DISMANTLING OF THE 50MW STEAM GENERATOR TEST FACILITY

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Abstract

We have been dismantling the 50MW Steam Generator Test Facility (50MWSGTF). The objectives of the dismantling are reuse of sodium components to a planned large scale thermal hydraulics sodium test facility and the material examination of component that have been operated for long time in sodium. The facility consisted of primary sodium loop with sodium heater by gas burner as heat source instead of reactor, secondary sodium loop with auxiliary cooling system (ACS) and water/steam system with steam temperature and pressure reducer instead of turbine. It simulated the 1 loop of the Monju cooling system. The rated power of the facility was 50MWt and it was about 1/5 of the Monju power plant. Several sodium removal methods are applied. As for the components to be dismantled such as piping, intermediate heat exchanger (IHX), air cooled heat exchangers (AC), sodium is removed by steam with nitrogen gas in the air or sodium is burned in the air. As for steam generators which material tests are planned, sodium is removed by steam injection with nitrogen gas to the steam generator. The steam generator vessel is filled with nitrogen and no air in the steam generator during sodium removal. As for sodium pumps, pump internal structure is pulled out from the casing and installed into the tank. After the installation, sodium is removed by the same method of steam generator. As for relatively small reuse components such as sodium valves, electromagnet flow meters (EMFs) etc., sodium is removed by alcohol process.

1. INTRODUCTION

The 50MWSGTF [1] that was constructed to evaluate the performance of Japanese first prototype FBR power plant Monju steam generator (SG) and secondary cooling system including reactor auxiliary cooling system (ACS) have been dismantling.

Several sodium removal methods such as steam injection in the air or in the nitrogen gas, sodium burning and alcohol circulation processes are applied. This report presents the status of dismantling the facility along with a description of the cleaning process.

2. CLEANING PROCESS

The various methods for sodium removal have been used and are available for large components cleaning [2]. Each method has some advantages and disadvantages. Table 1 summarizes the characteristics of three methods for sodium removal, the first is alcohol cleaning method, the second is steam with inert gas injection and the third is sodium burning. The second method is used both in the air and inert gas.

2.1 Alcohol process

The alcohol cleaning method is used for sodium removal for relatively small components. We can remove sodium easily and safely for short time without caring the damage to the material of components. The reaction rate with sodium is controlled by the alcohol temperature. Although this method is applicable to sodium removal of all components, the construction cost of the removal system and the alcohol price are relatively high compared to other methods. Also, it is noted that alcohol itself is flammable. This cleaning system is placed at the sodium processing facility (SPF).

TABLE 1 SODIUM REMOVAL METHODS

Meth-ods	Advantages	Disadvantages	Application
Alcohol	1. can remove sodium besides in the narrow crevice. 2. no alkali corrosion 3. controllable 4. short removal time	1. Alcohol is flammable 2. Possibility of hydrogen explosion 3. Relatively high cost	Reuse components and material tests
Steam /water	1. can remove sodium besides in the crevice. 2. easy to dispose water 3. relatively low cost	1. Possibility of alkali attack 2. Possibility of hydrogen explosion 3. Long time operation	Reuse components
Burning	no hydrogen generation	1. Cannot use to large components 2. Cannot use for the material test	Small scale components and solid sodium block

2.2 Aqueous process

We have the two kinds of aqueous method, the one is steam injection with inert gas in the air and the another is steam injection in the close system filled with inert gas.

As for the disposal components that would not be examined after cleaning, steam is injected to the components while dismantling at the SPF. This method requires personnel's who have enough experience and technique of the sodium removal. Components that surface is covered by sodium should be carefully dismantled to avoid any unexpected sodium fire or hydrogen evolution. When we have to avoid any damage to the material, it is difficult to use this process.

As for the components that post test material examinations or reuse of the components are planned, steam is injected with inert gas to the component shell or a tank that contains the cleaning objects and filled with inert gas to prevent oxidation or stress clack corrosion. The reaction rate can be controlled by the steam and inert gas flow rate and the temperature of the objects. Both steam injection methods are available at the SPF.

2.3 Sodium burning

Sodium burning method is used for disposal components having large amounts of residual sodium. Sodium is removed from the components physically or sodium is left as resided and placed in the burning room that have an air ventilation and aerosol filter. Several kg of sodium can be burned at the SPF. This method can be applied only small parts of the large components or small components.

2.4 Sodium processing facility

Above mentioned sodium removal methods are available at the SPF. The alcohol cleaning system [3] that consists of an alcohol tank that placed underground, a circulating pump, pipes and valves, heat exchanger with water cooler for alcohol temperature control, a vacuum pump and hydrogen release system. A hydrogen and oxygen meter are installed in the gas release system. The alcohol cleaning system has flammable gas meters to detect leakage of alcohol. The alcohol volume in the tank is 3 m^3 and flow rate is 12 m^3/h.

The steam injection equipment in the air is available. Maximum flow rate of steam and nitrogen is 40 and 80 m^3/h respectively. The sodium burning room is covered by steel plate and has gas burners, water shower and nitrogen supply. Sodium contained water is drained to a water tank and neutralized by adding hydro-chloric acid. The volume of the water tank is about 30 m^3.

