PHR Capacity Analysis of Nuclear Heating Reactor HAPPY 200

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INTRODUCTION

Faced with environmental challenges and growing heating demand, China is developing fossil free heating systems. China's nuclear technology is also ready to push-off and construct some nuclear heating reactors.

SPICRI (State Power Investment Corporation Research Institute), as the institute of one of the largest nuclear corporations in China, also develops a new conceptual design of heating-reactor. It named Heating-reactor of Advanced low-Pressurized and Passive safetY system (HAPPY).

HAPPY200 is consisted of three circuit systems and safety systems. The main structure of HAPPY primary system is shown as Fig. 1. The core is seated inside the pressure vessel, which is deployed inside a shielding and cooling pool with thermal insulation measure. In the pressure vessel, it is a little trifle-pressurized. The secondary system is the intermediate heat exchange circuits. While the thirdly systems are the heating circuits which are connected with the urban heat-supply network supplying the heat to the residents.

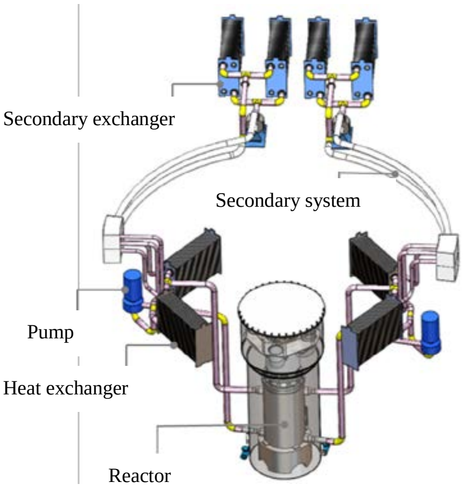

Fig. 1. The structure of HAPPY Primary system.

The safety systems of HAPPY200 is consisted of the Passive coolant Feed-Bleed system (PFB), the Passive residual Heat Removal system (PHR) and Passive pool Air-Cooling System (PAC). The Passive coolant Feed-Bleed system is consisted of Automatic Depressurization System (ADS) and Passive Coolant Injection system. Moreover, the shielding and cooling pool, which is isolated from the primary circuit, will provide radiation shielding during normal operation, and act as a heat sink, ensuring core flooding and residual heat removal during the accident condition.

SIMULATION OF HAPPY200

RELAP5 is selected as the analysis code. The graphical representation of the RELAP5-Model using SNAP (Symbolic Nuclear Analysis Package software). The model mainly includes the pressure vessel, the pressurizer and surge line, pumps and other reactor coolant system (RCS) pipes, the plate heat exchangers and the passive safety systems.

Before initiating the transients, the model is validated by comparing the steady-state calculation result of RELAP5 model with the design values, which shows a good agreement, as shown in TABLE I.

TABLE I. Steady state simulation results compared with design values

Variable	Nominal values	Simulation values	Relative Error (%)
Core power (MWt)	200	200	-
Core mass flow rate (kg/s)	1184	1187.5	±0.3
Core exit pressure (MPa)	0.6	0.6	-
Core inlet temperature (K)	353	354.6	0.45
Core exit temperature (K)	393	394.6	0.41
Temperature of water pool (K)	313	313	-

SBO analyses of different HAPPY PHR design and conditions, i.e. different heights and friction coefficients are compared to provide a reference for the design and optimization of HAPPY safety system. For example, three friction coefficients (0.0, 0.5 and 2.0) are analyzed. While the vertical height of 0.9m, 1.3m and 2.1m are also compared, whose fiction coefficient use 0.0.

RESULTS

The results of primary pressures, core exit temperatures, PHR mass flow rates and heat transferred by PHR are shown in Fig.2. to Fig.5. The results show that the current passive residual heat removal system design can build the natural circulation successfully and remove the core residual heat after the SBO accidents. As a natural process, the establishment and effect of natural circulation is influenced by many factors automatically, for example the height difference and friction coefficients. Larger friction coefficients lead to lower PHR mass flow rate and less heat transfer which results in higher core exit temperatures and primary pressure. However, the effect of the vertical height of PHR is not linear. The result corresponds to the vertical height of 1.3m is much better than 0.9m and 2.1m. Generally speaking, higher height contributes to larger driving force of natural circulation. But when the height is too high, the gravity of the coolant which exerts adverse effect to the natural circulation would counteract the driving force. It is worth noting that, the effect of height is relatively less than the friction coefficients. In the future, more calculations and verifying experiments will be carried out to provide a reference for the design and optimization of HAPPY safety system.

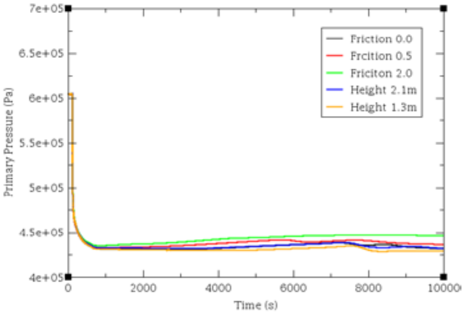

Fig. 2. The primary pressure.

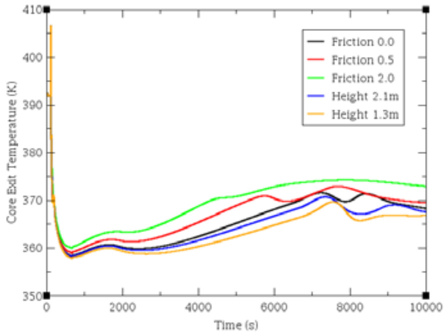

Fig. 3. The core exit temperature.

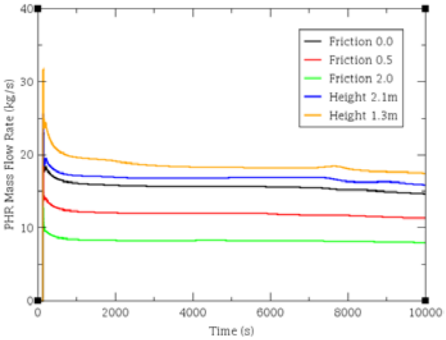

Fig. 4. The PHR mass flow rate.

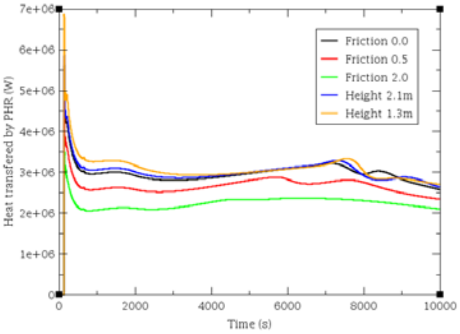

Fig. 5. Heat transferred by PHR.

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