Annals of Nuclear Energy 55 (2013) 331–340

Contents lists available at SciVerse ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene

Thermal-hydraulic analysis of SMART steam generator tube rupture using TASS/SMR-S code

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ARTICLE INFO

Article history:
Received 5 June 2012
Received in revised form 21 November 2012
Accepted 1 January 2013

Keywords:
SMART
TASS/SMR-S
SGTR
Integral leak
Thermal-hydraulic

ABSTRACT

A steam generator tube rupture (SGTR) accident analysis for SMART was performed using the TASS/SMR-S code. SMART with a rated thermal power of 330 MWt has been developed at the Korea Atomic Energy Research Institute. The TASS/SMR-S code can analyze the thermal hydraulic phenomena of SMART in a full range of reactor operating conditions. An SGTR is one of the most important accidents from a thermal hydraulic and radiological viewpoint. A conservative analysis against a SMART SGTR was performed. The major concern of this analysis is to find the thermal hydraulic responses and maximum leakage amount from a primary to a secondary side caused by an SGTR accident. A sensitivity study searching for the conservative thermal hydraulic conditions, break locations, reactivity and other conditions was performed. The dominant parameters related with the integral leak are the high RCS pressure, low core inlet coolant temperature and low break location of the SG cassette. The largest integral leak comes to 28 tons in the most conservative case during 1 h. But there is no direct release into the atmosphere because the secondary system pressure is maintained with a sufficient margin for the design pressure. All leaks go to the condenser. The analysis results show that the primary and secondary system pressures are maintained below the design pressure and the SMART safety system is working well against an SGTR accident.

1. Introduction

Recently, small and medium sized reactors (SMRs) for non-electric applications of nuclear energy are getting much attention from the international nuclear community because large capacity power reactors are not economically viable for non-electric applications. These SMRs thus diversify the peaceful uses of nuclear energy in the areas of seawater desalination, district heating, process heat generation, and ship propulsion IAEA (International Atomic Energy Agency), status of advanced light water reactor designs (IAEA, 2004). In this regard, various kinds of SMRs are currently under development worldwide, and some of them are ready for construction. One beneficial advantage of an SMR is the easy receptivity of advanced design concepts and technology. A drastic safety enhancement can be achieved by adopting inherent safety features and passive systems. Economic improvement is also pursued through system simplification, component modularization, on-shop fabrication, and reduction of the construction time.

The System-integrated Modular Advanced Reactor (SMART), a small-sized integral type pressurized water reactor (PWR) with a rated thermal power of 330 MWt, is an advanced SMR. The single reactor pressure vessel contains major primary components such as a reactor core, a pressurizer, steam generators, and reactor coolant pumps. The integrated arrangement of a reactor vessel assembly enables the large-size pipe connections to be removed, which results in an elimination of large break loss of coolant accidents. In addition, by adopting a passive residual heat removal system for long-term core cooling, an overall safety improvement has been accomplished. To identify the safety margin for the design basis events of the SMART and to evaluate its design performance, a series of safety analyses has been performed using Transient And Setpoint Simulation/System-integrated Modular Reactor-Safety (TASS/SMR-S) code.

Abbreviations: CSS, containment spray system; FMHA, flow mixing header assembly; FTC, fuel temperature coefficient; FWIV, feedwater isolation valve; IAPWS, international association for the properties of water steam; IV, isolation valve; KAERI, Korea Atomic Energy Research Institute; KEPCO, Korea Electric Power Corporation; LOOP, loss of offsite power; MDNBR, minimum departure from nucleate boiling ratio; MSIS, main steam isolation signal; MSIV, main steam line isolation valve; MSSV, main steam safety valve; MTC, moderator temperature coefficient; NSSS, nuclear steam supply system; PRHRAS, passive residual heat removal actuation signal; PRHRS, passive residual heat removal system; PWR, pressurized water reactor; RCP, reactor coolant pump; RCS, reactor coolant system; SBCS, steam bypass control system; SCS, shutdown cooling system; SG, steam generator; SGTR, steam generator tube rupture; SI, safety injection; SIS, safety injection system; SMART, system-integrated modular advanced reactor; SMR, small and medium sized reactor; SSAR, standard safety analysis report; TASS/SMR-S, transient and setpoint simulation/small and medium reactor.

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0306-4549/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.anucene.2013.01.007

Together with the Korea Electric Power Corporation (KEPCO) consortium, the Korea Atomic Energy Research Institute (KAERI) submitted a standard safety analysis report (SSAR) for the application of standard design approval in 2010 (KEPCO and KAERI, 2010). The licensing has been approved by the Korean nuclear regulatory authority in 2012.

In SMART, 8 steam generators with helically coiled heat transfer tubes are adopted to generate superheated steam in normal operating conditions. The primary coolant flows downward through the shell side of the steam generator, and the secondary coolant flows upward into the helically coiled tube of the steam generator. These coolant paths are opposite those of commercial reactors: the primary and secondary coolant flows into the tube and shell sides of U-tube, respectively. In addition, the coolant volume of the secondary side of the steam generator is comparatively small compared to that of commercial reactors. Therefore, the thermal hydraulic phenomena resulting from a steam generator tube rupture (SGTR) in SMART is somewhat different from those of commercial reactors. However, the phenomena resulting from an SGTR accident are not fully understood, and the sensitivity evaluations of thermal hydraulic parameters affecting the safety criteria, such as radiological consequences, have not been performed for an integral type PWR until now.