3. DESCRIPTION OF THE 50MWSGTF

3.1 50MWSGTF system

Figure 1 shows the main system of the 50MWSGTF. The facility consisted of primary sodium loop with sodium heaters by gas burning as heat source instead of reactor, secondary sodium loop with ACS and water/steam system with steam temperature and pressure reducer instead of turbine, it simulated the 1 loop of the Monju cooling system besides a reactor and turbine. The rated power of the facility was 50MWt and about 1/5 of the Monju. The objective of the 50MWSGTF was to evaluate the performance of Monju steam generator and secondary cooling system. The facility has been operated for over 40000 hours.

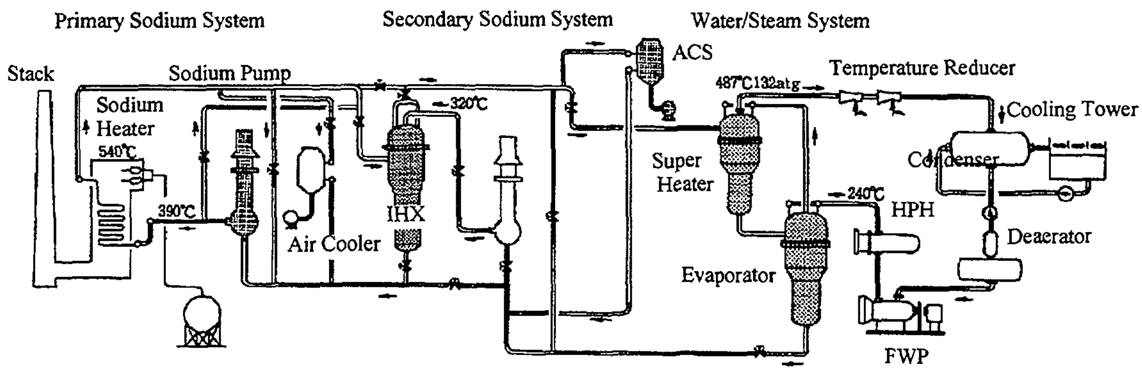

Figure 1 Schematic Diagram of 50MWSGTF

3.2 Steam generator

The steam generator is a helical coil type unit consisting of two parts, an evaporator and a superheater. Both of which have a diameter of about 2 m and respective height of about 12 and 8 m. Figure 2 shows the evaporator schematic. The material is ferritic steel (2 1/4 Cr - 1 Mo steel) for the evaporator and austenitic stainless steel (SUS321) for the superheater. Each component has 33 helical coiled heat transfer tubes with downcommer section.

Sodium flows into the SG through sodium inlet nozzle located at the top of the SG and sodium is distributed at ring header. Then sodium goes down in the inner shroud exchanging heat with water/steam and flows out through exit nozzle located at the bottom of the SG. Water flows inner side of tubes. Upper internal of the SG was covered by argon gas. An examination of the SG geometry indicated that no sodium block could be resided in the SG.

