EXPERIENCES ON REMOVAL OF SODIUM-WATER REACTION PRODUCTS IN SWAT-3

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ABSTRACT

This report summarizes experiences and information concerning the removal of sodium water reaction products (SWRP) obtained through large leak tests of the Steam Generator Safety Test Facility (SWAT-3) at PNC/OEC, which were conducted to validate the safety design of steam generators of a prototype LMFBR Monju. The following three problems are discussed here: (1) drainability of SWRP, (2) removal of SWRP by using a cold trap, and (3) steam cleaning of SWRP.

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1. INTRODUCTION

When a sodium-water reaction occurs in a steam generator of an LMFBR, a leak detection system and a plant protection system will work to terminate the reaction. It is essential to remove sodium-water reaction products (SWRP), such as sodium hydroxide, sodium oxide, and sodium hydride, prior to repairing and restarting the steam generator. What should be done first after the reaction ceases is draining sodium together with SWRP into a dump tank. It is not always easy to drain it without choking drain piping, however, because the solidifying temperature of SWRP is higher than the general operating sodium temperature. Hence, the drainability is the first problem in removing SWRP.

If the damage of the steam generator is small, the plant system will be restarted after plugging some damaged tubes. The problem is how to remove the SWRP before restarting, which exists mainly in the dump tank and may still remain in the secondary sodium system even if the draining is successful. A hot sodium circulation method can be used for this purpose, where impurities such as hydrogen and oxygen dissolve into the hot sodium and deposit in a cold trap. Since cold traps are presently designed to remove only a small amount of impurities in the secondary sodium, however, it should be confirmed whether they can be utilized for the removal of the large amount of SWRP. This is the second problem.

On the other hand, if the damage is too serious to re-use the tubes, the damaged internals should be pulled out from the vessel and subjected to detailed inspections. Therefore, the steam generator involving a large amount of SWRP should be cleaned by hot sodium, steam, alcohol. As the steam cleaning is one of the choices to remove SWRP from the steam generators, the validity of the steam cleaning of SWRP is to be studied as the third item.

Seven large leak tests were conducted by use of the Steam Generator Safety Test Facility (SWAT-3) at PNC/OEC to validate the safety design of JAPAN's Monju steam generators against the sodium-water reaction.[1)~3)] The three problems described above: drainability of the reaction products, validity of removing products by a cold trap, and steam cleaning of the steam generator containing SWRP, were studied through these tests and many related data were obtained from the tests. They will be discussed in Chapter 3, 4, and 5, respectively, in this paper.

2. OUTLINE OF SWAT-3 LARGE LEAK TESTS

2.1 Test Facility

SWAT-3 was constructed in 1975 to validate the safety design of the Monju steam generators against the sodium-water reactions. A flow diagram of SWAT-3 is shown in Figure 2.1. The evaporator (EV) of SWAT-3, which was the reaction vessel in all tests, is a 2/5-scale model of Monju, and a secondary cooling circuit is also installed including a superheater (SH) and an intermediate heat exchanger (IHX). There are also a pressure relief system such as the reaction product tank (RT), and the purification system involving a cold trap (CT) and a plugging meter in the SWAT-3 system. Water/steam injected in each test is generated in a water heater tank (WH).

Drain lines V301, V351, V304 and V306 are connected to EV, SH, CT, and RT, respectively. The layout of the sodium outlet piping and the V301 drain piping is shown in Figure 2.2. The drain line V301 was connected at a point close to the bend from vertical to the horizontal pipe. After Run 3, the V302 drain piping was connected to the vertical part of the sodium outlet pipe of EV as a backup in case the V301 line was choked with SWRP.

2.2 Test Conditions

Large leak tests, Runs 1 through 7, were carried out from 1975 to 1978 with varying parameters such as internal structures, the location of the leak, and water and sodium conditions. The conditions of these tests are summarized in Table 2.1. The leaks were located in the lower region of the helically coiled tube bundle except in Run 4 where water was injected in the upper region of that, and Run 7 in the down-comer region.

The leak rate ranges from 6.5 kg/sec in Run 1 to 15 kg/sec in Run 5. The amounts of injected water are in the range of 61 to 150 kg. The highest initial sodium temperature is 445°C in Run 6 and the lowest is 245°C in Run 7.

3. DRAINABILITY OF SWRP

3.1 Drainability Experience in SWAT-3 Tests

About 70 to 175 liters of SWRP was generated by injecting 60 to 150 kg of water/steam into sodium in each SWAT-3 large leak test. The handling of the SWRP needs great care because its solidifying point is high enough to choke piping easily and are corrosive as well. A great deal of valuable experience concerning its handling was obtained through the tests described as follows.

The sodium and SWRP in EV were generally dumped through drain line V301 after the pressure of EV had been equalized with that of DT. In Run 1, they were drained at the outer wall temperature of the drain line of 404°C and the operation seemed to be completed successfully; however, after disassembling the pipe, it was observed that there remained a large amount of SWRP in the horizontal part of the sodium outlet pipe and the drain pipe and that the SWRP had been about to choke the drain line. The amounts of SWRP were observed to be 60 and 30 liters in the evaporator and the sodium outlet and drain pipes, respectively. Draining conditions and results of Run 1 are summarized in Table 3.1 with the other tests of SWAT-3.

In Run 2, after having drained approximately half of the entire sodium from EV, drain line V301 was choked. Although drain line V303 was used instead, it was also choked, and there remained about 900 liters of sodium and SWRP in EV. In Run 3 draining was impossible from the beginning due to the choking of the V301 line.

3.2 Investigation of the Cause of Choking

In both Runs 2 and 3, the sodium in EV was solidified by cooling after the choking, and sodium outlet pipe and drain pipe were disassembled to investigate thoroughly the cause of choking. Then it was observed that the SWRP deposited up to half of the cross section of the horizontal pipe and that almost 100 % of V301 drain line upstream of the valve was filled with SWRP as shown in Figure 3.1. But there was some gas space downstream of the valve and it increased with approaching DT. The amount of the SWRP in the piping was more than 70 liters in each test. From the results, it is concluded that the choking occurred around the V301 valve in both tests and that the cause of the choking was the low temperature of drain pipe, especially, the valve.

