# Piping System, Risk Management Based on Wall Thinning Monitoring and Prediction

Toshiyuki Takagi[1,2], Philippe Guy[3], Yutaka Watanabe[4], Hiroshi Abe[4], Shinji Ebara[4], Tetsuya Uchimoto[1,2], Takayuki Aoki[4], Mitsuo Hashimoto[1], Ryoichi Urayama[1], Hongjun Sun[1], Thomas Monnier[3], Jérôme Antoni[3], Bernard Normand[3], Nicolas Mary[2], Ryo Morita[5], Shun Watanabe[5], Atsushi Iwasaki[6], Hiroyuki Nakamoto[7], Christophe Reboud[8], Pierre Calmon[8], Edouard Demaldent[8], Vahan Baronian[8], Xavier Artusi[8], Sylvain Chatillon[8], Alain Lhemery[8]

[1] Institute of Fluid Science, Tohoku University, 2-1-1 Katahira, Aoba, Sendai, 980-8577, Japan

[2] ELyTMaX UMI 3757, CNRS – Université de Lyon – Tohoku University, International Joint Unit, Tohoku University, Sendai, 980-8577, Japan

[3] Université de Lyon, INSA-Lyon, MATEIS CNRS UMR 5510, Villeurbanne F-69621, France

[4] Graduate School of Engineering, Tohoku University, 6-6-01-2 Aoba, Aramaki, Aoba-Ku, Sendai 980-8579, Japan

[5] Central Research Institute of Electric Power Industry, 2-6-1 Nagasaka, Yokosuka, Kanagawa, Japan

[6] Department of Mechanical System Engineering, Gunma University

[7] Graduate School of System Informatics, Kobe University, 1-1 Rokkodai, Nada, Kobe, 657-8501, Japan

[8] CEA-LIST, Laboratory Methods for the Control, 91191 Gif-sur-Yvette, France

## ABSTRACT

Cooling water circulation is an essential guarantee for the safety of Fukushima Daiichi Nuclear Power Plant during decommissioning. However, when removing fuel debris, a flow with high concentration debris of various kinds occurs in the cooling water pipe. Pipe wall thinning by Slurry Flow induced Corrosion (SFC) under solid-liquid two-phase has been anticipated. This may seriously affect the safety of the cooling system. We aim at developing new tools and techniques to quantify pipe wall thinning, and provide a risk management system based on prediction-monitoring of pipe wall thinning due to SFC in piping systems.

## 1. Introduction

Cooling water circulation is an essential guarantee for the safety of Fukushima Daiichi Nuclear Power Plant during decommissioning. However, when removing fuel debris, a flow with high concentration debris of various kinds occurs in the cooling water pipe. Carbon steels are the principle coolant pipe materials in nuclear and fossil fuel power plants. Pipe wall thinning by Slurry Flow induced Corrosion (SFC) under solid-liquid two-phase has been anticipated. This may seriously affect the safety of the cooling system. Therefore, it requires structural evaluation of these pipes to maintain the integrity of these piping systems. Locations with the most severe wall thinning and maximum wall-thinning rates may be revealed by experiments and numerical simulations.

We aim at developing new tools and techniques to quantify pipe wall thinning, and provide a risk management system based on prediction-monitoring of pipe wall thinning due to SFC in piping systems.

## 2. Progress of the Project

### 2.1. Modeling of SFC and prediction of wall thinning

To understand pipe wall thinning by SFC, the mechanism of accelerated corrosion due to disturbance of the concentration boundary layer by repeated contact with particles must be studied (Fig. 1).

The mass flux and mass transfer coefficient evaluation method through a diffusion-controlled limiting current measurement under flow by using a rotating cylinder electrode has been developed. Also, it can be seen from the experiments, the mass transfer coefficient near the wall surface evaluated in the glass particle containing solid-liquid two phase flow is higher than that in liquid single phase flow.

To clarify the solid particle behavior in a piping flow, especially in the vicinity of the channel wall, a water-circulation loop was fabricated for the evaluation of solid particle -liquid two-phase flow.

A water-circulation loop was fabricated for the evaluation of solid particle -liquid two-phase flow, which can clarify the solid particle behavior in a piping flow, especially in the vicinity of the channel wall. Three dimensional solid-liquid two-phase flow calculation around elbow was conducted with a solid-particle simulation model. Flow drift and separation around the elbow were compared with experiment the above and the qualitative agreement was validated. After the validation, the effects of the solid particle conditions to the flow structures and the flow factor of the wall thinning were evaluated. As a result, we have found that the flow velocity profile and mass transfer coefficient were affected relatively large by the particle diameter, and found that it could be possible to normalize solid particle effects by Reynolds number, Stokes number and so on.

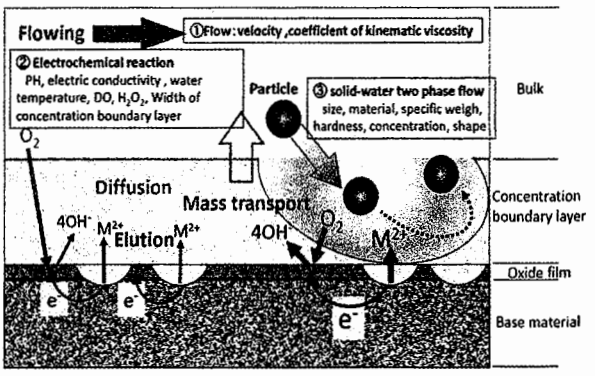


Fig. 1 Pipe wall thinning induced by Slurry Flow induced Corrosion (SFC).

