Experimental Investigation of the Sodium-Water Reaction Phenomena in a LMR Steam Generator for a Small Water/Steam Leak

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1. Introduction

Sodium cooled fast reactors adopt sodium heated steam generators in a secondary sodium circuit to raise the steam to drive the turbine. In most cases these steam generators are of the shell-in tube type, with a high pressure water/steam inside the tubes and a low pressure sodium on the shell-side, with a single wall tube as a barrier between these fluids. So small leak sodium-water reaction events may occur when material faults such as pinhole or cracks occur in the heat transfer tube wall. And the small water leaks are very difficult to detect.[1, 2] When such a leak occurs, there results an important phenomenon, so called "wastage" which may cause damage to or a failure of the adjacent tubes. In general, wastage is defined as the decreasing thickness of the materials caused by the erosion or corrosion effects of the sodium-water reactions. Understanding of the wastage effects of a sodium-water reaction resulting from a small leak is one of the key issues for the system design. The goal of this work is to generate, reaction phenomena analysis data for an early detection and an establishment of the safety measures in a small leak sodium-water reaction event.

2. Theoretical considerations

2.1 Chemical Reaction

The representative reaction between the sodium and water/steam can be expressed by the following equation form, where A, B, C and D are the reaction constant and Q is an exothermic reaction energy produced by the reaction. Also the term α is a molar conversion ratio of the unit mole of the water/steam to hydrogen gas.[3]

$$A \cdot Na + H_2O \rightarrow B \cdot Na_2O + C \cdot NaOH + D \cdot NaH + \alpha H_2 + Q$$

As shown in the relation, the sodium reacts with the unit mole of the water/steam and then various reaction products, such as NaOH, NaH, Na_2O and hydrogen gas, are produced with an exothermic reaction heat. The NaOH and Na_2O are corrosive, the hydrogen gas causes the pressure on the sodium-side of the steam generator to increase and the heat causes the temperature of the heat transfer tubes in a steam generator to increase. It is well known that the importance of each of these effects is dependent on the size of the leak. The heat generated and the corrosive reaction products can damage the surrounding tubes, causing the event to escalate.

2.2 Definition of the leak size [4]

2.2.1 Micro leaks

Micro leaks are essentially leaks which are too small in magnitude to be detected. Typically, leaks of less than 0.1g/s (<0.05g/s in Japan) can be considered to fall into this category. After an incubation period, such a leak may develop into a small leak.

2.2.2 Small leaks

A small leak is one in which a coherent reaction jet of a size capable of impinging on one or two heat transfer tubes is formed, causing damage to them mainly by wastage. Small leaks are generally in the range of 0.1 to 50g/s (0.05 to 10g/s in Japan).

3. Experimental

3.1 Experimental apparatus

As shown in Figure 1, about a 1/10 scale-down mock-up test facility is being designed. It mainly consists of a reaction vessel, sodium circulation circuit, sodium and steam supply system, reaction product relief system, and a drain system etc. The entire loop including the reaction vessel and piping lines are fill with sodium, and the high pressure steam is inject into the reaction vessel. The reactor vessel (300mm in diameter, 2000mm high) contains ~110kg of sodium and a cover gas space above the free surface. For the leak detection, a hydrogen detector (in cover gas) and an acoustic detector (in sodium) will be used. The injection nozzle is sealed before the initial steam injection to protect it from a plugging by the sodium.

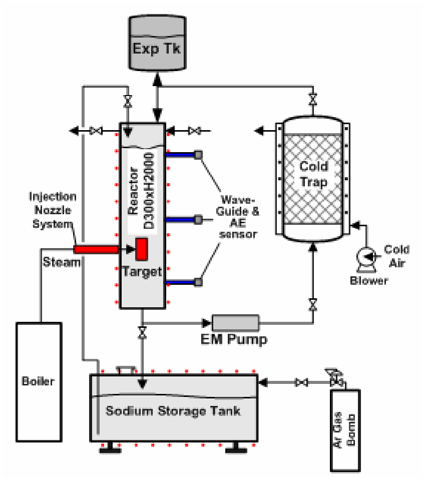

Figure 1. Schematic diagram of an experimental apparatus

3.2 Experimental conditions

The temperature of the sodium is 400℃; it was obtained by the initial temperature of a steam generator in KALIMER. Based on the previous works, the sodium level above the steam injection point is established variably. Because it was proven that the effect of the sodium level on the wastage is negligible so long as the target tube is submerged in the sodium. The 2.25Cr-1Mo steel was chosen for the target material, because this material was specified for the heat transfer tubes in KALIMER. Nozzle-to-target distance (L) to nozzle diameter (D) ratios (L/D) from 15 to 100 was selected for the test. The steam pressure and temperature will be chosen to produce steam injection rates for the selected nozzle diameter

The experimental conditions are summarized in Table 1.

Table 1. Experimental conditions

Cover gas	Argon
Pressure	0.11 *MPa* (initial)
Temperature	Room (initial)
Circulating Fluid	Sodium
Temperature	400 ^{o}C (variable)
Flow rate	suspense
Injection Fluid	Compressed steam/water
Temperature	300 ^{o}C (variable)
Flow rate	~ 0.1 g/*sec*
Pressure	2 *MPa*
Position in bundle	Between Top and Bottom

3.3 Work scope

The items to be established through this study are as follows.

- L/D for the maximum wastage rate
- Width of the wastage
- Relation between the wastage rate and injection rate
- Temperature distribution around the sodium-water reaction zone
- Frequency band of the sound for a small leak sodium-water reaction

3. Conclusions

A 1/10 scale-down mock-up test facility is being designed to investigate the phenomena during a small leak sodium-water reaction. And we have started the theoretical studies related to the safety problems caused by the sodium-water reaction event. In the near future, lots of information for the small leak sodium-water reaction phenomena will be obtained. The data obtained from this study will be used widely for the leak detection and protection system design of the KALIMER steam generator.

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REFERENCES

[1] Riqiang DUAN, et al., "Numerical Simulation of Sodium-Water Reaction Products Transport in Steam Generator of Liquid Metal Fast Breeder Reactor on Small Water/Steam Leak", *J.* of Nucl. Sci. and Technol., Vol. 38(7), 527-532 (2001)

[2] NAOMICHI KANEGAE, et al., "The Effects of Nozzle-to Target Distance on Wastage in Small-leak Sodium-Water Reactions", Nucl. Technol., Vol. 40, 261-277 (1978)

[3] M. Hori, "Sodium-Water Reactions in Steam Generators of Liquid Metal Fast Breeder Reactors", Atomic Energy Review, Vol. 18(3), 707-778 (1980)

[4] A. M. Judd, et al., "The Under-Sodium Leak in the PFR Superheater 2, February 1987", Nucl. Energy, Vol. 31(3), 221-230 (1992)