After the inspection, sodium was drained at the pipe wall temperature of 240 to 280°C using temporary pipe connected with the vertical part of sodium outlet pipe of EV. Twenty-five liters of SWRP still remained at the bottom of EV after draining in Run 2. After Run 3, a new drain line was installed at the vertical part of the sodium outlet pipe as a backup.

In Run 4, the solidifying temperature of SWRP was measured by sampling the SWRP which was stored in the horizontal pipe while sodium was drained through the V302 line. According to the measurement, the temperature was in the range of 320 to 380°C.

3.3 Demonstration of Hot Draining

A new method was derived from the experiences of Runs 1 through 4 and examined in the draining after Run 5 injection. Based on the above results, cold points were eliminated in the drain line by reinforcing thermal insulating material and temperature monitoring. At first, 350°C was selected as the temperature of outer wall of the drain piping, which was similar to the previous SWAT-3 conditions. The draining was unsuccessful as expected; therefore, it was increased up to 390 or 430°C two hours later. In this case the draining was successful. Inspection after disassembling the piping revealed that only a small amount of SWRP remained in the piping and the hot draining method proved to be successful.

In Runs 6 and 7, draining was completed without any troubles by heating the drain line up to about 420°C. The reason why a great amount of SWRP remained in the evaporator in Run 7 is attributed to the low sodium temperature. That is, the SWRP deposited and quickly solidified on the bottom of EV and the horizontal pipe due to the low temperature but the SWRP in the pipe was dumped owing to the high temperature of the drain line. Therefore the sodium temperature was another important factor to affect the drainability in the SWAT-3 tests.

What was learned through these experiences was that most of the reaction products generated by a sodium-water reaction accident is expected to drain under the condition that the temperature of the drain line is about 420°C or more and that there are no cold points in the drain line. It should also be noted that some amount of SWRP may deposit on the bottom of the vessel because the operating sodium temperature is generally lower than the solidifying point of SWRP in the lower plenum of the evaporator.

4. REMOVAL OF SWRP BY COLD TRAP

4.1 Objectives

Most of the reaction products generated by a sodium-water reaction accident will be removed from the secondary sodium system by the hot draining. Some amount of SWRP, however, will remain in the system, especially in the horizontal sodium outlet pipe of EV and the drain pipe. In such a case, the hot sodium circulation method with a cold trap can be used to remove it. Moreover, the SWRP should also be removed from the dump tank and an overflow tank anyway. In the case of a large leak, the amount to be removed may come to more than hundreds of kilograms. The cold trap may be applied to such cases, too.

To validate this method, a test of removing sodium-water reaction products by a clod trap (RECT) was planned in SWAT-3. Because it was the first experience to cold-trap SWRP, it was planned that the amount of the SWRP would be less than ten kilograms. At first, a part of SWRP was intentionally left in the secondary system when sodium was drained after Run 6 injection and the purification system was operated to remove it. The objectives of RECT are as follows:

i) To quantitatively clarify the potential of cold-trapping SWRP.

ii) To find the dominant parameter of the trapping rate.

iii) To disclose unknown difficulties for cold trapping SWRP, if any.

4.2 Test Installation

A cold trap (CT) of SWAT-3 is shown in Figure 4.1 and major specifications are listed in Table 4.1. The basic structure is an annulus with a settling chamber. Sodium is initially cooled during flowing down in the outer region and then flows upward in the inner region to make super-saturated impurities deposit on the surface of the stainless mesh. There is an economizer (EC) at the inlet/outlet of CT as well.

Such instrumentations are installed as flowmeters F101 and F201 (in the main and purification circuits, respectively), and a plugging meter (PM) to obtain data concerning the cold trapping capacity, and several thermocouples were equipped to measure the temperature distribution in CT and EV.

4.3 Test Results

4.3.1 General Description

Ninety kilograms of water was injected into sodium in SWAT-3 Run 6 on March 8, 1978. About three hours after the injection, a major part of SWRP was drained as well as sodium into the dump tank. After cooling down, the inside of the sodium outlet pipe of EV was observed.

Following the observation, sodium was charged and purification began the next day. During the period, the oscillation of the CT flow rate F201 occurred, which meant a tendency of CT choking by impurities. Since a serious decrease of the flow rate finally occurred, SWRP was dumped with sodium from CT at 400 C on the seventh day to restore the CT. This is called Step 1.

Step 2 was initiated by charging sodium again and terminated because it was found that most of the SWRP had already been cold-trapped. After the operation, the inside of the piping was observed and a chemical analysis of SWRP composition was conducted.

4.3.2 Operational History

(1) Step 1.

The profiles of some temperatures and a flow rate are shown in Figure 4.2, that is, T102: the main circuit temperature, T214: the cold trap bottom temperature, T-PM∞: the plugging temperature of the main circuit, T-PMo: the plugging temperature of the CT outlet, and F201: the flow rate of CT.

The sodium temperature was 200°C in charging and was increased to 270°C. The main sodium temperature is stable at 270±5°C during Step 1 while the cold trap temperature is almost constant at 200°C. The plugging temperature of the main circuit which is initially 250°C, begins to decrease after the operation starts. When the CT flow rate is in the range of 1.7 to 1.0 ton/hr during the third and fourth day, it comes to 235°C, approximately, which means that the amount of the trapped impurities balances with that dissolved into sodium. When the flow rate is increased to 2.5 ton/hr, the main plugging temperature goes down, and when it is decreased to 1.0 ton/hr, the temperature goes up.

The CT flow rate began to fluctuate largely on the sixth day, possibly because the impurities separated from sodium was choking the mesh of CT. An increase in the plugging temperature was observed while the CT flow ceased because of choking.

When sodium was dumped from the entire system at the end of Step 1, the impurities from CT caused the choking of an electro-magnetic pump (MP) in the main circuit and the plugging meter. It was dissolved by another charging and draining.

The total amount of impurities trapped during Step 1 can be evaluated from the inlet and outlet plugging temperatures and the CT flow rate. Those approximate values are as follows:

T-PM∞	(Plugging temperature of CT inlet)	= 235°C
T-PMo	(Plugging temperature of CT outlet)	= 205°C
F201	(Cold trap flow rate)	= 1.5 ton/hr

Thus, the trapped impurities come to about 2.4 kg in total, which is reduced to oxygen, or 0.25 kg, reduced to hydrogen.

