Sodium Leak at Monju (II)
- Sodium leak, burning and aerosol behavior -

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Abstract

The amount of leaked sodium was estimated as approximately 640 kg during the 220 minute leak. The ventilation duct and the walkway grating under the leak site were severely damaged by Na-Fe- O reaction, but the floor liner and the concrete wall were not. A total 100 kg of sodium aerosol was deposited in the reactor auxiliary building and 230 kg was released to the atmosphere. The sodium concentration at the site boundary was calculated as 0.05 mg/m^3,NaOH equivalent, which was low in comparison with the permitted level of 2 mg/m^3. The tritium quantity released was estimated as 4.4×10^7 Bq, which was about 0.03 % of the average released value per month for a LWR.

1. Introduction

A sodium leak occurred in one of the secondary sodium circuits of the prototype fast breeder reactor, Monju on December 8, 1995. In the paper we describe the outline of the incident and discuss the effects of the sodium fire and combustion products.

2. Estimation of sodium quantity leaked

The estimation of the quantity of leaked sodium was based on the comparison of changes in the sodium overflow tank levels between the three secondary loops (C and A, B), using recorded MIDAS(Monju Integrated Data Acquisition System) data. In addition to the overflow tank, the level changes in the pump, pump overflow column, evaporator and super-heater were also taken into account for the calculation, as shown in Fig.1. The constant leak rate of around 180 kg/hr(50g/sec) was obtained by the least squares method for the period prior to the start of the drain as shown Fig.2. There was no marked change in the leak rate before and after the reactor trip.

It was estimated the leak stopped at 23:27 by the analysis of the drain rate and drain mode of the loop C from the MIDAS data, as shown in Fig.3. The duration of the leak was 220 minutes from 19:47 to 23:27.

The total amount of sodium leaked was calculated as 640 ± 42 kg, considering the sodium pressure at the leak site during the drain.

3. Effects of leaked sodium on structural materials and components

The trickle of burning sodium, with some small splash drops, fell on the floor liner after contact with the ventilation duct and the walkway grating. The cone of sodium drops and the zone affected by sodium burning are illustrated in Fig.4. The liner was not significantly damaged, but the duct and grating were severely damaged by high temperature Fe-Na-O reactions.

From metallurgical microstructure examinations, the maximum temperature at the grating(3.0 mm thick steel, which had a 42 cm x 39 cm damaged hole) was estimated to be 1000-1150°C.

The maximum temperature of the floor liner was 650-750°C. The liner(6.1-6.2 mm, steel) was reduced in thickness by 0.5-1.5 mm.

The concrete wall was discolored and dehydrated locally by contact with the burning sodium and combustion products, but the structural strength and shielding properties were not influenced by the leak.

Concepts for Fe-Na-O reactions are illustrated in Fig.5.

4. Sodium leak and combustion behavior

The output of the failed thermocouple during the initial period of the leak is shown in Fig.6, compared with that of the sodium leak experiment, conducted at Oarai Engineering Center of PNC. The temperature variation of the thermocouples between Monju and leak experiment agrees well, which indicates;

- The sodium leaked in the thermocouple well decreased the electric insulation between compensation wires which were short-circuited.(①-④)
- The leak rate was very small during the first 35-40 seconds and then increased to a constant rate of 50 g/sec within a few minutes.

The sodium chemical compound deposits(about 310 kg-equivalent Na metal) were formed underneath the site of the leak, mainly on the floor liner as shown in Fig.7. The main chemical composition of the compounds was Na_2O(~90 wt%). The sodium oxide deposits of the floor liner seemed to protect the liner from high temperature chemical corrosion reactions involving leaked sodium.

The kidney-shaped sodium deposit on the floor shown in Fig. 7 is explained as a result of changes of sodium fall path when the duct was damaged.

5. Sodium aerosol diffusion behavior

(1) Fire alarm sensors and sodium leak detectors

The fire alarms actuated by the aerosol are shown in Fig 8 together with the ventilation system layout for the reactor auxiliary building(loop C). The ventilation system continued to operate during the leak. The first fire alarm was actuated after 20 sec. from the start of burning and a total of 66 fire alarms were actuated during the leak. During this time there were two periods of 15 to 30 minutes without additional alarms.

The signals of sodium leak detectors(Radiative Ionization Detector, RID) are shown in Fig.9. The figure shows three peaks of aerosol concentration in most detectors. The first peak was attributed to the initial increase of sodium dispersion after contacting with the duct surface. The second peak was caused by the increase of pool burning area and subsequent increase of aerosol returned through the ventilation duct and by the decrease of aerosol returned due to the closure of the fire prevention damper in the exhaust duct, as described later. The third one corresponded to the stop of ventilation system and consequent increase of aerosol in the building.

(2) Aerosol diffusion in the auxiliary building

The sodium aerosol behavior estimated from the sequence of fire alarm and RID signals is as follows;

- Part of the aerosol combustion products released to the outside atmosphere through the ventilation exhaust duct were returned to the reactor auxiliary building through the neighboring ventilation inlet duct of loop C. This resulted in wide spread aerosol diffusion in the loop C area.

The aerosol ratio of returned/released for C loop ventilation system was calculated as about 0.2 from three dimensional diffusion analysis. The amount of returned aerosol was at most ~5% of the total deposited aerosol in the building.

- A fire-prevention damper installed in the ventilation exhaust duct in the leak room was automatically closed at approximately 70 minutes after the leak started. The closure of the damper stopped the exhaust of the aerosol and increased the internal pressure of the loop C rooms, which resulted in the aerosol diffusion outside the loop C area.

  From the RID signals, the aerosol concentration in the room where sodium was burning appeared to be gradually decreased after the damper closure. This showed the reduction of sodium burning and aerosol generation when the ventilation of the room was stopped.

- After the ventilation system stopped due to the sodium drain(Na low level alarm in SG tank automatically actuated the stop signal for the ventilation), the aerosol diffused mainly by natural convection.

(3) Aerosol deposition in the reactor auxiliary building

The distribution of the aerosol on the reactor auxiliary building is shown in Fig. 10. The total amount of sodium aersol deposited in the reactor auxiliary building is estimated as 100 kg and most of them have been recovered. The aerosol deposition was greatest(40 - 80 g/m^2) on the floor of the room where the sodium leaked and burned(A-446). It exponentially decreased with the distance from the room. The amounts of aerosol on the walls or ceilings were about 1% of those of floors.

