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Analysis of accumulators configuration in LB-LOCA for Bushehr NPP

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A B S T R A C T

This research focuses on a sensitivity analysis of accumulators configuration in a Large Break Loss of Coolant Accident (LB-LOCA) in Bushehr Nuclear Power Plant (BNPP). In this way, primary and secondary side components are modeled using RELAP5/MOD3.3 code. Having modeled the BNPP in a steady state hot full power operation, the thermal hydraulic consequences of a LB-LOCA in the reactor inlet is considered and sensitivity analysis for four major different configurations of accumulators are studied in detail. It is shown that any arrangement of accumulators in the Reactor Pressure Chamber (RPC) or Reactor Collection Chambers (RCC) leads to variation of fuel and clad temperatures during the accident and it is important to study the worst condition. Meeting the needs of the safety criteria necessitates tracing of fuel and clad temperatures in short time following the accident in the worst case, emphasizing on the importance of this study. Performance of accumulators when connected to the RCC is also compared to the case of their connection to the RPC and it is shown that the former has a superior efficiency over the latter. Finally, it is proved that in all accumulator arrangements, fuel and clad temperatures do not cross the safety red line despite some variations in the core cooling process following the accident.
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1. Introduction

Investigation of the anticipated accidents and assessment of the emergency core cooling system (ECCS) operation are important parts of a plant safety analysis. Simulation of accident through valid computer codes is the only way to assess the efficiency and safety of the plant. Extensive research activities have been performed to develop best estimate thermal–hydraulic codes like RELAP5 (Fletcher and Schultz, 1999; Aghaie et al., 2012), ATHLET (Wolfert et al., 1989) and CATHARE (Micaelli et al., 1995) in past few decades, which enable a more realistic simulation of nuclear reactor systems (Lin et al., 2005). The RELAP5 code was developed for best estimate of transient simulation of LWR systems during the postulated accidents. LOCA, as a low probable but the most important design basis accident which can cause core damage so sever safety violations, must be studied in detail to ensure the safeguard regime. In a LB-LOCA a very rapid loop depressurization occurs and the primary circuit loses almost all the coolant (except a few in the vessel bottom), in 15–20 s. In the meantime, the reactor scrams instantly and the safety injection through the accumulators and then high and low-pressure pumps would be initiated thereafter. The core is re-flooded in some tens of seconds (when the fuel reaches its worst condition in the transient) and then the core cools steadily (Petrangeli, 2006). LOCA research activities might be divided into two categories. The first category includes the LOCA simulation in a test loop (Lee et al., 2008; Kim et al., 2007) while the second contains LOCA simulation in an actual plant (Plit et al., 2000; Garsia et al., 1998; Prosek et al., 1994). Importance of the current study lies in the sensitivity analysis of accumulators configuration in an as built model of BNPP (V-320 model) which is a unique plant with WWER-1000 designing but several discrepancies in its primary side pipelines.

In Section 2, we describe our methodology and objective of the work. Fundamental assumptions employed in our simulations are also expressed in this section. Features and characteristics of the pilot plant (BNPP) is enumerated and explained in Section 3. Thermal–hydraulic model adopted for the simulation as well as plant nodalization prepared for the RELAP5 code is described in detail in Section 4. Section 5 contains steady state results for the normal operation of the plant based on the assumed nodalization. The LB-LOCA and its general consequences as well as events timeline are presented in Section 6 while detailed discussion on the output of our simulations are assigned to the Section 7. We finally terminate this investigation with a conclusion and discussion in Section 8.

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2. Methodology and objective of the study

Objective of this study is to analyze the effect of accumulators configuration on the thermal–hydraulic parameters during a LB-LOCA at the BNPP. The BNPP has four accumulators, two of which are connected to the RCC and the rest are connected to the RPC. The worst LB-LOCA occurs when the break is in cold leg. Assuming a guillotine-like break at the cold leg of loop 4 with functioning of three accumulators out of four, the core cooling condition during the accident varies with the accumulator configurations. In this case, if the accumulator is connected to the RPC, the core dries sooner than the case of connection to the RCC. So, the worst configuration obtains when two accumulators are connected to the RPC and the other to the RCC. For sensitivity analysis of these cooling configurations, simulation is prepared for four desired possible active accumulators arrangement (Table 1) and for the worst condition simulation, the first accumulator is fixed in the RCC and remained two accumulators connections are changed in RPCs. The accumulators connections are planned to study the worst cases to prevent probable uncontrollable accidents. Loops 1 and 3 are symmetric. Therefore, only loop 3 connections are considered.

