Preliminary Test for Full Scale Compartment Fire Test (Lubricant Oil Fire Test: Part 1)

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ABSTRACT

This study reports on two kinds of fire tests: one kind intended for the purpose of understanding the burning characteristics of turbine oil in a free space and a second kind intended for elucidating the fire characteristics in a compartment. The latter were carried out using methanol and investigated how the ventilation pattern and the position of the fire source affect fire behavior.

In the former, five different sized oil pans (0.1 - 4.0m^2) were utilized and the burning rate, radiation heat flux, etc. were measured. Test results showed no difference in characteristics for the two turbine oils VG32 and VG56. Empirical equations for the burning rate and radiant emittance of turbine oil were obtained from the data.

In the compartment tests, the burning rate, room temperature and radiation heat flux were measured in a 6x7x5m compartment constructed of fire resistant board. They were determined for a total of nine different combinations of three ventilation patterns and three positions of the fire source, using methanol in an 0.5m^2 oil pan. The test results showed that the room temperature in a fire is related to the ventilation pattern caused by the presence of openings such as doors, while the burning rate and radiation heat flux are not significantly related to the ventilation pattern or the location of the fire source.

INTRODUCTION

Although turbine oil is used as lubricant in many industrial plants, its burning characteristics, especially in a confined space or a compartment, are not well-known. To clarify these burning characteristics, tests were conducted in oil pans of five different sizes which were filled with several liters of turbine oil (VG32 and/or VG56) as a fire source to measure the burning rate, flame height, radiation heat flux, etc. Compartment fire tests were also carried out to investigate how ventilation patterns (i.e. locations of air intake and exit) and position of the fire source affect fire behavior. Nine cases were tested in a fire resistant board compartment using methanol in a burning oil pan as the fire source.

BURNING CHARACTERISTICS OF TURBINE OIL IN A FREE SPACE

Test Conditions

To obtain the burning characteristics of the turbine oil, fire sources were made using several liters of turbine oil in steel pans of five different sizes (0.1, 0.5, 1.0, 2.0 and 4.0m^2). The tests were carried out in a laboratory to eliminate wind effects. Light oil and methanol were also used as fuel sources.

Test Results and Evaluation

Table 1 compares the individual burning characteristics. Since the characteristics of turbine oil VG32 in the 0.5m^2 pan were the same as that of turbine oil VG56, further tests were carried out with VG32. All the measured values increase with increases in the oil pan size.

Estimation of turbine oil VG32 burning rates. The burning rate of combustible liquid varies with the oil pan diameter. With larger diameters, the burning rate is controlled by the radiation heat flux and approximately given by the following equations.[1)]

$$V = V_\infty (1 - e^{kD}) \tag{1}$$

where V : Burning rate of "D" meter oil pan (mm/min)
V_∞ : Burning rate with no effect from oil pan size. (Burning rate of a sufficiently large oil pan) (mm/min)
D : Oil pan diameter (m)
k : Constant (m^{-1})

and

$$V_\infty = \frac{0.076\ Hc}{Hv + \int_{t}^{t_B} Cp \cdot dt} = \frac{0.076\ Hc}{Hv + \overline{Cp} \cdot \Delta t} \tag{2}$$

Table 1 Summary of Results

Fuel Source	Oil Pan size (m^2)	Burning Rate $kg/m^2 \cdot min$ (mm/min)	Radiation Heat Flux (kw/m^2) at 3m	Radiation Heat Flux (kw/m^2) at 5m	Flame Height (m)	Flame Width (m)	Calorific Heat (kw/m^2)
Turbine Oil VG32	0.1 (φ0.36m)	0.5 (0.6)	0.18	0.058	0.8	0.3	370
	0.5 (φ0.80m)	1.2 (1.4)	1.75	0.76	2.0	0.8	870
	1.0 (φ1.13m)	1.7 (1.9)	4.07	1.98	2.5	1.0	1160
	2.0 (φ1.60m)	2.0 (2.3)	10.1	4.07	3.8	1.3	1400
	4.0 (φ2.26m)	2.2 (2.5)	17.2	6.86	4.3	2.1	1500
Turbine Oil VG56	0.5 (φ0.80m)	1.2 (1.4)	1.75	0.76	2.0	0.8	870
Light Oil	0.5 (φ0.80m)	1.5 (1.8)	1.98	0.81	1.8	0.8	1070
	2.0 (φ1.60m)	2.2 (2.6)	10.1	4.07	3.8	1.7	1500
Methanol	0.5 (φ0.80m)	1.4 (1.6)	0.41	0.18	1.3	0.6	440