- Effects of aerosol on electrical equipment and components

  Checks of the electrical boards and control panels were conducted after the cleaning of the rooms in order to investigate the effects of aerosol on electrical equipment and components. The aerosol deposition was about 4.3 g/m^2 in the control panels of room A-445. No marked effects have been found up to now on the electrical equipment and components except for the room with sodium leak and the neighboring room.

(4) Aerosol released to the atmosphere

The total amount of aerosol released to the atmosphere was estimated as approximately 230 kg from the difference in leaked and recovered sodium weights in the reactor auxiliary building. No significant increase in sodium content was detected in the soil samples around the reactor buildings.

6. Computer analysis of the incident

- Sodium burning analysis

Sodium burning analyses are being performed reflecting the results of sodium burning experiments simulating Monju incident at Oarai Engineering center, PNC. The outline of the results will be described in other papers.

- Atmospheric diffusion analysis

A steady state atmospheric diffusion analysis was performed using a three dimensional diffusion code, FLUENT. This considered the weather condition on the day, and the result is shown in Fig.11. The maximum concentration of the aerosol at the site boundary was calculated as 0.03 mg/m^3, equivalent of sodium metal(0.05 mg/m^3 NaOH equivalent), which was low in comparison with the permitted level of 2 mg/m^3 NaOH which is recommended as a criteria level for working conditions in most countries.

The total amount of tritium leaked from the secondary sodium circuit was 5.4×10^7 Bq ,of which 1.0×10^7 Bq was found in the sodium combustion products recovered in the reactor auxiliary building. The value of 4.4×10^7 Bq released to the atmosphere in the accident corresponded to about 0.03% of the average value released per month for a LWR as reported by the United Nation, Science Committee in 1993.

- Circulation analysis

Part of the aerosol after release to the outside from the exhaust duct returned into the building through the neighboring inlet ventilation duct of loop C. The return ratio under the wind velocity of 11m/sec. at the time was calculated as about 20 %, using three dimensional thermo-hydraulic code, STREAM, as shown in Fig. 12..

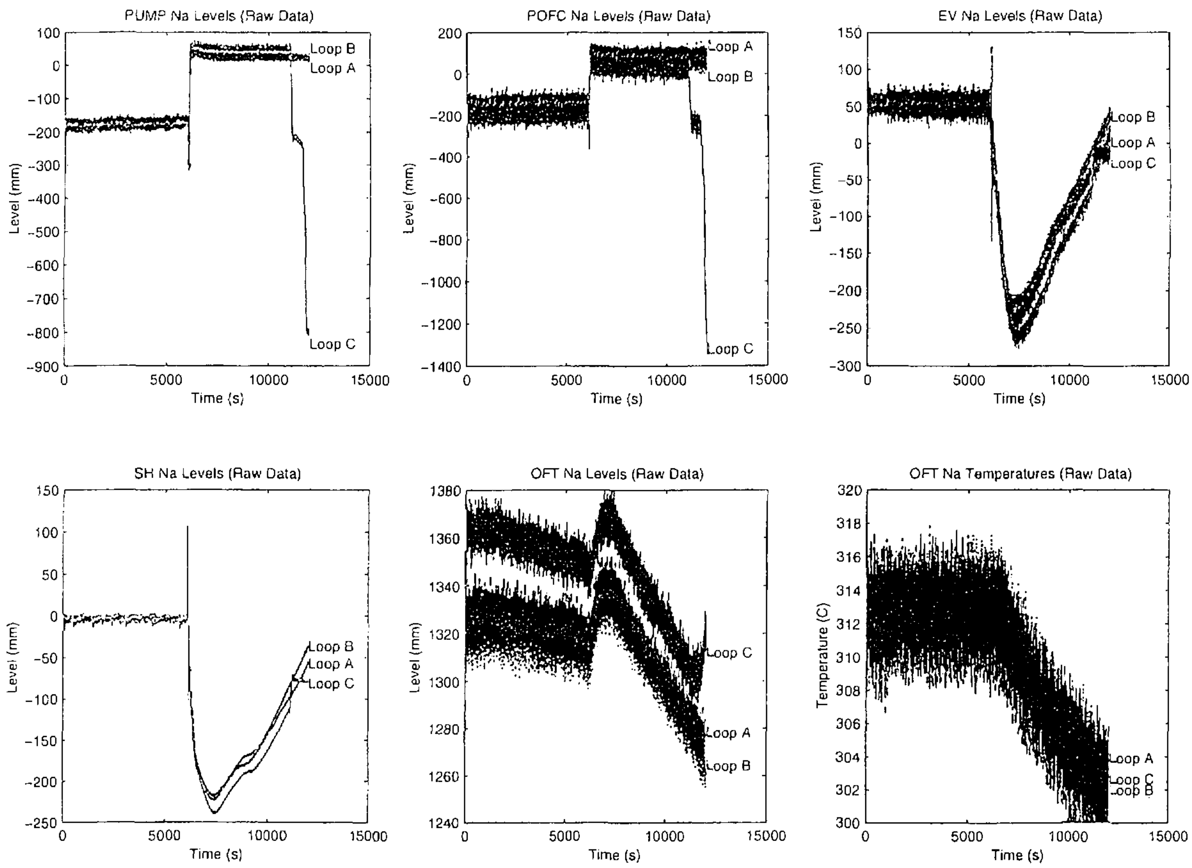


Fig.1 Sodium level changes during leak.

