# Development of Transmitter with Hybrid-IC for Post-accident Monitoring Instrumentation

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ABSTRACT

After the TMI accident, Post-accident Monitoring (PAM) Instrumentation based on the U.S. Guideline (R.G.1.97) was applied to Japanese PWRs. And we have back-fitted the PAM Instrumentation to old plants step by step.

Recently, new type transmitters arrive on the market. They have better accuracy, and stability than old type. However, they cannot be applied as the PAM instrumentation, because new type are insufficient in a qualification for the PAM instrumentation and a modification to endure in-containment accident conditions. Hence, Japanese PWR utilities and Mitsubishi Heavy Industries are developing a new type transmitter for PAM instrumentation to improve accuracy and stability in the period of 1994 through 1996. This paper describes nowadays results in this development of a new PAM transmitter.

## 1. INTRODUCTION

Transmitters are field equipment, and are generally installed in severer environments than the other instrumentation (ex. control rack, control board). In ordinary industries, typical environmental requirements for installing a transmitter are temperature, pressure and moisture. Therefore packaging material and airtightness are important for ordinary transmitters.

In addition to ordinary environment requirements, in-containment PAM transmitters need radiation resistance to monitor the post-accident plant condition.

Current movements of a transmitter are down sizing, intellectualizing and improving of accuracy and long term stability. These movements are concerned with new detecting technology and improvement of signal processing technology. However, in general, transmitters based on new technology are gradually degraded by irradiation (alpha rays, gamma rays, neutron) and go to fail in radioactive field. Then new type transmitters for ordinary industries does not have enough endurance as the in-containment PAM instrumentation.

Hence, we are developing a new PAM transmitter to grade up the operating PAM transmitter by performing a modification and qualification tests of a new type transmitter.

## 2. REQUIREMENTS FOR PAM INSTRUMENTATION

In Japanese PWRs, the PAM instrumentation is required to provide following information:

- minimum information for understanding plant status during and after accident
- minimum information for the judgment of rapid manual operation to assure safety
- main information of safety systems and components

Basic design requirements of the PAM instrumentation (ref. to Table 1) are specified in the following Japanese guideline: JEAG4611 "Guide for Design of Instrumentation & Control Equipment with safety functions"

Environment requirement under the accident condition is very severe and significant for the in-containment PAM instrumentation. The ordinary transmitters based on new technology cannot be applied, and appropriate modifications and several qualification tests are needed for the appliance.

The in-containment PAM Instrumentation in Japanese PWRs are shown as follows:

- Neutron flux (source range)
- Thot and Tcold (wide range)
- RCS pressure
- Pressurizer level
- Steam generator level (narrow range)
- Steam generator level (wide range)
- Containment temperature
- Containment water level (narrow range)
- Containment water level (wide range)

## 3. ENVIRONMENT QUALIFICATION FOR PAM INSTRUMENTATION

In-containment environment during and after accident is determined as a condition during design basis events (LOCA and MSLB) and post accident aging. This environmental requirement is different plant by plant, because of in-containment volume, etc.

Then in the qualification test for the PAM instrumentation, the severest environmental condition in Japanese PWRs is applied. At the qualification test for the PAM instrumentation, we applied a sequential test procedure based on IEEE-323.

## 4. DEVELOPMENT OF NEW TYPE TRANSMITTER FOR PAM INSTRUMENTATION

The development program of a new type PAM transmitter is shown as follows:

(1) Study of detection technology
(2) Study of structure technology
(3) Design and manufacturing of prototype samples
(4) Execution of environment tests (radiation test, heat test)
(5) Manufacturing of product samples
(6) Execution of qualification tests program

Items (5) and (6) are planned to be executed in the period of 1995 – 1996. This paper describes the items (1) – (4) which have been already performed.

