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# Engineering Scale Test on Sodium Leak and Fire Accident and Its Consequences in Auxiliary Building of Fast Breeder Reactors



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# Engineering Scale Test on Sodium Leak and Fire Accident and Its Consequences in Auxiliary Building of Fast Breeder Reactors

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## Abstract

Using sodium from 180kg to 3 metric tons, a series of tests has been conducted to develop the fire mitigation system and to study a design basis sodium leak accident and its consequences in the auxiliary building of the fast breeder reactor.
In the test, flow pattern of a realistic leak from the sodium piping was investigated at first. Combustions of sodium in an open pool and a pool with a reduced opening were also studied together with combustion and flow of a sodium on an inclined steel liner and in a drain piping. Transient thermal conduction of a steel lined floor concrete during a sodium leak was tested and evaluated. In next, based on the results obtained, a fire mitigation system was developed and was mounted in a two storied concrete test rig. Then, a large scale test starting from a leak and ending by a self-extinguishment of a fire in the smothering tank was carried out. In final, consequences of sodium aerosols deposition on the reactor components and the electrical instruments have been experimentally studied.

## 1. Introduction

In the secondary system of the liquid sodium cooled fast breeder reactors, a sodium leak from the sodium piping is postulated as one of the design-basis accident. Size of the leak so far given by LBB (the leak before break theory) is Dt/4, where D is the pipe diameter and t is the pipe wall thickness. This size leads to a comparatively large sodium leak whose flow rate ranges several tens of kilograms per second and generates a combustion heat as well as sodium aerosols.
To mitigate thermal and chemical consequences of the accident, the sodium fire mitigation system is installed in the auxiliary building of the reactor. However, no systematic study has been ever made in regard to the fire mitigation system. Studies so far reported are limited with investigation of individual phenomenon(1),(2),(3); pool fire, spray fire, and aerosol behavior, and performance of individual component of the fire mitigation system(4), i.e., liner and smothering tank.
In the present study, a series of tests has been carried out to develop a reliable mitigation system as well as to make realistic evaluation of the accident sequence and its consequences.

## 2. Leakage Flow Pattern from Sodium Piping

In the safety evaluation of the design-basis sodium leak accident, a spray fire that gives the largest possible combustion heat has been postulated. This postulate gives the most pessimistic consequences. However, relation between a realistic leak and the postulated one has not been made clear. To investigate a real flow pattern and associated combustion during a leak, tests have been conducted using water and sodium as working fluids.

(1) Water Simulation Test

Full size mockups of the prototype sodium pipings ( straight pipe, T-pipe, and L-pipe) each of which has a leak hole on the wall and is equipped with inner and outer jackets and a thermal insulator were used in the test. Water pressure at the rated flow conditions of the reactor secondary system was added to the pipe, then a leak flow pattern was visually investigated.

The results revealed generating no spray, but dispersion flows through the gaps of the outer jacket.

(2) Sodium Leak Test

The outer jacket of the straight piping was remodeled based on the above water simulation test to suppress generating the dispersion flows effectively. Then, its 1/2.6 reduced scale model was sodium tested(5) in the stainless steel vessel, SOLFA- 2 (10 m in height, 3.4 m in diameter, and 100 $m^3$ in inner volume), in the SAPFIRE facility(6) in Oarai Engineering Center, PNC. Figure 1 shows arrangement of SOLFA-2 for the test. In the test, a 2.4 tons of sodium at 505°C was fed to the test pipe at flow rate of 3.1 kg/sec for 13 minutes. Then, a leakage flow pattern and the combustion rate during a leak were investigated.

Pictures taken by a video camera and an infrared camera showed that the flow pattern is a downward column, as shown in lower part of Fig.2, along which no remarkable ignition of the droplets occurred. Only the rebound droplets from the floor ignited and burnt. This leakage flow pattern was also confirmed by the transient spatial temperature distributions determined by more than 200 thermocouples arranged below the test pipe. Fraction of a leakage flow burnt during a leak was 4 %, while, in another spray fire test, that fraction was 30%.

One important conclusion from the present test is that a realistic leak is a column whose combustion is milder than that of a spray.