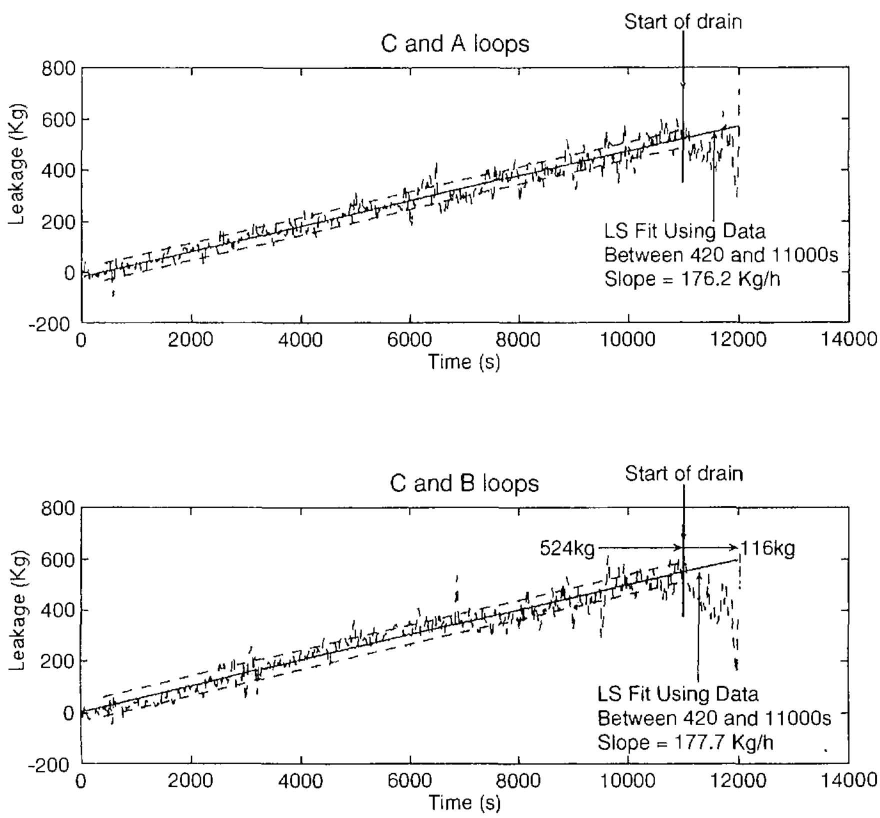


Fig.2 Least-squares fit for calculation of sodium leak quantity.