(2) Step 2.

Operational history of Step 2 is shown in Figure 4.3. Sodium was charged in the system at the temperature of 227°C and purification began under the conditions that the cold trap temperature was about 200°C and the cold trap flow rate was 1.8 ton/hr. Though the main sodium temperature was increased to 300°C later, no increase was observed in the plugging temperature. Even though the sodium temperature increased again to 330°C, the plugging temperature did not go up either. Therefore, the behavior of the plugging temperature was observed after the CT flow had been stopped on the twelfth and thirteenth day. As only a slight increase occurred in this case, the dissolution rate of the impurities into sodium proved to be very small. Later the sodium temperature of the main circuit was increased to 360, 390, and 420°C, and similar observations were conducted respectively, but there was no evident increase in the plugging temperature. The above results indicated that there remained almost no SWRP in the sodium system.

4.3.3 Results of Internal Observation

According to the experience obtained from the previous SWAT-3 tests, SWRP deposited mainly on the bottom of the evaporator and in the horizontal part of the sodium outlet pipe. Before and after the cold trapping operation, a fiber scope was inserted into the evaporator and the piping through flange openings and pressure transducer taps to compare the appearance of the SWRP deposits.

(1) Bottom of the Evaporator

Before the operation, hard SWRP which looked like concrete deposited to a depth of 5 to 10 mm; the amount of SWRP was smaller than those of the other tests because most of the SWRP was dumped owing to the hot draining. After the operation, SWRP was completely removed and only a small amount of sodium remained there.

(2) Sodium Outlet Pipe and Drain Pipe

Figure 4.4 shows the state of the SWRP deposits in the sodium outlet pipe before the cold trapping operation. The amount of SWRP was observed to be a few liters. It was also much smaller than in other tests. Only a small amount deposited on the wall of the V301 drain pipe. After the operation, SWRP was completely removed from there and nothing except some sodium droplets remained in the pipes.

(3) Dead-End Pots

Two dead-end pots were installed into the bottom of the horizontal part of the sodium outlet pipe to simulate a stagnant region, because it was supposed that the dissolution rate of SWRP into sodium was smaller in the stagnant region than the other regions of the system where sodium flowed. The size of the pots was 30.6 mm in inner diameter and 100 mm in depth. The pots were electrically heated to keep a similar temperature as the circulating sodium. After the injection of Run 6, SWRP flowed into the pots, whose depths were shown by dotted lines in Figure 4.5.

The two pots were almost completely filled with the SWRP. As some amount of the SWRP in the pots was consumed as samples for a chemical analysis, the depths before the operation were further reduced as shown in the figure. Post test examination showed that the dissolution behavior was different between the two pots. The length of the SWRP in Pot A did not change so much while three quarters of the SWRP was removed from Pot B.

The reason why there was such a difference in the dissolution behavior cannot be clearly explained. One explanation is that the boundary between sodium and SWRP in Figure 4.5 was drawn based on the difference of the appearence. As explained in the next paragragh, the composition of oxygen and hydrogen in the SWRP decreased very much in Pot A. Therefore, it can be said that the dissolution progressed in Pot A as well as Pot B.

4.3.4 Chemical Analysis of SWRP

A chemical analysis was performed for the SWRP sampled before and after the operation. Initially, the amount of hydrogen distilled from the samples in vacuum was measured by a gas chromatographer, and sodium condensed back from vapor was also weighed. By a neutralization titration on the remaining samples, the masses of sodium hydroxide and soidum oxide were measured. The results were summarized in Table 4.3. The percentage of the sodium hydroxide is much different from pre- to post-operation. However, it is not clear whether it is because hydrogen dissolved into sodium due to the operation, or because it did not distribute uniformly before the operation. It is also noted that sodium oxide was rich in SWRP on the bottom of EV.

4.3.5 Evaluation of Dissolution Rate

The dissolution rate is defined as the amount of impurities which dissolves into sodium in a certain period. It is evaluated from the cold trapping rate under such a balanced condition that the plugging temperature is stable. It is also derived from the rate of rise of the plugging temperature when the cold trap was stopped. Mass transfer coefficient can also be evaluated from the dissolution rate if the total surface area of the SWRP is known.

Both the dissolution rate and the mass transfer coefficient in the test are summarized in Table 4.3, where the surface area is approximately estimated by adding one third of the inner surface of the sodium outlet pipe to the bottom area of EV. Eichelbarger's and Vissers' equations are used to calculate the concentration of hydrogen and oxygen, respectively. As it is not clear which impurity is mainly measured, the numbers are derived for the both substances. The numbers reduced with the progress of the operation possibly because the surface area of SWRP decreased gradually.

4.4 Concluding Remarks from the RECT Test

The results obtained from the RECT test are summarized as follows:

i) Maximum dissolution rate and the mass transfer coefficient are 21 g/hr and 2 - 3 x 10^{-5} g/cm^2hr ppm, respectively and reduced gradually as the operation proceeded.

ii) The SWRP exposed to sodium stream dissolved into sodium and deposited in the cold trap; however the removal of them in the stagnant region was less efficient.

iii) As the impurities tends to choke the cold trap if a large amount of SWRP is transfered into it, some modifications of the cold trap design will be desirable.

5. STEAM CLEANING OF SWAT-3 REACTION VESSEL AFTER TEST

If the cold trapping of SWRP is not adopted because, for example, tube damage is so serious that pulling out the internals is necessary, the steam generator will be cleaned by steam, alcohol or hot sodium. Although the vessel of the Monju steam generator will not be cleaned by steam in the case of leak, the steam cleaning is still one of the choices for removing SWRP. After each test of SWAT-3, the reaction vessel was cleaned by steam. The method used in SWAT-3 may not be directly applicable to actual plants because the steam cleaning of SWAT-3 were made in order to restore the test facility for the next run. Nevertheless some deductions could be derived from the experience obtained in SWAT-3.

Prior to the start of cleaning, the evaporator was isolated from other system by cutting off the sodium outlet and inlet pipe and renewing the burst rupture disc of the pressure relief line. Cutting off the sodium outlet pipe is necessary anyway if there is a great deal of SWRP in the outlet pipe as same as in Runs 2, 3, and 4. The amount was dependent on cases but more than a hundred kilogram of SWRP deposited on the bottom of EV in Runs 2 and 7. SWRP did not deposit elsewhere in the evaporator. Sodium mainly remained on the bottom, but also attached thinly to the surface of the internals. It remained in the space between the vessel wall and the outer shroud in Run 4.