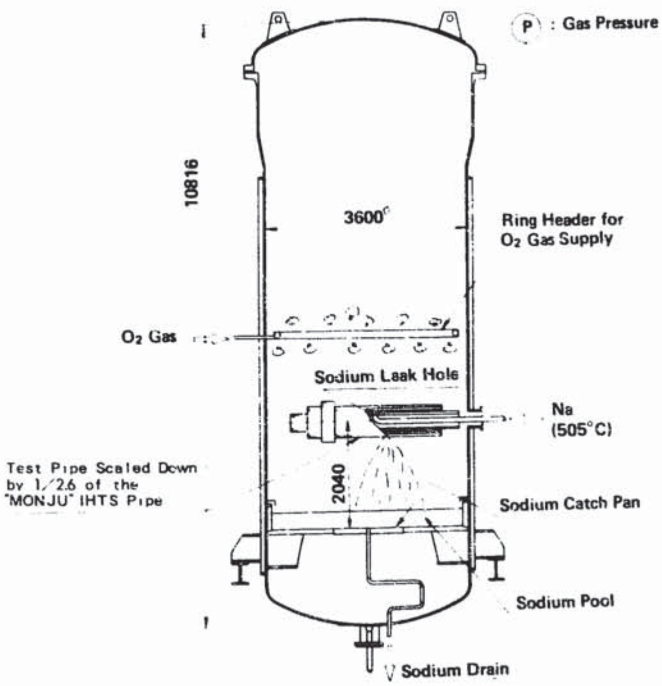


Fig. 1 Schematic of Test Rig for Run-E 2

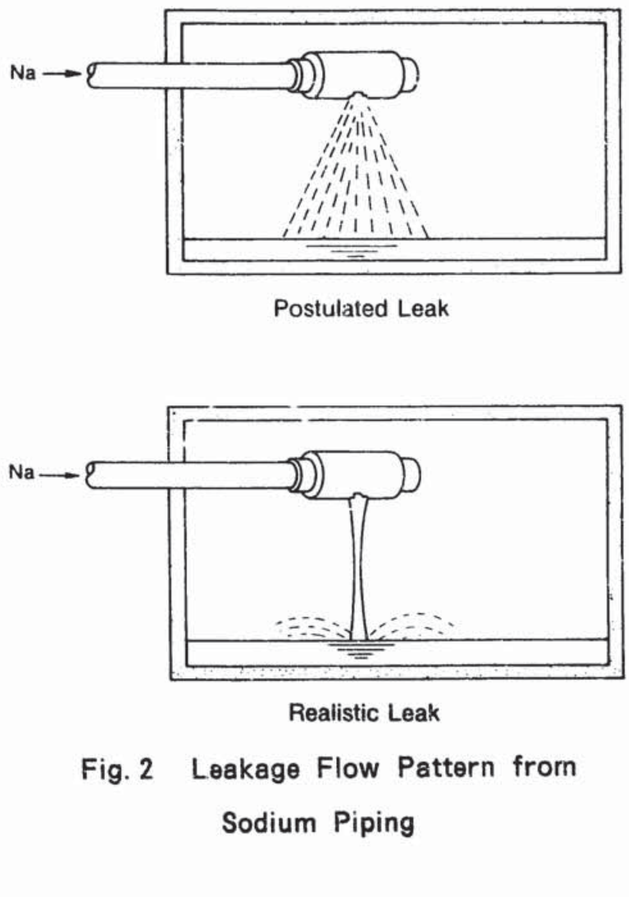


Fig. 2 Leakage Flow Pattern from Sodium Piping

## 3. Development and Demonstration of Fire Mitigation System

### 3.1 Basic Tests

### (1) Sodium Pool Combustion Tests

Combustion of an oper odium pool and a pool having reduce pening ratio were measured.

Figure 3 shows a test arrangement of SOLFA-1 for an open pool combustion. The results obtained are shown in Fig.4 in which the wall and ceiling temperatures of the test rig are plotted together with the code calculated results by ASSCOPS.

