this study, an integral effect test (IET) was conducted on a loss of coolant accident (LOCA), which requires the operation of the primary makeup system. The H-SIT (SITs #1 and #3) injection starts successfully when the primary side pressure falls to 10.0 MPa, and the MP-SIT (SITs #2 and #4) injection starts when the pressure falls further to 4.21 MPa. The coolant injection of H-SIT occurs intermittently at certain points of time, rather than continuously. It can be seen that the flow generation of the H-SIT near the pressure plateau occurs exactly when the secondary side is depressurized.

1. Introduction

The passive emergency core cooling system (PECCS) proposed by Korea Hydro and Nuclear Power (KHNP) is designed to maintain core cooling and prevent nuclear fuel damage in the event of NPP design basis accident (DBA). It has a design feature that allows an unpowered passive injection in lieu of the pump-driven injection method (Kang and Kim, 2013). As illustrated in Fig. 1, the PECCS is composed of an injection system with two hybrid safety injection tanks (H-SIT), two medium pressure safety injection tanks (MP-SIT) and an automatic depressurization system (ADS) with four stages. The H-SIT ensures emergency coolant injection into the core in the high-pressure region between the reactor coolant system (RCS) operation pressure (15.0 MPa) and the MP-SIT operation pressure (4.21 MPa). While its tank design is identical to that of a conventional SIT, the nitrogen space placed in the upper part of the tank and the cold leg are connected with a pressure balancing line (PBL), and the gravity-driven injection of cooling water from the tank into the reactor takes place at high pressure. The MP-SIT is designed to inject cooling water at medium pressure ($\leq$4.21 MPa) by the aid of pressurized nitrogen gas charged in the upper part of the tank as in the conventional SIT. The low pressure injection system (LPIS) is designed to inject cooling water from the in-containment refueling water storage tank (IRWST) to the RCS, driven by the difference in water head. Since the cooling water injection is hampered in an MP-SIT or LPIS when the RCS pressure is high, depressurization valves are installed along the pressurizer and RCS main piping to implement RCS depressurization so that the MP-SIT or LPIS can function smoothly. The ADS is made up of four stages. Automatic depressurization valves (ADVs) #1 $\sim$ #3 are connected to the upper end of the pressurizer to implement the depressurization of the primary system and discharge the mass and energy of the primary system to the IRWST. ADV #4 is connected to the hot leg and discharges to the containment atmosphere when implementing depressurization.

In order to verify the validity of the H-SIT design, some researchers investigated the overall thermal-hydraulic phenomena of the H-SIT. Kwon et al. (2011a,b) analyzed the SBO situation of the APR1400 using the MARS-KS code in order to evaluate whether the operation of the H-SIT has an effect on the cooling performance of the RCS. According to their analysis, when the actuation valve on the pressure balancing line (PBL) is opened, the H-SIT's pressure rises rapidly, forming equilibrium with the RCS pressure; subsequently, a flow is injected from the H-SIT into the reactor vessel through the direct vessel injection (DVI) line. In addition, Kang and Kim (2013) discussed the applicability of H-SIT and proper design combinations during small break loss of coolant accident (SBLOCA) for the PECCS by using the system analysis code, RELAP5/MOD3.3. Ryu et al. (2016a) theoretically derived the pressure-equalizing point of the SIT. A parametric study was conducted by changing the coolant level, length of the PBL, and opening rate of the flow control valve (FCV) by using a separate effect test (SET) facility (Ryu et al., 2016b). The results confirmed that the condensation rate of the SIT is a major parameter in determining the pressure-equalizing time, and the results were analyzed

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https://doi.org/10.1016/j.anucene.2018.09.023
0306-4549/

Nomenclature

g	acceleration of gravity (m/ s^2)
h	level difference (m)
P	pressure (Pa)
ρ	density (kg/m^3)