Table 1 Importance classification of I&C system and design requirements

| I&C system with safety functions | | | redundancy or diversity | independency | environment | seismic | emergency power supply | testability | QA | record | remark |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PS-1 | ---- | | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ◎,○:required(*) |
| MS-1 | Protection system | | ◎ | ◎ | ◎note1 ○ | ◎ | ◎ | ◎note2 | ◎ | △ | △:recommended |
| | System to directly control MS-1 system or component | | ◎ | ◎ | ◎ | ◎ | ◎ | ◎ | ◎ | △ | ×:not required |
| PS-2 | ---- | | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ----:not applicable |
| MS-2 | system to directly control MS-2 | supply water to fuel pool | × | × | ○ | ◎ | ◎ | ◎ | ◎ | ---- | |
| | | prevent release of radioactivity | ◎note3 | ◎note3 | ○ | ○ | × | ◎ | ◎ | ---- | (*)environment<br>◎:accident condition |
| | | *mitigate abnormal condition* | ◎note3 | ◎note3 | ◎ | ◎ | ◎ | ◎ | ◎ | ---- | ○:anticipated transient or normal operation |
| | system or component | safe shut down from out side of MCR | × | × | ○ | note4<br>◎ ○ | note4<br>◎ | ◎ | ◎ | ---- | (*)seismic<br>◎:class A or As<br>○:class C |
| | Information display system providing minimum required information for understanding plant status during and after accident | | ◎ | ◎ | ◎ | ◎ | ◎ | ◎ | ◎ | ◎ | |
| | Information display system providing minimum required information for the judgment of rapid manual operation to assure safety | | ◎ | ◎ | ◎ | ◎ | ◎ | ◎ | ◎ | ◎ | |
| | Information display system providing main information of MS-1 system and component | | ◎note5 | ◎note5 | ◎ | note5<br>◎ ○ | ◎ | ◎ | ◎ | △ | |
| PS-3 | System that may cause abnormal condition | | × | × | ○ | ○ | × | ◎ | ◎ | △ | |
| MS-3 | System with safety functions except MS-1,2 | | × | × | ○ | ○ | × | ◎ | ◎ | △ | |

note1: *necessary function during accident*

note2: required testing during operation

note3: same requirement as system or component which the I&C system control

note4: functions related to safe shut down from MCR

note5: especially important information (maintain sub-critical, heat removal after shut down, ECCS)

4.1 Study of detection technology

(1) Targets to be studied

The following three detection methods have been studied, the principle and features of which are shown as follows:

1) Electrostatic capacity type transmitter

Fig. 1 shows the functional diagram of electrostatic capacity type transmitter. Its feature is that it has durability against radiation peculiar to the nuclear power plant, since its detecting section is composed of metal plates.

2) Semiconductor type transmitter

Fig. 2 shows the functional diagram of semiconductor type transmitter. Its feature is that the characteristics, such as linearity, hysteresis, etc. are superior, since the repeatability and linearity of the strain gauge of the semiconductor used for detecting section are superior in its performance.

3) Oscillatory type transmitter

Fig. 3 shows the functional diagram of oscillatory type transmitter. Its feature is that its resolution is high because the detecting section gives an output signal by frequency, and that the oscillation element is composed of mono-crystal material, and is precise and stable in operation.

