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Multi-target Wastage Phenomena on Steam Generator Tubes During an SWR Event (II)

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1. Introduction

The Korean sodium-cooled fast reactor, KALIMER-600 (Korea Advanced LIquid MEtal Reactor), the electric output of which is 600MWe, was developed. The steam generator (SG) of this system is a shell-and-tube type counter-current flow heat exchanger, which is vertically oriented with fixed tube-sheets. A direct heat exchange occurs between the shell-side sodium and tube-side water at the SG unit [1]. Feed-water enters the inlet nozzle at the lower part of the unit, and flows upward along the helically coiled heat transfer tubes. The inflow sodium is cooled down at the bundle region, and then flows out through the sodium outlet nozzle at the bottom of the unit. The typical configuration of the KALIMER-600 SG is shown in Figure 1.

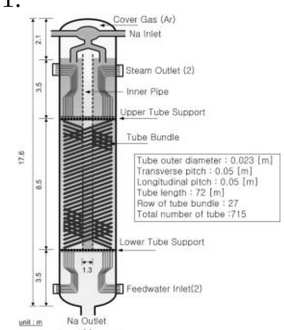

Figure 1 Schematic of KALIMER-600 Steam Generator

In a steam generator, sodium and water are separated by the heat transfer tube wall, which makes a strong pressure boundary between the shell-side sodium and tube-side water/steam. For this reason, if there is a small hole or crack, even with a pin hole, on heat transfer tubes, a large amount of water/steam would leak into the liquid sodium due to a high pressure difference of more than 150 bars [1], and an exothermic sodium-water chemical reaction takes place as a result. This type of sodium-water reaction (SWR) has been considered as one of the most important safety issues to be resolved.

From previous studies [2][3], it was obviously determined that the number of ruptured tubes during an SWR event is one of the most significant factors to determine the temperature and pressure transient. Any subsequent tube rupture behavior in the vicinity of the initially postulated single ruptured tube should be evaluated by considering the single- and multi-target wastage phenomena.

Wastage is defined as damage to the structural material (e.g., heat transfer tubes) due to an impingement of the highly corrosive reaction product. Since the impingement may cause wastage of the neighboring heat transfer tubes, a subsequent tube failure can occur in a very short time [4-5]. This is called “multi-target wastage.”

Therefore, it is very important to predict these phenomena quantitatively from the viewpoint of designing a steam generator and its leak detection systems.

In this study, to investigate the additional tube rupture behavior near the failed tube, multi-target wastage tests were carried out for the simulated target assembly made with a modified 9Cr-1Mo steel tube bundle.

2. Experimental

2.1 Experimental apparatus

The tube bundle wastage tests were conducted at KAERI using a second version of the sodium-water reaction test facility. A schematic diagram of this facility is shown in Figure 2.

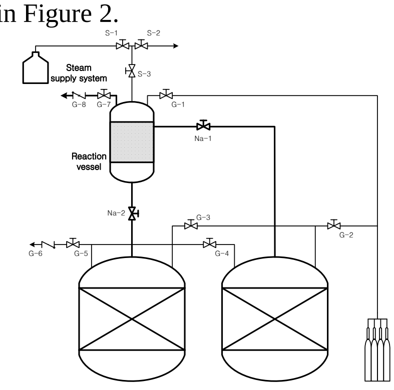

Figure 2 Experimental apparatus

The facility consists of a reaction vessel, sodium storage tank, sodium dump tank, and steam supply system. The reaction vessel is a 50-cm-diameter by a 100-cm-long stainless steel vessel. Steam was supplied into the reaction vessel at a pressure of 150kg/cm^2, which was achieved using a gas booster. The tube bundle assembly with a 5×5 layer was made out of a modified 9Cr-1Mo steel pipe. Figure 3 shows the reaction vessel installed with the tube bundle assembly.

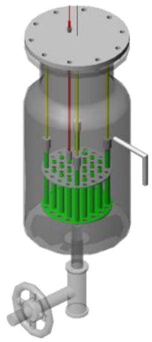

Figure 3 Reaction vessel and tube bundle assembly

3.2 Experimental conditions

Circular type defects were simulated in the tests, the diameters of which ranged from 0.8-1.0millimeters.

The target assembly directly simulates a real-scale tube size with a pitch-to-diameter ratio. It was immersed into stagnant sodium with an intermediate leakage rate of steam at 450℃. Steam was injected into the target tubes at a 150kg/cm^2 pressure and 350℃ temperature.

Figure 4 Model of tube bundle assembly

3. Results and Discussion

Experimental study on multi-target wastage and the consequential surface degradation effect was carried out for the reference steam generator tube bundle model. The test conditions are totally based on the prototype SFR design, and the postulated steam leak rate was set for the intermediate leak condition. Figure 4 shows the post-test views of the multi-target wastage test performed with a stagnant sodium condition. As compared with the small-leak test results, which only showed pit type wastage, it was found that there were various wastage patterns on the target surface with respect to the target distance between the nozzle and target tubes.

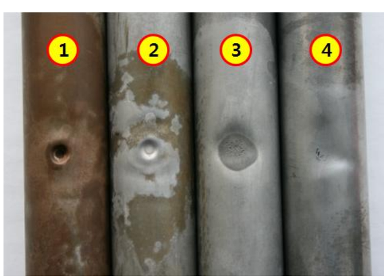

Figure 4 Wastage patterns of target tubes
(1, 2 longitudinal, 3 transverse, 4 diagonal)

Also, Figure 5 is a typical measurement instance for a post-test examination of target tubes. It was performed with an ATOS 3D Digitizer, which delivers three-dimensional measurement data for industrial components.

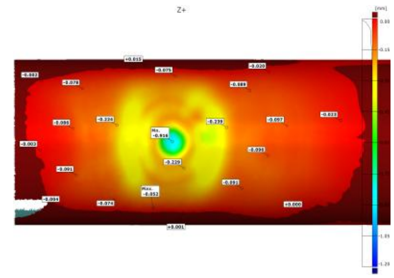

Figure 5 Instance of a poet-test examination

From the test results, the event propagation model (Figure 6) was preliminarily developed. It is expected that the model can predict the process of stepwise leak propagation (e.g., micro leak to large leak) during an SWR reasonably.

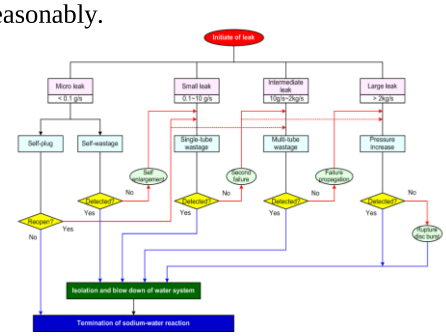

Figure 6 SWR event propagation model

4. Conclusions

A series of intermediate-scale wastage tests were conducted to investigate the multi-target wastage behavior of modified 9Cr-1Mo steel used as the SG tube material in a KALIMER-600. The obtained test data will be used to develop the design criteria of rupture propagation due to wastage. It is also expected that the results of this study will significantly contribute to a more detailed evaluation study of multiple tube rupture behavior in the future.

ACKNOWLEDGEMENT

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