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Invited Article

Overall System Description and Safety Characteristics of Prototype Gen IV Sodium Cooled Fast Reactor in Korea

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ABSTRACT

The Prototype Gen IV sodium cooled fast reactor (PGSFR) has been developed for the last 4 years, fulfilling the technology demonstration of the burning capability of transuranic elements included in light water reactor spent nuclear fuel. The PGSFR design has been focused on the robustness of safety systems by enhancing inherent safety characteristics of metal fuel and strengthening passive safety features using natural circulation and thermal expansion. The preliminary safety information document as a major outcome of the first design phase of PGSFR development was issued at the end of 2015. The project entered the second design phase at the beginning of 2016. This paper summarizes the overall structures, systems, and components of nuclear steam supply system and safety characteristics of the PGSFR. The research and development activities to demonstrate the safety performance are also briefly introduced in the paper.

1. Introduction

The light water reactor (LWR) has been operated and has played a significant role of a stable electricity supply and in economic growth in Korea since 1978. There are 22 LWRs and four CANDU type reactors currently in operation, four pressurized water cooled reactors (PWRs) under construction and four additional PWRs planned by 2029 based upon the 7th National Electricity Demand and Supply Plan. The construction of the nuclear power plant also supports the Paris Agreement on new climate change agreed at United Nations Climate Change Conference (COP21) in 2015 and the 2nd National Basic Energy Plan, which targets a nuclear share of 29% by 2035.

One serious obstacle in constructing an LWR is a problem with spent nuclear fuel (SNF) management because of high radiotoxicity and long half-life of SNF. Annually, about 760 tons of SNF are discharged from PWRs and the total stored SNF amounted to14,468 tons as of December 2015. In this context, the Public Engagement Commission on Spent Nuclear Fuel made 10 recommendations on future SNF management policy in 2015. One of the key recommendations is to

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establish a research and development (R&D) plan for volume and toxicity reduction of SNF.

The SNF problem has been a common concern among countries which have utilized nuclear energy for a long time or have a plan to extend the utilization of nuclear energy. A sodium cooled fast reactor (SFR) has been widely recognized as a technical alternative to effectively manage the SNF, owing to its transmutation capability of long lived radiotoxic nuclides included in the SNF. It can be accomplished by using abundant high energy excessive neutrons in the core. For this reason, the SFR development plan is always accompanied with the policy for the extension of nuclear energy in many countries.

The long term development plan for the future nuclear energy systems was authorized by the Korean Atomic Energy Commission in 2008 and updated in 2011; it includes a construction of a prototype SFR by 2028, with preparation of a preliminary safety information document by 2015, issue of a specific design safety analysis report by 2017, and its approval by 2020.

The Korea Atomic Energy Research Institute (KAERI) has been developing SFR design technologies since 1997 under a national nuclear R&D program. The goals of the SFR design technology development project were to secure strategic key technologies and to develop the conceptual design of a SFR, which are necessary for an efficient utilization of uranium resources and a reduction of a high level waste volume and toxicity. To this end, conceptual designs of KALIMER-150, breakeven core design of KALIMER-1200, and the transuranics (TRU) burner of KALIMER-600 have been completed as the main outcomes of those studies [1,2].

The national project to develop the Prototype Gen IV sodium cooled fast reactor (PGSFR) was initiated to achieve the national mission stated above in 2012. For this, the Sodium Cooled Fast Reactor Development Agency dedicated to the PGSFR development was established in the middle of 2012. R&D works of the PGSFR project are mainly carried out by KAERI, KEPCO E&C, and Doosan Heavy Industry. KAERI is in charge of the design and the validation of the nuclear steam supply system and fuel development, and KEPCO E&C is responsible for balance of the plant system design. Doosan Heavy Industry is involved in the evaluation of a mechanical design and fabrication of major components. KAERI is closely working with Argonne National Laboratory under an agreement on the joint development program approved as a work-for-others contract. Argonne National Laboratory supports KAERI with their experiences in SFR development and is jointly working on the developments of codes for fuel rod performance analysis and severe accident analysis.

The first design phase of the PGSFR was completed at the end of 2015 and the second phase of the development was entered at the beginning of 2016 [3]. All of the basic design concepts of structures, systems and components were determined and incorporated into the preliminary safety information document [4,5], which includes basic design requirements and system descriptions and the results of safety analysis for representative accident scenarios.

This paper summarizes the PGSFR design and its safety characteristics performed in the first design phase of PGSFR. Other papers on the safety analysis results of PGSFR, the metal fuel development and its verification, and the safety and performance tests for the PGSFR will be published separately with this paper. Duplicated contents of those papers are briefly introduced in this paper.

2. System descriptions of the PGSFR

2.1. *Top-tier design requirements and general descriptions*

The main goal of the PGSFR development is to demonstrate transmutation capability of TRU which are major long-lived radiotoxic elements included in the LWR SNF. A high level of safety and efficient electricity generation are also requirements of the PGSFR. The major items of top tier requirements of PGSFR are listed in Table 1.

The PGSFR is a pool-type having two intermediate heat transport system (IHTS) loops with two steam generators (SGs) and its electrical capacity is 150 MWe. The PGSFR is a fast neutron spectrum reactor and uses liquid sodium as a coolant. The core generates nuclear heat of 392.2 MWt and is loaded with metal fuels of U-Zr in the initial core and of U-TRU-Zr in the final equilibrium core. All of the structures, systems, and components of the primary heat transport system (PHTS) are contained in the reactor vessel. The system operates under atmospheric pressure so that there is no possibility of high pressure release by pipe breaks, unlike in loop-type LWRs. The large sodium inventory inside the reactor vessel provides a large thermal inertia which relieves a thermal transient and allows a relatively longer grace period in an accident condition.

The initial core of the PGSFR is loaded with low enriched uranium metal fuel (U-10% Zr) for a system performance demonstration and as a test bed for TRU fuel irradiation as shown in Table 2. Several lead test rods and lead test assemblies containing TRU fuel made of recycled from LWR SNF (LWR-TRU) will be loaded and qualified during this period.

Table 1 – Top tier design requirements of Prototype Gen IV sodium cooled fast reactor (PGSFR).

Parameters	Requirements
General requirement	Demonstration of TRU burning capability and fully closed fuel cycle with pyro-processing technology
Fuel	U-10% Zr fuel for initial core U-TRU-Zr fuel for final equilibrium core
Power	More than 150 MWe
Outlet temperature	More than 545°C (Thermal efficiency ~ 40%)
Design life time and capacity factor	60 yr and more than 75% average capacity factor
Safe shutdown earthquake	0.3 g (seismically isolated)
Core damage frequency	Less than 10^{-6}/reactor-yr
Operator grace period	More than 2 hr
SBO coping time	More than 72 hr

SBO, station black out; TRU, transuranics.

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