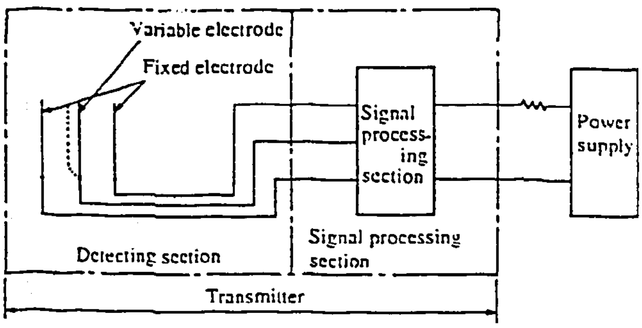



Fig. 1 Functional diagram of electrostatic capacity type transmitter

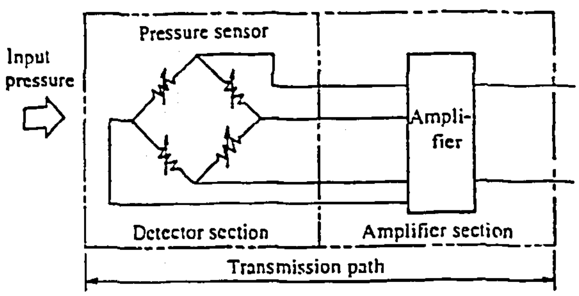



Fig. 2 Functional diagram of semiconductor type transmitter

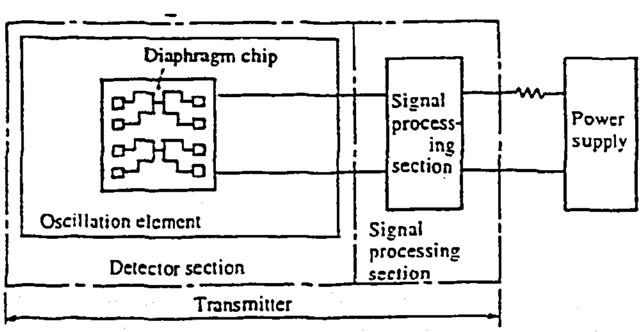



Fig. 3 Functional diagram of oscillatory type transmitter

(2) Results of studies

1) Electrostatic capacity type transmitter

It was confirmed that silicon oil used in the detection has no problems in its heat resistance and radiation resistance, which meant that it has enough environment resistance.

2) Semiconductor type transmitter

It was determined that this type can hardly be used for the detecting section of the PAM transmitter, because special product of high-temperature enforced type is now under research, and because ordinary products are ready to change their properties in high temperatures.

3) Oscillatory type transmitter

It was determined that it is difficult to use this type of transmitter for the detecting section of the PAM transmitter, because the microprocessor for special use of the signal processing section was destroyed in high radiation exposure. If we use this type, it must be necessary to develop a radiation-hard microprocessor.

Judging from the above results, electrostatic capacity transmitter has been selected as the detecting section for the prototype.

4.2 Study of transmitter structure

By assuming that electrostatic capacity type, which is superior in environment resistance, is selected for the detecting section, "remote signal processing" and "one body signal processing" were compared with each other.

(1) Remote signal processing

By isolating the signal processing section from the detecting section in container vessel of plants, it has a merit of being free from influence by environmental conditions in accident. However, it was learned difficult to apply this method, because it is affected by the floating capacity of the cable between the detecting section and the signal processing section.

(2) One body signal processing

The signal processing section must have an environment resistance. Here, a method may be applied to stand the environmental conditions, by using the technology of environment resistance Hybrid-IC[*1] as a means to improve the environment resistance of signal processing section.

*1 environment resistance Hybrid-IC (HIC)

HIC whose radiation resistance and heat resistance have been improved by packaging electronic devices, such as ICs, etc. with radiation insulator. HIC operated normally after the following tests.

1) Radiation test: Total radiation dose $1 \times 10^8$ rad

2) Heat test: 155°C, for 5 hours continuously

4.3 Design and manufacturing of prototype samples

By judging from the study results of detection technologies and structure technologies, the following prototype samples have been manufactured:

(1) Electrostatic capacity has been selected for detection.

(2) One body signal processing section, in which environment resistance HIC is used for amplifier circuit, has been selected for structure.

### 4.4 Environment tests

The radiation resistance test and then heat resistance [illegible] have been conducted with three units (No.1 – 3) of prototype samples (differential pressure transmitter). What was done, and its results are shown in the following paragraphs:

#### 4.4.1 Radiation exposure test

(1) Test conditions

1) Source of radiation: cobalt 60 (Co-60) $\gamma$ ray
2) Total radiation dose: $7.2 \times 10^7$ rad
3) Dose rate: $1.5 \times 10^6$ rad/hr
4) Time of radiation: 48 hrs
5) Measured data:
   * 0% output error in irradiation (zero-point drift)
   * I/O characteristics before/after irradiation

(2) Test results

Fig. 4 and 5 show the test results. Its summary is as follows:

1) Max. error in irradiation (zero-point drift) was 0.57% at most.

2) The change of I/O characteristics before/after irradiation was less than 1.5% of full span.

#### 4.4.2 Heat test

This test was done after radiation exposure test for same samples. The samples were put into a tank of constant temperature, and temperature was raised/lowered in the air. (Steam spray was not used.)