Combustion of a pool having reduced opening ratio was measured with the opening ratio at 1%. Results are show in Fig.5 where the left hand side shows combustion rate of an open pool and the right hand side shows that of a pool having the reduced opening ratio. Combustion rate is seen to be reduced effectively,i.e., to be less than 3% of that during the open pool combustion, simply by reducing an opening ratio.

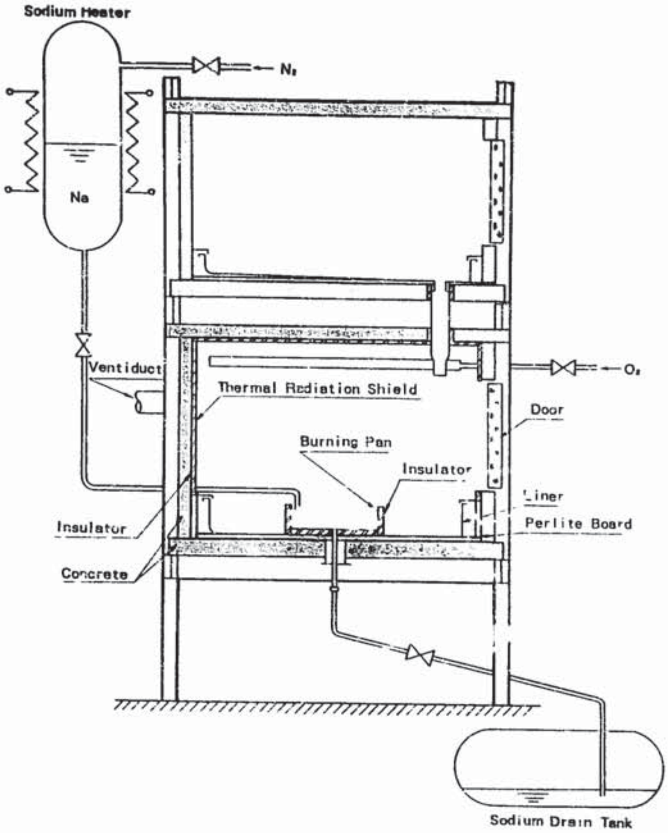


Fig. 3 Arrangement of Test Rig in SOLFA-1 for Run-D1

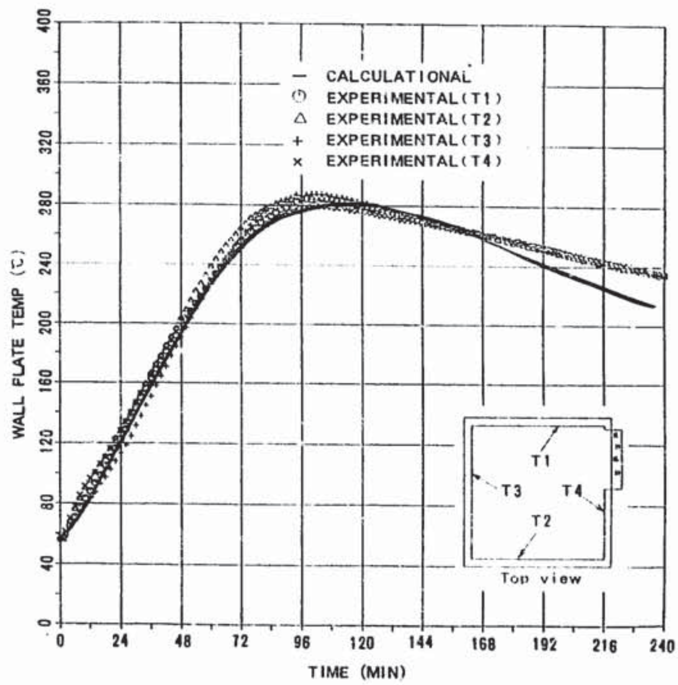


Fig. 4 Comparison between Calculational and Experimental Results of Temperature Changes at Thermal Radiation Shields of Walls

