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Cause Analysis of Flow Accelerated Corrosion and Erosion-Corrosion Cases in Korea Nuclear Power Plants

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Significant piping wall thinning caused by Flow-Accelerated Corrosion (FAC) and Erosion-Corrosion (EC) continues to occur, even after the Mihama Power Station unit 3 secondary pipe rupture in 2004, in which workers were seriously injured or died. Nuclear power plants in many countries have experienced FAC and EC-related cases in steam cycle piping systems. Korea has also experienced piping wall thinning cases including thinning in the downstream straight pipe of a check valve in a feedwater pump line, the downstream elbow of a control valve in a feedwater flow control line, and failure of the straight pipe downstream of an orifice in an auxiliary steam return line. Cause analyses were performed by reviewing thickness data using Ultrasonic Techniques (UT) and, Scanning Electron Microscope (SEM) images for the failed pipe, and numerical simulation results for FAC and EC cases in Korea Nuclear Power Plants. It was concluded that the main cause of wall thinning for the downstream pipe of a check valve is FAC caused by water vortex flow due to the internal flow shape of a check valve, the main cause of wall thinning for the downstream elbow of a control valve is FAC caused by a thickness difference with the upstream pipe, and the main cause of wall thinning for the downstream pipe of an orifice is FAC and EC caused by liquid droplets and vortex flow. In order to investigate more cases, additional analyses were performed with the review of a lot of thickness data for inspected pipes. The results showed that pipe wall thinning was also affected by the operating condition of upstream equipment. Management of FAC and EC based on these cases will focus on the downstream piping of abnormal or unusual operated equipment.

Keywords : *FAC, erosion-corrosion, pipe wall thinning, numerical simulation*

1. Introduction

Flow-Accelerated Corrosion (FAC) and Erosion Corrosion (EC) have always evoked operating and safety problems in nuclear power plants (NPPs). The fatal accident at the Surry-2 of U.S in 1986, the Mihama-3 of Japan in 2004[1)] and other failures of steam cycle systems in nuclear power plants have made utilities to perform actions to predict and inspect pipe wall thinning. Without a sysmetic pipe management, ruputre of piping component caused by FAC and EC is inevitable.

Pipe wall thinning management programs for FAC & EC rate prediction such as EPRI CHECWORKS, EdF BRT CICERO, and AREVA COMSY have been used in many NPPs. They are composed of several functions, such as performing FAC and EC rate prediction, prioritizing piping componets for inspection, demonstrating reliability of thickness data and making decisions regarding replacement or continuous service based on the remainning life of the component. Since 1996, Korea NPPs have used CHECWORKS program for FAC and EC prediction and accumulated many inspection data.

Although the most important function of pipe wall thinning management program is to predict FAC and EC, it is difficult to find out real cause for pipe wall thinning using precdiction program. This paper represents future plan and results of the cause analysis on FAC and EC cases in KOREA NPPs and future plan.

2. Analyses procedure

Cause analyses were performed by case studies through EPRI TPM (Total Points Method) evaluation using UT (Ultrasonic Techniques) inspection data for pipe wall thinning, SEM (Scanning Electron Microscope) image observation for the failure pipe, and numerical simulation to analyze the extent and the cause of thinning for the