Subscripts

SIT coolant	SIT coolant water level

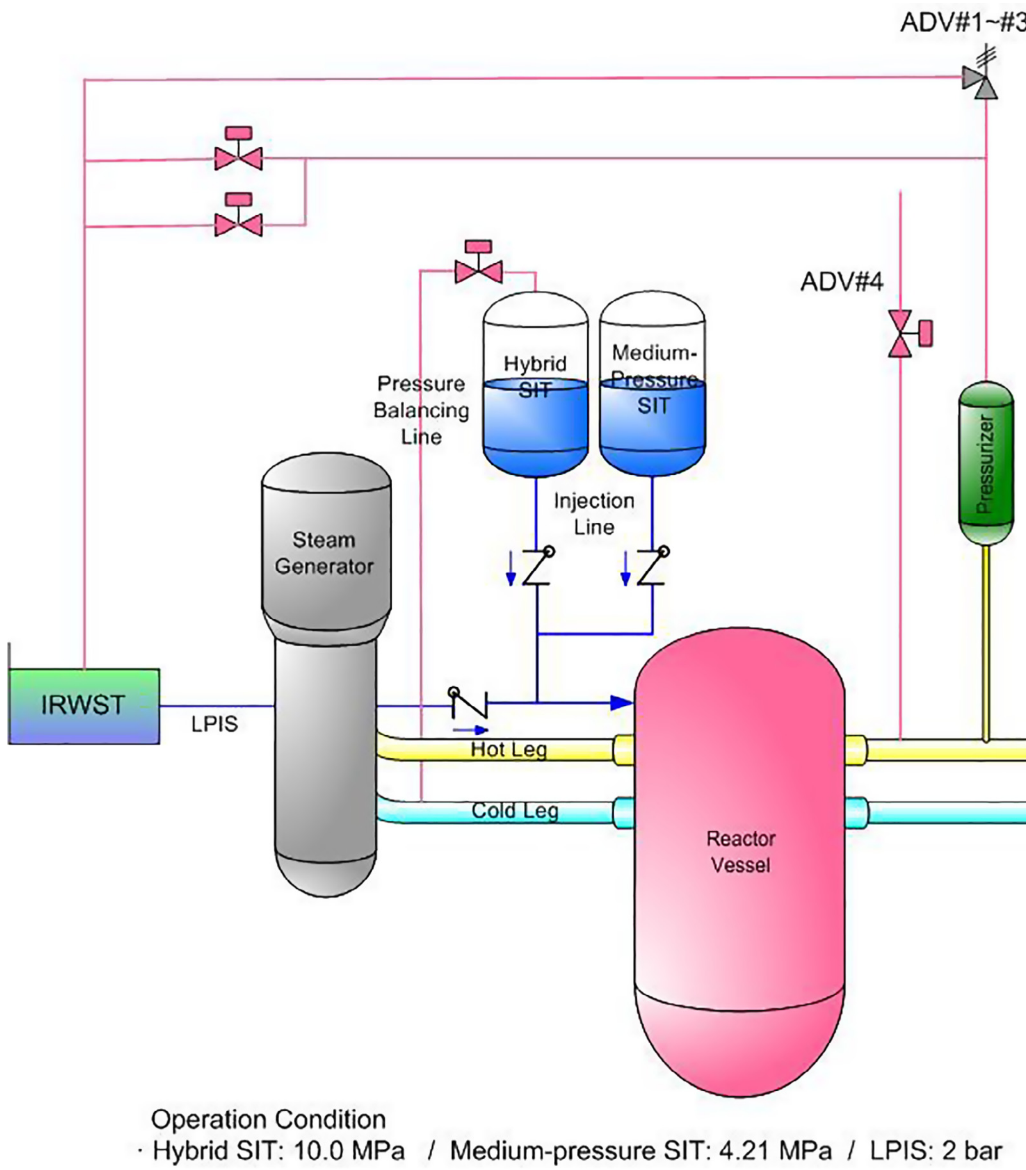

Fig. 1. The composition of the passive emergency core cooling system.

quantitatively. Kim et al. (2018) suggested a prediction method for estimating the time required to reach the equalizing pressure between two tanks for the H-SIT system. Despite these efforts, researches have so far been limited to using numerical methods and a separate effect test (SET) facility to evaluate to performance of H-SIT. In this case, there is a limitation to identify the cooling performance of the H-SIT and its effect on the overall system.

In this study, an integral effect test (IET) was conducted on a loss of coolant accident (LOCA), which requires the operation of the primary makeup system, in order to inspect the performance of each PECCS component. A LOCA is an accident caused by a pipe break in the reactor coolant pressure boundary that results in a loss of reactor coolant at a rate in excess of the capability of a normal reactor coolant makeup system. A classic small break LOCA (SBLOCA) scenario with a break area of 0.024 square feet (two-inch break) was selected for PECCS performance analysis. The PECCS performance test aimed to assess the performance of each PECCS component in the event of a LOCA and to identify various