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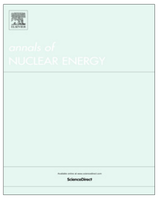

Natural circulation heat transfer model development over vertical tube bundle in the condensate heat exchanger

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ABSTRACT

A 330 MWt integral type nuclear power plant, SMART, was developed for electricity generation and seawater desalination. Advanced design concepts were adopted such as an integral arrangement of the major components, and a passive residual heat removal system (PRHRS) to enhance the safety capability. The TASS/SMR code was developed using various thermal-hydraulic models reflecting the design features of SMART, such as the condensate heat exchanger in the passive residual heat removal system. The development and validation of the condensate heat exchanger model were performed using POSTECH and IIT heat transfer test results. The TASS/SMR code predicted well or slightly under-predicted the heat transfer coefficient at the condensate heat exchanger shell side compared with the experimental data. The heat transfer correlation considering the tube bundle effect improved the prediction of the heat transfer for a vertical tube bundle geometry.

1. Introduction

Small and medium sized reactors (SMRs) provide an opportunity to create an energy system that is more flexible, and more suitable for an energy strategy (Rowinski et al., 2015). SMART (system-integrated modular advanced reactor) is an integral-type small-sized pressurized water reactor (PWR) and has 330 MW of thermal power for dual purposes of electricity generation and non-electrical applications for various facilities (IAEA, 2005). The SMART plant adopts an advanced design concept containing the major components, such as reactor coolant pumps (RCPs), steam generators (SGs), and a pressurizer in a single leak-tight reactor pressure vessel (RPV), as shown in Fig. 1. The SMART design makes an attempt at minimizing the potential for the occurrence of transients and accidents. To achieve this purpose, the design philosophy is to enhance the accident-resistance through passive features such as a passive residual heat removal system (PRHRS) (Kim et al., 2014). Fig. 2 shows a schematic diagram of the passive residual heat removal system. The passive residual heat removal system is connected to the feedwater and main steam pipes. The system consists of a condensate heat exchanger submerged in an emergency cooling tank (ECT), a make-up tank, and valves.

The PRHRS isolation valves are closed and a feedwater system is used to remove the heat generated from the core via the forced convection during normal operation conditions. However, the feedwater isolation valves (FIVs) and the main steam isolation valves (MSIVs) are closed, and the PRHRS isolation valves are opened when some accidents or transients occur in SMART, such as a malfunction of a turbine stop or a loss-of-coolant-accident (LOCA). Then, a closed loop with natural circulation is established in the passive residual heat removal system, and heat is transferred to cooling water in the emergency cooldown tank through the condensate heat exchanger. Hot water, which is transferred from the condensate heat exchanger, is located at a low part of the emergency cooldown tank, and cold water is located at an upper part. Therefore the water in the emergency cooldown tank is circulated around the heat exchanger by gravity force. A thermal hydraulic code should properly predict these phenomena to analyze a system transient.

A thermal hydraulic analysis code, TASS/SMR, was developed and validated to apply an analysis of the SMART performance and safety (Chung et al., 2015a). The governing equations are the mixture mass, steam mass, mixture energy, steam energy, and mixture momentum, which take into account a drift flux model to consider the velocity difference for a two-phase condition. The code reasonably predicts the thermal hydraulic phenomena occurred in a small break LOCA. The code has various heat transfer models reflecting the design features of SMART. One of them is a heat transfer model over a vertical tube bundle geometry in a condensate heat exchanger. The model is used to simulate the heat transfer using the relevant heat transfer correlations for various

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Nomenclature

C_p	specific heat (J/kg K)
D	hydraulic diameter (m)
F	Reynolds number factor
Gr	Grashof number
h	heat transfer coefficient (W/m^2 K)
k	thermal conductivity (W/m K)
Pr	Prandtl number
Ra	Rayleigh number
Re	Reynolds number
S	suppression factor