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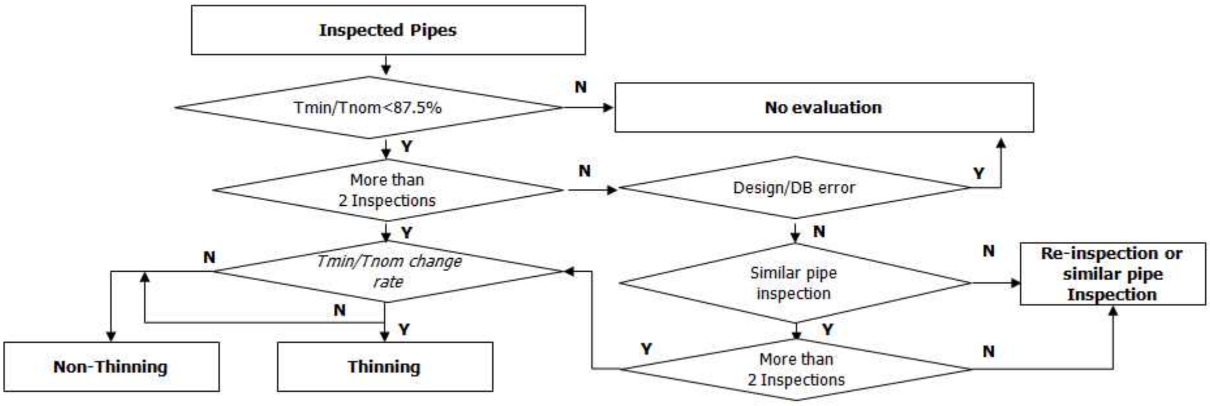


Fig. 1. Flow chart for the diagnosis of thinned pipe based on the inspection data.

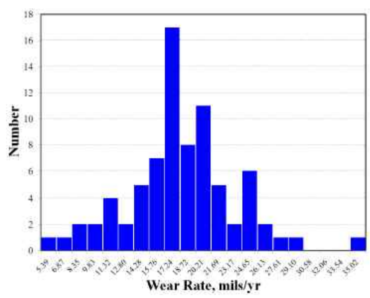


Fig. 2. EPRI TPM evaluation result.

FAC and EC cases. In order to investigate more cases, additional analyses were performed by the review of a lot of thickness data for inspected pipes. Distinguishing method of thinned pipe based on the inspection data is shown in the Fig. 1. The results of the analyses for 6 pipe wall thinning cases are introduced in this paper.

3. Analyses of pipe wall thinning cases

3.1 Case studies

It was disclosed that many nuclear power plants have experienced FAC and EC, based on the analyses for pipes leaked in operation or the analyses for thinned pipes founded at inspection during the RFO (Refuelling Outage). This section describes two FAC cases founded at inspection and one FAC and EC case founded at leak.

3.1.1 Case 1[2)]

Wall thinning was founded in the straight pipe (A106 Gr. B) on the downstream of the motor operated stop check valve in feedwater system during the RFO-8. The pipe was replaced and upstream valve nozzle of pipe was internally repaired with welding. Nominal thickness of the pipe is 1.5 inch and code required minimum thickness is 1.296 inch. Measured minimum thickness is 1.161 inch in the RFO-8 and the wear rate determined in the PTP (Point To Point) method applying EPRI Max. Delta option from the RFO-6 to the RFO-8 is 0.060 inch per cycle. Thickness of valve nozzle and adjacent replaced pipe areas was decreased below code required minimum wall thickness. Wall thinning of the pipe and the valve nozzle was observed from internal visual inspection.

As shown in Fig. 2, it was identified that pipe wall thinning goes along resulting from EPRI TPM (Total Points Method) evaluation using 3 cycles UT data. In order to analysis wall thinning cause, numerical simulation was performed using CFD (Computational Fluid Dynamics) code, FLUENT. Fig. 3 shows the water flow distribution, radial water velocity distribution, and turbulence intensity

