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Experimental observation of adverse and beneficial effects of nitrogen on reactor core cooling

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ABSTRACT

Noncondensable gases, if present in the reactor cooling system, affect the coolability of the nuclear reactor core. In Loss-Of-Coolant Accidents (LOCA), nitrogen from hydroaccumulators will enter the reactor systems, and can temporarily alter the water level in the core by a piston effect. The piston effect on the downcomer side can increase water level in core and improve core cooling (Damerell et al., 1993).

The effect of nitrogen on core cooling in LOCA situations was studied experimentally in the PWR PACTEL facility. The main goal of this testing was to independently verify whether the claimed positive effect of nitrogen on the core cooling can be reproduced and to generate data for the development and validation of thermal-hydraulic system codes.

Four experiments with an accumulator injection to a cold leg were performed with the PWR PACTEL facility. In two of the experiments, the break was in the other cold leg and in the other two in the hot leg. The cold leg injection experiments confirmed that nitrogen injection had a small positive impact on the core cooling, but not by shortly redistributing water masses in the vessel as expected. The presence of nitrogen reduced the break water flow rate, delaying the core level depletion and thus postponing core heatup by few minutes. In contrast, with the hot leg break, the injection of the accumulator nitrogen into the primary side had a negative impact on the core cooling. The nitrogen accumulated in the steam generator tubes, blocking the primary side depressurization and causing a core heatup.

1. Introduction

Noncondensable gases, if present in the reactor cooling system, affect the coolability of the reactor core in many ways (Kral et al., 2015). The driving force of the accumulator injection water is the pressurized nitrogen volume at the top of the accumulator tanks. In some plants, the release of gaseous nitrogen to the primary side is prevented with an automatic closure of the accumulator injection line at the end of the discharge. If the automatic closure system fails, nitrogen can flow to the reactor cooling system after the accumulators are empty of water. The accumulator water is saturated with dissolved nitrogen, so a quantity of nitrogen will always enter the primary system with the accumulator discharge.

Nitrogen released into the primary cooling system can have a direct effect on reactor cooling conditions, such as on water distributions and condensation. Nitrogen released and flowing to a cold leg can cause with a suitable flow conditions a pressure rise in the cold leg end and the downcomer top parts with respect to the upper plenum pressure. Hence, the nitrogen can temporarily increase the water level in the core by a piston effect, i.e. shortly redistributing water masses in the vessel, (Fig. 1).

The accumulator nitrogen discharge to the primary system has been studied with the UPTF (Damerell and Simons, 1993), and BETHSY (Barbier et al., 1996) test facilities. In the UPTF large break LOCA test, the break located in the cold leg and nitrogen was discharged directly to the upper part of the downcomer. In this test, the aim was to study piston effect. The pressure rise in the loop was observed, but the impact on the core cooling could not be assessed due to the restrictions of the facility. The nitrogen discharge continued only less than a second until automatic shutdown ended the experiment. In the BETHSY test, the break was located at the bottom of the hot leg and accumulators were connected in the cold legs, near the downcomer. The objective of the test was to study the nitrogen migrating in the primary system and the effect of closed/open loop seals on the presence of nitrogen in the steam generators. According the test data available in the reference (Barbier et al., 1996), the piston effect was not observed in the test.

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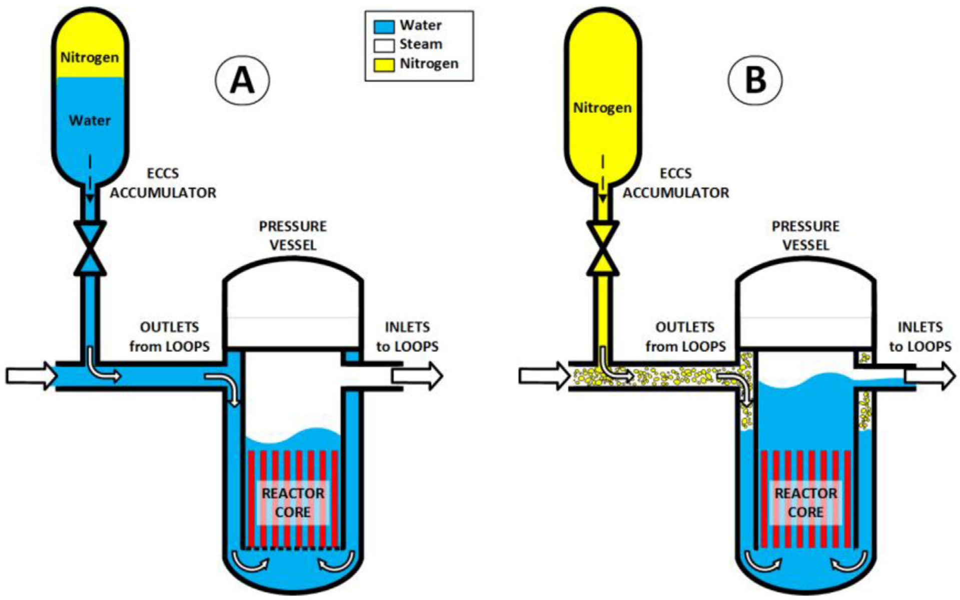

Fig. 1. Anticipated behavior of the reactor cooling system during LOCA when nitrogen is injected from the accumulator.