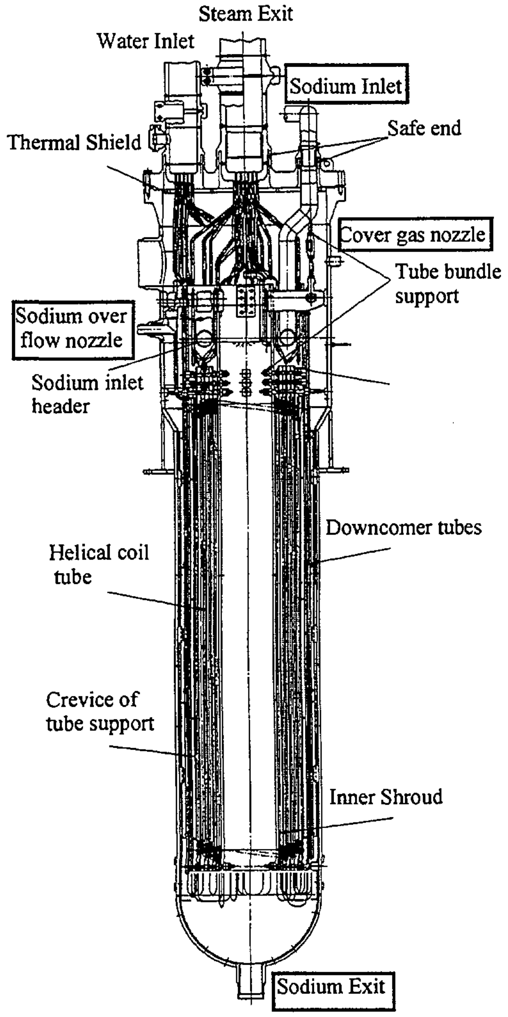

Figure 2 Structure of #2 50MW Steam Generator

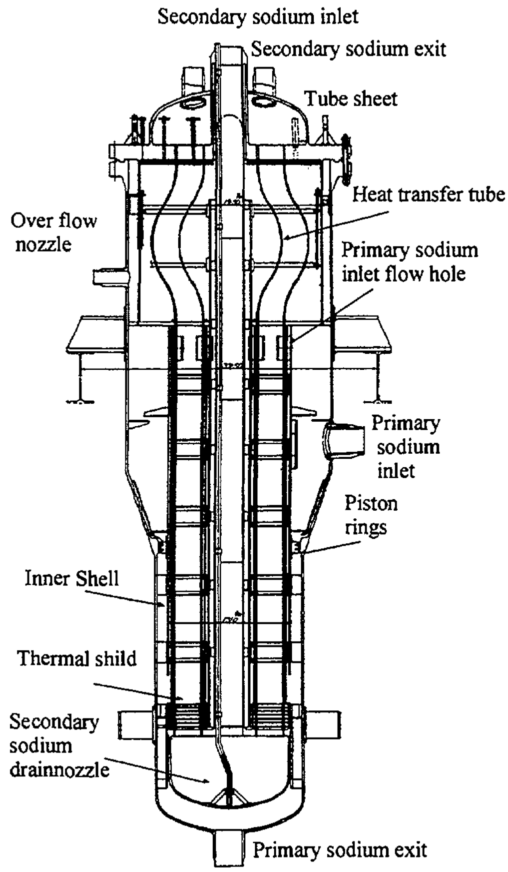

Figure 3 50MW IHX Structure

3.3 Intermediate heat exchanger

Figure 3 shows the IHX schematic. The IHX has about 2000 straight heat transfer tubes. The diameter is about 2.5 m, height is about 8.2 m and major material is austenitic stainless steel (SUS304). Primary sodium flows the shell side and secondary sodium flows inside tubes. A large amount of sodium could be resided at the bottom of the secondary downcommer that could not be drained and at the piston rings that separate inlet and exit primary sodium and have small flow holes.

3.4 Other major components

Other major sodium components are air cooled heat exchangers (AC), mechanical sodium pumps, sodium heater by gas burning, electro-magnetic pumps, sodium purification system, sodium valves, mixing tees. There were two air cooled heat exchangers, the one had 12 MWt and the other had 3 MWt heat removal rate. Both ACs had finned heat transfer tubes connected to inlet and exit sodium headers. Two mechanical sodium pumps were used for circulating sodium in primary and secondary loop. The rated flow rate is about 20 m^3/h, and the pump height is about 2.5 m. The diameter of main piping was 0.3 m.

4. CLEANING AND DISMANTLING PROCESS

4.1 Process

The 50MWSGTF components were classified into 3 category. The first one is the components that will be reused for the planned large scale thermal hydraulics test facility. Sodium pumps, valves and purification system fell into this category. The second one is the component that material examination is planned. The SG fell into this category. The rest of the components such as IHX, ACs and piping were disposed without any material examinations.

As mentioned previous section, three sodium cleaning processes are practically available. The alcohol process is used for sodium removal of small to medium size reuse components such as sodium valves, EMFs. This process is conducted at the SPF. The steam cleaning method in inert gas is used for sodium removal of mechanical pumps and the SG. Sodium removal oh the SG was performed in place at the 50MWSGTF. Following sodium removal, the dismantling of the evaporator is underway and the material examination of heat transfer tubes and tube sheet, etc., will be conducted. Sodium removal of pumps will be performed at the SPF. Sodium removal of other components is carried out by steam injection in the air or sodium burning at the SPF while dismantling components. Sodium removal of the ACs, piping mixing tees have already been conducted and sodium removal and dismantling of the IHX is underway.

4.1 Piping

At first, sodium piping including valves, mixing tees was removed from the 50MWSGTF. Sodium pipes were cut to 2 to 3 m at the facility and moved to the SPF for

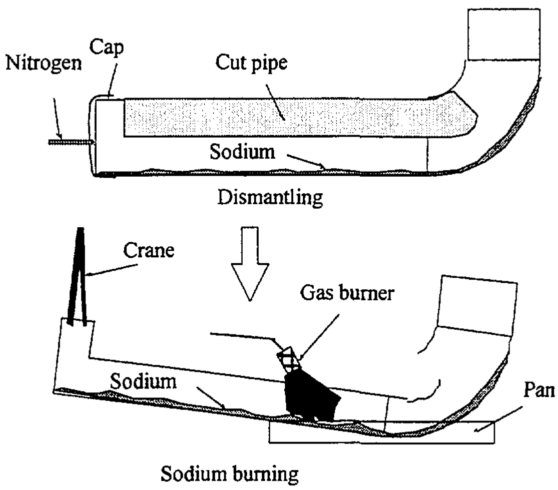

Figure 4 Sodium removal process of piping

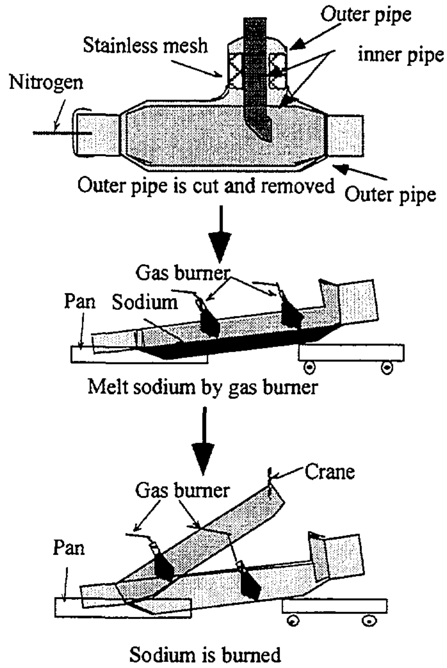

Figure 5 Shape and dismantling process of mixing tee

sodium removal by steam injection in the air. During dismantling the pipes, when large amount of sodium was resided in pipes, upper side of the pipe was cut with nitrogen gas blow to avoid sodium burning during dismantling and sodium was burned in the burning room. Figure 4 shows the process.