The method of the cleaning is schematically explained in Figure 5.1. There is a special nozzle for cleaning in the lower part of the evaporator vessel. Steam was injected through the nozzle at the average rate of 4 kg /hr. To dilute the steam, nitrogen gas was injected in the same way at the rate of 14 normal m3/hr. The steam and nitrogen and generated hydrogen were expelled to the atomosphere through a line containing a flame arrester, a steam condenser, and a paraffin trap. The gases were also branched into a hydrogen meter to monitor the hydrogen concentration in the evaporator. The cleaning was performed slowly enough to avoid generating local hot spots and injecting steam was stopped if the hydrogen concentration exceeded a certain value which was generally set to be eight percent. The lower part of the evaporator was observed by a fiber scope through one of pressure transducer taps. Sodium was changed to sodium hydroxide at the average rate of 1 kg/hr.

Significant improvement was made on the cleaning method in Run 4. Till then, a difficulty was becoming clear, i.e. viscous strong solution of sodium hydroxide covered the unreacted SWRP layer where sodium was involved and prevented steam from reacting with SWRP and sodium. Removing sodium hydroxide was essential to continue the efficient cleaning. Hence, as a measure, a drain pot, 200 mm in ID and 3 m in length, was connected to the sodium outlet nozzle after cutting off the pipe in each steam cleaning. The solution was saved in this pot and the SWRP on the bottom was easily exposed to steam by this improvement. The pot was electrically heated to evaporate water to prevent sodium water reaction in the pot. This countermeasure proved to be so successful that the period of cleaning was reduced very much. As the pot was heated to more than 100 C during cleaning, the sodium hydroxide solidified after cooling and the drain pot which was filled with crystallized sodium hydroxide was disposable.

Amounts of the consumed steam and nitrogen, generated hydrogen, and the disposed sodium in each cleaning are listed in Table 5.1. It should be kept in mind that the establishment of the hot draining has greatly lessened the load of the cleaning since Run 5, although the period of the cleaning in Run 7 was rather long because the amount of sodium was large as well as that of SWRP due to the low sodium temperature.

6. CONCLUSION

To remove SWRP from the steam generator, a combination of the following three procedures should be chosen according to circumstances.

i) Hot draining of SWRP
ii) Cold trapping
iii) Steam/alcohol cleaning.

Whether the leak is small or large, the first procedure is to be performed initially reduce the amount of SWRP in the next stage. According to experiences obtained in the SWAT-3 tests, it is essential to heat the sodium/drain piping up to about 420 C in order to complete draining without choking.

The SWRP remaining in the secondary sodium system can be removed by cold trap after hot draining. RECT in SWAT-3 suggests that some design modification is needed to prevent the cold trap from choking by the depositing impurities because cold traps are generally designed to remove only a small amount of impurities under normal conditions.

Some deductions could be obtained from the post-test steam cleaning in SWAT-3. For instance, since the cleaning period depends on the amount of remaining SWRP, the combination with other dispositions is preferable. To maintain the efficient cleaning, the sodium hydroxide solution should be removed, otherwise, it covers the unreacted SWRP layer and keeps it from being exposed to steam.

- REFERENCES -

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Table 2.1 Test Conditions of SWAT-3

Items	Unit	Run - 1	Run - 2	Run - 3	Run - 4	Run - 5	Run - 6	Run - 7
Date of test	-	Jun 9, 1975	Jan. 26, 1976	Sep. 16, 1976	Mar. 18, 1977	Sep. 22, 1977	Mar. 8, 1978	Oct. 26, 1978
Injection rate (quasi-steady)	kg/sec	6.7	14.2 ∿ 9.7	8.8 ∿ 7.9	9.0 ∿ 7.2	15 ∿ 11	9.4 ∿ 8.3	10.6 ∿ 7.9
Total amount of injected water	kg	61.2	122	78	83	150	90	85
Duration of injection	sec	7.6	9.9	9.5	9.4	9.7	9.5	9.5
Leak site	-	100mm above bottom of T.B., most inner (1st) layer	about 200mm above bottom of T.B., middle (5th) layer		640mm below free surface, middle (5th) layer	300mm above bottom of T.B., middle (4th) layer	220mm above bottom of T.B., middle (5th) layer	825mm above bottom of downcomer
Pressure of water	kg/cm²a	153	154	149	155	154	154	124
Temperature of water	°C	343	260	300	306	280	305	298
Injection hole	-	15mmφ disk type	10mmφ × 8 multihole nozzle			11mmφ × 18 multihole nozzle	8mmφ × 18 multihole nozzle	19mmφ disk type
Sodium temperature	°C	378	320	398	380	360	334	245
Cover gas	kg/cm²G	0.5 (Argon)						

Table 4.1 Key Characteristics of Cold Trap in SWAT-3

Items		Contents
Vessel	Size	820 mm ID × 2600 mm H
	Material	SUS 304
Settling chamber	Size	697 mm ID 1032 mm H
	Weight	80 kg (0.2 kg/l)
	Mesh Size	30 mesh (0.3mmϕ)
Fin	Direction	Vertical
	Number	40 rows
	Size	30 mm H × 1300 mm L × 3 mm T
Sodium Inventory		1150 kg
Turn-around time		15 min
Oxygen capacity		50 kg

Table 4.2 Result of Composition Analysis of SWRP

Position \ Composition	NaOH	Na_2O	H_2	Na	Others	Total
Pot A (pretest)	65%	16%	1.5%	11%	11%	104.5%
Pot A (posttest)	6	5	0.4	72	20	103.4
Pot B (pretest)	31	45	1.8	8	14	99.8
Pot B (posttest)	6	42	0.3	37	18	103.3
Evaporator Wall(pretest)	8	72	1.0	20	0	101.0

