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Technical Note

PX–An Innovative Safety Concept for an Unmanned Reactor

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ABSTRACT

An innovative safety concept for a light water reactor has been developed at the Korea Atomic Energy Research Institute. It is a unique concept that adopts both a fast heat transfer mechanism for a small containment and a changing mechanism of the cooling geometry to take advantage of the potential, thermal, and dynamic energies of the cold water in the containment. It can bring about rapid cooling of the containment and long-term cooling of the decay heat. By virtue of this innovative concept, nuclear fuel damage events can be prevented. The ultimate heat transfer mechanism contributes to minimization of the heat exchanger size and containment volume. A small containment can ensure the underground construction, which can use river or seawater as an ultimate heat sink. The changing mechanism of the cooling geometry simplifies several safety systems and unifies diverse functions. Simplicity of the present safety system does not require any operator actions during events or accidents. Therefore, the unique safety concept of PX can realize both economic competitiveness and inherent safety.

1. Introduction

A simple safety system is one of the major design features that can assure the inherent safety and passive operation of a nuclear power plant. In light of the Fukushima Daiichi nuclear accident, the need for simpler safety systems has become more pressing. This will call for radical design concepts that can eliminate human error and miscommunications more effectively. Furthermore, an ultimate passive cooling mechanism should be considered to prevent severe accidents, as well as beyond-design-basis accidents in a station blackout scenario. Recently, the newly developed design concepts of both large-sized conventional light water reactors of an European Simplified Boiling Water Reactor (ESBWR) and Advanced Plant 1000 MWe (AP1000), and small- and medium-sized reactors of mPower, Modular Scalable Nuclear Power (NuScale), and System-Integrated Modular Reactor (SMART) [1,2] have aimed to enhance both inherent safety and competitive economics. However, it is not easy to resolve both contradictory needs at the same time. Most safety systems of currently operating light water reactors have a large containment, additional tanks, and complex piping systems compared to the volume of the reactor pressure vessel. In these reactors, typical systems for design-

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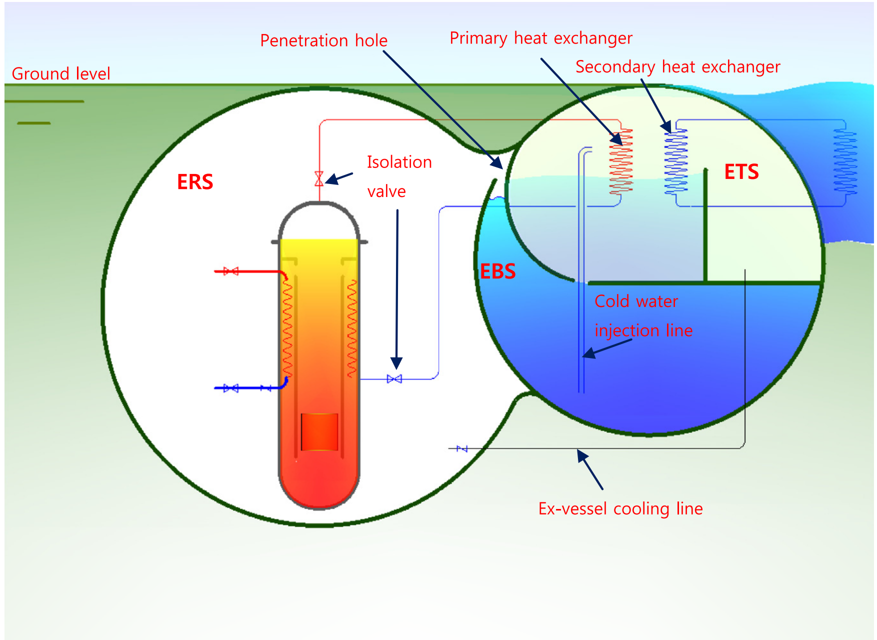

Fig. 1 – Schematic view of the innovative safety concept of PX. EBS, energy buffer space; ERS, energy release space; ETS, energy transfer space.

basis accidents are the safety injection system, residual heat removal system, depressurization system, and containment cooling system, and for a severe accident, the molten core cooling system. However, these diverse safety systems have not yet achieved the absolute safety, even though the structures and volumes become more complex and larger to contain these safety components. These systems can expose these reactors to other unexpected human errors and accidents that are linked to external hazards or the possibility of a pipe break. To find a successful path toward solving these problems, it is necessary to simplify the system and unify the diverse functions. This will provide a guarantee of absolute safety and passive operation. Therefore, in this paper, an innovative concept is introduced to enhance reactor safety.

2. Concept of PX

The conceptual geometry of PX has three volumes, i.e., an energy release space (ERS), energy buffer space (EBS), and energy transfer space (ETS) in twin containments, as shown in Fig. 1. The ERS is in the left containment, and both the ETS and the EBS are in the right containment, in the upper and lower parts, respectively. The reactor vessel, which is presumed to be a kind of integrated-type light water reactor, is in the left containment, and the primary heat exchanger, secondary heat exchanger, and injection spray line, which is connected to the EBS, are in the upper part of the right containment. The lower part of the right containment is a water reservoir, which is fully filled with cold water initially. The name PX originated from the P of peanut owing to the shape of the twin containments, and X, which indicates the shape of the flow pattern in the twin containment during an accident. It has the following conceptual working sequences after reactor shutdown conditions: (1) There are three spaces of ERS, EBS, and ETS, respectively, for the release, buffer, and transfer of energy to cool down the residual heat of the core after a reactor shutdown. (2) The pressure of the ERS increases when the steam is discharged out of the reactor vessel, steam line, or feed water line during mass release accidents. (3) The cold water in the EBS is injected into the primary heat exchanger tubes of the ETS by virtue of the high pressure of the ERS. (4) The cold water injected cools down the primary heat exchanger and is evaporated on its surface. (5) The hot steam in the ETS is condensed on the surface of the secondary heat exchanger tubes. (6) The secondary heat exchanger transfers the energy in the ETS to a pool outside of the containment, which functions as an ultimate heat sink.

For the innovative safety system introduced in this paper, two key physical concepts are adopted in PX, i.e., the fast heat transfer mechanism in the ETS and the changing mechanism of the cooling geometry (CCG) between the three spaces of ERS, EBS, and ETS.

2.1. *Fast heat transfer mechanism*

To remove the heat out of the reactor into the atmosphere, a possible method of maximum heat transfer is two-phase spray jet quenching in the ETS, as shown in Fig. 2. A sprayed droplet is evaporated on the outer surface of the primary heat exchanger tube, and the steam is condensed inside the tube. At the same time, the vaporized hot steam in the ETS is condensed on the outer surface of the secondary heat exchanger tube, while the water inside is boiled.