Dismantling the mixing tees was rather complicated compared to piping. The mixing tee had double hull to mitigate temperature fluctuation on the outer pipe that foam sodium boundary to the air. Figure 5 shows the geometry and dismantling process of the mixing tees. Large amount of sodium was resided at the bottom of the mixing tees. Upper part of the mixing tee (T-junction section) was cut away with nitrogen gas blow and upper parts of the outer and inner pipe were cut away. After removal of upper structure, sodium was melted by heating of gas burner, then inner pipe was removed. Finally all sodium was burned on the outer pipe and pan. The pipe and mixing tee during dismantling are shown in Photograph 1 and 2.

Dismantling the air coolers was rather easy. Heat transfer tubes were cut at both inlet and exit headers and sodium of each tubes and headers were removed by steam injection in the air. Sodium was only resided inner surface of the tubes and headers as thick film.

4.2 IHX

Dismantling the IHX is underway. That will be conducted at the SPF. The internal structure will be drawn out at the 50MWSGTF and moved to the SPF. The IHX was filled with carbon-dioxide and most of sodium or sodium-oxide could be changed to sodium-carbon-trioxide that is easily handled. The IHX internal will be drawn out by the crane in the vinyl cask that is filled with nitrogen gas to prevent accidental sodium fire. Then the IHX internal moves to the SPF where the IHX is dismantled and sodium is removed in the air.

At first, sodium of the outer surface will be removed by steam injection and then steam injection holes will be opened and inner side of the IHX inner shroud (primary sodium side) is cleaned by steam injection through the steam injection holes. After sodium removal of the primary side, upper and lower section will be cut away. Then steam will be injected inside the heat transfer tubes.

The expected residual sodium of primary and secondary side is about 60 and 46 kg respectively. After completing the dismantling and sodium removal of the IHX internal, the IHX outer shell will be moved to the SPF from the 50MWSGTF to dismantle and remove sodium. The estimated operation day is about 40 days.

5. SG SODIUM REMOVAL

5.1 Cleaning system

Steam injection in nitrogen gas atmosphere was selected because of the large inventory of SG sodium side and a planned material examination. Sodium removal of the SG was performed in place at the 50MWSGTF. Sodium inlet pipe, exit pipe, cover gas nozzle and sodium over flow nozzle (evaporator) were connected to steam supply unit. Nozzles on the upper plates were connected to the steam, nitrogen and hydrogen release system.

Figure 6 shows the P & I drawing of the sodium removal system. The sodium removal system consists of 3 units. The one is boiler unit that generates saturated steam and supplies it to the steam supply unit. The rated steam generating ratio is 60 kg/h and pressure is 0.3 MPa (g).

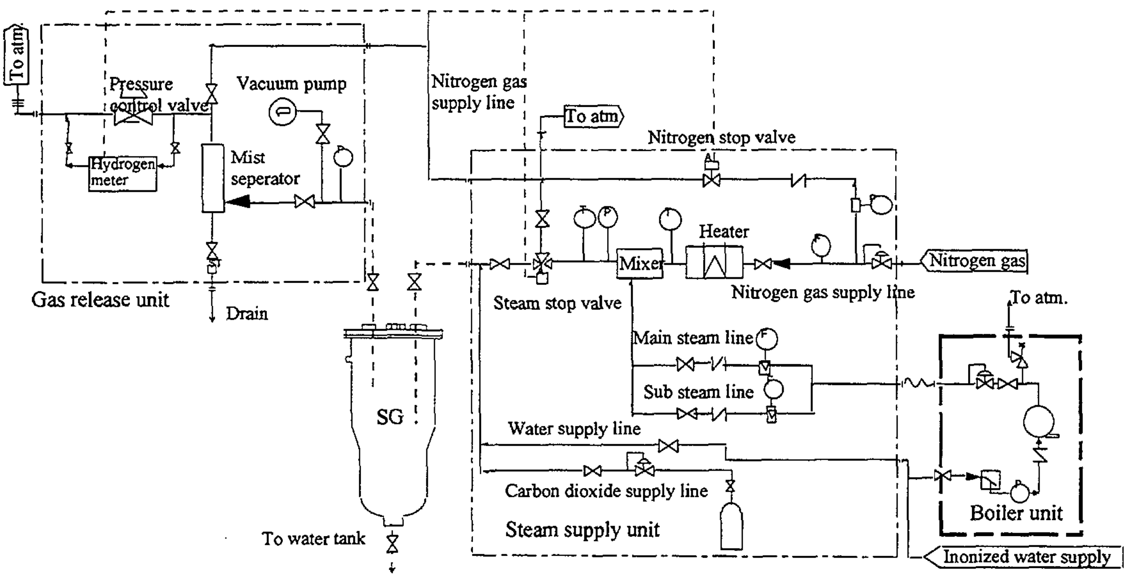

Figure 6 P & I drawing of the SG cleaning system

The second unit is the steam supply system that consists of nitrogen gas line with heater and mixer of nitrogen and steam, water line, carbon dioxide gas line. Emergency steam stop valve and nitrogen supply valve to the release system are in this unit to stop the sodium water reaction and to dilute hydrogen at abnormal burst sodium and steam reaction. The rated nitrogen gas flow rate is 60 Nm^3/h and highest temperature is 140 deg-c. This unit provides mixing gas of steam and nitrogen to the SG in 1st step of sodium removal, provides water to the SG in 2nd step and carbon dioxide for stabilizing the residual sodium-hydroxide.