In this analysis, the accumulator configurations are detailed in Table 1, which encircles the worst possible situations. The accident is simulated for four cases. The configuration of accumulators in each case illustrates the RPC and RCC connections. Accumulator IDs are 199, 299, 399 and 499 in Fig. 1. The accumulator connection to the RPC (downcomer 811) is eliminated because of its symmetry with 388 (downcomer 813). The volume IDs that are pointed out in these configurations as well as all configurations listed in Table 1 is depicted in Fig. 1, clearly. According to Table 1 and Fig. 1 we have following configurations:

Case a: Accumulators 199, 299 and 399 are connected to volumes 850 (RCC), 850 (RPC) and 812 (RPC), respectively.

Case b: Accumulators 199, 399 and 499 are connected to volumes 850 (RCC), 812 (RPC) and 813 (RPC), respectively.

Case c: Accumulators 199, 399 and 499 are connected to volumes 850 (RCC), 812 (RPC) and 814 (RPC), respectively.

Case d: Accumulators 199, 399 and 499 are connected to volumes 850 (RCC), 813 (RPC) and 814 (RPC), respectively.

3. Plant components description

3.1. Reactor pressure vessel

The BNPP is a pressurized water reactor plant, which generates 3000 MW thermal power. The reactor core consists of 163 hexagonal fuel assemblies. The active length of the core is 3.53 m. Each fuel assembly consists of 311 fuel rods, 18 guide channels, a measurement channel, a central channel, and 15 grid spacers (BNPP FSAR, 2008).

3.2. Main coolant pipeline

The primary side of the plant contains four cooling loops, the primary side of steam generators and the main coolant pumps. While in a standard WWER-1000 NPP each primary loop contains 3 knee joints, each loop of the BNPP suffers of 5 knee joints, one in the hot leg four others in the cold leg. These excess knees would cause more pressure drop in the primary loop. Also, BNPP primary

Table 1
Active accumulators configurations.

Case study	Accumulator 1	Accumulator 2	Accumulator 3
a-Relap5-(1)	(RPC) Volume No. 850	(RPC) Volume No. 850	(RPC) Volume No. 812
b-Relap5-(2)	(RPC) Volume No. 850	(RPC) Volume No. 812	(RCC) Volume No. 813
c-Relap5-(3)	(RPC) Volume No. 850	(RPC) Volume No. 812	(RCC) Volume No. 814
d-Relap5-(4)	(RPC) Volume No. 850	(RPC) Volume No. 813	(RCC) Volume No. 814

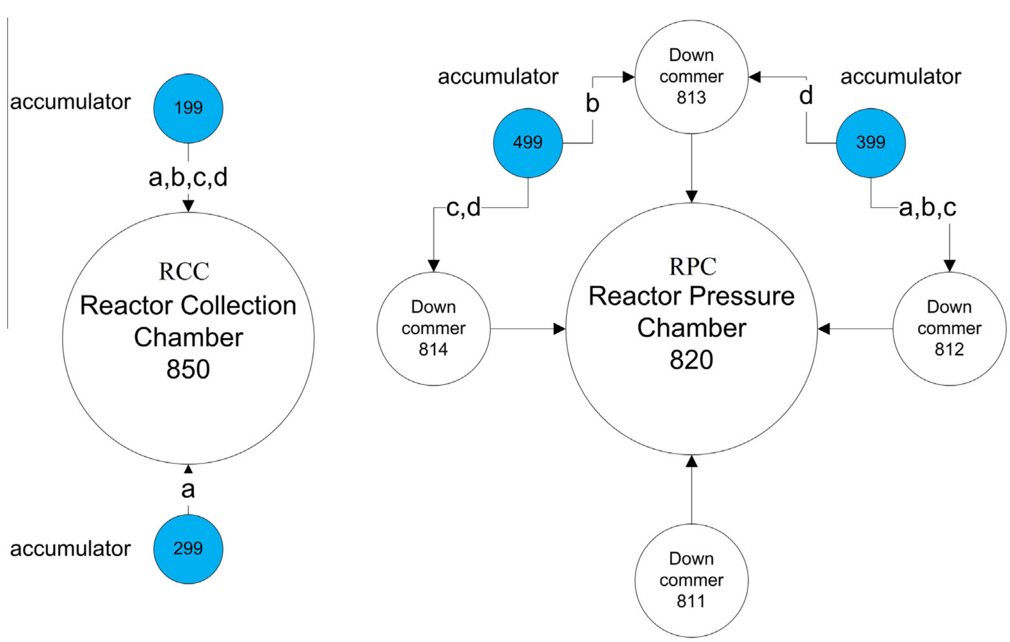

Fig. 1. Accumulators configurations.

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