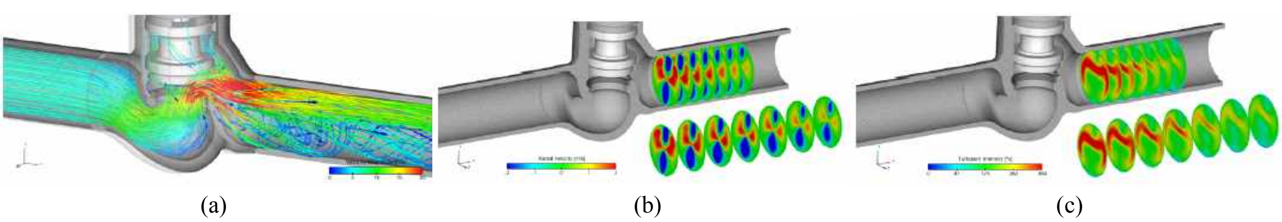
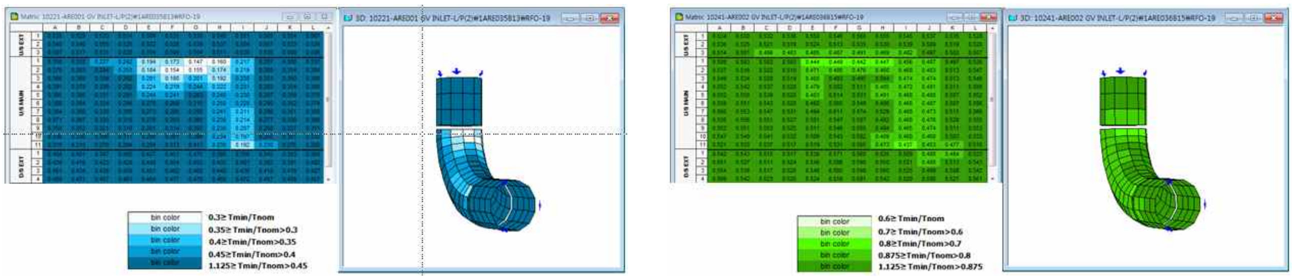


Fig. 3. Numerical simulation results of the check valve and downstream pipe ; (a) Water flow distribution, (b) Radial water velocity distribution, (c) Turbulence intensity distribution.



(a) (b)

Fig. 4. UT data distribution of the elbow and pipes at (a) SG1 and (b) SG2.

distribution as the numerical simulation results of the check valve and downstream pipe. Water flow is faster at upper side of the check valve and downstream pipe than the other side. Radial velocity is also faster and turbulence intensity is higher at upper side of the check valve and downstream pipe than the other side. Wall thinning was generated by internal water flow shape of swing type check valve upstream of the pipe. Internal water flow shape of some check valve can evoke wall thinning of downstream pipe. It is concluded that the main cause of the wall thinning for the downstream pipe of the check valve is FAC caused by the water vortex flow due to internal flow shape of the check valve.

3.1.2 Case 2[3)]

Wall thinning was founded in a bending elbow (A106 Gr. B) of SG1 line in feedwater system during the RFO-18. The elbow was replaced and similar elbows of other lines inspected. The elbow of SG (Steam Generator)3 line was also thinned but the elbow of SG2 line was not thinned.

Analyses of UT data were performed to find the wall thinning difference between two elbows installed in SG1 and SG2 lines. Fig. 4 shows UT data distribution of the elbows and pipes at SG1 and SG2. The elbow of SG1 was being thinned at the intrados and was thinner than the upstream pipe. The elbow of SG2 was little thinned and had the similar thickness with the upstream pipe.

OM (Optical Microscope) image observation was performed to investigate thickness difference between SG1 elbow and upstream pipe. Fig. 5 shows the microstructure image of the upstream pipe, the weld area, and the elbow for the direction of water flow. As the protruding part exists at the upstream pipe by thickness difference, it is possible for pipe wall to be thinned by the protruding part of the upstream pipe. Or, if welding bid had existed at the weld area, it is possible for pipe wall to be thinned by welding bid. Fig. 6 shows Isometric drawing of SG1 elbow line. As the control valve (242VL) is located in the upstream of the elbow, it is also possible for pipe wall to be thinned by the control valve. To investigate wall thinning cause of the elbow by the control valve, the welding bid, and the protruding part of the upstream pipe, CFD numerical simulations were performed.

Fig. 7 (a) shows numerical analyses results for wall thinning affected by the welding bid, where V+7.0B means existing of 7.0mm bid at the downstream elbow of valve. Fig. 7 (b) shows numerical analyses results for wall thinning affected by the protruding part of upstream pipe. The welding bid affects elbow wall thinning. The thickness difference by the protruding part of upstream pipe also affects elbow wall thinning. The main cause of the wall thinning for the downstream elbow of the control valve is FAC due to the water vortex flow by the welding bid or the thickness difference.