The third unit is gas release system that consists of a mist separator, a pressure control valve, a vacuum pump and a flame arrestor. Hydrogen evolved in the SG was introduced to this unit with nitrogen gas and released to the air with monitoring and controlling hydrogen concentration in nitrogen gas. A majority of connecting pipe and horse is 50 mm diameter. Steam and nitrogen gas flow rate, pressure and temperature, hydrogen concentration in nitrogen gas, moisture in nitrogen gas, pressure in the SG and SG internal temperatures were measured and controlled. Ionized water, nitrogen gas, compressed air and water neutralization tank were available.

5.2 Cleaning procedure

A review of the SG geometry and results of the sodium piping dismantling indicated that average sodium film thickness could be expected about 5 mg/cm^2 where sodium draining temperature was 200 deg-c, it was estimated that total amount of residual sodium was about 24 kg and 20 kg for the evaporator and super-heater respectively. It was expected that a majority of sodium was film remaining on the surfaces and very little sodium remaining in the crevices of tube and tube-support.

The initial steps of sodium removal were to vacuum the SG and to fill the SG with nitrogen gas. Nitrogen gas started flowing to the SG with 20 Nm^3/h, and kept almost constant flow rate, then steam with nitrogen gas flow was initiated to the SG through sodium exit nozzle where located the bottom of the SG. Initial steam flow rate was about 0.3 kg/h not to exceed the hydrogen concentration of 1 % in nitrogen gas.

Hydrogen evolution is assumed to be governed by following direct reaction of sodium with water [2]

$$Na + H_2O \rightarrow NaOH + 1/2H_2 \text{ (gas)} \qquad (1)$$

Other reactions shown below are minor source of hydrogen evolution.

$$Na + NaOH \rightarrow Na_2O + 1/2H_2 \qquad (2)$$
$$Na_2O + H_2O \rightarrow 2NaOH \qquad (3)$$
$$Na + 1/2H_2 \rightarrow NaH \qquad (4)$$
$$NaH + NaOH \rightarrow Na_2O + H_2 \qquad (5)$$

where nitrogen flow rate is 20 Nm^3/H
Then steam flow rate is about 0.6 kg/h for hydrogen concentration of 1 % in nitrogen gas.

After hydrogen concentration reaching plateau or decreasing, steam flow rate was increased. When steam flow rate reached 20 kg/h and no hydrogen concentration increase was observed, the steam flow rate reduced to 0.3 kg/h and steam was flowed through sodium over flow nozzle, cover gas nozzle and sodium inlet pipe. Then again steam flow rate increased to 60 kg/h according to hydrogen concentration. During the steam injection, water samples were taken periodically when condensed water drained.

5.3 Results

5.3.1 Steam injection

Initial 2 days, no water was drained, because steam weight in nitrogen gas was smaller than saturated moisture weight. Figure 7 shows the hydrogen concentration change with steam flow rate. For 5 days after initiation of steam injection, increasing steam flow rate increased the hydrogen concentration then hydrogen concentration decreased almost 0 %. When steam was injected through all nozzles and steam flow increased, hydrogen concentration increased again according to steam flow rate.

Figure 8 shows the SG internal temperature. The SG was heated by steam and the internal temperature was decided by heat addition from steam and heat loss from the SG surface. The SG internal temperature was kept below 70 deg-c to avoid cold stress clack corrosion.

