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Invited Article

A Preliminary Safety Analysis for the Prototype Gen IV Sodium-cooled Fast Reactor

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ABSTRACT

Korea Atomic Energy Research Institute has been developing a pool-type sodium-cooled fast reactor of the Prototype Gen-IV Sodium-cooled Fast Reactor (PGSFR). To assess the effectiveness of the inherent safety features of the PGSFR, the system transients during design basis accidents and design extended conditions are analyzed with MARS-LMR and the subchannel blockage events are analyzed with MATRA-LMR-FB. In addition, the in-vessel source term is calculated based on the super-safe, small, and simple reactor methodology. The results show that the PGSFR meets safety acceptance criteria with a sufficient margin during the events and keeps accidents from deteriorating into more severe accidents.

1. Introduction

Sodium-cooled fast reactor (SFR) design technologies have been developed in Korea since 1997 under a National Nuclear R&D Program to achieve an enhanced safety, an efficient utilization of uranium resources, and a reduction of a high-level waste volume. In 2015, the preliminary specific design of the Prototype Gen-IV Sodium-cooled Fast Reactor (PGSFR) was completed, which is a pool-type SFR with the thermal power of 392.2 MWt and uses metallic fuel of U–10%Zr for a core having inherent reactivity feedback mechanisms and high thermal conductivity.

Fig. 1 shows the overall configuration of the PGSFR, which consists of the primary heat transport system (PHTS), the intermediate heat transport system (IHTS), the steam generators (SGs) including balance of plant, and the decay heat removal system (DHRS).

The PHTS is placed in a large pool to make the system transients slower, thus giving a higher probability to terminate the abnormal events before they propagate into

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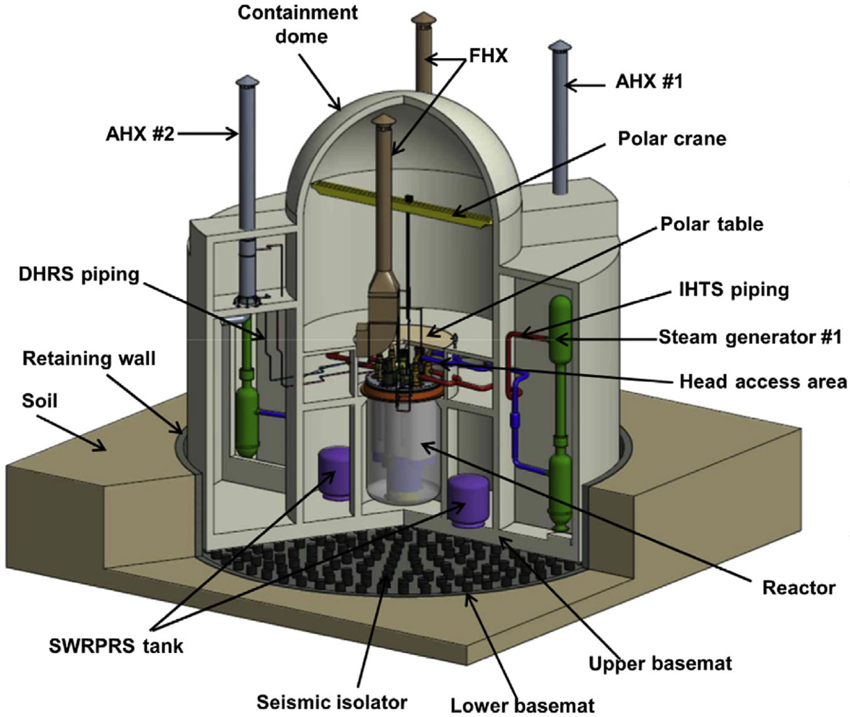

Fig. 1 – Overall configuration of the Prototype Gen-IV Sodium-cooled Fast Reactor. AHX, natural-draft sodium-to-air heat exchanger; DHRS, decay heat removal system; FHX, forced-draft sodium-to-air heat exchanger; IHTS, intermediate heat transport system, SWRPRS, sodium water reaction pressure relief system.

accidents. The IHTS loop is thermally coupled to the PHTS and the SGs. The IHTS transfers the reactor-generated heat from the intermediate heat exchanger (IHX) of the PHTS to the SG. The IHTS consists of two loops, and each loop has two IHXs, one electromagnetic (EM) pump, one expansion tank, and one SG. The SGs consist of two independent steam-generation loops and convert the subcooled water to a superheated steam. The DHRS with the heat transfer capability of 10 MWt is composed of two units of passive decay heat removal system (PDHRS) and two units of active decay heat removal system (ADHRS). In addition, a damper driven by the emergency diesel generator is attached to the natural-draft sodium-to-air heat exchanger (AHX) and the forced-draft sodium-to-air heat exchanger (FHX). The damper is designed with the concept of the passive fail-open type. The ADHRS has been designed to operate at half capacity by the natural circulation, even if the EM pump of ADHRS stops [1].

The fundamental approach to design a nuclear reactor with safety is defense-in-depth. The multiple, independent, and redundant means of the design assure the performance of safety functions in normal operation and in accident conditions. The cladding and end seals of fuel pin are the first barrier to protect the escape of radiological material to the environment. Table 1 shows the safety acceptance criteria of the fuel and cladding for each event category. An acceptance criterion for anticipated operational occurrences (AOOs) and design basis accident (DBA) Class 1 is established on the basis of cumulative damage function (CDF). CDF is introduced as a measure to protect against rupture due to thermal creep. A combination of temperature and duration limits is accepted as a design guideline in the sense that it is derived from the CDF equation, which is a function of time, temperature, and stress. CDF in MARS-LMR [2] can be defined by Eqs. (1–3).

$$CDF = \int_{t=0}^{t=t} \frac{1}{t_r} dt \quad (1)$$

$$t_r = \theta \exp \frac{Q}{R} \cdot \frac{1}{T} \quad (2)$$

$$\ln\theta = -34.8 + tanh\frac{\sigma - 200}{50} + \frac{12}{1.5 + 0.5\ tanh\frac{\sigma-200}{50}} \ In\left[In\frac{730}{\sigma}\right] - 0.5\left[1 + tanh\frac{\sigma - 200}{50}\right] \cdot \left\{0.75\left[1 + tanh\left(\frac{\dot{T} - 58}{50}\right)\right]\right\} \quad (3)$$

Table 1 – Safety acceptance criteria for event category.

Event category	AOO	DBA Class 1	DBA Class 2	DEC
Fuel/cladding	$CDF^*_{\sum AOO}$ < 0.05 Strain <1%	CDF_{event} < 0.05 Strain <1%	Fuel T <Solidus T Clad T <1,075°C Coolant T <Boiling T	Coolant T <Boiling T

AOO, anticipated operational occurrence; CDF, cumulative damage function; DBA, design basis accident; DEC, design extended condition.

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