The purpose of this study is to identify the bounding cases for an SGTR accident of the SMART plant as well as to investigate thermal hydraulic phenomena for the integral type reactor under an SGTR accident. Major safety parameter of an SGTR accident is a radiological consequence to the atmosphere. A parametric study is performed to find the most limiting case from the integrated break flow point of view because a radiological consequence is proportional to the integrated break flow through the tube rupture. The results of the thermal hydraulic analysis with the most conservative condition are described.

2. Overall description of SMART

Contrary to commercial nuclear power plants, the leak-tight reactor pressure vessel of SMART contains most of the primary components, i.e., a core, steam generators, reactor coolant pumps, control rod element driving mechanisms, and a pressurizer, as shown in Fig. 1. In addition to the arrangement of the major components into the reactor pressure vessel, SMART has peculiar designs for a reactor coolant system. In SMART, there is no separate component for a pressurizer. The free space between a reactor cover and upper guide structure support barrel is functioned as a pressurizer, which controls the system pressure at a nearly constant level. In addition, the canned motor reactor coolant pump, which has no pump seals, is adopted. Therefore, the loss of coolant associated with a pump seal failure can be prevented. The helically coiled steam generator is another design characteristic of SMART, compared to that of a commercial reactor. In SMART, 8 steam generator cassettes are located at the circumferential periphery with an equal spacing between a reactor vessel and a core support barrel. The steam generator cassettes are located relatively high above the core to provide a driving force for a natural circulation.

The flow direction of the reactor coolant in SMART is shown in Fig. 1. After removing the heat generated in the core, the reactor coolant flows upward through the core, enters the suction of the reactor coolant pump (RCP), discharges to the top of the steam generator, and flows downward through the shell side of the 8 steam generator cassettes. The coolant at the exit region of the steam generators flows into the flow mixing header assembly (FMHA) and reenters the core. Through the feedwater nozzle located at the side of the reactor vessel, the secondary side feedwater enters the bottom of the helically coiled tube of the steam generator, flows upward through the helically coiled tube to remove the heat by the shell side of the steam generator, and exits

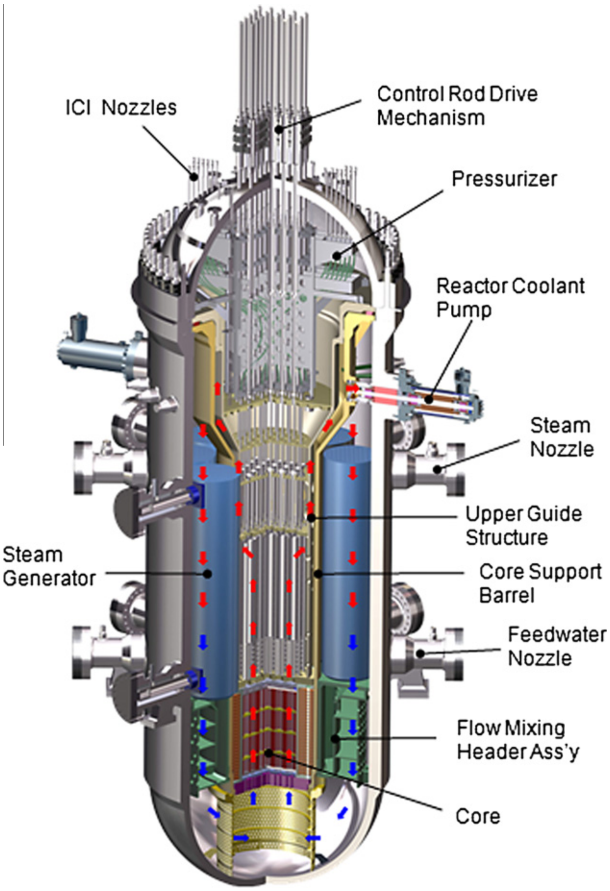

Fig. 1. SMART reactor coolant system overview.

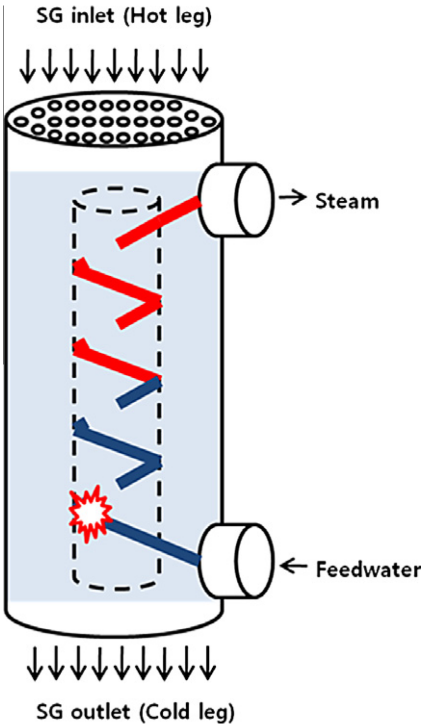

Fig. 2. Steam generator flow path.