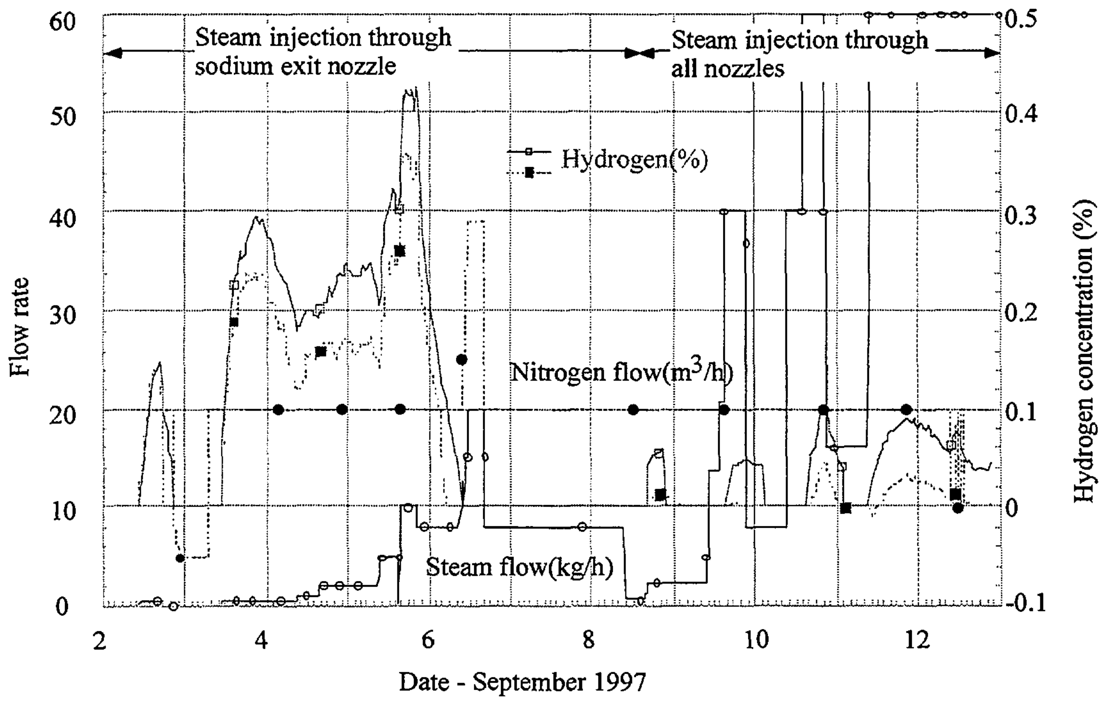

Figure 7 Hydrogen concentration history

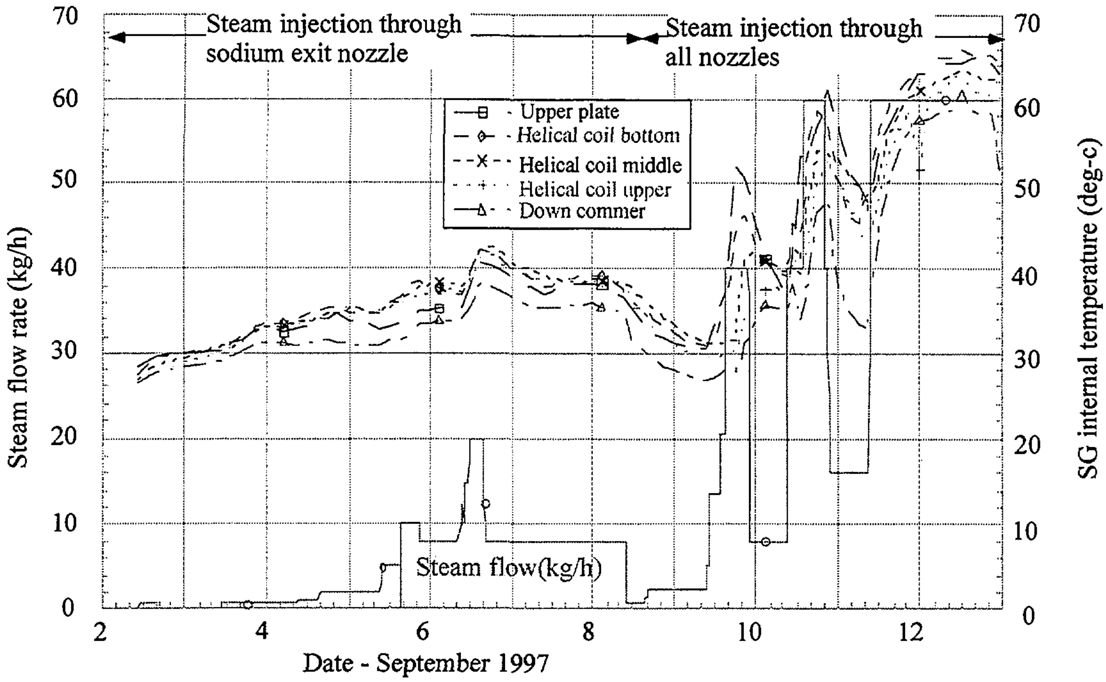

Figure 8 SG temperature during steam injection

After 12 days of steam injection, hydrogen concentration in nitrogen decreased and sodium concentration in the drained water was lower than 1000 ppm, it was decided to stop steam injection and move to next step of water filling. Figure 9 shows the sodium concentration in the drained water measured by neutralization and Figure 10 shows the accumulated sodium removal weight that was calculated from the hydrogen concentration in nitrogen gas.

