JAPANESE POSITION PAPER ON SODIUM-WATER REACTION TESTING AND DESIGN

M. SATO, H. HIROI, H. TANABE, O. MIYAKE, M. KUROHA
Oarai Engineering Center,
Power Reactor & Nuclear Fuel Development Corp.,
Oarai-machi, Higashi, Ibaraki-ken

T. TAKAHASHI, Y. OHMORI
Power Reactor & Nuclear Fuel Development Corp.,
Tokyo

Y. HOSHI
FBR Engineering Co., Ltd,

Japan

1.0 INTRODUCTION

PNC has been developing the steam generator with helically coiled heat transfer tube bundle and downcommer tubes for the prototype fast reactor Monju since 1968. To establish the safety design against the sodiumwater reaction accident was one of the most important R&D items at the start of the development.

PNC started the experimental study initially in the large leak region in 1970. Untill now, during twelve years, the experimental studies have been performed, which covers the phenomena from a micro leak to a large one, with the use of the SWAT-1 rig, SWAT-2 loop, SWAT-3 loop, and SWAT-4 rigs.

The reliable leak detection system is necessary to minimize the damage by the sodium-water reaction. Two groups of efforts have been paid for developing the detection system. One is to develop the leak detector itself, and another is to grasp the hydrogen transport behavior in the sodium in the steam generator and the secondary piping system. Four sodium loops have been used for the development.

The development of computer codes has also progressed in parallel with the sodium-water reaction experiments. Three codes have been accomplished for the design tools against the sodium-water reaction.

Through the efforts mentioned above, sufficient experiences were obtained for designing and operating the Monju steam generator system.

2.0 LARGE LEAK TESTS

PNC performed the large leak sodium-water reaction tests using SWAT-1 and SWAT-3. They are briefly reviewed as follow:

2.1 First Stage

SWAT-1 was constructed in 1970. The rig consists of a reaction vessel of 400 mm in diameter which contains about 150 kg of sodium, a pressure relief system, and a water injection system. The reaction vessel, which simulates the failed steam generator, is a 1/8 scaled model of Monju. About forty tests in total, with the leak rate up to 3 kg/sec, were carried out to obtain the large leak data for the computer code development. The major works of the large leak study were transfered to SWAT-3. Then, SWAT-1 was used for the tests of the special purposes: ex. the test on the thermal and stress transients of the pressure relief system in which the piping was not preheated before the pressure release, the measurement of the transient water flowrate immediately after the opening of the large leak hole, and the multiple wastage tests.

2.2 Second Stage

SWAT-3 was constructed in 1975 to demonstrate the safety design of the Monju steam generator against the large leak accident.

Objectives of the large leak tests were:

(1) To obtain the data of large leak phenomena including pressure, flow, temperature etc.

(2) To obtain the data of secondary tube failure due to the large leak s odiumwater reaction.

(3) To obtain the experience of the decontamination of reaction products after the sodium-water reaction.

In each of the SWAT-3 tests, a double-ended guillotine rupture of the actual size heat transfer tube was simulated in a 1/2.5 scaled test vessel to the Monju evaporator. The sodium system consists of an evaporator model (reaction vessel), a superheater model, an intermediate heat exchanger model, the piping circuit simulating secondary cooling system, the pressure relief system, and the cold trapping system. The inventory of the sodium is about 7 tons. Seven tests in total were carried out for obtaining the large leak data with a water leak range of 5 to 18 kg/sec.

Following the completion of the large leak tests, SWAT-3 was directed to the leak propagation study. The water injection system was modified to demonstrate the progression of leak propagation under the actual operating condition.

3. LEAK DEVELOPMENT TESTS

Plenty of investigation has been performed on the sodium-water reaction phenomena from a micro leak to a large one to select a DBL for the Monju steam generator.

3.1 Micro and Small Leak Tests

The experimental work focused on the self-enlargement and the self-plug of the micro defect of the heat transfer tube. Preliminary tests were started with SWAT-2. The studies on the micro leaks, moreover, have been performed with SWAT-4 since 1981 and thirty experiments have been conducted with test pieces of 2-1/4Cr-1Mo steel and stainless steel so far. SWAT-4 consists of three reaction vessels, which enable three parallel test operations.