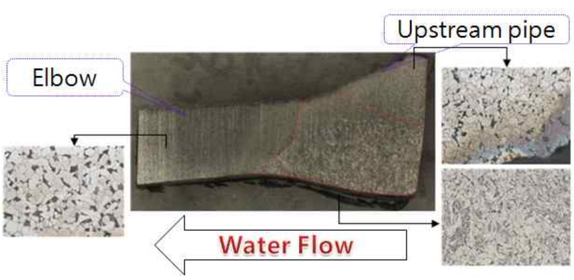


Fig. 5. OM image at SG1 elbow and upstream pipe.

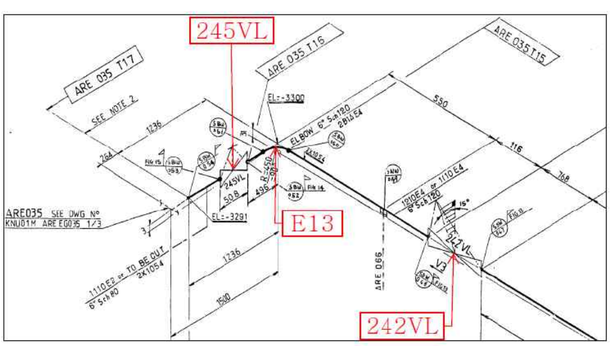
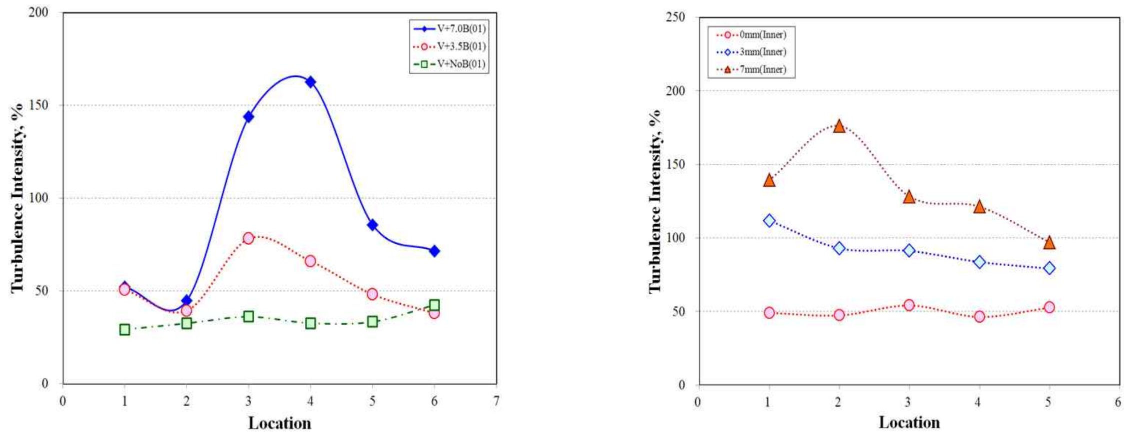
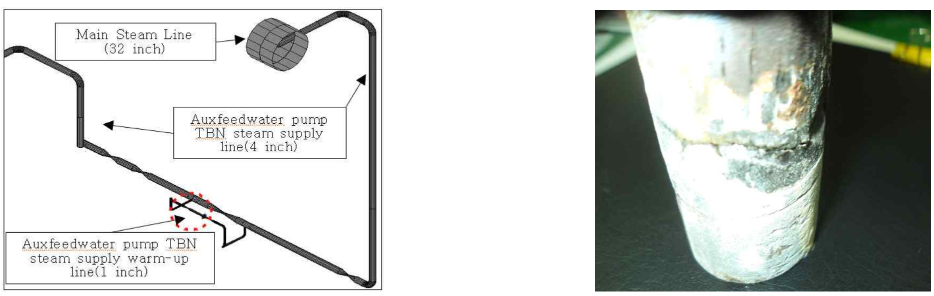


Fig. 6. SG1 elbow line isometric drawing.