Table 3.1 Conditions and Results of Draining in SWAT-3

Run No.	1	2	3	4	5	6	7
Amount of Water injected	61 kg	122	78	83	150	90	85 kg
Sodium Temperature before Injection	378 °C	320	398	380	360	445	245 °C
Evaporator Bottom Temperature after Injection	367-397°C	308-409	383-445	348-382	385-445	391-476	236-285°C
Temperature of Drain Pipe Outside	404 °C	355	405	-	330/421	415	425 °C
Temperature of Drain Valve V301	404 °C	344	300	V302 401	344/390	414	425 °C
Time from Injection to Draining	120 min	77 min	68 min	43 Hours	137/232 min	168 min	147 min
Drainability	Successful	Choked in the midway	Choked from the begining	Choked	Successful	Successful	Successful
Remaining SWRP in Evaporator	60 lit	75	30	35	13	9	150 lit
Remaining SWRP in Piping	30 lit	70	80	15	2	1	10 lit
Total Amount of Remaining SWRP	90 lit	145	110	50	15	10	160 lit

Table 4.3 Dissolution Rates and Mass Transfer Coefficients Calculated from RECT

	Test data	Dissolution rate (g/hr.)	Mass transfer coefficient ($g/cm^2hr\cdot ppm$)
	Step 1. 4/12; 12:00 ∼ 20:00 $Tpm_\infty \simeq$ 235°C $Tpm_o \simeq$ 205°C T_∞ 275°C $F_{201} \simeq$1.7ton/hr., F_{101}=18ton/hr.	Q_O=21 Q_H=2.2	$K_O=2.8\times10^{-5}$ $K_H=2.5\times10^{-5}$
	Step 1. 4/13; 12:00∼4/14; 12:00 $Tpm_\infty \simeq$235°C $Tpm_o \leq$205°C $T_\infty \simeq$270°C $F_{201} \simeq$1.07ton/hr. F_{101}=18ton/hr.	Q_O=13 Q_H=1.3	$K_O=2.1\times10^{-5}$ $K_H=1.8\times10^{-5}$
	Step 1. 4/15; 12:00 ∼ 4/16; 12:00 $Tpm_\infty \simeq$216°C $Tpm_o \simeq$205°C $T_\infty \simeq$270°C F_{201}=1.8ton/hr. F_{101}=18ton/hr.	Q_O=6.6 Q_H=0.66	$K_O=0.81\times10^{-5}$ $K_H=0.69\times10^{-5}$
	Step 1. 4/16; 18:00 ∼ 4/17; 10:00 Tpm_∞=215° ∼238°C $T_\infty \simeq$270°C	Q_O=0.25 Q_H=0.30	

Table 5.1 Results of Steam Cleaning of SWAT-3

Run No.	-	1	2	3	4	5	6	7
Steam injected	kg	204	248	287	224	93	58	183
Nitrogen injected	kg	1162	2029	951	942	279	222	879
Hydrogen generated	kg	1.54	2.69	2.81	2.66	0.38	0.12	2.35
Sodium disposed	kg	35.3	61.8	64.7	61.1	8.8	2.8	54.0
Period of cleaning	days	5	6	7	7	2	2	6

