ISSN 0429-8284

Whole Number 219

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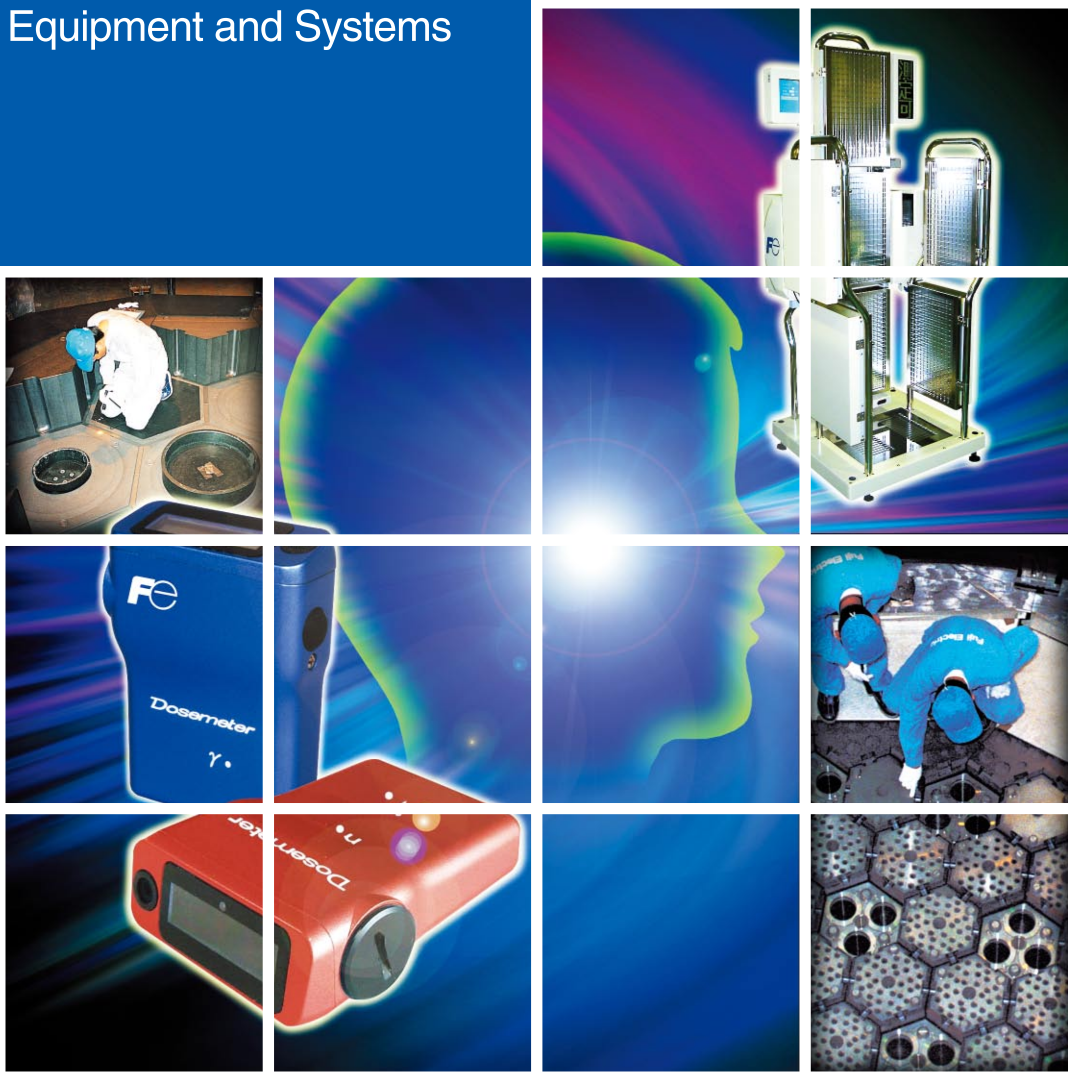
FUJI ELECTRIC REVIEW

4

2007 VOL.53

Radiologic Equipment and Systems



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Highly accurate and reliable equipment useful to our customers

Fuji Electric actively develops various types of essential radiation measuring instruments and computer systems to contribute to the safety control of nuclear power plants and other facilities that use radiation.