(1) Test conditions

190°C – 5 min, 152°C – 3 hrs, 135°C – 20 hr, and 123°C – 2 days were sequentially applied. (Fig. 6)

(2) Test results

Fig. 7 and 8 show the test results. Its summary is as follows:

1) Max. error in test (zero-point drift) was 10.6% at most. However, the error was temporary, and the average in each temperature condition was 4% or less. (Table 2)

2) In comparing I/O characteristics before and after test, that after test tends to be smaller than that before test. It is thought to be the result of effect by baking under high temperatures, in which the performances of electronic devices were recovered. (Table 3)

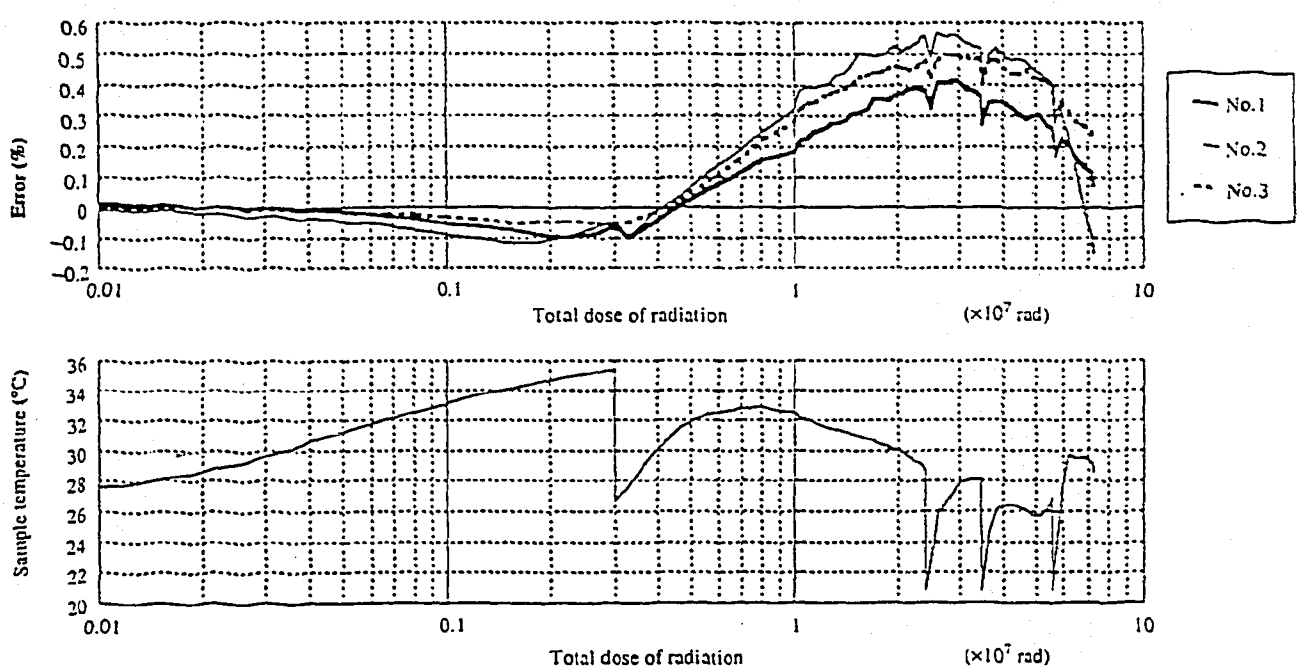
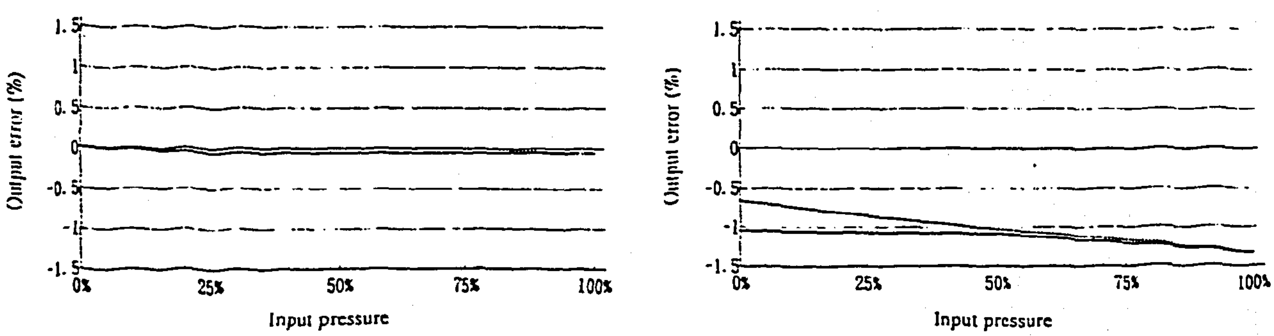



