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Original Article

EVALUATION OF AN ACCIDENT MANAGEMENT STRATEGY OF EMERGENCY WATER INJECTION USING FIRE ENGINES IN A TYPICAL PRESSURIZED WATER REACTOR

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ABSTRACT

Following the Fukushima accident, a special safety inspection was conducted in Korea. The inspection results show that Korean nuclear power plants have no imminent risk for expected maximum potential earthquake or coastal flooding. However long- and short-term safety improvements do need to be implemented. One of the measures to increase the mitigation capability during a prolonged station blackout (SBO) accident is installing injection flow paths to provide emergency cooling water of external sources using fire engines to the steam generators or reactor cooling systems. This paper illustrates an evaluation of the effectiveness of external cooling water injection strategies using fire trucks during a potential extended SBO accident in a 1,000 MWe pressurized water reactor. With regard to the effectiveness of external cooling water injection strategies using fire engines, the strategies are judged to be very feasible for a long-term SBO, but are not likely to be effective for a short-term SBO.

1. Introduction

A state-of-the-art reactor consequence analysis (SOARCA) project was created by the *United States Nuclear Regulatory Commission* (USNRC) to make the best estimates of the offsite consequences of potential severe reactor accidents for two pilot plants: the Peach Bottom Atomic Power Station and the Surry Power Station [1]. A short-term station blackout (STSBO) and a long-term station blackout (LTSBO) were identified as the major groups of accident scenarios for analysis. Both types of scenarios involve a loss of all alternating current (AC) power. The risk management features for the SBO are to be enhanced [2].

In terms of severe accidents caused by an earthquake or tsunami that are beyond expectation, a special safety inspection for operating plants, following the Fukushima accident, has been conducted by the government of Korea to verify that nuclear power plants are adequately designed to

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respond to extreme accidents [3]. The inspection results show that Korean nuclear power plants in operation have no imminent risk for an expected maximum potential earthquake or coastal flooding, based on the up-to-date investigation. However, there is a need to implement long- and short-term safety improvements in order to secure safety for natural beyond-design-basis events [4].

One of the measures to increase the mitigation capability during a prolonged station blackout (SBO) accident is installing injection flow paths to provide emergency cooling water of external sources using fire engines on the steam generators (SGs) or reactor cooling system (RCS). Therefore, it is necessary to develop some guidelines or strategies to cope with an extreme severe accident scenario using the newly installed injection flow paths and fire engines. SOARCA-like analyses, which are limited to accident progression with the exception of offsite consequences, were conducted at the Korea Atomic Energy Research Institute for a typical 1,000 MWe pressurized water reactor. In this paper, an assessment is presented for the mitigative effectiveness of the external cooling water injection strategies using fire engines during a potential extended SBO accident.

A brief outline of the typical 1,000 MWe pressurized water reactor design with special reference to the mitigation capability during an extended SBO accident is provided in this section. The reactor uses pressurized water with a core thermal output of 2,815 MWth. For secondary heat removal, feedwater may be supplied to the steam generators using one of several pumps; for instance, the main feedwater, start-up feedwater, and auxiliary feedwater (AFW). However, the turbine driven auxiliary feedwater (TD-AFW) pumps can be credited as a unique means of supplying feedwater during an SBO event. TD-AFW pumps can provide feedwater until all station batteries, the capacity of which is a minimum of 4 hours, are depleted. The secondary steam can be removed through the main steam safety valves (MSSVs) or atmospheric dump valves (ADVs), which need an operator action in order to be opened [5]. The major design parameters of the reference plant are summarized in Table 1.

The safety injection system of the plants consists of four safety injection tanks (SITs), and high-pressure, and low pressure safety injection pumps. The passive SITs automatically discharge into the reactor coolant system if the RCS pressure decreases below the SIT pressure (4.31 MPa) during the reactor operation. Because the pressure of the RCS is maintained above the SIT injection set point in most transient accident sequences, SIT injection occurs only after depressurization of the RCS, vessel breach, or other induced RCS failure. If secondary heat removal is unavailable owing to failures in either the AFW system or steam removal system, core decay heat must be removed using a feed and bleed operation of RCS to prevent core damage. It is necessary that only the operator aligns a bleed line of the safety depressurization system (SDS) for the feed and bleed operation because the high-pressure safety injection pumps will automatically inject water from the refueling water tank into the RCS once the RCS is depressurized below the shutoff head of the pumps for the feed and bleed operation [5].

New injection flow paths for emergency cooling water into the RCS and SGs were installed as one of the postaction items after the Fukushima accident. The emergency cooling water system consists of a fixed pipe connected from the RCS or SGs to the outside of the containment. A standby valve is installed on the pipe. Following the occurrence of an SBO, movable equipment (e.g., a fire truck hose) can be connected to the pipe hole at the opening of the isolation valve. In many accidents with very hazardous work conditions, the inside of the containment cannot be made accessible or manageable. However, because the emergency cooling water system can be operated from outside of the containment, it has the advantages of high accessibility and maintenance during an accident [6].

2. Analysis methodology

The analyses consider several types of mitigation measures, including those specified in the emergency operating

Table 1 – Major input modeling parameters of the reference plant of 1,000MW pressurized water reactor.

Design parameter		Modeling input
Plant type		1,000 MW PWR (2 SG, 2 Hot legs, 4 Cold legs)
Power		2,815 MW_{th}
Coolant inventory	2 Steam generators	134×10^3 kg
	Reactor coolant system	215×10^3 kg
	4 Safety injection tanks	208×10^3 kg
Core Material	UO_2	86×10^3 kg
	Zircaloy	24×10^3 kg
Mitigation system against SBO		TD-AFW with battery power (Minimum battery power: 4 hr)
RCS depressurization system		2 trains of safety depressurization system (62.6 kg/sec/valve at 17.927 MPa)
SG depressurization system		2 atmospheric dump valves (1 ADV/SG) (106.2 kg/sec/valve at 9.308 MPa)
Fire engine capacity	Water flow into SG	0.0 lpm at 13.53 kg/cm^{2}g (SG pressure) 779 lpm at 1.0 kg/cm^{2}g (SG pressure)
	Water flow into RCS	1,336 lpm below 13.53 kg/cm^{2}a (RCS pressure)
Reactor cavity floor area		62.54 m^2
Containment free volume		79,300 m^3
Containment failure pressure		1.236 MPa(g)

ADV, atmospheric dump valves; PWR, pressurized water reactor; RCS, reactor cooling system; SBO, station blackout; SG, steam generator; TD-AFW, turbine driven auxiliary feedwater.