About one hundred and fifty tests in total were carried out in SWAT-2 to accumulate the small leak wastage data ($\sim$ 10g/sec) of 2-1/4Cr-1Mo steel and stainless steel and empirical formulas concerning such as wastage rate were determined.

3.2 Intermediate and Large Leak Tests

The SWAT-1 failure propagation tests have been carried out in an intermediate leak region. A tube bundle that contained about thirty tubes was suspended in the reaction vessel. The material of the tubes was 2-1/4Cr-1Mo steel, the same as in the design of the Monju evaporator. Though the tubes of the Monju design are helically coiled, straight tubes were used in the tests to provide advantages for the wastage measurement. Nitrogen gas was applied to the inside of several main target tubes so as to simulate the tube bursting. Other tubes had both ends open.

More than fifty thermocouples were distributed around the tubes for the measurement of the reaction temperature. After each test the internals were pulled out from the test vessel and were disassembled to tubes. The state of the wastage was recorded by an automatic measuring and plotting system and metallurgical examinations were also conducted.

In the seven large tests no failure propagation occurred and damage to adjacent tubes was slight.

3.3 Sequential Propagation Tests

On a basis of the above-mentioned test data, near prototypical and sequential failure propagation tests proved to be necessary. Thus, the failure propagation test program was planned and performed using SWAT-3.

In the SWAT-3 failure propagation tests, tube specifications such as the size, the material, and the arramgement were chosen so as to provide a much more explict simulation of the Monju design. In the initial conditions, main target tubes were filled with water or nitrogen gas pressurized up to about 150 ata (15 MPa). Ten tests have been conducted so far by changing the conditions such as the initial leak rate, the direction of the leak jet, and the phase of water. From the test results it was concluded that a dominant mechanism was tube wastage, and it took more than one minute until each failure propagation occurred. Also, the total leak rate in full sequence simulation tests including a water dump was far less than that of one double-ended-guillotine (DEG) failure.

Using such experimental data, a computer code, LEAP (Leak Enlargement and Propagation), has been developed for the purpose of estimating the possible maximum leak rate due to failure propagation.

4.0 LEAK DETECTOR DEVELOPMENT

4.1 In-sodium Hydrogen meter

The PNC type in-sodium hydrogen meter was developed for applicating to Monju in 1976. The short term tests using SWAT-2 showed satisfactory performance on the sensitivity, the response time, and the range of concentration measurement. Next, the dynamic and static chambers were separated from each other in the vacuum system, so that it became possible to calibrate the meter with more accuracy and shorter time. The five meters had been tested using four sodium loops at PNC/OEC for evaluating the long-term performance from 1977 to 1980, and the test results showed the good durability of the meter. Prospect of preventing the signal drift and prolong the operating time of the ion pump was also obtained by reducing the surface area of the nickel membrane and installing an orifice in the vacuum line. This meter is specified for Monju as the small leak detector.

4.2 In-Cover Gas Hydrogen Meter

The two types of in-cover gas hydrogen meters, with forced and natural gas-circulation, have been developed because they are effective to detect a water leak in a downcomer portion, a cover gas space, and an upper portion of heat trasfer tubes in the Monju steam generator. These meters are based on the in-sodium hydrogen meter. The both types showed the good performance in the short time test. Accumulation of data on the durability is needed in future.

4.3 In-sodium Oxygen Meter

Electrochemical in-sodium oxygen meters, six westinghouse and eight GE/Toshiba types, had been investigated on performance and durability in order to ascertain a usefulness for the leak detector at PNC/OEC. It was found from the test results that the differences among the characteristics of each meter were large, so more durability is required for the application to Monju.

4.4 Acoustic Meter

The basic characteristics on the sodium-water reaction sound and the sound propagation in a vessel have been obtained for studying a usefulness of the acoustic leak detectors using SWAT-2 and a simulated steam generator model. The preliminary test results show that it is easy to measure accelerations on the wave-guide rods on the vessel, however, is by no means inferior to other methods. An acoustic background of the evaporator in the 50 MW steam generator test facility (50MWSGTF) was also measured using the same accelerometers and wave-guide rods. Considering the S/N ratio based on these acoustic background data, the current acoustic detectors of PNC may be applicable to the detection of an intermeadiate leak.