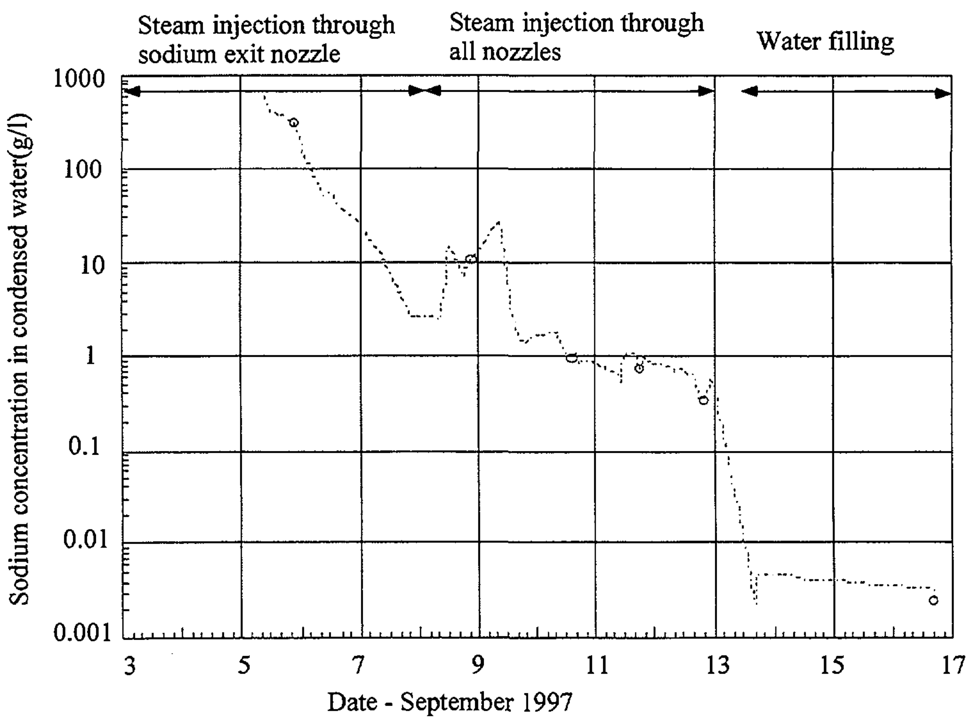

Figure 9 Sodium concentration in condensed water

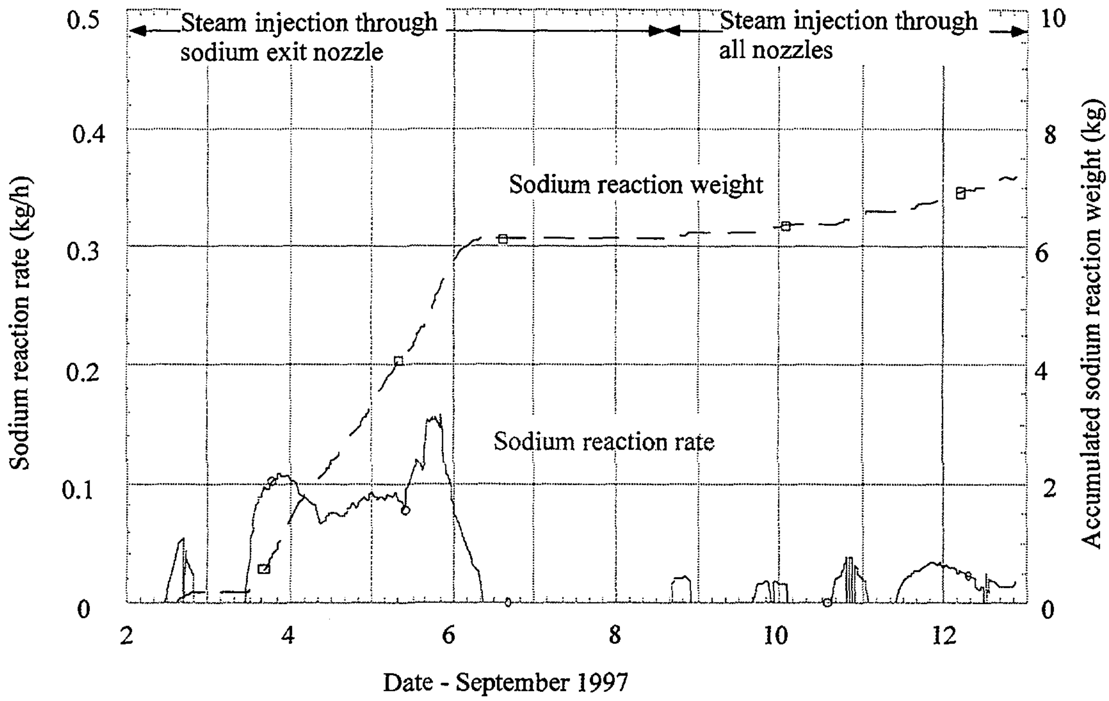

Figure 10 Sodium reaction rate

Sodium removal weight $= FN_2 * H_2/100 * rH_2 * 23$ (kg/h)   (6)

Where

FN_2: Nitrogen flow rate (m^3/h)

H_2: Hydrogen concentration in nitrogen gas (%)

rH_2: hydrogen specific weight (kg/m^3)

23: Hydrogen to sodium weight conversion coefficient (-)

By integrating above equation, the estimated reacted sodium weight was about 8.4 kg. Total removed sodium calculated by the neutralization at the drain water tank was about 23 kg that was almost same as expected. The differences of these values could be mainly caused by accuracy of hydrogen concentration in nitrogen gas.

5.2.2 Water filling

After stopping steam injection to the SG, the SG was filled with nitrogen gas again. Then ionized water was filled for about 1 hour to clean sodium hydro-oxide from the SG inner surface. During filling water into the SG, no hydrogen increase was observed. When draining water, samples were taken and sodium concentration was measured by neutralization method. The sodium concentration in drained water was several mg/liter. This procedure was conducted twice and took 2 days. Sodium removal weight was about 0.1kg in this water filling. Almost all residual sodium was removed by steam injection.