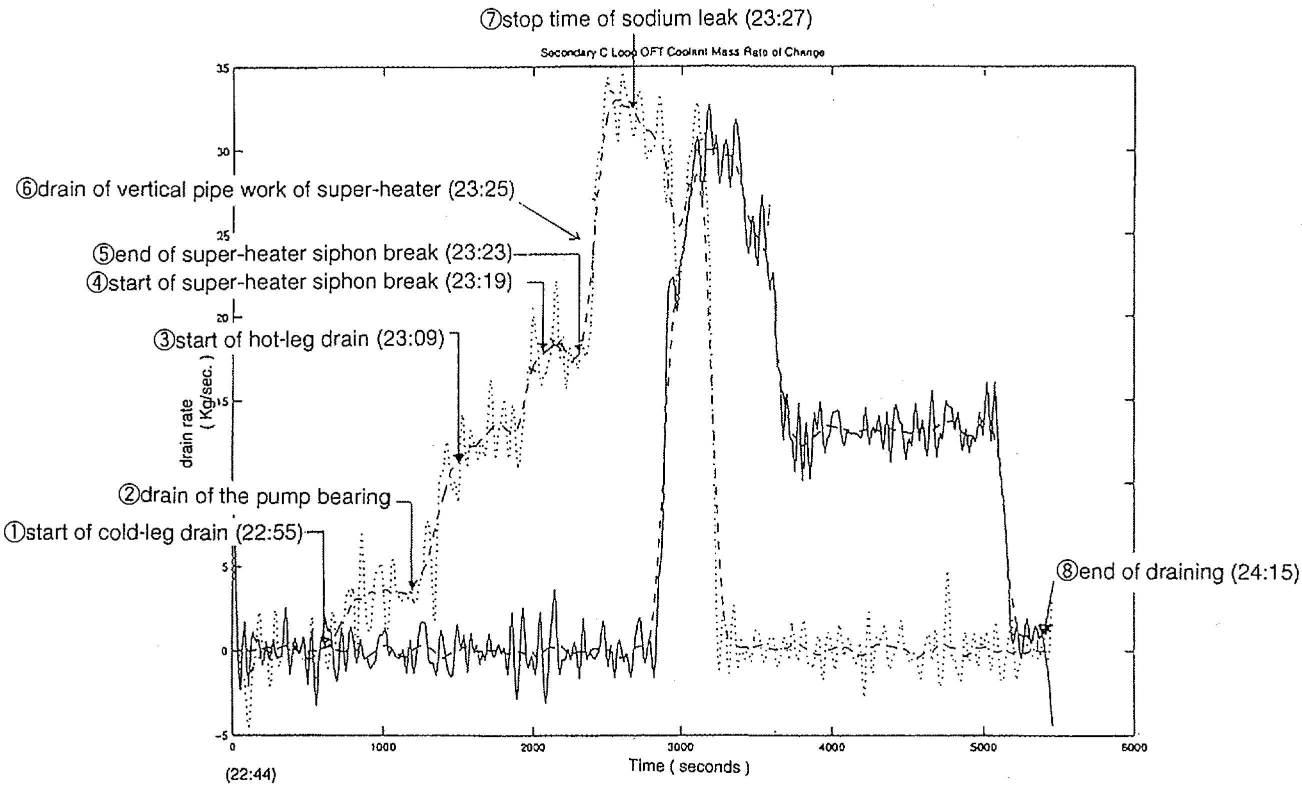


Fig.3 Sodium over-flow tank level changes during draining

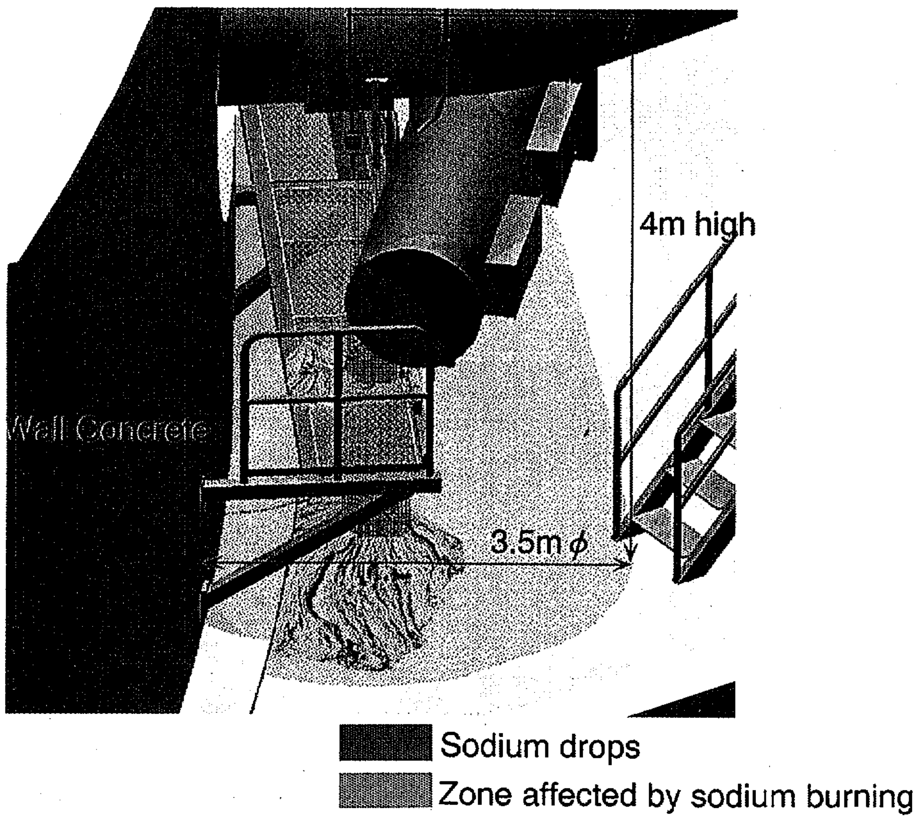


Fig.4 Sodium drops and the zone affected by sodium burning

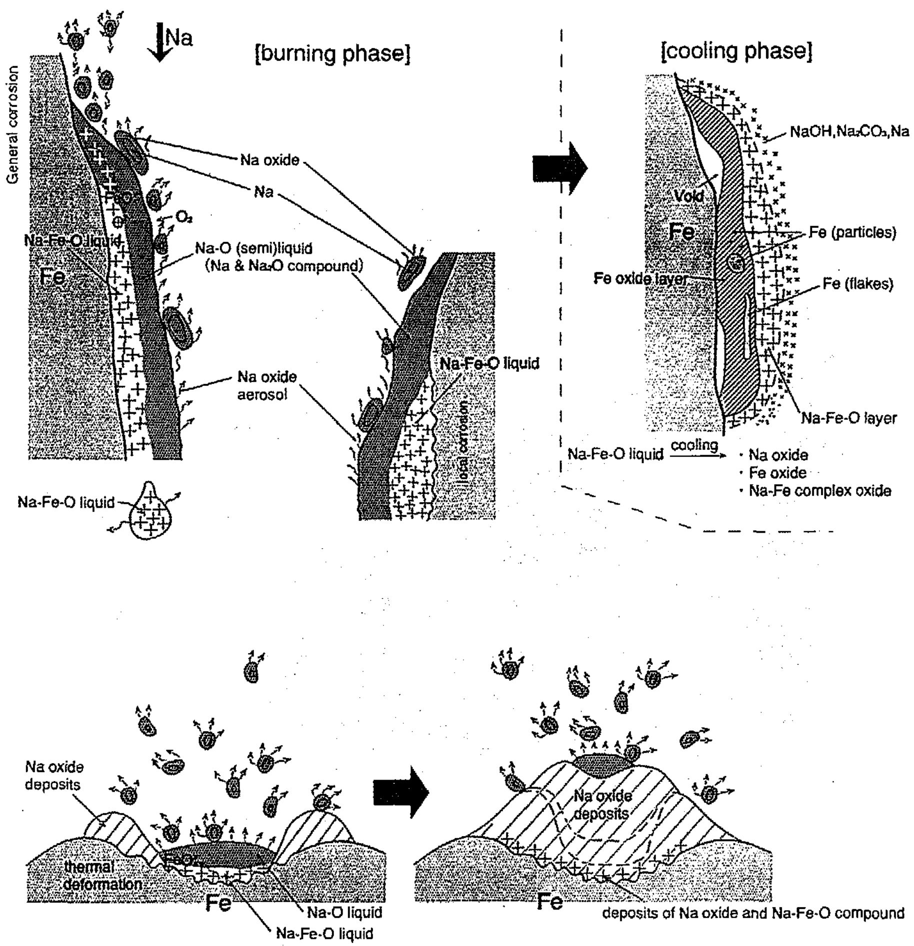
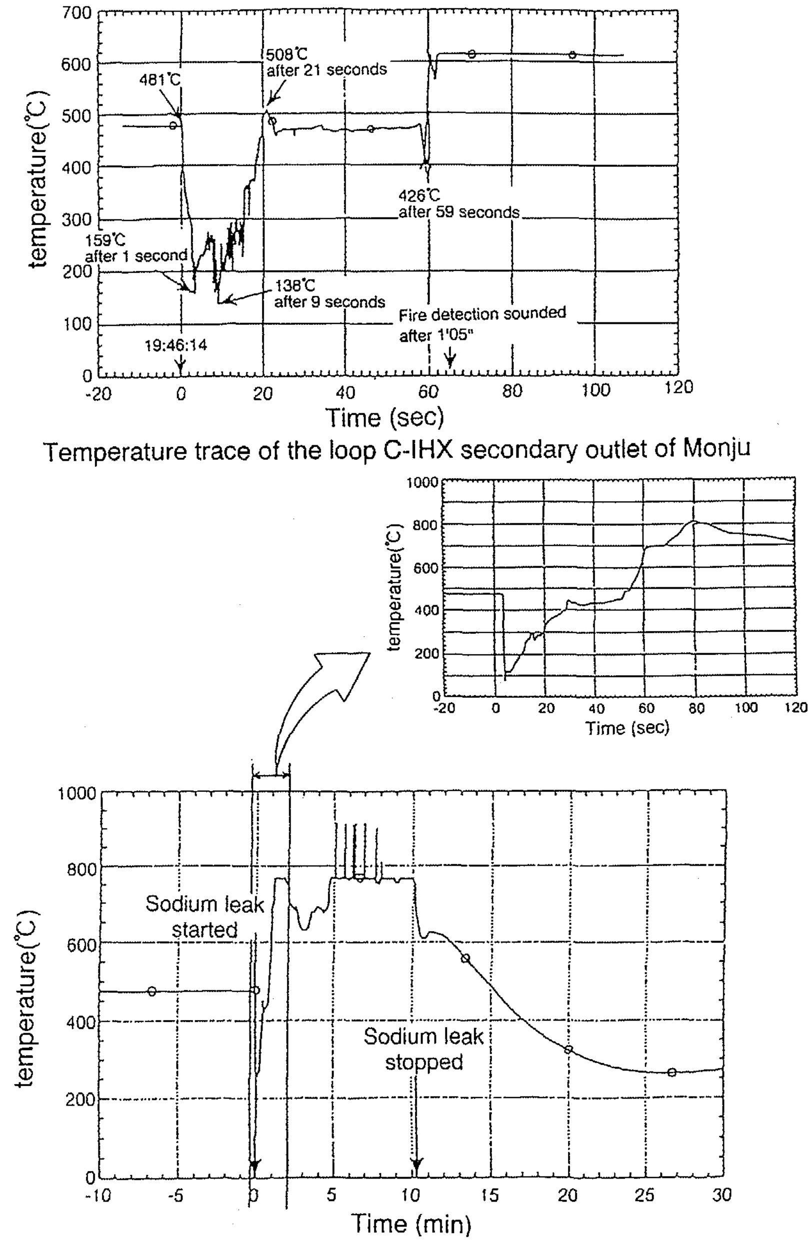