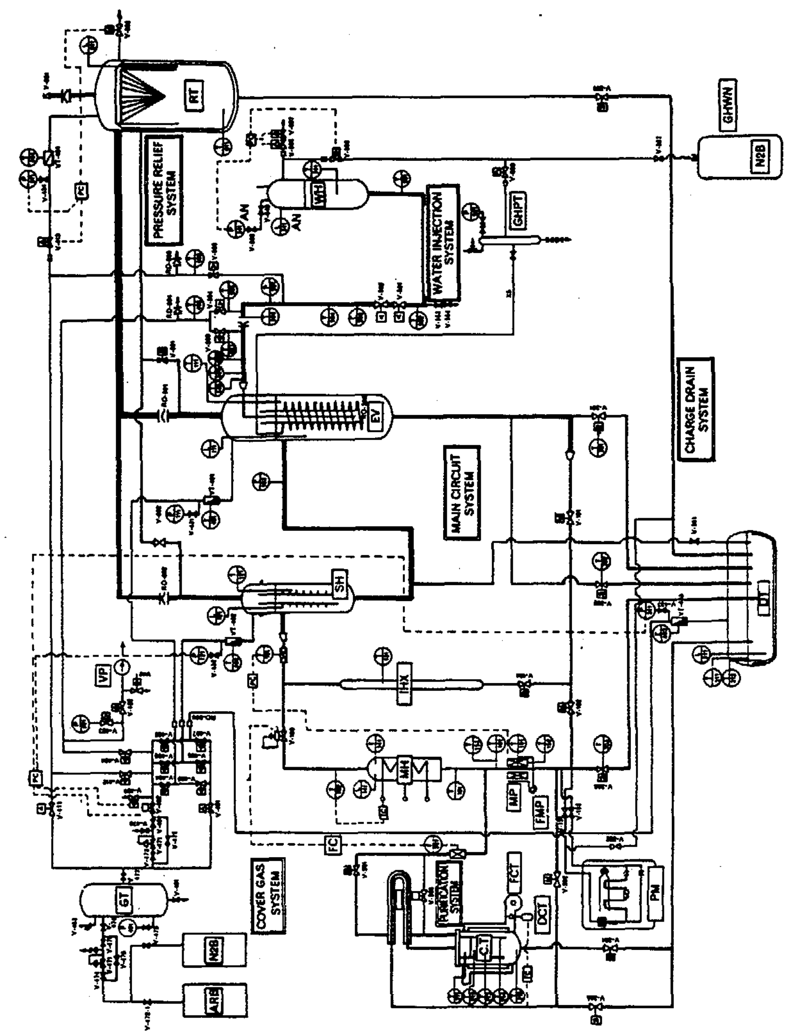

Fig. 2.1 SWAT-3 Flow Diagram

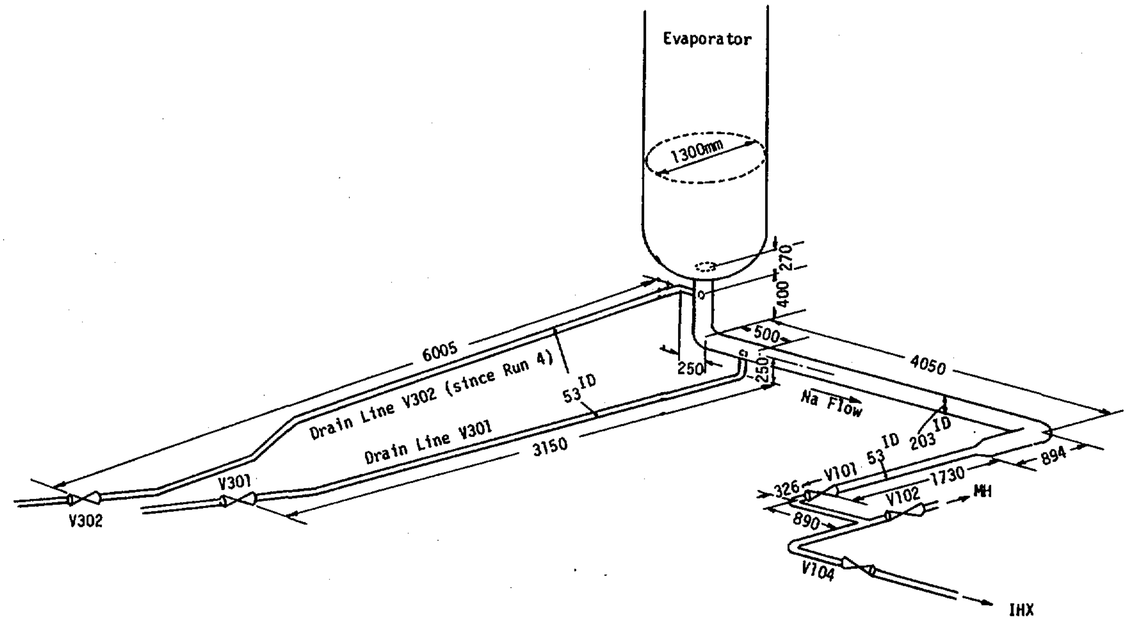

Fig. 2.2 Schematic Diagram of Sodium Outlet Piping and Drain Piping of Evaporator

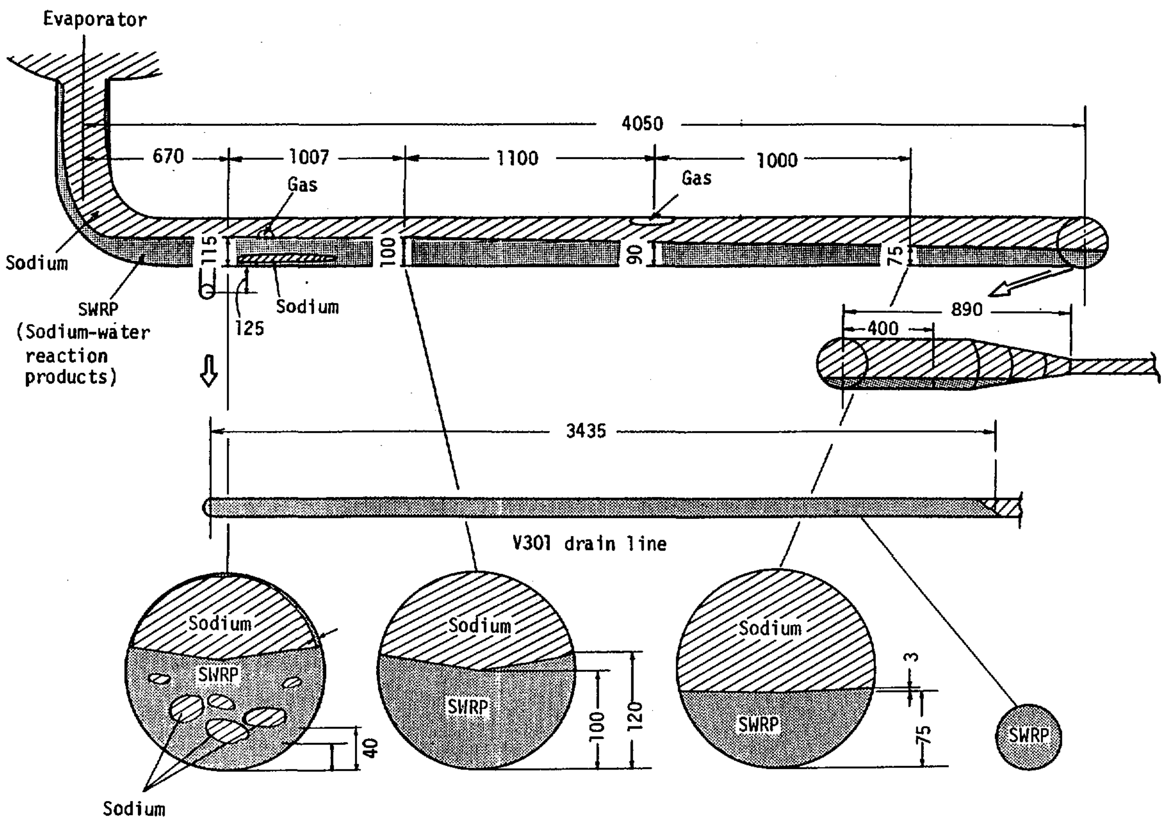

Fig. 3.1 Distribution of Sodium-Water Reaction Products in Sodium Outlet Pipe and Drain Pipe in SWAT-3 Run 3

