Evaluation of Steam and Gas-flow for APR1400 IRWST using GOTHIC 6.1b

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1. Introduction

The In-Containment Refueling Water Storage Tank (IRWST) of APR1400 is installed at the bottom of the containment building to promote the plant safety functions during an accident. This design feature brings about uncertainty factors that may necessitate improvement or revision of the conventional prediction of temperature and pressure of the containment building in the event of an accident. The hot steam that is released from a RCS break enters the IRWST through four Pressure Relief Dampers (PRDs). The steam is expected to be condensed with water stored in the IRWST, in which water is colder than the incoming steam.

The purpose of this study is to investigate the influence of IRWST and PRDs on back pressure and temperature in APR1400 containment by utilizing a containment code: GOTHIC 6.1b (Generation of Thermal-Hydraulic Information for Containments)[1]. For this purpose, a multi-compartment and detailed three-dimensional model was developed to predict the steam and gas flow-rate in IRWST.

2. Analysis Methods

In this section, the basic modeling method of APR1400 IRWST and the containment building is described. In order to develop and evaluate this model, GOTHIC-6.1b code is used. The GOTHIC code is an integrated, general purpose thermal-hydraulics software package for design, licensing, safety, and operating analysis of nuclear power plant equipment, pipes, and containments.

Thus, a multi-compartment and detailed three-dimensional GOTHIC model was developed and assessed to predict the steam condensation on IRWST pool surface.

2.1 APR1400 IRWST Design Features

The APR1400 containment building is a pre-stressed cylindrical structure of concrete that has a net free volume of 3.3×106 ft^3 as a maximum. The altitude of the lower floor is 100 ft and the maximum height of the upper part is 329.5 ft. IRWST is an annular concrete structure located at the bottom of the containment and is connected to other containment compartments by four PRDs, and has a nominal free volume of 117,416 ft^3. The altitudes of the lower and upper floors are 81 ft and 97 ft, respectively [2]. Fig. 1 illustrates these design features.

In this study, the developed containment model does not incorporate the HVT (Holdup Volume Tank), as we are only concerned with early transients during a period of 1,000 seconds from a design basis accident.

The PRDs are located at the lowest floor of the annular containment compartment and are configured such that there is approximately 90° between PRDs. The net flow area for each PRD is designed to be 36 ft^2. When the pressure difference between containment and IRWST reaches 0.5 psia, the PRD is opened, allowing steam and air flows on both sides.

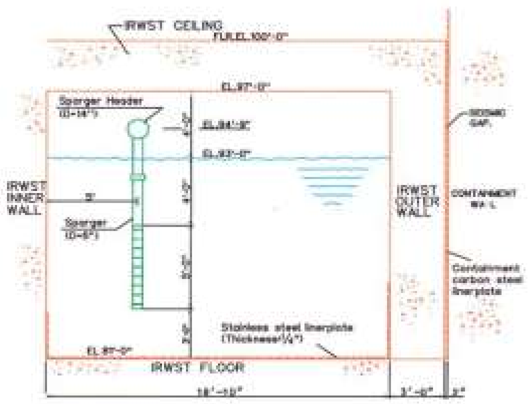

Fig. 1 Inner structure of IRWST(APR1400)

2.2 Other Design Features

The ESFs considered in this study are two trains of containment spray systems and safety injection systems, respectively. All these systems intake water of about 14,000 gpm from sumps located at the bottom floor of the IRWST during an accident [3][4]. This suction flow can open the PRD by creating a vacuum inside the IRWST over a time interval of approximately 1 minute. A passive heat sink is another factor that influences pressure and temperature [5]. For analysis purposes, the maximum allowable passive heat sinks are applied in consistency with material properties. RCS Mass and Energy Release data from an accident analysis for a design basis accident are used in this study. Initial containment conditions were assumed as follows: the temperature is 50 ˚F, pressure is 14.7 psia, and humidity is 90 %, consistent with other models. In the IRWST, the cooling water level is 11.5 ft.

2.3 Modeling of IRWST and PRDs

A 3-D model for the IRWST was generated because the disposition is not symmetric considering the location of the sparger, pump, and suction sump. Therefore, the IRWST is simulated with not only detailed three-dimensional behavior but also independent flow paths for four PRDs.

3. Analysis Results

Figs. 2 and 3 show the analysis results of the IRWST 3-D model. Fig 2 represents the steam flow-rate through each PRD, and Fig 3 depicts the Non-condensable Gas Fraction in the IRWST.

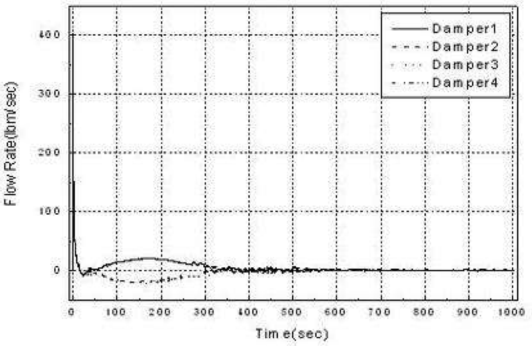

Fig.2 Steam flow-rate of PRDs by IRWST 3-D model

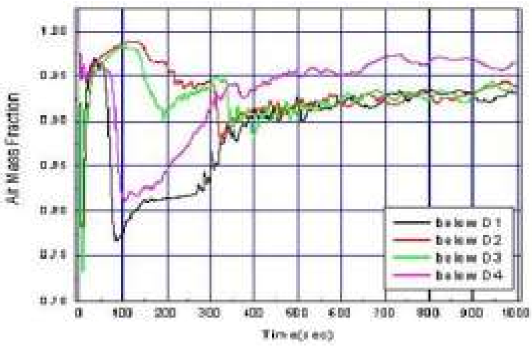

Fig. 3 Non-condensable gas fraction in IRWST

When an accident occurs, hot steam is released from the RCS and then enters the IRWST. In the early stage, steam flows into the PRDs rapidly. At the end of this state, i.e., about 50s later, 2 of 4 PRDs open into the containment. This phenomenon is shown in Fig. 2. Also, Fig. 3 shows non-condensable gas of below the each PRD exist at least 70% over. As steam flows to the IRWST, the pressure of the IRWST increases at an early period of the transient. However, the state becomes thermally stratified and is maintained as an equilibrium state.

The results imply that the PRDs have a small impact on the pressure distribution between the upper compartment and the IRWST. Steam condensation on the pool surface has no significant effect on the thermally stable condition of IRWST. In other words, the condensation on the pool surface is not effective for the pressure drop of containment due to low steam and high non-condensable concentration of the IRWST atmosphere.

4. Conclusions

In order to investigate the influence of PRDs on the pressure and temperature in APR1400 containment, a multi-compartment and detailed three-dimensional model was developed to predict the steam and gas flow-rate in IRWST. Quantitative calculations on the steam condensation and flow-rate in the IRWST pool surface and air space were performed using GOTHIC code to evaluate their effect on the containment pressure and temperature. From the results, it is found that, the effect of steam condensation and flow-rate may be not distinct although steam flow and condensation seem to appear at an early time of the transient.

REFERENCES

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