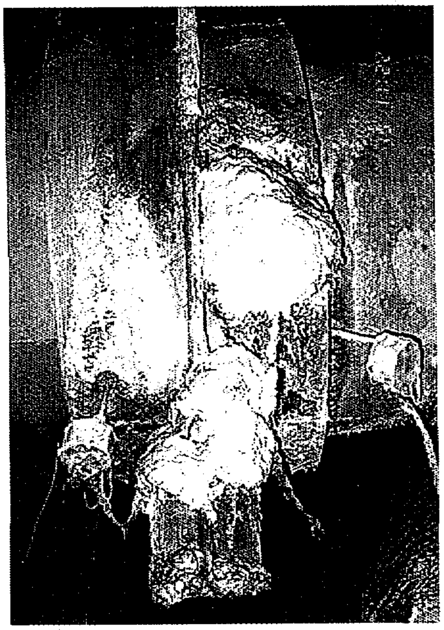
Fig.5 Concepts for high temperature chemical reactions (corrosion).



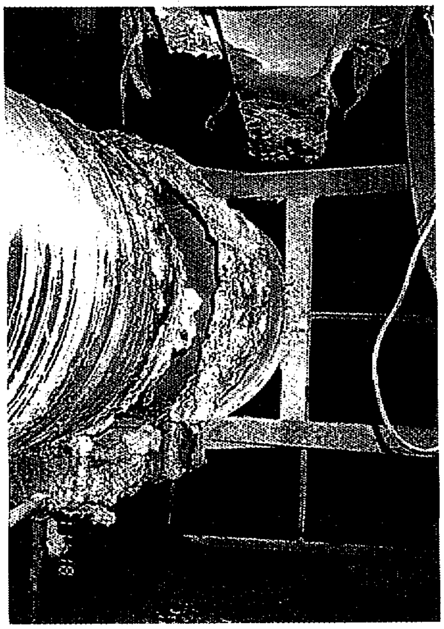
Temperature trace of the loop C-IHX secondary outlet of Monju

Temperature trace of the sodium leak experiment

Fig.6 Comparison of temperature indications with the sodium leak experiment

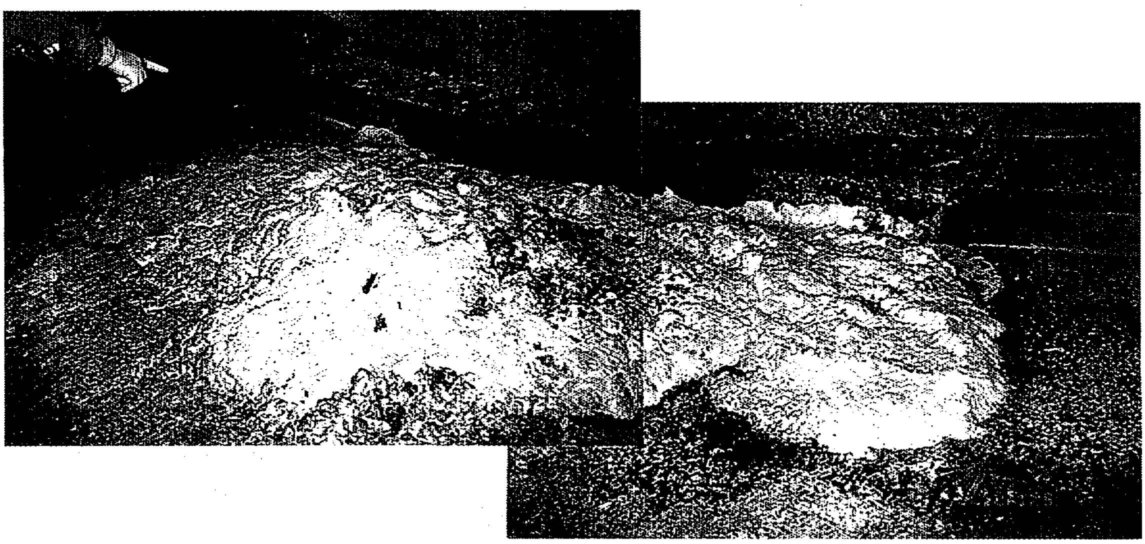


Thermocouple box and pipe hanger



Ventilation duct

Walkway grating



Floor liner

Fig.7 Sodium chemical compounds formed under neath site of the leak.