(a) (b)

Fig. 7. Numerical simulation results of the elbow wall thinning ; (a) Turbulence intensity by the welding bid and (b) Turbulence intensity by the thickness difference.



(a) (b)

Fig. 8. Diagram and picture of small bore pipe line ; (a) 3D of small bore pipe line and (b) Failure picture of small bore pipe.

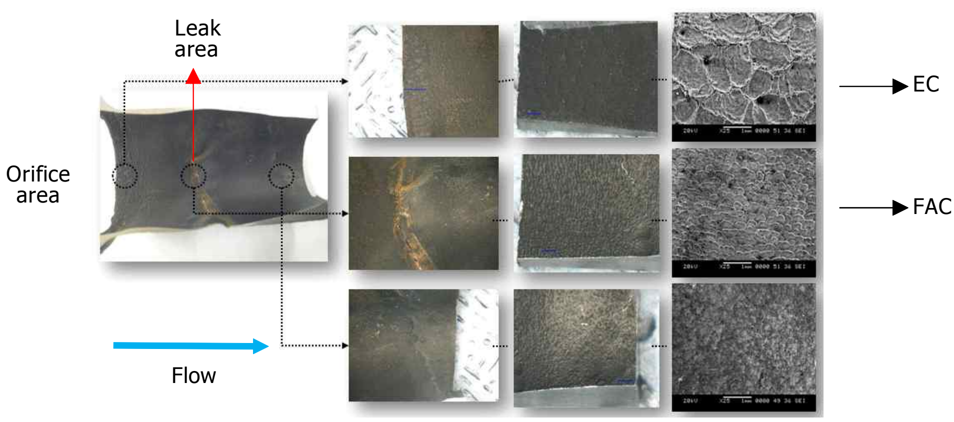


Fig. 9. Surface of small bore pipe.

3.1.3 Case 3[4)]

Steam leak was founded in a small bore pipe (SA106 Gr. B, Class3) located in the downstream of the orifice at SG A in main steam system. The function of the pipe is warming-up the auxiliary feedwater pump turbine with main steam and flowing steam goes to the condenser as shown in Fig. 8. The pipe was replaced and the same pipe at SG B and the other plants were inspected. All inspected thicknesses of the same pipe at SG B and other plants were thicker than nominal thickness. In order to find the cause of the wall thinning for the downstream pipe of the orifice at SG A, investigation for operating condition and SEM image observation were performed.

According to the operating condition history, high quality steam was flowing through this line. It seems that steam quality was changed after replacing of the steam

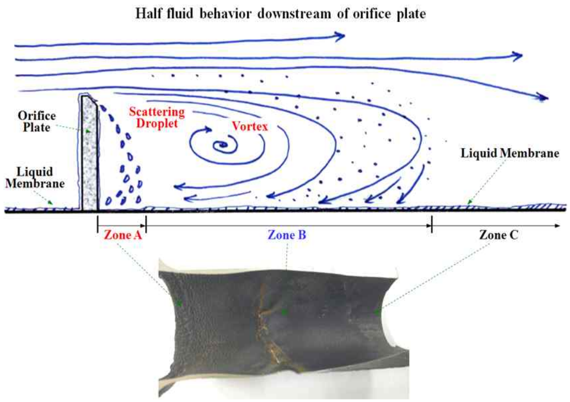


Fig. 10. Fluid behaviour for the downstream pipe of the orifice.

generator moisture separator re-heater and power up-rate. Fig. 9 shows surface analyses results by stereoscopy and SEM for three areas from the orifice. At the near surface of the orifice, damaged shapes by erosion were observed. At the near leak area, the FAC degradation like orange peel shape was observed. And, at the farther area of the orifice, surface damages were not nearly observed.