### 2.2. Development of EMAT monitoring system

To apply in Fukushima Daiichi Nuclear Power Plant, a system that can monitor pipe wall thinning by SFC with

Corresponding author: Toshiyuki Takagi; Philippe Guy
*E-mail address*: takagi@ifs.tohoku.ac.jp; philippe.guy@insa-lyon.fr

high accuracy and high radiation to environmental factors is being developed. This system is using an electromagnetic acoustic transducer (EMAT) with electromagnetic acoustic resonance (EMAR) method to perform the pipe wall thinning monitoring [1].

Because corrosion often produces a scallop pattern, its detection requires a probe with high spatial resolution. In this study, we are increasing the EMAT spatial resolution by focusing the ultrasonic wave. The design focusing type EMAT, as shown in Fig. 2. Figure 3 shows the Evaluation of focusing performance of focusing type EMAT. Because the coils are hand-made, the focus of the two semi-circular coils slightly deviates. However, it is clear that the ultrasound is focusing on the center point.

However, the EMAT has the disadvantage of low signal-to-noise ratio (SNR). Therefore, the EMAR (Electromagnetic acoustic resonance) method has been proposed for improving the SNR [2]. In this study, we take advantage of the fast electromagnetic and ultrasonic semi-analytical models implemented in the CIVA software [3] to carry out the simulations. A simulation example is shown in Fig. 4, which shows the input signal of 1 MHz burst signal in time and frequency domain.

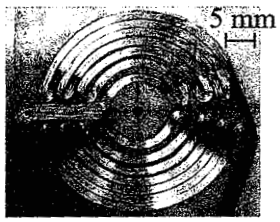


Fig. 2 Focusing type EMAT.

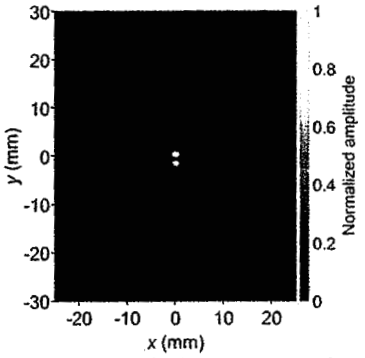


Fig. 3 Evaluation of focusing performance of focusing type EMAT.

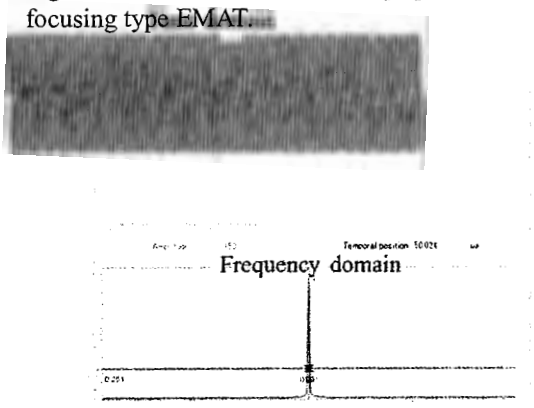


Fig. 4 Input signal of 1 MHz burst signal in time and frequency domain.

2.3. Engineering risk evaluation

A probabilistic evaluation method of future damage was proposed. In the proposed method, by evaluating the damage progression rate as the degree of belief by Bayesian estimation, the evaluation error of the diagnostic method and the uncertainty of the progression rate due to uncertain factors are considered (Fig. 5).

In the risk prediction using the proposed method, future thinning in the inner surface of the pipe was estimated by a Bayesian estimation using data of measurement results at different measurement timings at multiple points, and the damage probability and risk were evaluated there. An EMAT was assumed as the thickness measurement method. The effectiveness of the risk evaluation method was clarified from the simulation that assumed the progress of thinning, which considering the EMAT measurement error. Furthermore, from the simulation, the influence of the measurement error, and the number of measurement points of EMAT was clarified.

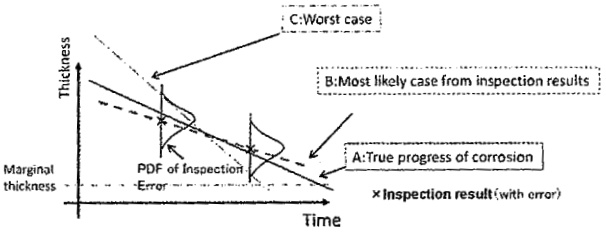


Fig. 5 Engineering risk evaluation based on PoF (Probability of Failure) evaluation.

## 3. Concluding Remarks

This project, which started in November 2017 and will continue for three years until 2020, is being carried out by an international collaborative research team with members from Japan and France. Currently, ongoing research is progressing towards our goal of developing effective risk management for piping systems.


## Acknowledgements

This study is the result of "Piping System, Risk Management based on Wall Thinning Monitoring and Prediction" carried out under the Center of World Intelligence Project for Nuclear S&T and Human Resource Development by the Ministry of Education, Culture, Sports, Science and Technology of Japan, and ANR of France.


## References


[1] R. Urayama, T. Uchimoto, T. Takagi, S. Kanemoto, *Online Monitoring of Pipe Wall Thinning by Electromagnetic Acoustic Resonance Method, E-Journal of Advanced Maintenance*, 5, 5, (2013), 155-164.

[2] T. Takagi, R. Urayama, T. Ichihara, T. Uchimoto, T. Ohira and T. Kikuchi, *Pipe wall thinning inspection using EMAR, Nuclear Engineering International*, 58 (2013), pp.18-21.

[3] http://www.extende.com