4.5 Hydrogen Behavior Tests

Another effects for developing the leak detection system was paid to know how the hydrogen behaves in the troubled steam generator and the secondary cooling system. For this objective, the hydrogen/water injection tests are being carried out using SWAT-2 and 50MWSGTF. The purpose of the SWAT-2 test is to obtain the fundamental data and the one of 50MWSGTF is to demonstrate the capability of the leak detection system using near actual sized facility. Untill now, the data have been accumulated for about seven years, used for the plant design and the validation of the SWAC-10 code.

5. COMPUTER CODE DEVELOPMENT

The computer code is required to extrapolate the results of R&D to the practical plant conditions. PNC has developed three computer codes for the sodium-water reaction, which are being used to design the Monju steam generator system.

5.1 SWACS Code (for large leak accident)

The SWACS code was developed to predict the pressure and flow behaviors during large leak sodium-water reaction.

SWACS consists of the following three calculating modules and a main control routine:

(1) Calculate the water Leak rate.

(2) Calculate the initial pressure spike and its propagation through the components and piping of the secondary cooling circuit.

(3) Calculate the quasi-steady pressure buildup and the release to the pressure relief system.

Five test data obtained by SWAT-3 were compared with code results. The analytical results indicated that the overall large leak event could be predicted in reasonable good agreement.

5.2 LEAP Code (for leak propagation phenomena)

If the water leak would occur from the heat transfer tube, steam generator plant detects it, isolates and blows the water from the failed one, and then the sodium-water reaction terminates. During these periods, the leak propagation may occur, and water leak rate increases to the maximum value and then decreases to zero. It is important for the plant designer to estimate the leak propagation sequence in the actual steam generator system during the sodium-water reaction. PNC is developing the computer code LEAP for satisfying this objective.

A deterministic procedure is adopted for the modeling of leak propagation phenomena in the code. Gathering the experimental data obtained by the SWAT rigs and the world wide data published, the leak propagation can be calculated under the various conditions in the evaporator. On the other hand, the code has the modules for the estimation of the leak detection time under various leak conditions. The code includes the modules of the judgment to act the emergency operation and the estimation of the time history of water side condition under the emergency condition. As the results, the LEAP code can estimate the sequence of the leak propagation during the sodium-water reaction.

Comparing the results of calculations and the experimental data obtained with SWAT-3, it is found that the calculation shows somewhat conservative results than those in the experiments, which means the code is endurable for practical use.

5.3 SWAC-10 code (for estimation of hydrogen detection time)

It is required for the plant designers and operators to estimate the hydrogen detection time of the leak detectors, which are installed at five points in the secondary cooling system against various leak rates, leak sites, and operating conditions. The computer code SWAC-10 was developed to simulate the hydrogen transport and the leak detection in the secondary cooling system including the steam generator.

The code has the following functions:

(1) Calculate the hydrogen background in the secondary system considering the purification performance.

(2) Calculate the dynamics of hydrogen bubble generated by the sodium-water reaction and the solubility of hydrogen into the sodium.

(3) Calculate the hydrogen transportation through the steam generator and the secondary piping system.

(4) Estimate the time at which the secondary failure occurs in the initial micro and small leak region.

Combining these functions, SWAC-10 can evaluate the width of the leak rate range in which the detector can find the leak before the occurrence of the leak propagation. This code was verified by the data obtained by the leak simulation experiments using SWAT-2 and 50MWSGTF.

6.0 MONJU DBL DESIGN

Despite the strenuous efforts improving the reliability of steam generators, it is required to select Desigen Basis Leak and to ascertain the safe shutdown at the leak.

6.1 DBL Selection

The analyses of the failure propagation phenomenon were carried out using the LEAP code to justify DBL selection for Monju. The parameters were selected for the severest case for the plant. The results showed that the largest values of the maximum leak rate were equivalent to about two DEG's in the small and intermediate leak region in spite of a little fluctuation. Therefore, the leak rate equivalent to one-instantaneous-DEG plus three-DEG's due to propagation was selected as DBL for Monju.

6.2 Structual Integrity for DBL

Steam generator and intermediate system components have to be checked against pressure wave from sodium water reaction. The SWACS code was used to calculate the pressure transients to evaluate the structural integrity. The results showed that for all the components in the intermediate system, strains due to pressure waves (spike and quasi-steady) are in the elastic range.

Temperature and pressure changes with fast steam blowdown were calculated using the BLOOPH code. Thermal transients are peculiar to evaporator inlet tubesheet. The tubesheet was checked against this transient and the stress and strain were well below the allowables.