The main cause for the leak on the downstream pipe of the orifice is EC due to the liquid droplet and FAC due to the water vortex flow presented by wet steam as shown in Fig. 10.

3.2 Analyses of thickness data for inspected pipes[5)]

Additional analyses were performed by the review of a lot of thickness data for inspected piping components.

3.2.1 Case 4

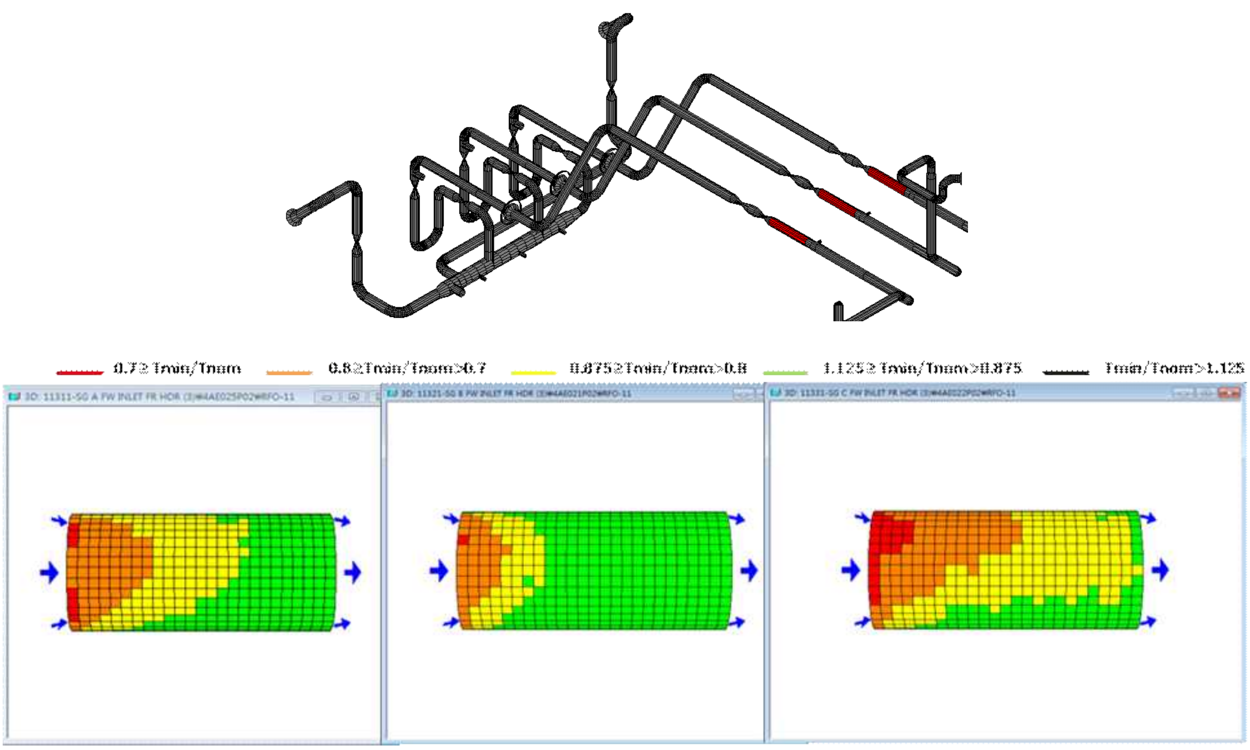
Wall thinning was founded at the downstream pipes of the feedwater check valve. The similar pipes were also thinned and replaced. Adjacent pipe areas of check valve were thinned as shown in Fig. 11. This case is very similar to the case1.

3.2.2 Case 5

Wall thinning was founded at the pipe and expander located in the downstream of the control valve. As time goes on, value of the measured wall thickness is below 70 % compared to that of the nominal thickness as shown in Fig. 12.

