Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, November 2-3, 2006

Flow behavior in the Steam Generator U-tubes of APR1400 during a Transient Operation

Doo-Hyuk Kang, Seung-Wook Lee and Bub-Dong Chung
Korea Atomic Energy Research Institute, 150 Dukjin-dong, Yuseong-gu, Teajon, Korea 305-353
dhkang@kaeri.re.kr, nuclist@kaeri.re.kr and bdchung@kaeri.re.kr

1. Introduction

Flow instability appears in a number of two-phase boiling systems such as a nuclear power plant. This instability may alter the heat transfer process to the point that the equipment fails to function as designed. An understanding of the flow instability mechanism is necessary to avoid problems under a natural circulation. Natural circulation is an essential decay heat removal mechanism during transients in pressurized water reactors (PWRs) following a loss of forced circulation [1, 2]. In this study, a postulated event in an advanced power reactor 1400 (APR1400) is analyzed by using the thermal-hydraulic system code MARS3.1 in order to identify the flow instability in the steam generator U-tubes during a natural circulation involving the SGTR (Steam Generator Tube Rupture) event. Also, characteristic flow is calculated to verify the threshold value, which may take place during a flow excursion in the steam generator U-tubes.

2. Methods and Results

2.1. MARS modeling for APR1400

APR1400 is an advanced light water reactor adopting the design features of a direct vessel injection (DVI) configuration and a passive fluidic device in the discharge line of the safety injection tank (SIT). The nuclear steam supply system (NSSS) and several safety systems relevant to the APR1400 such as the core, downcomer, upper head ,bottom head and two steam generators are modeled by the Multi-D component to analyze the full 3D system effect of a NPP.

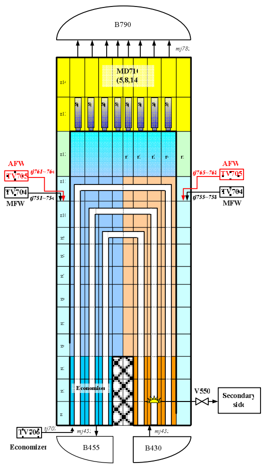

Figure 1. S/G modeling.

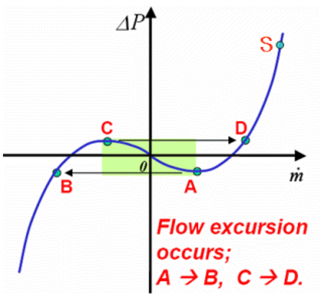

Figure 2. Flow excursion.

The modeling of a steam generator in APR1400 for the analysis of the flow instability during transient operation is shown in Figure 1.

2.2. Flow excursion

Figure 2 shows the flow excursion curve for a steam generator U-tube. If it gradually decreases, the pressure drop (initially from point S in Figure 2), and the mass flow rate will also be gradually decreased. However, when reaching point A in Figure 2, a flow excursion will occur, that is, the flow direction suddenly changes from point A to point B. This is a typical Ledinegg instability. At point A, the slope of the pressure drop versus the mass flow rate is zero.

2.3. Accident condition

In order to verify the flow behavior, a transient in the steam generator U-tubes is simulated by the following conditions. The primary-side water is always subcooled, where the inlet water temperature is 575 K at 13.6 MPa . The secondary-side steam-water mixture is saturated at a temperature of 564 K and a pressure of 7.6 MPa. For the purpose of simulation, Firstly, the SGTR event occurs to process the transient. The reactor coolant pump (RCP) trip was modeled as a control system component. The RCP trip will occur if the temperature of the saturated water minus the temperature of coolant is under 10 Celsius degree. Table 1 provides the accident conditions of APR1400 during a transient operation.

Table 1. Accident conditions of APR1400 during transient.

	Condition	Remark
Primary system	Subcooled water (575K) at 13.6 MPa	
Secondary system	Saturated water (564K) at 7.6 MPa	
SGTR event	A single U-tube rupture	44.95e-5 m^2
RCP Trip	Hot-leg saturation	$T^s - T_f < 10K$

2.4. Results

Figure 3 shows the sequence of events for APR1400 during a transient operation. The primary-side pressure drops very rapidly following a tube rupture and this leads to a RCP trip. After a RCP trip, the primary-side flow rate gradually decreases and forms a natural circulation.

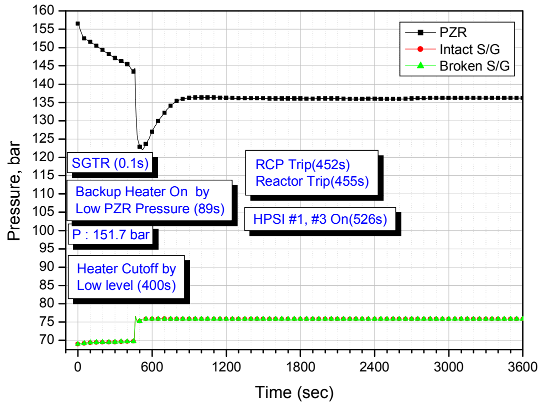

Figure 3. Sequence of events for transient.