After finishing the water filling and draining, carbon-dioxide gas flowed into the SG and retained for 1 day to stabilize residual sodium hydro-oxide that was evolved from sodium water reaction. By introducing carbon dioxide, sodium hydro-oxide becomes sodium carbon-trioxide or sodium carbon-trioxide hydrogen that stable and no toxic. Then the SG was dried by introducing heated nitrogen gas.

The dismantling of the evaporator is now underway. The sodium removal of the mechanical sodium pumps will be conducted by using the same cleaning equipment that was used for the SG sodium removal.

6. CONCLUSION

The 50MWSGTF is just being dismantled. A current status of dismantling the facility is as follows. Air cooled heat exchangers and pipings were dismantled and sodium was removed by aqueous method. Sodium valves and EMFs were removed from the facility and sodium was removed by alcohol process. Sodium in the steam generator was removed. The SG dismantling and the IHX dismantling and sodium removal are now underway. Sodium removal of the mechanical pumps will be conducted next year. Up to now, sodium removal and dismantling are conducted effectively and safely. Dismantling the sodium system will be finished in 2 years.

References

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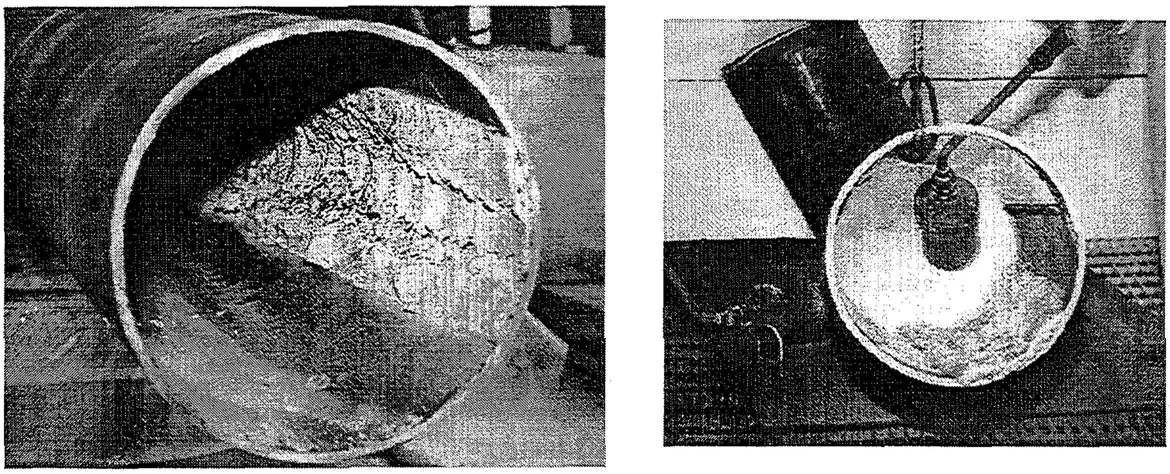
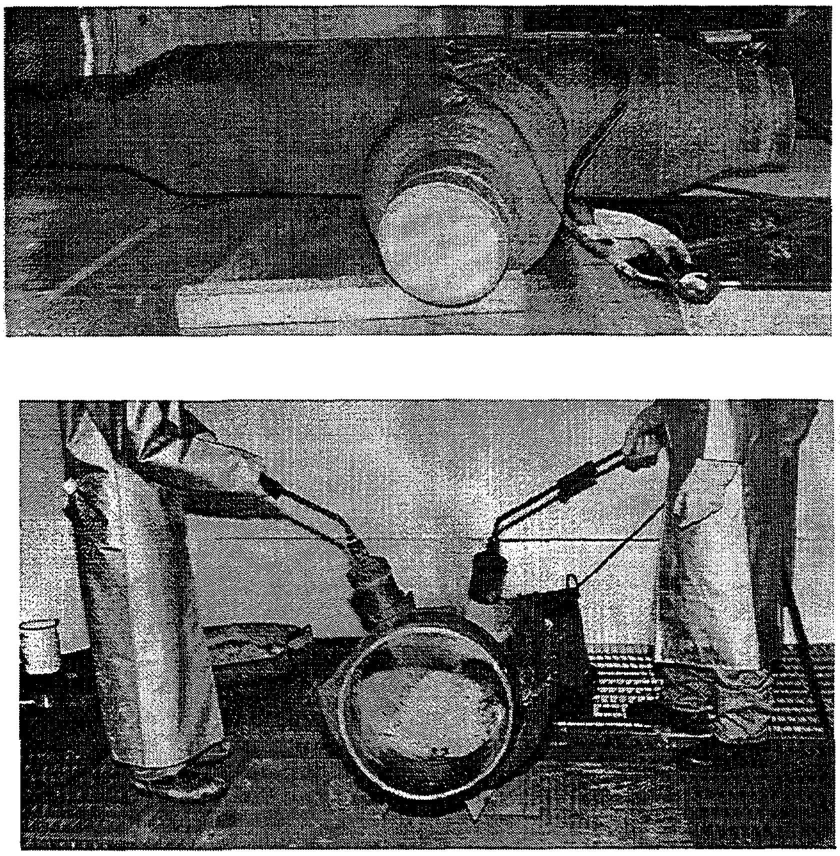


Photograph 1 Sodium removal of piping



Photograph 2 Sodium Removal of Mixing tee (sodium burning)