Fig. 4 Zero-point drift (0% output error), and temperature of sample body during radiation exposure test




[Before test]

[After test]
(Total dose of radiation $7.2 \times 10^7$ rad)

—— raised
—— lowered

Fig. 5 Typical data of I/O characteristics before/after radiation exposure test

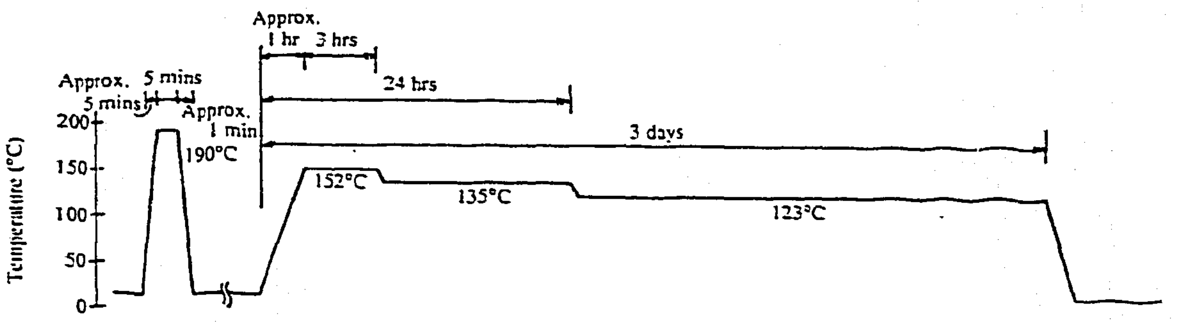



Fig. 6 Temperature sequence

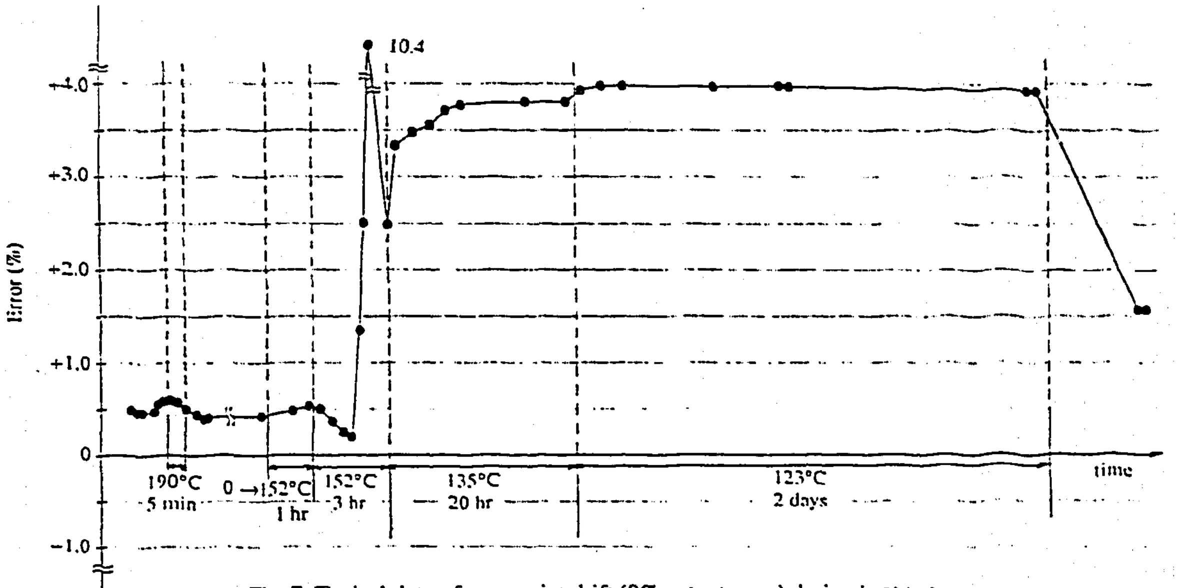



Fig. 7 Typical data of zero-point drift (0% output error) during heat test

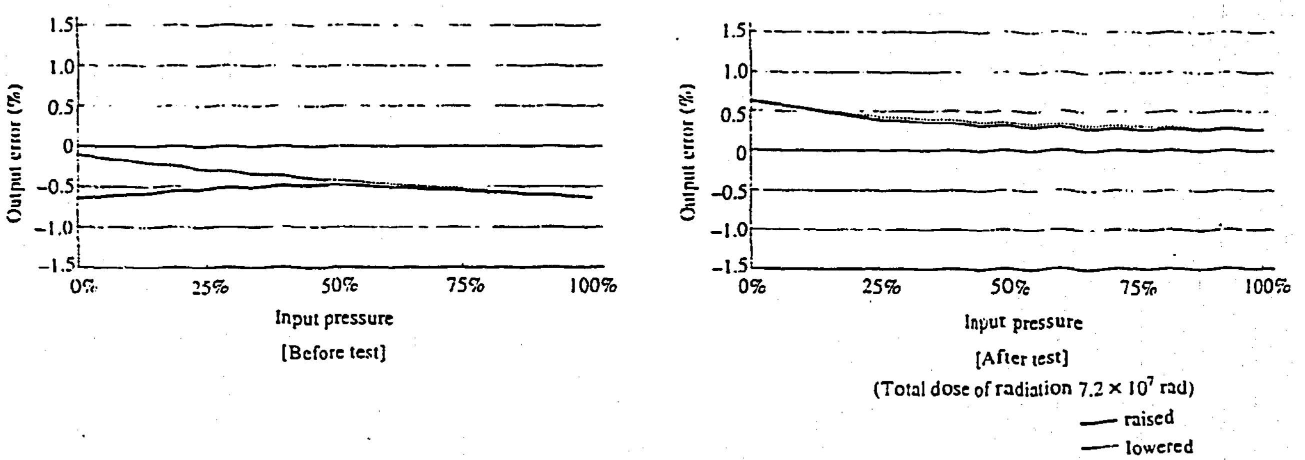



Fig. 8 Typical data of I/O characteristics before/after heat test

Table 2 Typical data of zero-point drift in heat test

| Temperature | 190°C | 152°C | 135°C | 123°C |
|---|---|---|---|---|
| Amount of zero-point drift | | | | |
| Average value | +0.6% | +2.2% | +3.7% | +4.0% |
| Max. value | — | +10.4% | — | — |

Table 3 Typical data of hysteresis error before/after test (max. value)

| | | Before test | After test |
|---|---|---|---|
| Error (max. value) | Under raising pressure (0 → 100%) | 1.2% | 0.2% |
| | Under lowering pressure (100 → 0%) | 0.8% | 0.2% |

4.4.3 Evaluation of test results

(1) Radiation exposure test

In the radiation exposure test results of 3 units of prototype samples, it was confirmed that all the 3 units operate normally under the max. total dose of $7.2 \times 10^7$ [rad] without damages.

Though the error occurred due to zero-point drift and I/O characteristics, the amount of the dose was less than 1.5%, which may well fall within the range applicable for PAM transmitter.

