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Original Article

# Comparative Experiments to Assess the Effects of Accumulator Nitrogen Injection on Passive Core Cooling During Small Break LOCA

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ABSTRACT

The accumulator is a passive safety injection device for emergency core cooling systems. As an important safety feature for providing a high-speed injection flow to the core by compressed nitrogen gas pressure during a loss-of-coolant accident (LOCA), the accumulator injects its precharged nitrogen into the system after its coolant has been emptied. Attention has been drawn to the possible negative effects caused by such a nitrogen injection in passive safety nuclear power plants. Although some experimental work on the nitrogen injection has been done, there have been no comparative tests in which the effects on the system responses and the core safety have been clearly assessed. In this study, a new thermal hydraulic integral test facility—the advanced core-cooling mechanism experiment (ACME)—was designed and constructed to support the CAP1400 safety review. The ACME test facility was used to study the nitrogen injection effects on the system responses to the small break loss-of-coolant accident LOCA (SBLOCA) transient. Two comparison test groups—a 2-inch cold leg break and a double-ended direct-vessel-injection (DEDVI) line break—were conducted. Each group consists of a nitrogen injection test and a nitrogen isolation comparison test with the same break conditions. To assess the nitrogen injection effects, the experimental data that are representative of the system responses and the core safety were compared and analyzed. The results of the comparison show that the effects of nitrogen injection on system responses and core safety are significantly different between the 2-inch and DEDVI breaks. The mechanisms of the different effects on the transient were also investigated. The amount of nitrogen injected, along with its heat absorption, was likewise evaluated in order to assess its effect on the system depressurization process. The results of the comparison and analyses in this study are important for recognizing and understanding the potential negative effects on the passive core cooling performance caused by nitrogen injection during the SBLOCA transient.



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## 1. Introduction

The accumulator (ACC) is a pressurized safety injection tank. It is one of the main components of a passive safety injection system in a nuclear power plant [1]. Under normal operations, the ACC contains both the cold coolant and the precharged nitrogen gas ($N_2$) in a single tank. In the event of a loss-of-coolant accident (LOCA) and when the reactor coolant system (RCS) pressure falls below the precharged nitrogen pressure, the coolant discharges from the ACC at high speed into the core.

In Generation III+ reactors, the passive safety pressurized water reactors (PWRs), including AP600 [2], AP1000 [3], and CAP1400 [4], rely only on natural forces or processes, such as gravity and compressed gas pressure, to provide the safety injection and to perform the function of the emergency core cooling system (ECCS). As shown in Fig. 1, these reactors have a two-loop RCS configuration and are equipped with a passive safety core cooling system (PXS). In the PXS, the spherical ACCs are connected to the reactor pressure vessel (RPV) through the direct vessel injection (DVI) lines. When the ACC is empty, the RCS is depressurized and $N_2$ is expanded. The $N_2$ in the tank is then injected into the system. The effects of this $N_2$ injection on the passive core cooling process under a small break LOCA (SBLOCA) scenario is a technical concern. Potentially, it could have negative effects, such as slowing down the depressurization and stopping the ECCS injection, leading to the failure of core cooling [5]. The SBLOCA phenomena identification and ranking table (PIRT) of the AP600 reactor once ranked the ACC noncondensable gas entrainment as "plausible (P)" [6]. This ranking indicates that the effects of $N_2$ injection on the passive core cooling system performance need to be evaluated.

In order to support the development and safety review of the AP600/1000 reactor, three integral test facilities have been developed. They are a full-height, full-pressure, and 1/30.5 volume scale integral test facility named the Rig of safety assessment (ROSA) of Japan Atomic Energy Research Institute (JAERI, Tokai-mura, Naka-gun, Ibaraki-ken 319-11, Japan) [7], a full-height, full-pressure, 1/395 volume scale test facility named the SPES-2 in Italy [8], and a 1/4 height scale and reduced-pressure integral test facility named the Advanced Plant Experimental (APEX) test facility in the United States [6]. By analyzing the experimental data from these three integral tests, the potential effects of ACC $N_2$ injection on the passive core cooling performance have been studied.