The PWR PACTEL integral test facility at the Lappeenranta University of Technology in Finland is used for safety studies related to thermal-hydraulics of pressurized water reactors (Kouhia et al., 2012, 2014). The facility serves as a platform for system behavior studies with the specific feature of the two EPR type loops with vertical steam generators. PWR PACTEL includes multiple measurement devices and hence detailed information on the system behavior is available. The recent experimental studies on nitrogen with PWR PACTEL are part of the INTEGRA project within the Finnish Research Programme on Nuclear Power Plant Safety 2015–2018 (Hämäläinen and Suolanen, 2017). The general objective of the INTEGRA project is to improve the understanding of thermal-hydraulic system behavior by performing integral and separate effects tests.

In this article, recent nitrogen experiments (Riikonen et al., 2016, 2017; Kouhia and Kauppinen, 2017) with the PWR PACTEL facility are presented. With these experiments, the effect of nitrogen on the core cooling during two types of LOCA situations was studied. The main goal of these experiments was to verify independently whether the claimed positive effect of nitrogen on the core cooling can be reproduced in LOCA conditions and to generate data for the development and validation of thermal-hydraulic system codes.

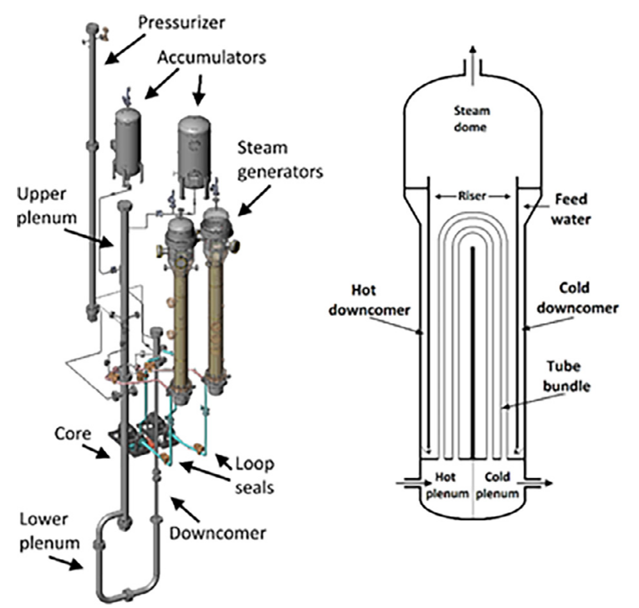

Fig. 2. PWR PACTEL test facility and the schematic view of the PWR PACTEL steam generators.

2. PWR PACTEL facility

The PWR PACTEL integral test facility is designed for safety studies related to thermal-hydraulics of pressurized water reactors (PWR) with EPR type vertical steam generators. The facility consists of a reactor pressure vessel model, two loops with vertical steam generators, a pressurizer, and emergency core cooling systems (ECCS) including nitrogen-driven accumulators. The PWR PACTEL facility has been used in studies of primary side accidents. The thermal-hydraulic research work with the facility include studies such as on small break LOCA (Kouhia et al., 2013), loop seal clearing (Kauppinen et al., 2015a) and flow reversal (Kauppinen et al., 2015b) related issues. The general view of the PWR PACTEL test facility and the schematic view of the PWR PACTEL steam generators are presented in Fig. 2. The main characteristics of PWR PACTEL are presented in Table 1.

The instrumentation in the facility comprises temperature, pressure, pressure difference, and flow transducers. The core power, the power of the heaters in the pressurizer, and the power of the main circulation pumps are measured also. The location and amount of nitrogen in different parts of the facility during the experiments is not measured directly. The possible presence of nitrogen is observed indirectly from the available temperature data.

Signals from the measurement instruments are recorded in volts with the National Instruments Compact FieldPoint distributed I/O system and then converted into engineering units using appropriate conversion equations and factors. Some parameters such as mass flow rates and liquid levels require calculation of the single-phase coolant density based on the local pressure and fluid temperature information using steam tables. The experiment data are checked manually. Data are reviewed for anomalous readings and mutually compared with the readings of nearby instruments. A more detailed description of the facility and its instrumentation can be found in (Kouhia et al., 2012, 2014).