where V_∞ : Burning rate of a sufficiently large oil pan (mm/min)
Hc : Calorific Power (kJ/kg) = 43,000 (kJ/kg)
Hv : Latent heat (kJ/kg) = 128 (kJ/kg)
Cp : Specific heat (kJ/kg·K)
t_B : Boiling point (K) = 645(K)
t : Initial oil temperature (K) = 293(K)
$\overline{Cp}$: Average specific heat in the temperature range between the initial oil temperature and the boiling point. (kJ/kg·K) = 2.52 (KJ/kg·K)
Δt : Temperature difference between oil temperature and boiling point. (deg) = 352 (deg).

As the burning rate of turbine oil VG32 of the sufficiently large pan (V_∞) is estimated to be 3.22 mm/min from the above equations, the burning rate of turbine oil can be expressed as Equation (3).

$$V = 3.22\ (1 - e^{-0.714D}) \qquad (3)$$

A comparison of the burning rate between Equation (3) and observed data is made in Fig. 1.

Estimation of the radiant emittance. If the flame is considered as a gray body, the radiation heat flux at any point is expressed by the equation given below.

$$E = \phi \cdot \varepsilon \cdot \sigma \cdot T^4 \qquad (4)$$

where ϕ : Shape factor of flame
ε : Emissivity of flame
σ : Stefan-Boltzmann Constant (5.77×10^{-11} kW/m^2·K^4)
T : Flame temperature (K)

Assuming the shape of the flame is cylinder, the shape factor ϕ is expressed by the following equation.[2]

$$\phi = \frac{1}{\pi Y}\tan^{-1}\cdot\left(\frac{X}{\sqrt{Y^2-1}}\right) + \frac{X}{\pi}\cdot\left[\frac{(A-2Y)}{Y\cdot\sqrt{AB}}\cdot\tan^{-1}\left(\sqrt{\frac{A}{B}\cdot\frac{(Y-1)}{(Y+1)}}\right) - \frac{1}{Y}\tan^{-1}\left(\sqrt{\frac{(Y-1)}{(Y+1)}}\right)\right] \qquad (5)$$

where $A = (1+y)^2 + X^2$
$B = (1-y)^2 + X^2$
$X = 2H/D$
$Y = 2L/D$
H = Flame height (m)
D = Flame Diameter (m)
L = Any point from the center of the flame (m)

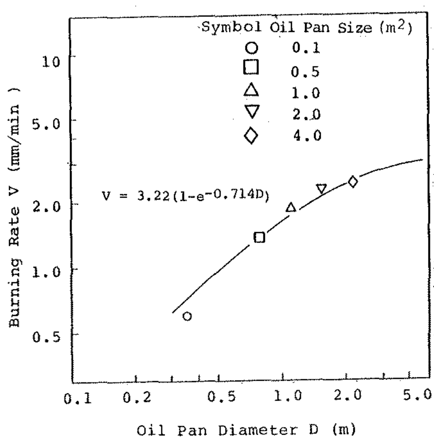


Fig. 1

Comparison of Burning Rate between Observed Data and Equation (3)

The calculated results of the shape factor obtained from Equation (5) are shown in Fig. 2.

The radiant emittance Rf can be calculated by using the radiation heat flux and the shape factor as follows.

$$Rf = \frac{E}{\phi} \qquad (6)$$

The radiant emittance is estimated by the following equation.[3)]

$$Rf = K \cdot V \cdot Hc$$

Where K : Constant
V : Burning rate ($kg/m^2 \cdot h$)
Hc : Calorific Power (kWh/kg)

The constant K is 0.02 according to Reference 3).

Then a comparison of emittance calculated from the experimental radiation heat flux data with that calculated from the experimental burning rate is made as shown in Fig. 3. It is clear that the emittance calculated from the burning rate (experimental data and calculated results) is smaller than that calculated from the experimental radiation heat flux data. As the constant K is determined to be 0.0384, the equation for the radiant emittance is written as follows.

$$Rf = 0.0384\, V \cdot Hc \qquad (7)$$

In Summary

As a result of the nine fuel source burning tests, the following conclusions were reached.