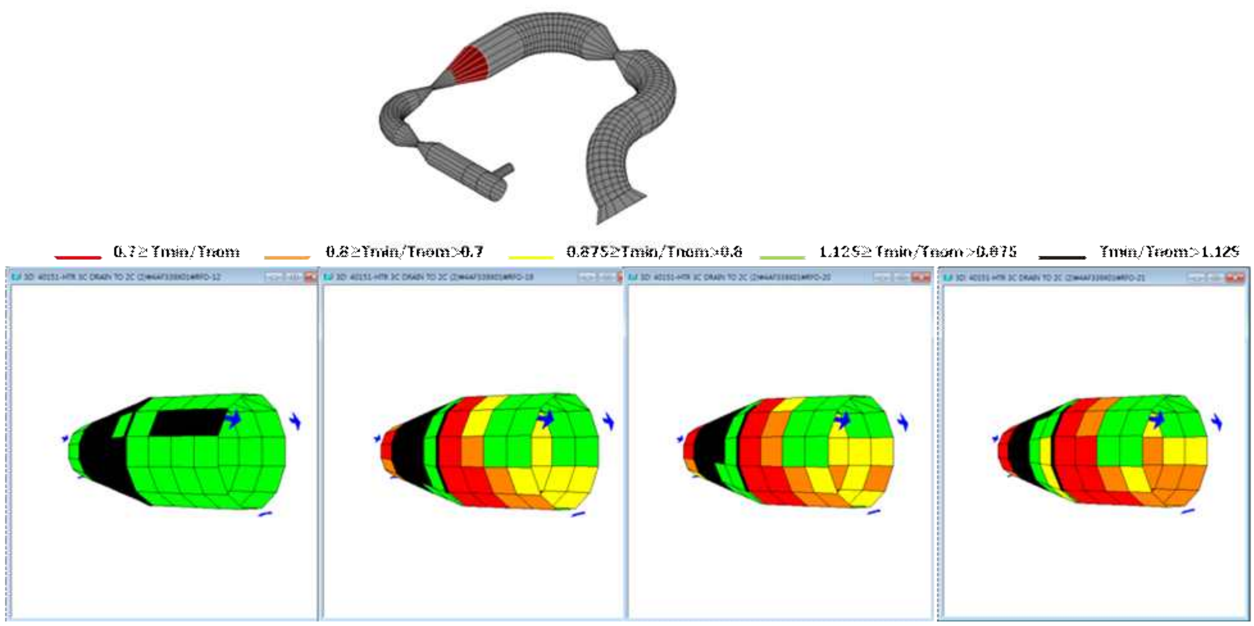
3.2.3 Case 6

Wall thinning was founded at the carbon steel nozzle located in the downstream of low alloy steel elbow. As time goes on, value of the measured wall thickness is below 70 % compared to that of the nominal wall thickness as shown in Fig. 13. This is FAC due to entrance effect.



