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Analysis of Reflux Condensation Phenomena During small Break Loss of Coolant Accident in Bushehr Reactor

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ABSTRACT: In this study, the reflux condensation phenomena are investigated during the small break loss of coolant accident in the VVER-1000 nuclear reactor. The accident is chosen as 25mm and 100mm of pipeline break in the cold leg between the main coolant pump and reactor inlet nozzle. The analysis is performed using the RELAP5/Mod 3.2 Code for nodalization and simulation of the nuclear power plant. The designed model for calculation is based on standardized performances of VVER-1000 reactor type. The results showed the high probability of this phenomenon in the 100 mm break, which was observed after 294 seconds and the fluid velocity reached -3 m/s. The duration of this phenomenon is until half of the reactor core is filled with water (1175 s). Also, in the 25 mm break, when the water level of reactor pressure vessel dropped below the reactor outlet, the liquid velocity was negated in the hot leg of loop no.2. Therefore, by converting steam to the liquid after the reactor shutdown, some of the decay heat is transferred to the secondary circuit and the reactor vessel is filled with water sooner. These factors provide better safety for the fuel rods and reactor core.

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1- Introduction

Reflux boiling-condensation is one of the important phenomena which appears in accidents with low periods of coolant depletion from the primary system such as Small Break Loss of Coolant Accident (SB LOCA). If the break area is sufficiently large to allow continued depressurization and loss of coolant inventory even with the high pressure in system pumps in operation, the reactor coolant level in the reactor vessel may recede toward or below the top of the reactor core. During this period of time, heat is removed from the reactor core by relatively quiescent pool boiling. If sufficient steam is produced in the coolant system by flashing and boiling, natural circulation through the steam generators by a continuous flow of high-density coolant around the coolant system loops will cease. Instead, steam generated in the core will flow to the steam generators where it will be condensed on the relatively cold steam generator tubes. This coolant will drain back into the reactor vessel to be boiled again and hence remove core heat. This mode of core heat removal is known as reflux boiling-condensation.

Various investigations have been done on the reflux condensation which reports about the test facilities. They are about BETHSY and ATLAS facilities in South Korea [1, 2], PKL in Germany [3] and IIST in France [4]. Also Moon et al. [5] studied the validity of RELAP5 code for simulating of reflux condensation phenomena.

In this study, the reflux condensation phenomena have been evaluated in the 25mm and 100 mm SB-LOCA of VVER-1000 reactor using RELAP5/Mod3.2 Code.

2- RELAP5/Mod3.2 Model

3. The RELAP5/Mod3.2 [6], developed model of Bushehr Nuclear Power Plant (BNPP), is used to simulate the small break loss of coolant accident. Therefore, reactor core, reactor pressure vessel, main coolant pipeline, main coolant pumps, pressurizer, steam generators, steam lines, main feed-water systems, and secondary safety valves are modeled by appropriate nodalization which is defined by RELAP5 Manuals. Furthermore, the accumulators, high pressure injection systems and low pressure injection systems, emergency feed-water systems and water injection from the containment sump are considered in the simulation. To activate and deactivate the systems and equipment, the trip cards are defined in the code. Data and information for the modeling of the systems and components are obtained from the FSAR of BNPP [7]. The description of model and analysis of SB-LOCA published in the Ref. [8].

In the simulation of SB-LOCA, the loss of power occurs at the start of the accident. Therefore, it is considered that the water supply from emergency systems into the primary coolant system has been delayed by 40s; comprising the time of DG start-up and transport delay. Also, as FSAR conditions, the failures are considered in the analysis of the accident under conservative conditions (single failure criterion for accumulators and double failure for the active part of emergency systems). After the SB-LOCA, it is assumed that in the calculation, the signal for reactor scram is generated with a delay of 1.4 s from the moment of reaching the scram set-point. Furthermore, the control protection system of control rod movement onset takes place with a 0.3 s delay. The safety systems are started with a latency of 2 s.

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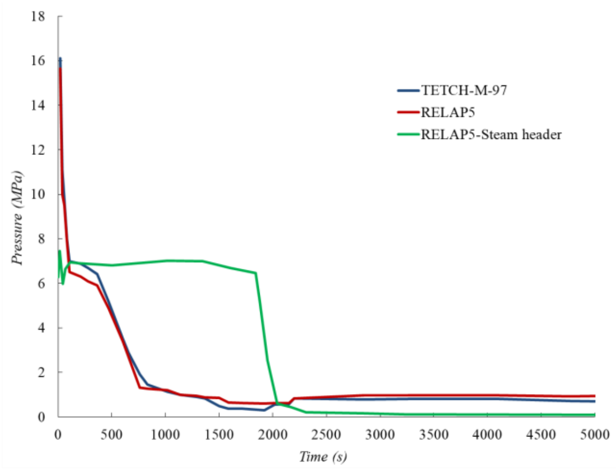