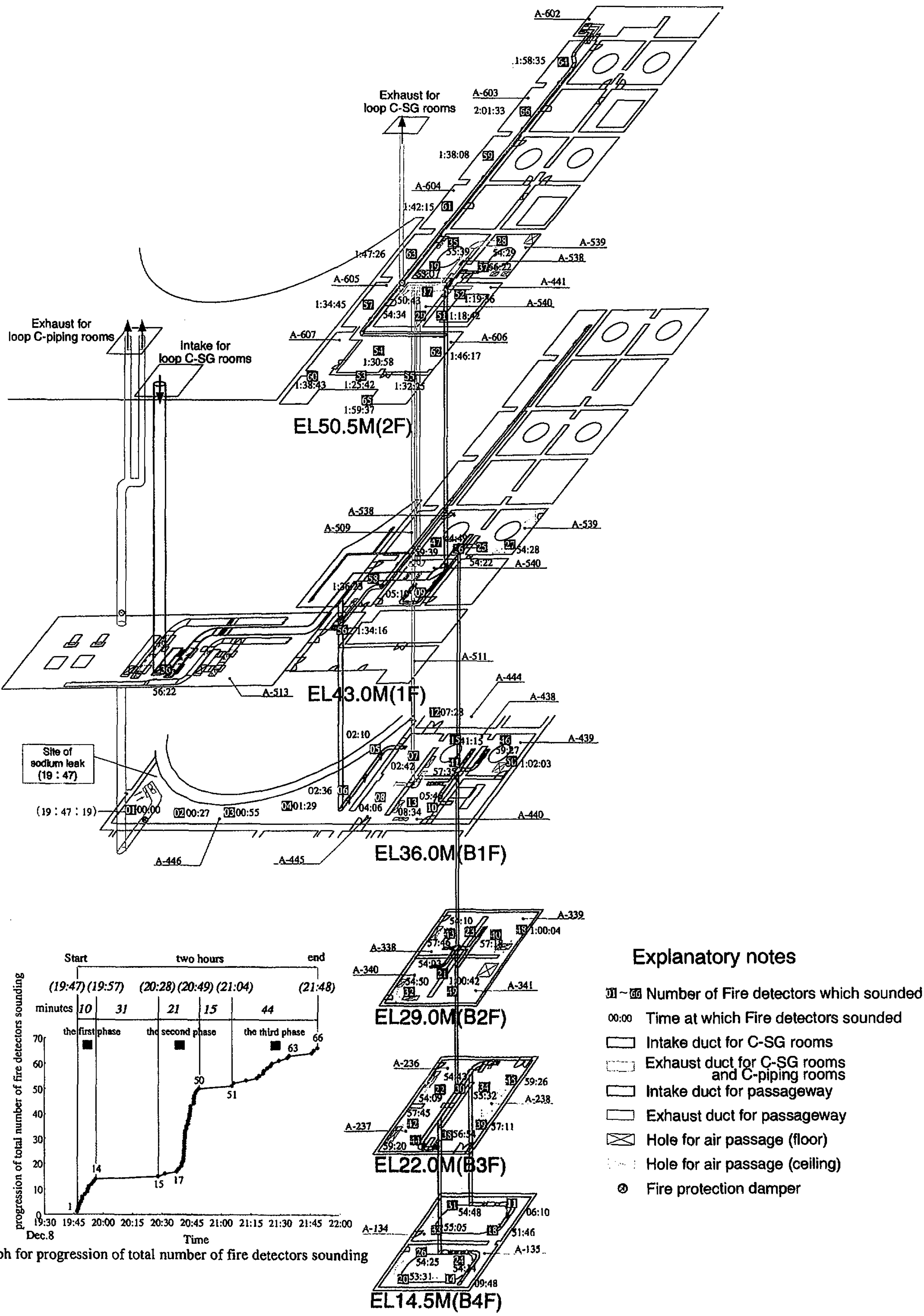


Fig.8 Number of fire detectors which sounded and arrangement of ventilation ducts.

