Evaluation of the PRT Rupture Disk Flow during an Inadvertent Safety Injection Event at Kori Unit 3

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1. Introduction

During a planned preventive maintenance on May 25 2008 at Kori Nuclear Unit 3, a functional test for the COPS (Cold Overpressurization Protection System) as a part of the ESF (Engineered Safety Features) test had been performed in the hot standby condition at Kori #3 Unit. Meanwhile, an operator extracted the RCS (Reactor Coolant System) temperature card without checking the state of the COPS switch and as a result, the RCS wide temperature fell to zero degrees Celsius, the COPS opened the pressurizer PORV (Power Operated Relief Valve) to prevent the RCS from being over-pressurized and the RCS pressure decreased drastically. The safety injection system was actuated when the RCS pressure reached the set-point of the RCS low-low pressure. The operator blocked the pressurizer isolation valve promptly as soon as he recognized that the cause of the RCS pressure loss was the pressurizer PORV open. Both that of the PORV isolation and the safety injection recovered the RCS pressure, however, the CIS (Containment Isolation Signal) related with the safety injection signal blocked the normal letdown flow path to the outside of the containment, so that the letdown flow was released to the PRT (Pressurizer Relief Tank). The inflow from the letdown line increased the PRT water level and over-pressurized the PRT. Eventually, the rupture disk was broken at its set-point and a small amount of water overflowed into the containment.

The transient simulation for the RCS including the pressurizer (PZR) PORV open has been performed by using RETRAN-3D [1] and the simulation for the PRT over-pressure has been performed by using MARS [2] since RETRAN-3D has some limitations to handle the system with non-condensable gas, steam and cold liquid. In this paper, a detail description of the event and the simulation results along with the plant data will be introduced and the accumulated water flow from the PRT will be estimated by the MARS calculation.

2. Analysis of PRT Disk Rupture Accident

The major plant parameters before the accident and the accident sequences are summarized in Table I and II, respectively [3].

2.1 Estimation of the PORV Flow

We performed a simulation of the PZR PORV open accident to estimate the relieving flow by using RETRAN-ViSA (Visual System Analyzer) [4] based on RETRAN-3D. RETRAN-ViSA has the same accuracy as well as many useful features for plant operations such as an interactive control function, plant mimic template and unit conversion function.

In order to achieve the initial condition of a hot standby mode for the simulation, the reactor was tripped manually and the plant maintained the hot standby mode by a control system. Then, once one of the PZR PORVs was opened by manual operation, the accident was initiated. As shown in Fig. 1, the initial PORV flow rate is estimated as 25 kg/s and the RCS pressure change also shows a good agreement with the plant data. The estimated PORV flow rate will be used as a boundary condition of the MARS calculation for a precise PRT simulation.

2.2 Simulation of the Pressure Relief Tank Rupture

The PRT plays a role of condensing the steam relieved from the PZR to prevent the RCS being over-pressurized. The overall layout of the PRT, PZR and related piping is shown in Fig. 2. The PZR PORV which is opened by the COPS actuation is PV-444B and the isolation valve which the operators closed manually after the safety injection is HV-6 in figure.

MARS was used for a more precise simulation of the PRT disk rupture. The PRT is modeled as a vertical pipe which consists of four subvolumes with a different flow area from each other to model a horizontal cylinder.

A dry non-condensable gas volume is modeled for considering a non-condensable gas in the PORV piping. As soon as the PORV opens, non-condensable gas in the piping will be injected into the PRT for 1.5 seconds. After the end of the non-condensable gas injection, saturated steam from the PZR is injected through a time-dependent junction for 72 seconds.

When the CIS related with the SI signal occurs, the RCS fluid starts to flow into the PRT through the letdown PSV. The state of the CVCS letdown fluid is determined based on the enthalpy of the RCS fluid. The pressure of the letdown fluid is assumed to be 50 bar considering the pressure drop at the letdown orifice. Therefore, the CVCS letdown fluid is set to be a saturated water-steam mixture with a temperature of 263 ^{o}C and a static quality of 0.0635. Homogeneous water-steam mixture will be injected into the PRT through time-dependent junction for 420 seconds. The CVCS letdown flow rate will be determined with trial error by controlling the velocity of vapor and liquid at the time-dependent junction. The pressure setpoint of rupture disk is set to minimum design value (86 psig).