Fig. 1. The reactor outlet and steam header pressure during SB-LOCA with 100 mm break

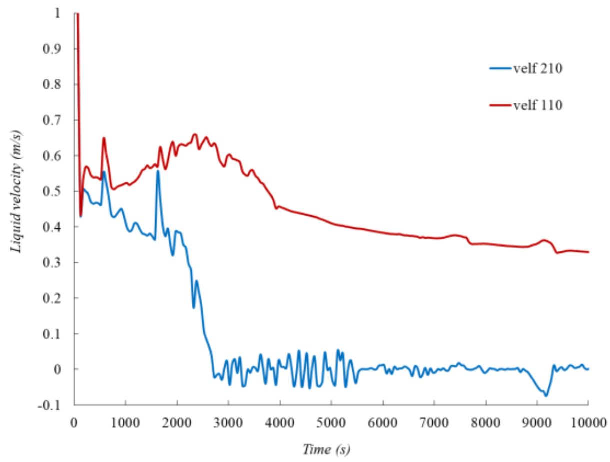

Fig. 3. Liquid velocity in the hot legs of first and second loops during SB-LOCA with 25 mm break

3- Results and Discussion

The pressure and liquid velocity in the hot legs during SB-LOCA with 100 mm break are shown in Figs. 1 and 2.

The highest rate of primary pressure decrease is in the first 95 s of the accident when the pressure is decreased from the initial value (16 MPa) to 6.5 MPa in time too small to be observed on Fig. 1. The depressurization continues until the flashing begins in the reactor vessel upper plenum. As a void is generated in the core and the mass inventory of the primary side is decreased, the natural circulation is terminated and the flow is reversed through the hot legs at 294 s (Fig. 2). The reverse flow remains until the half of reactor pressure vessel level refills with high-pressure injection systems and accumulators at 1175 s and then the flow rate is changed to positive and negative velocity alternatively. The negative value of liquid velocity does not directly imply the occurrence of reflux condensation but gives an idea for the potential occurrence of such a phenomenon. Because the generated steam in the top section of the reactor core moves to the hot legs and then it is condensed by heat removal from the secondary side of steam generators. By injecting of emergency water to the loops 1 and 4 and filling the reactor vessel with water, the liquid velocity is stabled in the first loop while the velocity in loops 2 and 3 goes to zero.

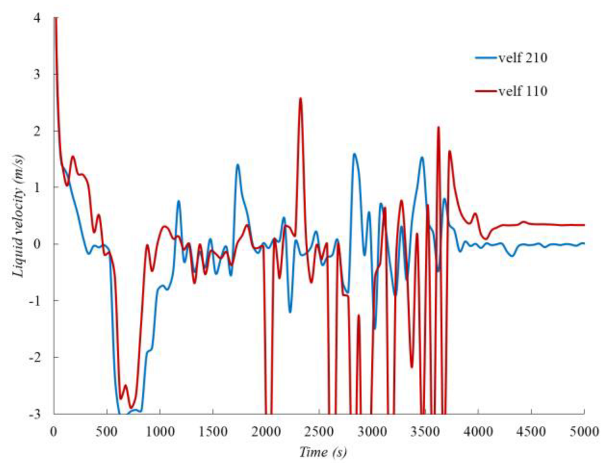

Fig. 2. Liquid velocity in the hot legs of first and second loops during SB-LOCA with 100 mm break

The liquid velocity in the hot legs of the primary system during 25 mm of break is shown in Fig. 3.

After the reactor coolant pumps coast-down, single-phase natural circulation produces heat transfer from the reactor core to the steam generators until the void is generated in the reactor core. The void in the upper plenum appears when the primary pressure reaches the secondary pressure. While in the inlets of the reactor pressure vessel, the void is shown when the two-phase flow begins in the system. When the collapsed liquid level in the reactor pressure vessel goes below the level of the hot leg (entrance), the potential for reflux condensation exists.

4- Conclusions

In this study, the potential for the occurrence of reflux condensation in 25 mm and 100 mm of break conditions has been studied. The results showed the high probability of this phenomenon in the 100 mm break, which was observed after 294 seconds and the fluid velocity reached -3 m/s. The duration of this phenomenon is until half of the reactor core is filled with water (1175 s).

Also, in the 25 mm break, when the water level of reactor pressure vessel dropped below the reactor outlet, the liquid velocity was negated in the hot leg of loop no.2 and reached about -0.05 to -0.1 m/s. This value is very low compared to a 100 mm break (-3 m / s).

Therefore, by converting steam to the liquid after the reactor shutdown, some of the decay heat is transferred to the secondary circuit and the reactor vessel is filled with water sooner. These factors provide better safety for the fuel rods and reactor core.

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