Therefore, it is concluded that the target radiation resistance for this study has been achieved as planned.

(2) Heat test

The amount of zero-point drift increased, though for a short time, under 150°C – 3 hrs, the I/O characteristics and amount of zero-point drift before/after test were small, and the transmitter operated normally without damages. This gave a good result for a prototype.

The subsequent examination showed that the max. drift error occurred in this test due to insufficient heat resistance of one of amplifier circuit parts (not HIC). It is planned to apply improved products in the future tests.

## 5. CONCLUSIONS AND FUTURE PLAN

In this paper we described nowadays results in the development of the new type transmitter for the PAM instrumentation[*2]. We have confirmed the excellent performance of highly radiation resistance and heat resistance for the prototype transmitter.

Currently, we are manufacturing product samples of the new PAM transmitter. And the qualification tests will be performed in the period of late 1995 through 1996.

We plan to apply this new PAM transmitter to the operating plants after the qualification tests.

*2 This is a joint study – "Study for the Development of a New Type Harsh Environment Resistive Transmitter" – performed by Japanese PWR utilities[*3] and Mitsubishi Heavy Industries.

*3 Japanese PWR utilities;
The Kansai Electric Power Co., Inc.,
Hokkaido Electric Power Co., Inc.,
Shikoku Electric Power Co., Ltd.,
Kyushu Electric Power Co., Ltd.,
The Japan Atomic Power Company.