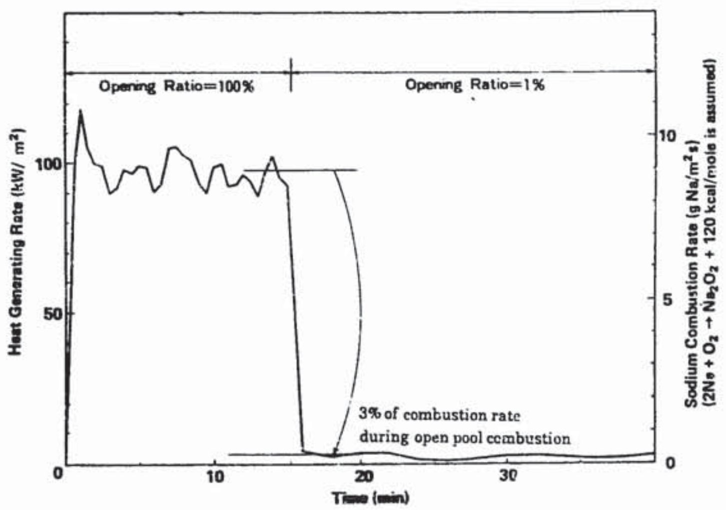


Fig. 5 Comparison of Heat Generation Rates with Open Pool Combustion and with Slit Board Combustion

### (2) Flow and Combustion Test on Liner and Drain Piping

Usually, the fire mitigation system is designed so that a spilled sodium on the floor liner flows naturally to the smothering tank through the drain piping by gravity. But, a question was asked in regard to that flow whether blockage w .ıld occur or not by the precipitates of combustion products on the liner and on the inner surface of the drain piping. Heat losses of a sodium to the floor liner and the drain piping may reduce the sodium temperature, then, in the drain piping, this may leads to the flow blockage of a sodium due to the sodium freezing. To investigate these possible flow blockages, flow and combustion tests of sodium on the liner and the drain piping was carried out using hot and cold sodium at 500oC and 250oC, respectively. Results indicated that no flow blockage occurres both on the liner and in the drain piping.

### (3) Evaluation of Temperatures of Steel Lined Concrete

Temperature rise of the steel lined floor concrete during a sodium leak accident is closely related to integrity of the concrete as well as to the amount of released water from heated concrete. Evaluation of that temperature is another important safety issue. So, thermal conduction test of steel lined concrete was carried out under the sodium spill accident simulated conditions(7). Figure 6 shows a concrete test section for this test. A gas burner unit mounted at the top of the test section is to simulate heating of the steel lined concrete by a spilled sodium. Between the steel liner and the upper concrete surface, perlite concrete was filled. A steam vent line is provided to release water vapor from heated concrete.

In parallel to this test, thermo-physical properties of the constitutional materials of the steel lined concrete were determined from the room temperature up to 500°C(7). Then, the thermal conduction of the test section was analyzed by the multi-dimensional thermal conduction code, FINAS, using the thermo-physical properties thus determined.

The results of vertical temperatures and their changes are shown in Fig.7. The solid lines represent the test results and the dotted lines represent the calculated ones. Agreement between the code and the test is comparatively well. It was also made clear that the concrete surface was well thermally insulated by perlite, thus, it was not heated up higher than about 80°C throughout the test. In conclusion, integrity of the structural concrete can be kept even in the sodium leak accident conditions.