(1) There was no significant difference in the burning characteristics including the burning rate, radiation heat flux and flame shape between turbine oil VG32 and VG56.

(2) The burning rate of VG32 was estimated to be $V = 3.22\,(1-e^{-0.714D})$ (mm/min).

(3) There was no significant difference between the turbine oil (VG32 and VG56) and light oil in terms of the flame height.

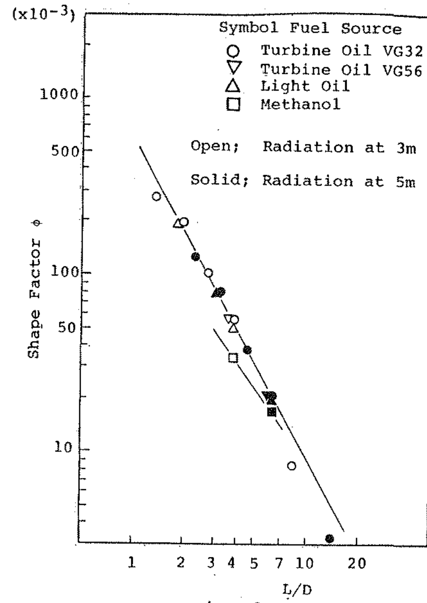
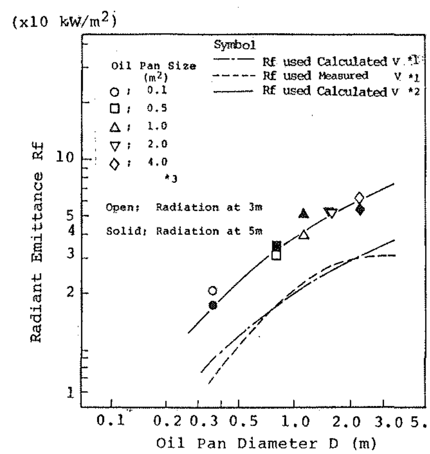


Fig. 2
Shape Factor ϕ VS. L/D



*1 $Rf = 0.02\ V \cdot Hc$
*2 $Rf = 0.0384\ V \cdot Hc$
*3 Calculated Rf by Radiation Heat Flux

Fig. 3
Radiant Emittance Rf VS. Oil Pan Diameter

(4) The turbine oil VG32 radiant emittance empirical equation is:

$$Rf = 0.0384\ V \cdot Hc\ (kW/m^2)$$

ON COMBUSTION WHEN CHANGING VENTILATION PATTERN AND LOCATION OF FIRE SOURCE IN A COMPARTMENT

Test Conditions

Test conditions, that is, the shape of the fire source, the kind of fuel, the combinations of ventilation patterns and the locations of fire source were selected as described below.

Shape of fire source. The round oil pan shown below was used as fire source in the test.

D = 0.798 m
H = 0.2 m
t = 3.2 mm

Kind of fuel. Methanol was used as the fuel because it produces little smoke, which helps in determination of the burning rate and radiation heat flux and therefore, identification of the direction of air movements induced by fire.

Test compartment. The outside dimensions of the test compartment were 6m wide, 7m long and 5m high. It was built by installing an angle steel frame on a concrete floor and attaching calcium silicate boards (t = 25 mm) to it.

Ventilation patterns. The ventilation patterns were assumed to influence the fire behavior. While paying particular attention to the location of air intake, the following three cases were examined.

Pattern I; Air is drawn naturally through the door opening ($2m^2$, 1m wide x 2m high) and exhausted forcibly in the vicinity of the ceiling on a diagonal line.

Pattern II; Without any opening in the walls, air is forcibly supplied through a duct at an elevation of 3m and forcibly exhausted in the vicinity of the ceiling on a diagonal line.

Pattern III; Air is drawn naturally through the door opening and supplied forcibly in the vicinity of the ceiling, and exhausted in the vicinity of the ceiling on a diagonal line.

Locations of the fire source. Three locations were selected for the tests.

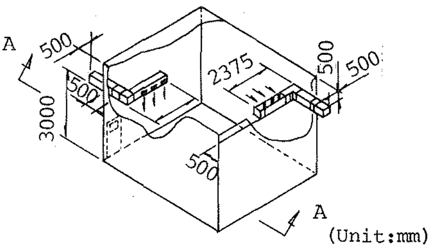
Center; at the center of the test compartment

Near wall (1); on the longitudinal center line, 1.5m from the wall on the intake side.