Greek letters

$\Delta T_{w,f}$	temperature difference between wall temperature and steam temperature based on total pressure (K)
$\Delta P_{w,f}$	pressure difference between pressure based on wall temperature and total pressure (Pa)
χ_{tt}	Lockhart–Martinelli parameter
β	volumetric thermal expansion coefficient (1/K)
μ	dynamic velocity (N s/m^2)
ρ	density (kg/m^3)
σ	surface tension (N/m)

Subscripts

b	boiling
fc	forced convection
f	saturated liquid
fg	difference between saturated liquid and vapor
g	gas
nc	natural convection
TP	two phase
w	wall

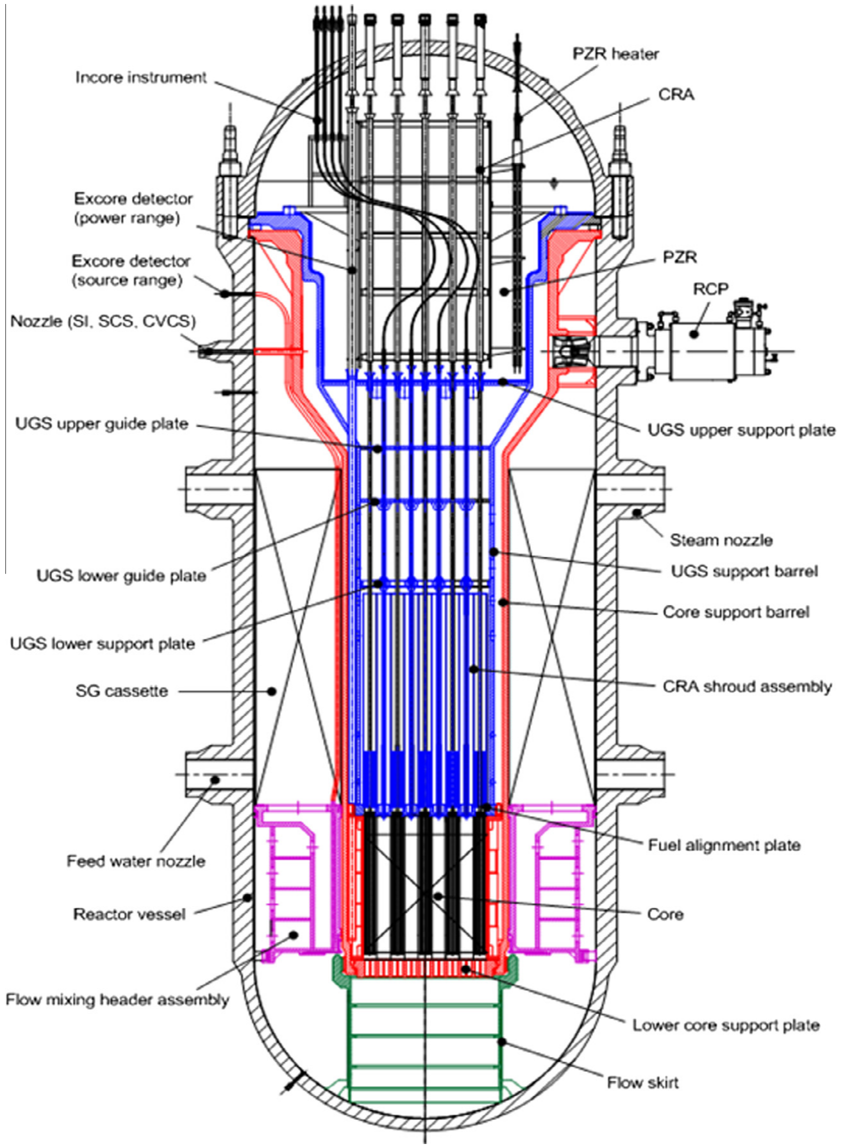

Fig. 1. General view of the SMART reactor vessel.