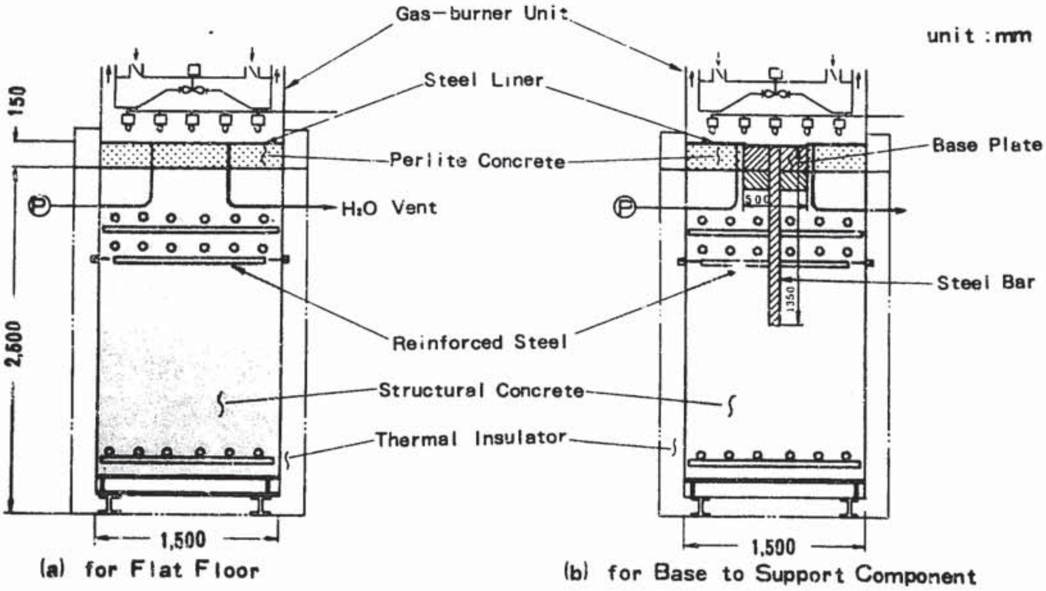


Fig. 6 Concrete Structures to Validate Thermal Conduction Codes

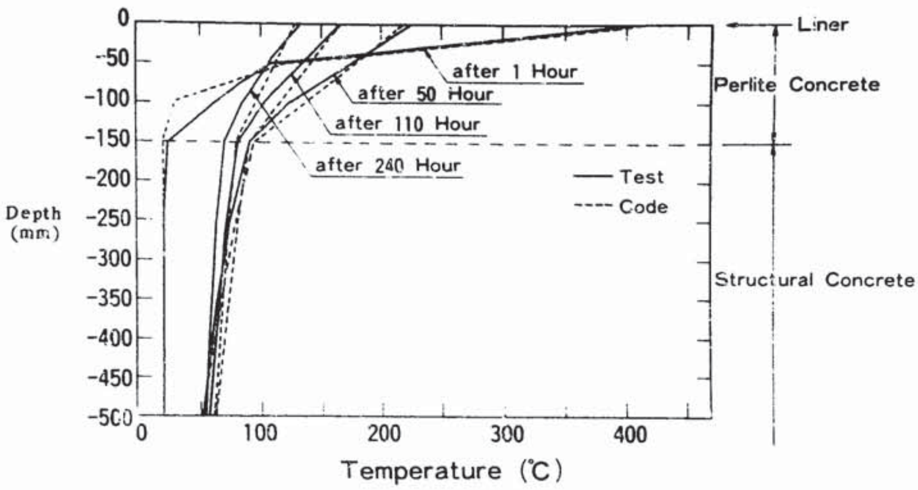


Fig. 7 Change in Vertical Temperature Profile in Perlite and Structural Concrete of Test Section

## 3.2 Large Scale Engineering Test

Followed to the above tests, prototype mitigation system was developed and was mounted in the two storied concrete test rig, SOLFA-1, as shown in Fig.8. In the upper cell of SOLFA-1, the similar 1/8 educed scale model of the sodium piping as described was installed, and a catch-pan type inclined floor liner were mounted on its floor. The smothering tank was mounted in the lower cell. A drain piping was installed to connect the floor liner in the upper cell and the smothering tank in the lower cell.

In the test, a 3 tons of sodium at 505°C was spilled from the pipe at the flow rate of 4 kg/sec for 15 minutes. Then, the sodium was allow to burn on the liner or in the smothering tank for 6.6 hours. During that time, the atmospheric oxygen concentrations in the upper and lower cells were kept nearly 21 % by ventilation or by feeding oxygen gas.

In the upper cell of SOLFA-1, the similar column flow as observed in SOLFA-2 was obtained with a leak from the piping. The maximum aerosol concentration determined was 23 g/m$^3$. Combustion rate due to mixed fires (rebound droplets and pool ) at the beginning of the test was from 100 to 130 kW/m$^2$ of floor liner, as shown in Fig. 9. This is only 1.1 to 1.3 times larger than that of a pool fire (100 kW/m$^2$). Combustion rate decreased gradually after termination of a leak due to the smooth draining of sodium in the smothering tank.