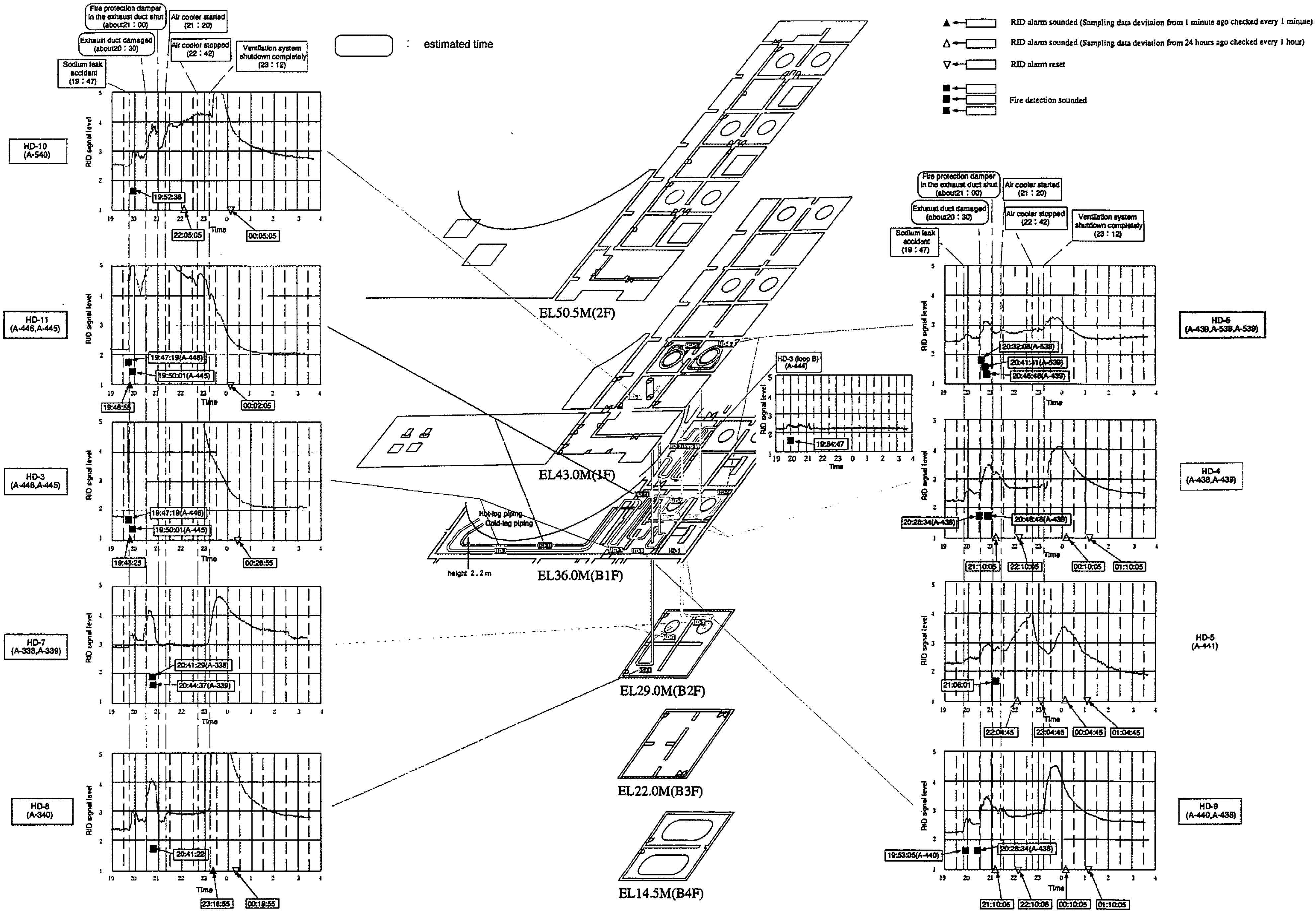
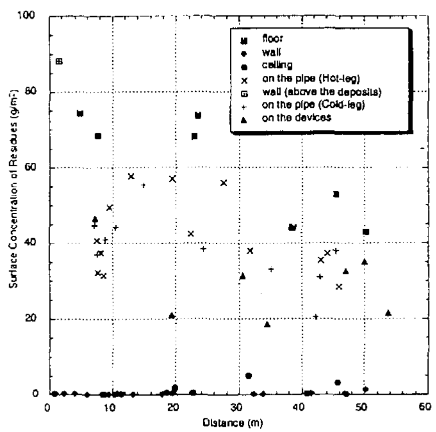
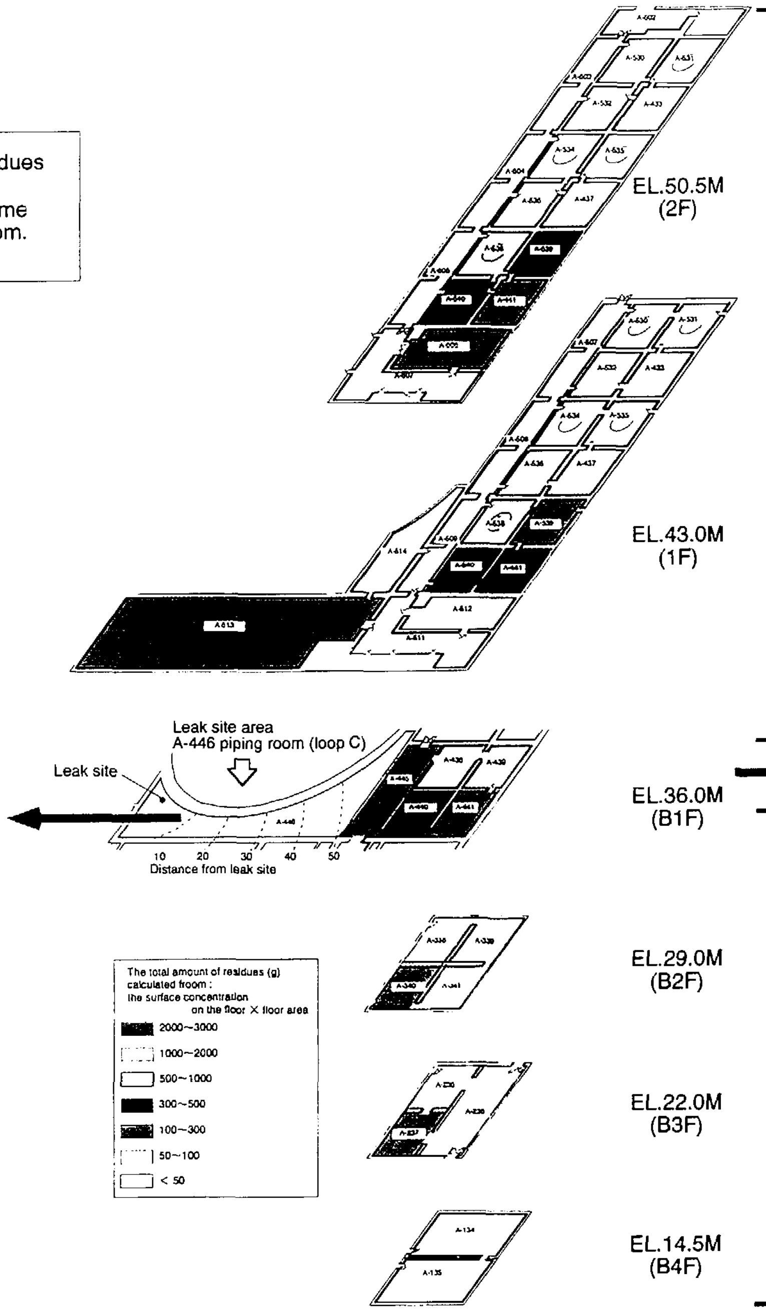


Fig.9 Signals of sodium leak detection system (RID)

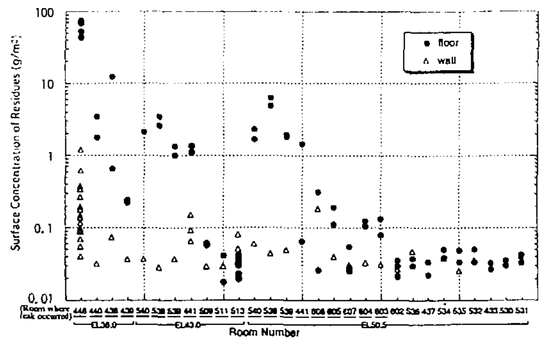
Area affected by the distribution of aerosol residues is about 5.580m^2 in total.
In the chemical analysis of aerosol residues some NaOH and Na_2O was detected in the piping room.
Elsewhere the deposits were of Na_2Co_3.