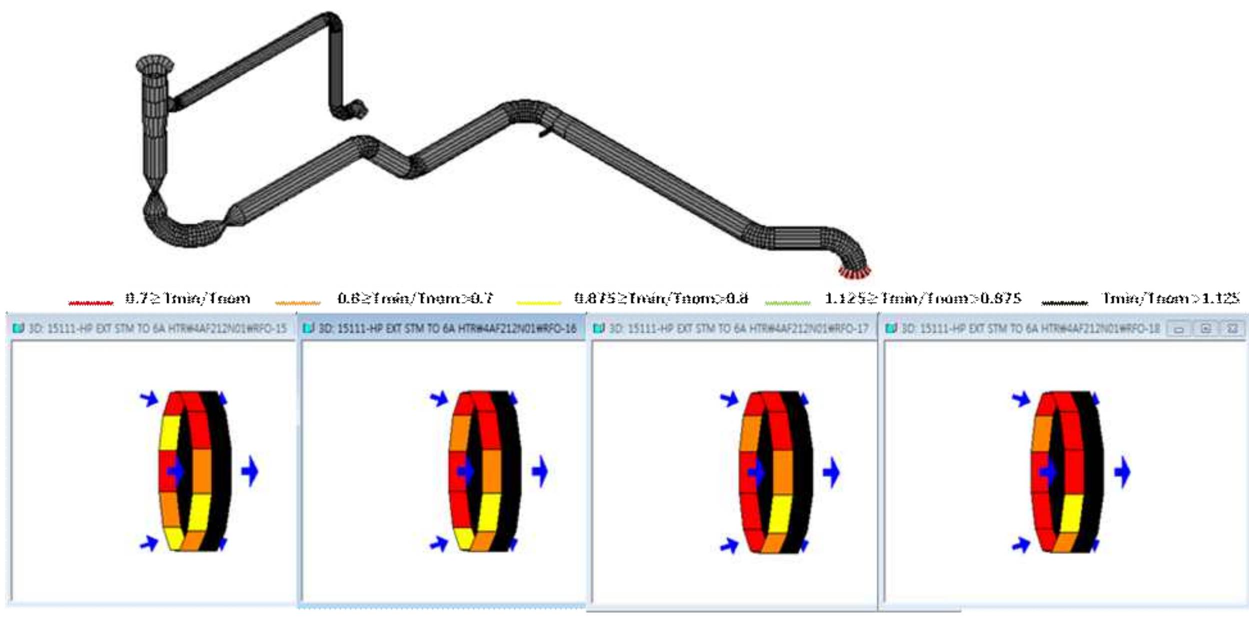
(a) (b) (c)

Fig. 11. Thickness changing rate distributions for the downstream pipe of the check valve ; (a) A straight pipe at SG A, (b) A straight pipe at SG B, (c) A straight pipe at SG C.



(a) (b) (c) (d)

Fig. 12. Thickness changing rate distributions for the downstream pipe of the control valve with inspection times (RFO) ; (a) RFO12, (b) RFO19, (c) RFO20, (d) RFO21.



(a) (b) (c) (d)

Fig. 13. Thickness changing rate distributions for the carbon steel nozzle with inspection times (RFO) ; (a) RFO15, (b) RFO16, (c) RFO17, (d) RFO18.

4. Summary

Recently, Korea has experienced pipe wall thinning degradation in operating nuclear power plants at the straight pipe located in the downstream of a check valve in a feedwater pump line, the downstream elbow of the control valve in a feedwater flow control line, and failure of the straight pipe located in the downstream of an orifice in an auxiliary steam return line.

The main cause for wall thinning at the downstream pipe of the check valve is FAC caused by the water vortex flow due to internal flow shape of the check valve, the main cause of wall thinning for the downstream elbow of the control valve is FAC caused by thickness difference with the upstream pipe, and the main cause of wall thinning for the downstream pipe of the orifice is FAC and EC caused by the liquid droplet and vortex flow.

As the results of additional analyses, it was identified that pipe wall thinning was also affected by operating condition of upstream equipment.

From these results, management for FAC and EC in Korea will focus on downstream piping of the abnormal or unusual operated equipment.

References

1. EPRI 1022295, Mentoring Guide for Flow-Accelerated Corrosion Engineers (2010).
2. S. K. Park, Y. S. Lee, and S. H. Lee, *Proceedings of the CSSK Annual Fall Meeting on A study on the wall thinning pipe at valve downstream*, p. 45, CSSK, Jeju (2013).
3. Y. S. Lee, S. H. Lee, J. G. Lee, and K. M. Hwang, *Proceedings of the CSSK Annual Spring Meeting on Cause analysis for abnormal wall thinning at a feedwater elbow of NPPs*, p. 30, CSSK, Seoul (2014).
4. K. M. Hwang, *Corros. Sci. Tech.*, **12**, 227 (2013).
5. Y. S. Lee, S. K. Park, and S. H. Lee, *Proceedings of the CSSK Annual Fall Meetings on Study of wall thinning experiences for carbon steel pipes at NPP steam cycle systems*, p. 53, CSSK, Jeju (2013).