As you can see in Figure 4, the pressure-drop versus the mass flow rate calculated in the cases from short U-tubes to long U-tubes. It is indicated that a flow excursion does not take place in any of the cases.

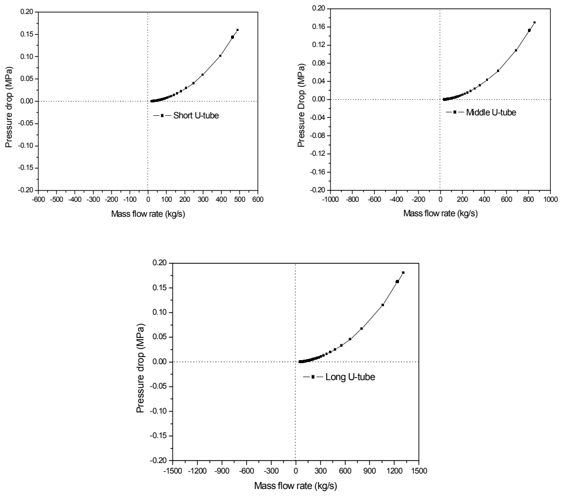

Figure 4. Pressure drop Vs mass flow rate during the transient.

Also, we have calculated the characteristic flows according to equation (1) for a single-phase flow.

$$\dot{m}_c = \frac{\pi D_i^4 g \bar{\rho}^2 \beta C_p \Delta T_{i-s}}{16(fL/D_i + K)U} \quad (1)$$

Table 2 indicates the characteristic flow in the steam generator U-tubes regarding both an intact and broken S/G.

Table 2. Characteristic flow in the steam generator U-tubes.

	Short U-tube 1	Short U-tube 2	Short U-tube 3	Short U-tube 4
Intact S/G	2.219	2.377	2.364	2.278
Broken S/G	2.313	2.399	2.416	2.314
	Middle U-tube 1	Middle U-tube 2	Middle U-tube 3	Middle U-tube 4
Intact S/G	2.207	2.323	2.296	2.195
Broken S/G	2.225	1.666	2.375	2.254
	Long U-tube 1	Long U-tube 2	Long U-tube 3	Long U-tube 4
Intact S/G	2.11	2.257	2.226	2.068
Broken S/G	2.115	2.31	2.335	2.168

As shown in Table 3, the mass flow rates in the steam generator U-tubes in both cases show higher values than those of the characteristic flow. It was found that a flow excursion does not occur during a transient operation because the mass flow rates are higher than the characteristic flow values.

Table 3. Mass flow rate in the steam generator U-tubes.

	Short U-tube 1	Short U-tube 2	Short U-tube 3	Short U-tube 4
Intact S/G	20.093	19.742	19.788	20.088
Broken S/G	19.977	19.69	19.626	19.969
	Middle U-tube 1	Middle U-tube 2	Middle U-tube 3	Middle U-tube 4
Intact S/G	35.222	34.469	34.643	35.295
Broken S/G	35.127	29.661	34.2	34.939
	Long U-tube 1	Long U-tube 2	Long U-tube 3	Long U-tube 4
Intact S/G	54.02	52.526	52.85	54.461
Broken S/G	54.021	52.129	51.896	53.496

3. Conclusion

The postulated event was simulated to identify the flow instability in the U-tubes of a vertical, inverted steam generator, which is modeled by a multi-dimensional component. It was found that the flow behavior in the steam generator U-tubes of APR1400 flow normally in the right direction under a natural circulation involving the SGTR event. It is concluded that a flow excursion does not occur in the steam generator U-tubes of APR1400 during a transient operation when using the MARS Code. Therefore, a safety analysis of APR1400 is no problem for this analysis.

REFERENCES

[1] Jeong J.J., et al, "Single-phase flow excursion in the primary side of a vertical, inverted U-tube steam generator," NInt. Comm. Heat Mass Transfer, Vol. 30, No. 5, pp.643~652, 2003

[2] Jeong J.J., et al, "Non-uniform flow distribution in the steam generator U-tubes of a pressurized water reactor plant during single- and two-phase natural circulations," Nuclear Engineering and Design 231, 2004

[3] Chung B.D., et al, 2005, "Development and assessment of multi-dimensional flow models in the thermal-hydraulic system analysis code MARS," KAERI/TR-3011/2005, KAERI.

[4] Chung B.D., et al, 2005, "Development of Nuclear Thermal Hydraulic Verification Test and Evaluation Technology," KAERI/RR-2520/2004, KAERI.

[5] Evaluation of Thermal-hydraulic Behavior following the Steam Generator Tube Rupture Event of Ulchin Unit 4, KINS/ER-056, 2003.

[6] Evaluation Report on Steam Generator Tube Rupture Event of Ulchin Unit 4, KOPEC, 2002.