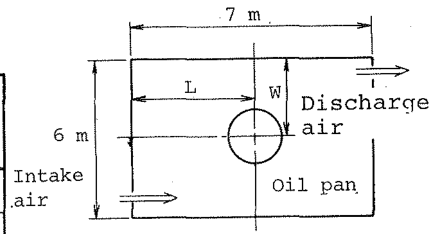
Near wall (2); at a corner, 1.5m from the wall on the intake side and 1.5m from its right wall.

Rough sketches of the ventilation patterns and locations of the fire source are shown in Fig. 4.

Ventilation Pattern / Factors (mm)	I	II	III
1. Duct size	350x350		
2. Exhaust size	300x200x3		
3. Intake size	—	300x300x3	
4. Doorway size	1,000x2,000	—	1,000x2,000



Fire source / Location (m)	Center	Near Wall (1)	Near Wall (2)
L	3.5	1.5	
W	3		1.5



A-A section

Fig. 4 Ventilation Patterns and Locations of Fire Source

Instrument layout. For instrument layout, the test room is longitudinally divided into six sections to identify spatial distributions of each measurement site in the test compartment. Sensors are arranged on a mesh in each section as shown in Fig. 5.

Data processing. For speedy processing, the data taken at a total of 130 measuring points are centrally routed to a sensor terminal for processing by a computing on data logger and personal computer. Graphs were automatically drafted by a X-Y plotter. Tests were monitored on a TV screen and burning conditions were recorded by a VTR.

Test Results

Burning rate. The burning rate was determined from weight loss of fuel using loadmeters. The results for each case are shown in Table 2.

Radiation heat flux. Figs. 6 through 8 show radiation heat flux at each position for various ratios of L/D, the linear distance between the oil pan and radiometer L to the diameter of oil pan D. The results for each case are summarized in Table 2.

Temperature and air flow velocity distributions and air flow characteristics. Fig. 9 shows the temperature and air flow distributions on the central longitudinal section for each ventilation pattern. Comparisons of temperature right above on flame and the mean temperature within the section for each case are also shown in Table 2.

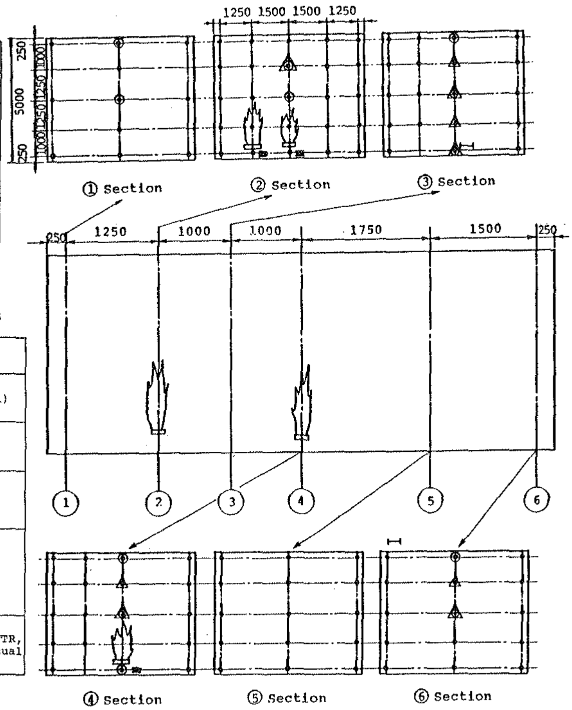
(Unit : mm)

(a) Instrumentation

Symbol	Instrument	Total
•	Thermocouple	104 sets
△	Radiometer	9 sets
○	Anemometer	12 sets
⊢⊣	Smoke density meter	2 sets
■	Loadmeter	3 sets on 50 kg range

(b). Items and purposes of measurements

Measuring Item	Purpose	Instrument
Temperature	To study temperature distribution in room	CA (chromelalumel) thermocouples
Air flow Velocity	To study the flow in room induced by burning	Pito-tube anemometer
Radiation Heat Flux	To understand the effect of radiation heat flux from burning flame on the room boundary	Radiometer
Burning rate	To investigate the difference in burning rate of oil (methanol) due to oil pan location and ventilation pattern	Loadmeter
Air flow direction	To study air flow direction caused by fire	Pyrotechnics smoke, using VTR, camera and visual observation