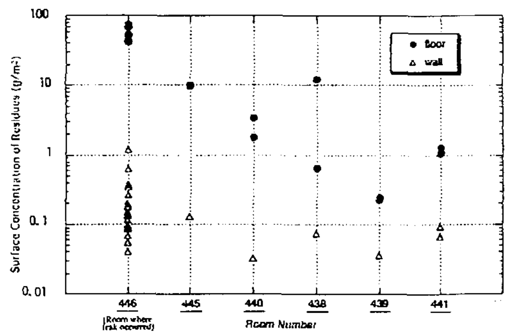
Surface concentration of sodium aerosol residues in piping room (loop C)



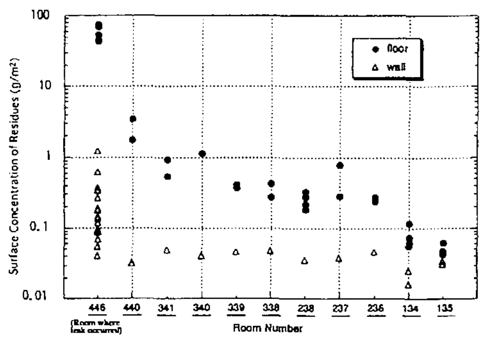
Surface concentration of aerosol residues in each room



Surface Concentration of aerosol residue in rooms above the level of the piping room (loop C)



Sur face concentration of aerosol residue in rooms on the same the level as the piping room (loop C)



Surface concentration of aerosol residue in rooms below the level of the piping room (loop C)

(The rooms in which alarms sounded are underlined)

Fig.10 Distribution of sodium compounds in the building

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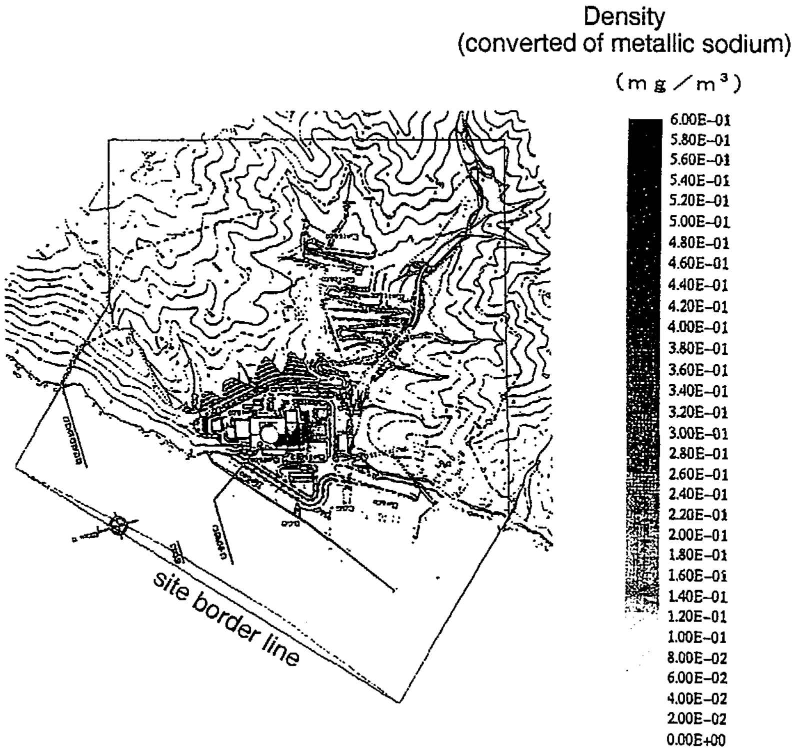
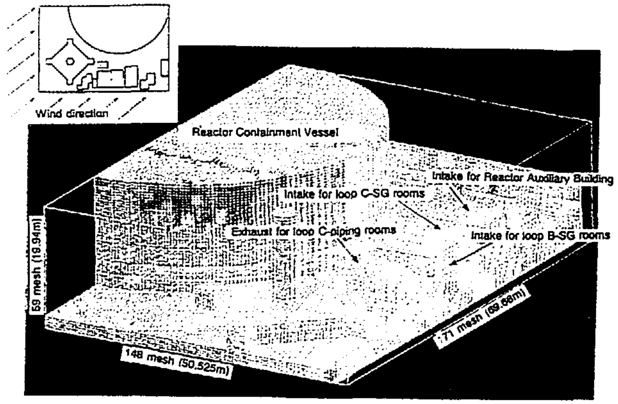
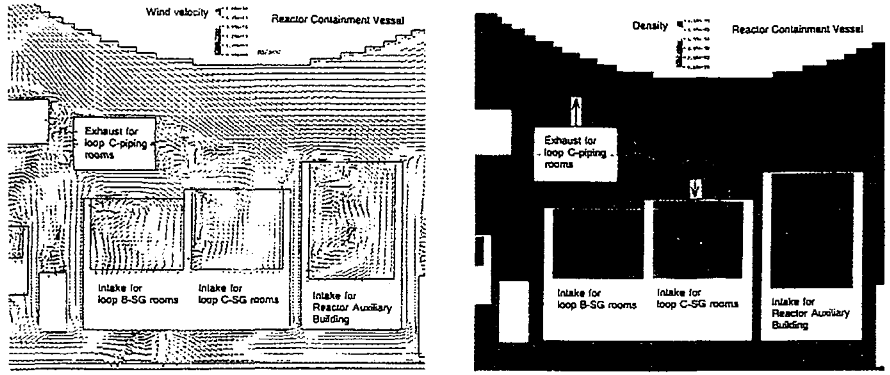


aerosol release rate	: 25g/sec
chemical form	: Na_2CO_3
aerosol density	: 0.3g/cm^3
aerosol diameter	: 10 μm
aerosol release velocity	: 4.6m/sec
wind direction	: NNW
wind velocity	: 11m/sec

Fig.11 Sodium aerosol density at the Monju site



(a) analysis model



aerosol flow velocity   aerosol flow density

Ventilation system	Return flow rate (%)
Intake for loop C-SG rooms	20
Intake for loop B-SG rooms	1
Intake for Reacter Auxiliary Building	2

aerosol from rooftop return flow rate

(b) Result (wind velocity 11m/sec)

Fig.12 Analysis of sodium aerosol on the rooftop