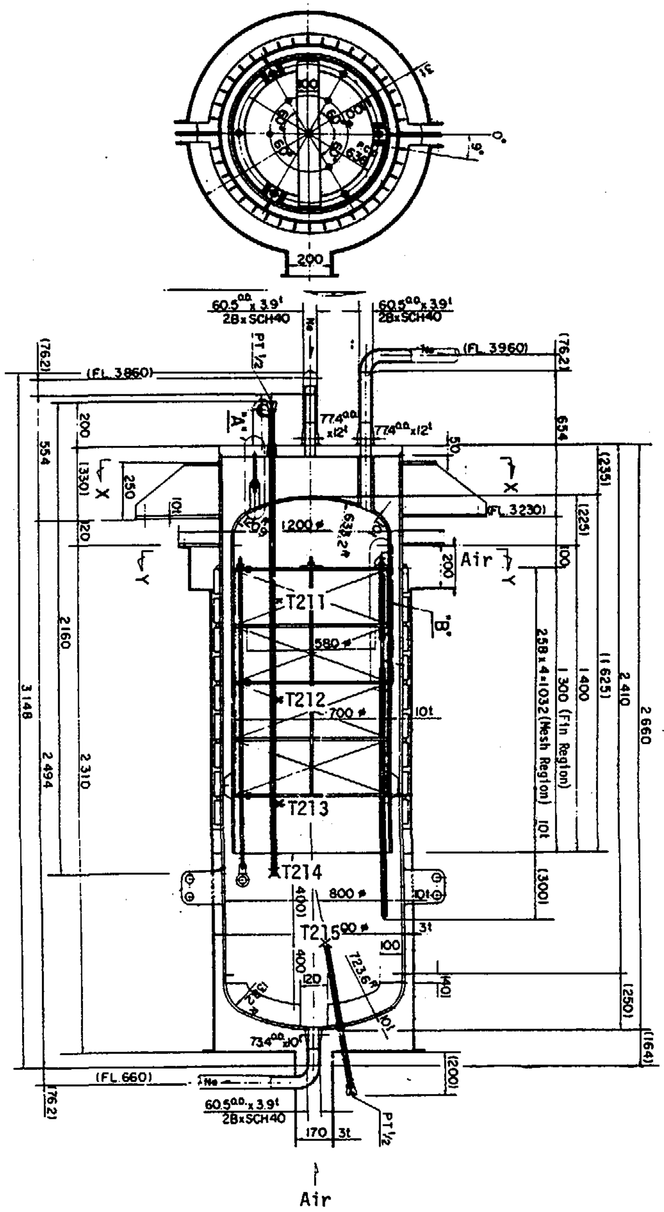

Fig. 4.1 Cold Trap of SWAT-3

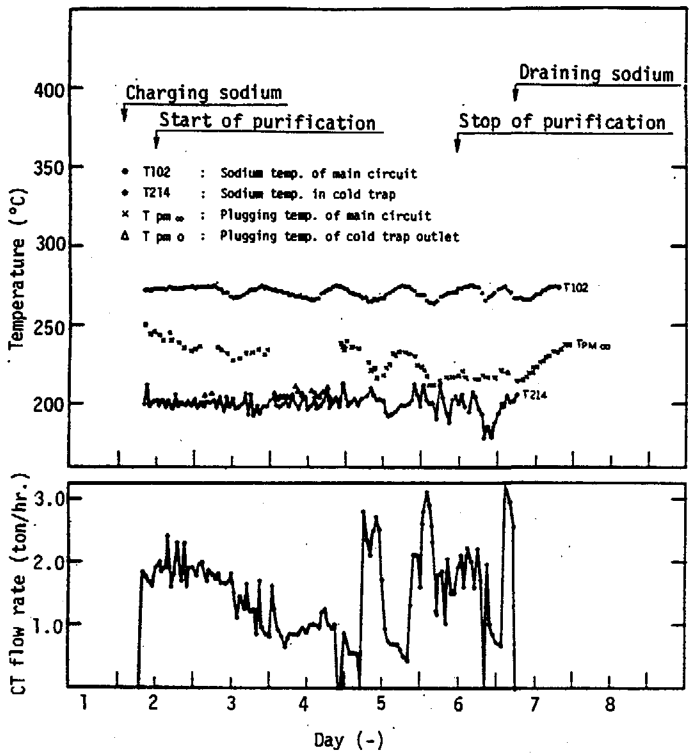

Fig. 4.2 Operation History of Step 1

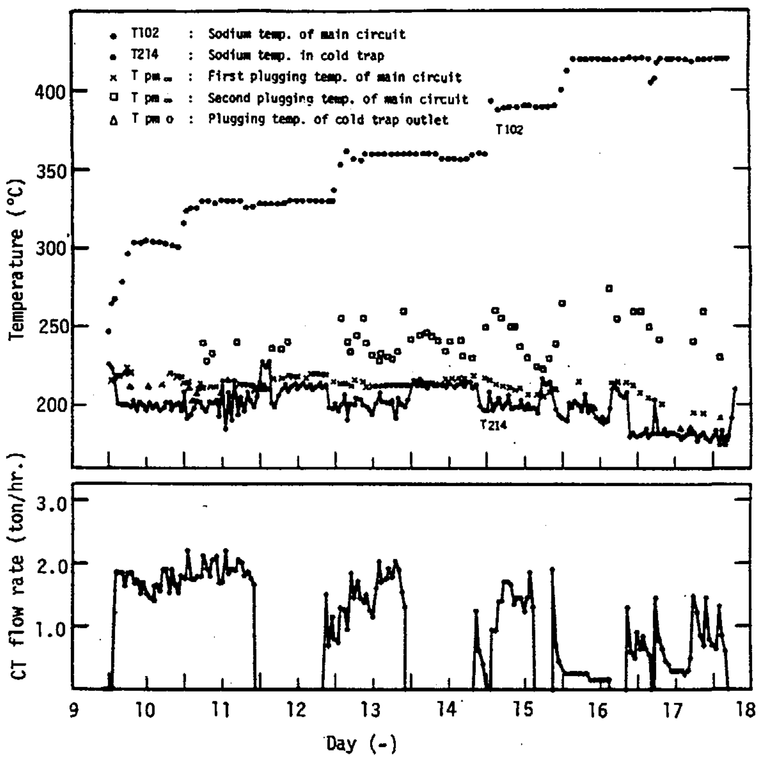

Fig. 4.3 Operation History of Step 2

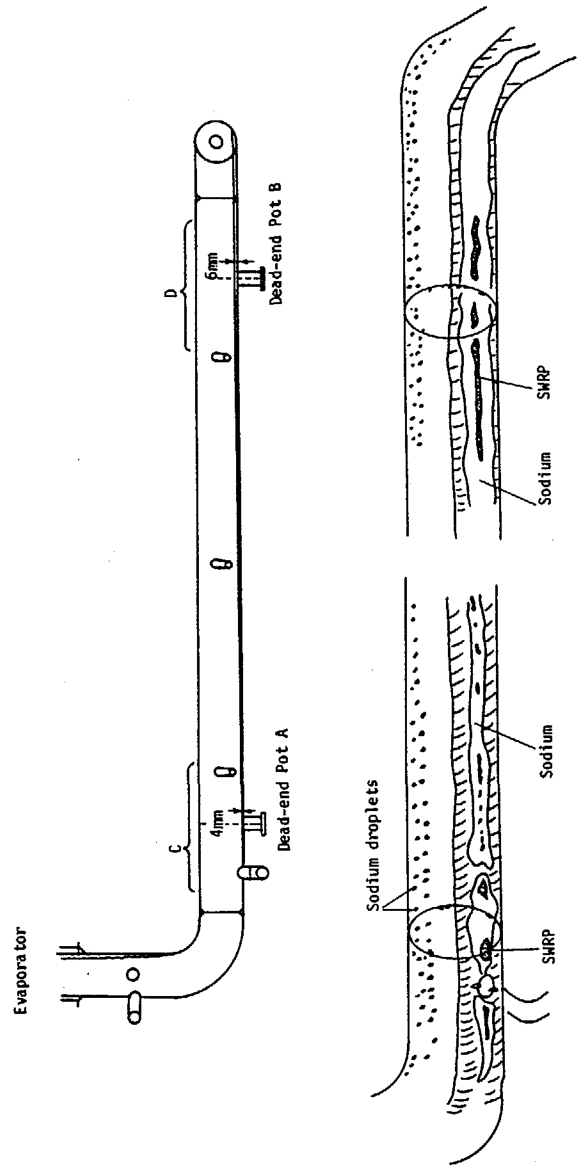

Fig. 4.4 SWRP and Sodium Distribution in Sodium Outlet Pipe before the RECT Operation