(c) Compartment longitudinal sections

Fig. 5 Instrument Layout

Table 2 Test Results

	Ventilation pattern / Fire source location	I	II	III
Burning rate (kg/m^2)	Center	1.38	1.30	1.37
	Near Wall (1)	1.42	1.32	1.45
	Near Wall (2)	1.36	1.24	1.39
Radiation heat flux (Kw/m^2)	Center	0.98	1.19	1.20
	Near Wall (1)	1.22	1.37	1.52
	Near Wall (2)	1.23	1.01	1.42
Temperature at a typical point* (K)	Center	432	449	436
	Near Wall (1)	430	466	440
	Near Wall (2)	423	448	432
Mean Temperature** (K)	Center	417	429	414
	Near Wall (1)	416	441	422
	Near Wall (2)	407	427	412
Height of neutral zone from floor (m)	Center	1.3	1.5	1.65
	Near Wall (1)	0.5	0.5 - 0.6	-
	Near Wall (2)	1.5 - 1.6	1.5 - 1.6	1.5 - 1.6

* Temperature at a point 250 mm under the ceiling directly above the flame, taken 15 minutes after ignition.

** Mean temperatures of the upper 18 thermocouples (2.5m above floor) which lie on the central longitudinal section, taken 15 minutes after ignition.

Oil pan - $0.5m^2$ (D = 0.798m)

5 times/hour of ventilation

Building height - 5m

L: Linear distance between radiometer and fire source (m)
D: Diameter of oil pan (m)

Mean value from 14 min. 32 sec. to 15 min. 20 sec. after ignition

Symbol	Location
—○—	Center
—△—	Near Wall (1)
—□—	Near Wall (2)