In the lower cell of SOLFA-1, combustion of the drained sodium in the smothering tank was self-extinguished after several tens of minutes because of the quick consumption of oxygen. This quick consumption of oxygen reduced combustion rate significantly from 50 kW/m$^2$ to be less than 5 kW/m$^2$ within several tens of minutes. This further resulted in monotonous decreasing of the drained sodium in the smothering tank, as shown in Fig. 10, where the calculated results by the ASSCOPS code is also drawn by a solid line. The maximum aerosol concentration determined was only 5 g/m$^3$ in the lower cell.

In the post-test examination, sodium and combustion products at various locations in the test facility were recovered, and their weights were measured. It was found that more than 90 % of a spilled sodium was drained naturally and was recovered in the smothering tank, as shown in Fig.11. The rest changed to aerosols ,and they deposited on the floors, walls, and ceiling and released to the scrubber.

**The conclusion from the present tests is that the system functioned properly. It recovered a spilled sodium effectively and extinguished fire without generating excess combustion heat and sodium aerosols.**

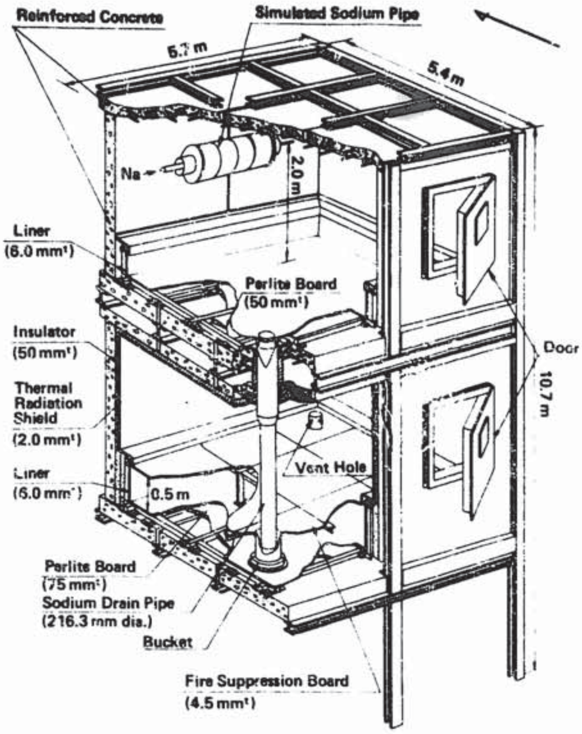


Fig. 8 Bird's-eyes View of SOLFA−1 for Run-D 2

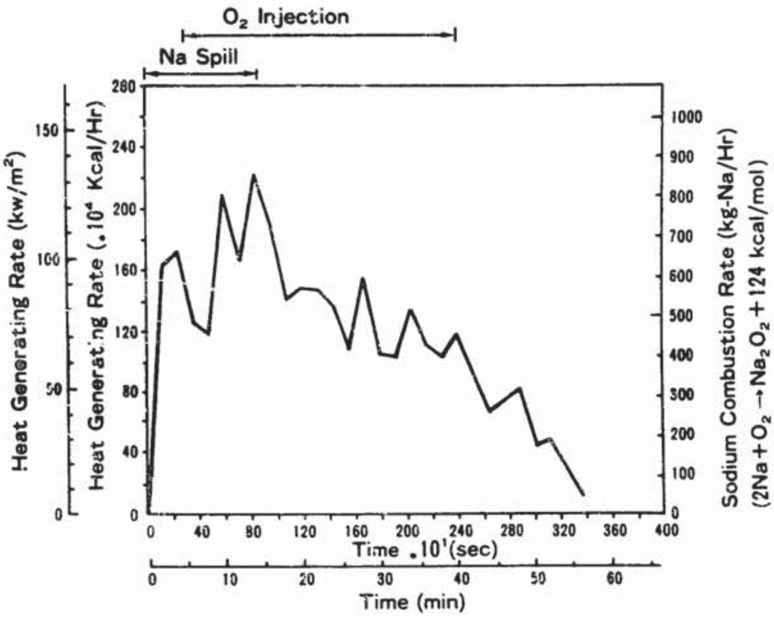


Fig. 9 Heat Generating Rate and Sodium Combustion Rate during the Test (Upper Cell)