2.4 Results of Simulation

Fig. 3 shows the PRT pressure and level comparison of the plant data and the MARS calculation results. As shown in figure, the MARS results are in good agreement with the plant data. The total rupture disk flow is estimated as 12.3 kg and 9 % of total rupture flow is discharged in the liquid phase.

3. Conclusions

The inadvertent PORV opening event on May 25, 2008 at Kori Nuclear Unit 3 has been simulated by using RETRAN-ViSA and we can find out the estimated PORV flow rate from the PZR to the PRT. MARS simulation of the PRT disk rupture event with the PORV flow rate as well as a few assumptions also has been performed. From the simulation results, the amount of total discharging water-steam-non-condensable gas flow through the PRT rupture disk is estimated to be 12.3 kg and 9 % of the total mixture is discharged to the containment in the liquid phase.

REFERENCES

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Table I: Major plant parameters before accident

Parameters	Value	Remark
Reactor Power (%)	0	Hot standby
Generator Power	0	
P_{RCS} (kgf/cm^2,gauge)	157	
RCS T_{avg} (^{o}C)	292	
$P_{S/G}$ (kgf/cm^2,gauge)	76	average pressure
$Level_{S/G}$ (%)	60	average level

Table II: Major Accident Sequences

Time	Plant status
10:00	Preparation of RCS RTD[1] Calibration Test
16:00 ~ 18:00	COPS Test (B-Train)
18:13:45	Inadvertent A/D converter card extraction RCS temperature fail-low COPS-B signal & pressurizer PORV open
18:14:48	Safety injection signal (RCS pressure : 126.5 kgf/cm^2)
18:15	PORV isolation valve closed manually
18:20:16	PRT rupture disk broken
18:20	Safety injection terminated

1 Resistance Temperature Detector

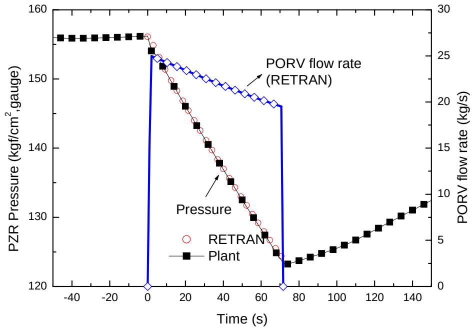

Fig. 1. Pressure comparison and estimated PORV flow

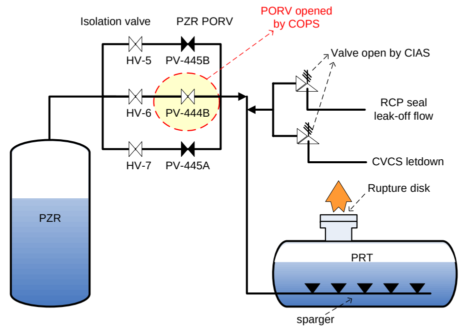

Fig. 2. Layout of PRT and related pipe & valves

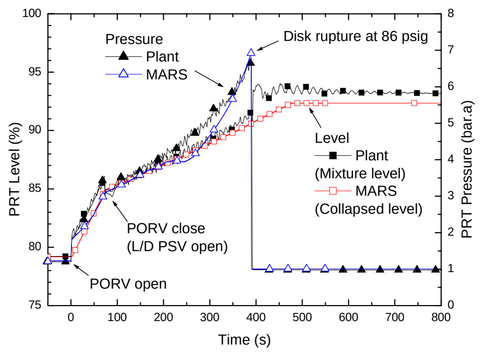

Fig. 3. Comparison of PRT pressure and level

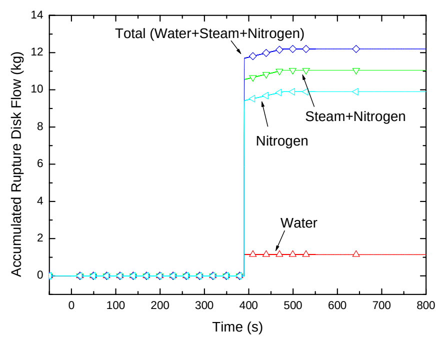

Fig. 4. Accumulated PRT rupture disk flow