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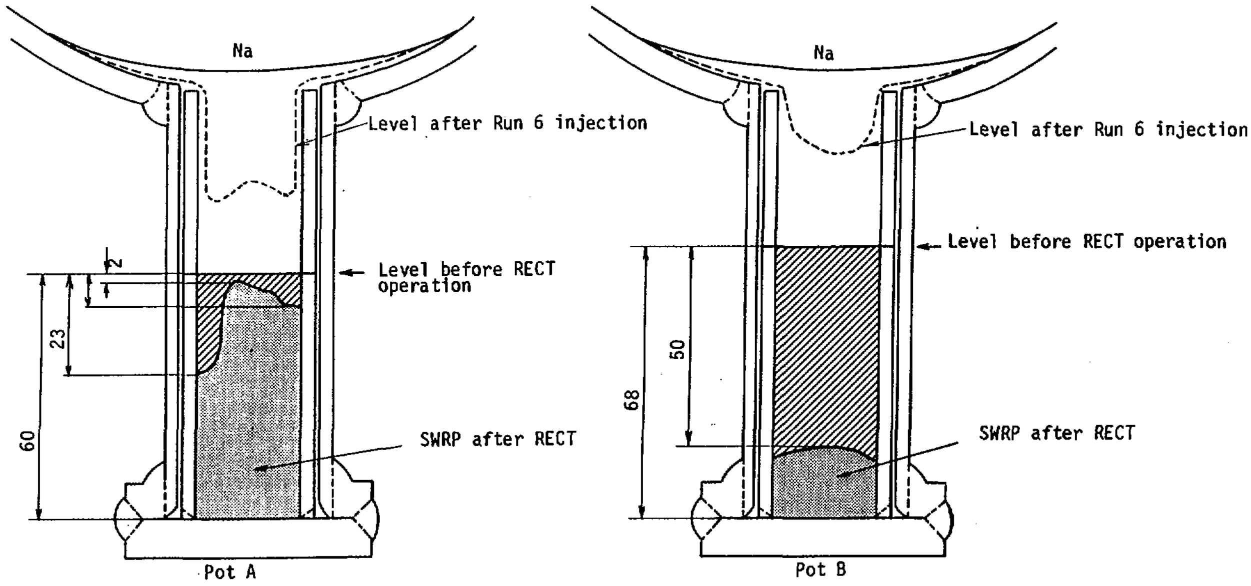

Fig. 4.5 Level Change of SWRP in Dead-end Pots

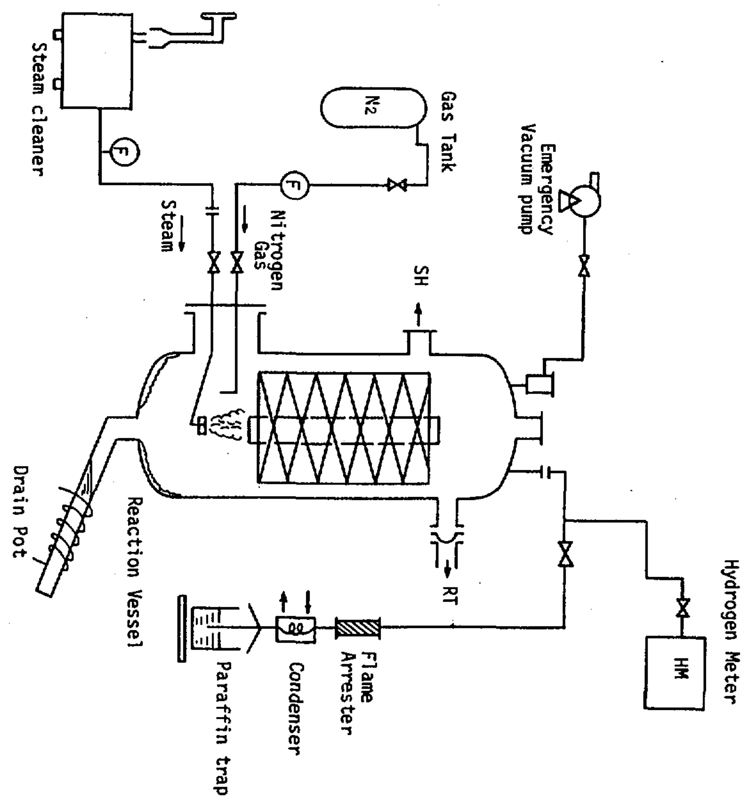

Fig. 5.1 Flow Diagram of Steam Cleaning of SWAT-3

Question and Answer

Session 4 Paper No. 10

Paper Title : Experiences on Removal of Sodium-Water Reaction Products in SWAT-3

1. O.Hayden

Q. What is the sodium inventory in the reaction vessel ?

A. It is four tons.