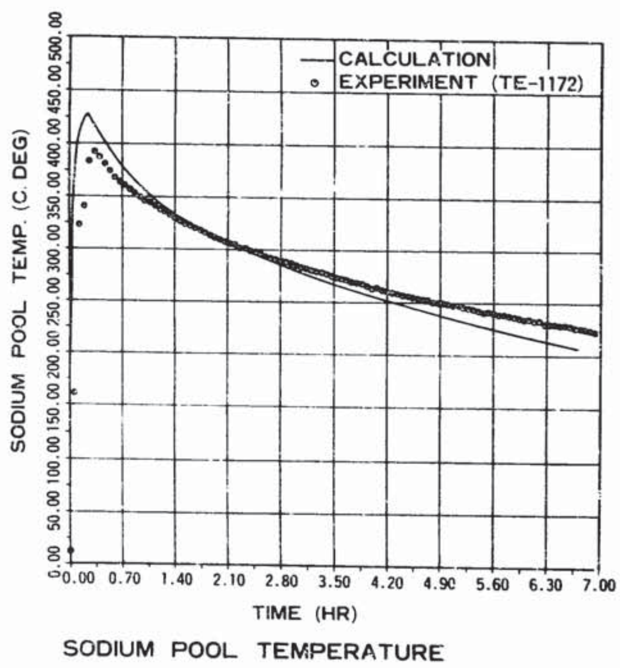


Fig.10 Sodium Temperature Drop in Smothering Tank -Comparison between code and test results-

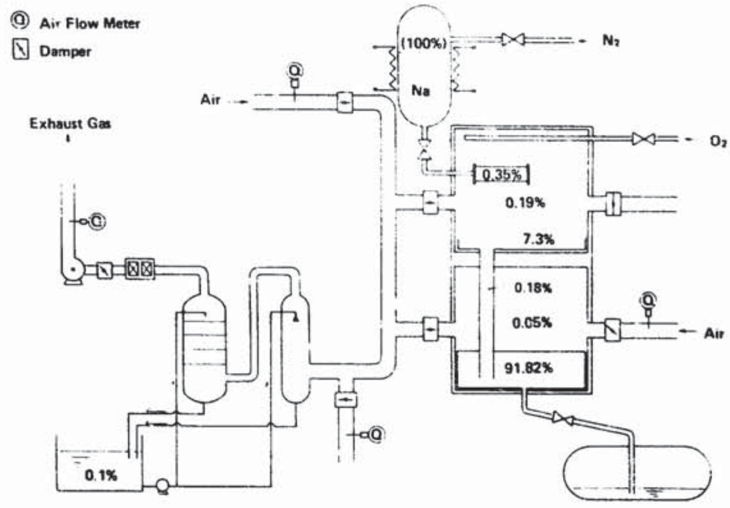


Fig.11 Post-Test Sodium Distribution in Test Rig

## 4. Consequence of Sodium Aerosols Deposition on Components and Electrical Instruments

A sodium fire releases aerosols such as sodium oxide, sodium peroxide, and sodium hydroxide that are chemically reactive. Their deposits on the reactor components and the electrical instruments may cause problems. In addition, the aerosols may be taken into an air cooler for a decay heat removal and may cause a decrease in its heat exchanging capacity.

To investigate such possible problems associated with the aerosol deposits, performance tests of the electrical instruments and the reactor key components ; the various monitors, cables, cable connectors, a pony motor of the mechanical pump,and an air cooler, have been conducted for the test duration from a day to several months with aerosol concentration from 0.1 to 1.0g/$m^3$.

In regard to the electrical instruments, reduction in their insulating resistance due to penetration of sodium hydroxide deposits was suspected. But, the test results revealed no reduction, except for those whose sealings or sealing materials were inadequate. The former result is probably attributed to the fact that sodium hydroxide changed to sodium carbonate after its reaction with carbon dioxide in air(8). For the connectors, test results revealed no need for the special measure against aerosols migration into them. For pony motor, it continued to work, although aerosols deposited in its cooling duct.