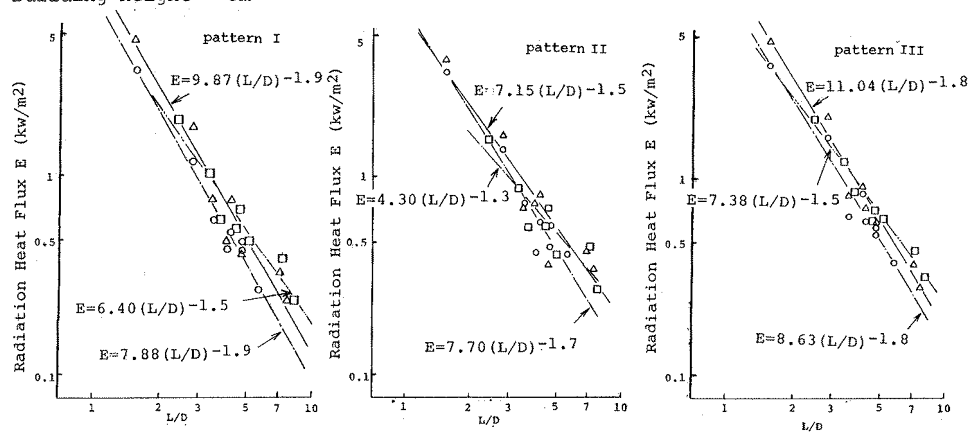


Fig. 6 Radiation Heat Flux; Influence of Oil Pan Location

Fig. 7 Radiation Heat Flux; Influence of Oil Pan Location

Fig. 8 Radiation Heat Flux; Influence of Oil Pan Location

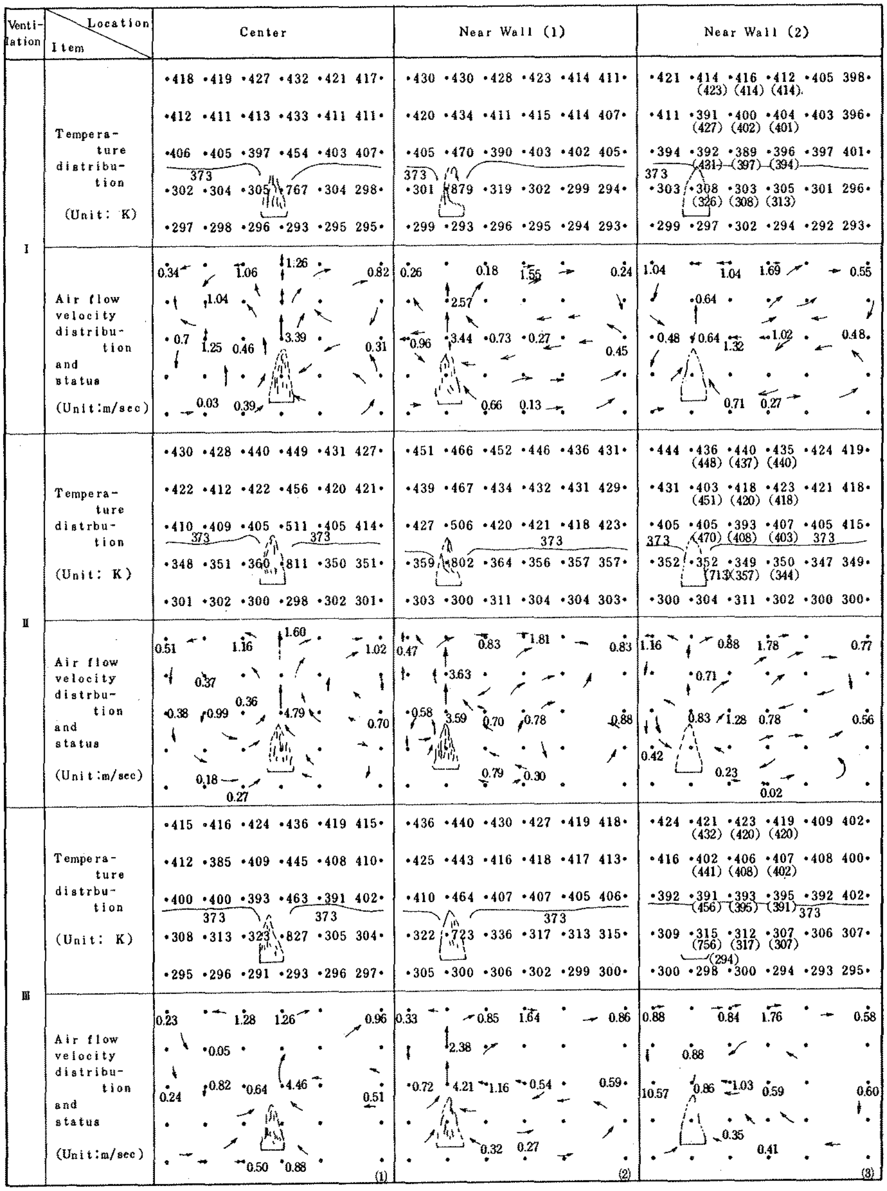
Height of neutral zone. All ventilation patterns become steady several minutes after ignition. The height of the neutral zone for each case is shown in Table 2.

In Summary

Based on the experimental data, the following conclusions can be derived on the effect of ventilation patterns and locations of fire source on firing status.

(1) The burning rate, radiation heat flux and temperature right above the oil pan were found to have no significant correlation with ventilation patterns and locations of fire source.

(2) However, it might well be said that the burning rate and radiation heat flux were the severest for ventilation pattern III and location of fire source near wall (1). Room air temperature was the highest in the case of ventilation pattern II and location of the fire source near wall (1). In ventilation pattern III, the blow-off of burnt hot air and the flow-in of ambient cool air through the opening appear to help reduce the room air temperature, in spite of the high burning rate.



Temperature and flow velocity measured 15 minutes after ignition

Values in parentheses are those taken on the section passing through the fire source

Fig. 9 Temperature Distribution, Air Flow Velocity Distribution, and Air Flow Status

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ACKNOWLEDGMENT

The tests were conducted in a joint study of the following companies.

Chubu Electric Power Company, Inc.
The Hokkaido Electric Power Company, Inc.
Tohoku Electric Power Company, Inc.
Tokyo Electric Power Company, Inc.
The Hokuriku Electric Power Company, Inc.
The Kansai Electric Power Company, Inc.
The Chugoku Electric Power Company, Inc.
Shikoku Electric Power Company, Inc.
The Kyushu Electric Power Company, Inc.
The Japan Atomic Power Company
Mitsubishi Heavy Industries, Ltd.
Toshiba Corporation
Hitachi, Ltd.

The authors wish to thank the many technical and engineering staff members for conducting the tests, especially Emeritus Prof. S. Hoshino (University of Tokyo), Emeritus Prof. H. Saito (University of Tokyo) and Prof. Y. Uehara (Yokohama National University) for valuable advice.