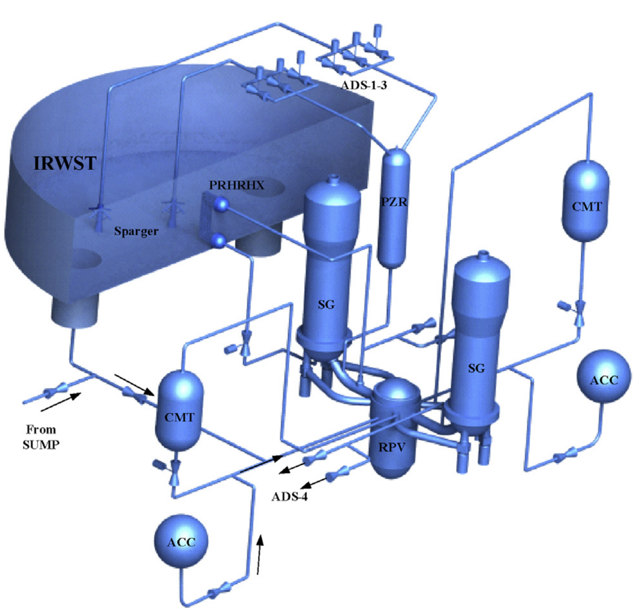

**Fig. 1 – Schematic diagram of the RCS and PXS in a passive safety PWRs. PWR, pressurized water reactor; PXS, passive safety core cooling system; RCS, reactor coolant system.**

The ROSA integral test results show that the impact of this noncondensable gas injection on the core cooling performance is insignificant. However, an analysis of the experimental data shows that when nitrogen enters the core makeup tank (CMT), it can suppress the steam condensation in the CMT, but improve the drainage of the CMT [5,7]. Further analysis of the SPES-2 SBLOCA experimental data shows that the injected $N_2$ can enter the CMT. Additionally, $N_2$ potentially reduces the effectiveness of the passive residual heat removal (PRHR) performance. This is because when the ACC $N_2$ injection starts, the PRHR heat removal role is already coming to an end [9]. Moreover, the $N_2$ transport in the system has been investigated experimentally at the APEX test facility [10]. The test data show that nitrogen can enter into the CMT, PRHR, RPV, and in-containment refueling water storage tank (IRWST); however, no quantitative information has been made available [11].

Although some experimental works have been carried out, the effects of $N_2$ injection on the core safety and the system responses and the control mechanisms still need to be studied. First, in addition to the investigation of how $N_2$ affects the local processes, such as CMT drainage and PRHR circulation, the effects of $N_2$ injection on system responses and core safety also need to be studied. This is because whether $N_2$ injection can change the core safety-related parameters, such as system pressure, cooling flow rate, and core level, is still unclear. Second, there are no comparative tests to show the effects of $N_2$ injection. As compared to the earlier analyses of the test data from the three facilities, an analysis of the comparative test results is a more convincing and effective approach to show the effects of $N_2$.

One comparative test group consists of two SBLOCA tests. All the initial and boundary conditions of the two tests—such as the break, the initial steady-state parameters, the decay power, and the safety system alignment—are the same. There is only one difference between the two tests. In one test, the ACC is allowed to inject its nitrogen into the system when it is empty, just like the process in the prototypes. In the other test, the ACC is isolated immediately once it is empty. Based on the experimental data from these two SBLOCA tests, system responses and important parameters were compared. From the comparison, the effects of $N_2$ injection on system performance and SBLOCA transient were determined. If such a comparative test group can be conducted in an integral test facility, this is a good way to study the effects of ACC $N_2$ injections. Unfortunately, such a comparative test cannot be conducted in the three integral test facilities mentioned earlier because the ACC and its injection line configuration in these test facilities are the same as that in the prototype.

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