For the air cooler, the test has been conducted by supplying sodium aerosols at the concentration of 0.1 g/$m^3$ for 24 hours. Then, changes in apparent heat transfer coefficients between the heater tubes and the flowing air were measured. Figure 12 shows a relationship between the decrease in average heat transfer coefficient and the average weight of aerosol deposits on the tube. It is seen that the decreasing rate is saturated at larger deposits weight than a certain value, i.e.,50 g/tube.

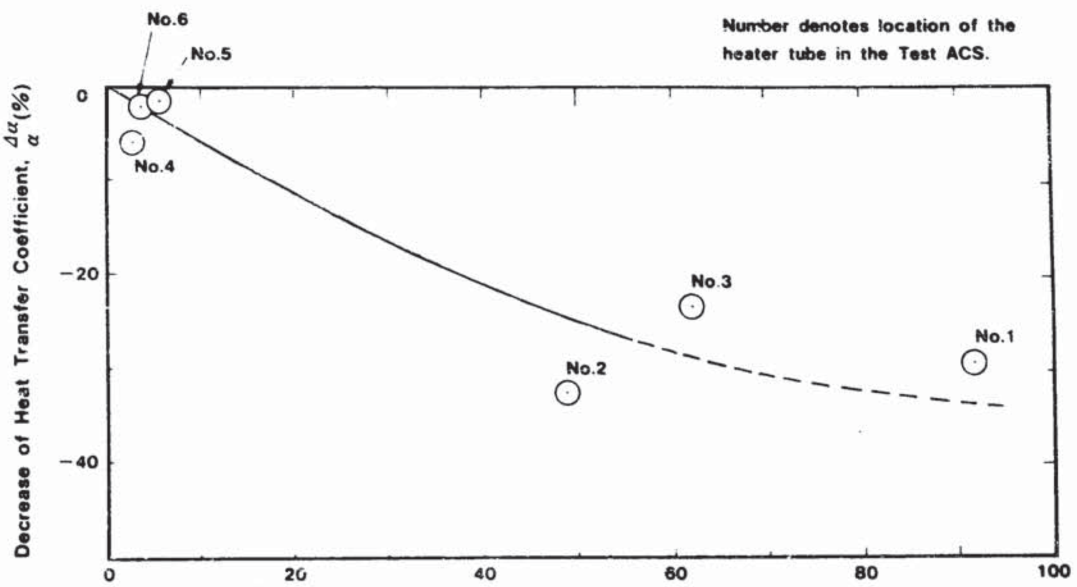


Fig.12 Decrease in Heat Transfer Coefficient due to Aerosol Deposition

5.Conclusions

1) With the sodium piping equipped with jackets , flow pattern of a leakage sodium becomes a downward column that generates smaller combustion heat than a spray.

2) Combustions of a pool can be reduced effectively, for example to be less than 3%, simply by reducing its opening ratio to be 1%. A flow of spilled sodium on the inclined floor liner and in the drain piping is not blocked by the precipitates of the combustion products on their surfaces. Flow blockage of the drain piping due to sodium freezing dose not happen. Transient thermal conduction from a spilled hot sodium to the floor concrete through steel liner can be evaluated with reasonable accuracy by the multi-dimensional thermal conduction code.

(3) A large-scale accident simulation test starting from a sodium leak and ending by self-extinguishment of the fire in the smothering tank using a newly developed fire mitigation system revealed that combustion rate of mixed fire; column and pool, at the beginning of a leak is only 1.1 to 1.3 times of that of a pool fire alone. It was also made clear that more than 90% of a spilled sodium can be drained and recovered smoothly in the smothering tank without generating excess combustion heat and sodium aerosols.

(4) Consequences of sodium aerosols deposits on the key electrical instruments showed that the deposits do not cause electrical problems as far as their sealings and sealing materials are adequate. No special measure against aerosols migration is necessary. Although aerosols deposited in the cooling duct, a pony motor continued to work properly. Decreasing in heat exchanging capacity of an air cooler due to aerosols deposition saturated beyond a certain amount of the deposits weight on the finned tube.

Acknowledgment

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