Wide range X/γ-ray survey meter

Personal dosemeter

Environmental radiation measurements

Environmental radiation monitor

Personal dose measurements

Iodine monitor

Body surface contamination monitor

Fuji Electric’s Radiation Control Systems

FUJI ELECTRIC
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Radiologic Equipment and Systems

CONTENTS

Cover photo:

In recent years, out of concerns for preventing global warming and for ensuring energy security, the utilization of nuclear power generation is being viewed favorably throughout the world. Also, the use of radiation is increasing in medical and industrial fields and for research and development. Radiologic equipment and systems measure the radiation generated from these facilities, and monitor and control the effects of radiation on the workers at such facilities and the residents in the surrounding areas.

Using radiation measurement, radiation control and data processing technology, Fuji Electric has been involved at all stages, from product development to production and marketing, of radiation control systems for personal dose control, facility and environmental radiation monitoring, radioactive contamination inspection equipment, and the like.

The cover photo shows a personal dosemeter used for personal dose control and a body surface contamination monitor, and depicts an image of the contribution to the safety of workers at facilities throughout the world that handle radiation.

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Overseas Business of Radiologic Equipment and Systems

Nobuyoshi Takeuchi
Toshiaki Fujimoto
Hideyo Nagama

1. Introduction

Radiologic equipment and systems are used to detect and measure the radiation emitted from radioactive material and radiation generators and also include data processing computers, and are used mainly in the following radiation handling facilities.

(1) Nuclear power plants and nuclear fuel cycle facilities (facilities for reprocessing, nuclear enrichment, burial, storage, etc.)
(2) Medical, pharmacy and science and engineering fields (hospitals, universities, research laboratories, accelerator facilities, etc.)
(3) Industrial uses (steel, chemicals, foods, etc.)
(4) National and local governments

Fuji Electric has been manufacturing radiation detectors, radiation measurement devices and radiation monitoring and control systems, and has delivered them to many customers in Japan. The "Fuji Electric Journal" has previously published four special issues that dealt with radiologic equipment and systems, and that introduced the latest technology and examples of delivery within Japan. This issue focuses especially on the overseas business of radiologic equipment and systems.

2. Background of the Overseas Business

In March 2007, the Atomic Energy Commission of Japan issued the "2006 White Paper on Nuclear Power." This report stated that "nuclear power generation is a key means for contributing to a solution for energy and global warming problems." For Japan, a country having few natural resources, and which has ratified the Kyoto Protocol pledging to reduce greenhouse effect gas emissions during the period from 2008 to 2012 by 6 % compared to 1990 levels, this white paper restated the importance of nuclear power generation as a domestic energy source that emits almost no greenhouse effect gases. This positive attitude toward nuclear power generation is not limited to Japan, and has spread throughout the world as a result of the acknowledgement that fossil fuel deposited worldwide are limited. Although various theories exist concerning the causes of the global warming trend, many reports confirm that global temperatures are rising year-by-year with the increasing emissions of greenhouse effect gases. Around the world, 429 nuclear power plants are in operation and 82 plants are under construction or in the planning phases. The construction plans of nuclear plants are on an increasing trend. The trends in several countries and regions are presented below.

In the United States, in consideration of soaring oil prices and stable supply of energy and prevent global warming, there is said to be a "nuclear power renaissance", and many construction plans of nuclear power plants are in progress thirty years after the Three Mile Island nuclear power plant unit 2 accident in March 1979.

In Asia, due to a growing population and increased demand for electric power as a result of industrial development, the construction of nuclear power plants is being planned. China has announced a policy of "increasing nuclear power up to four percent of the total generated electrical power capacity by 2020" and is advancing plans for nuclear power plant construction throughout the country.

In Europe, many countries have held a negative attitude regarding nuclear power ever since the Chernobyl nuclear power plant unit 4 accident in March 1986, but recently, because of environmental issues such as the prevention of global warming and in order to ensure a supply of energy, nuclear power strategies are being reconsidered.

Meanwhile, in the medical, industrial, and research and development fields, radiation application technology is being used and advanced throughout the world.

Thus, nuclear power is again being used throughout the world, and with radiation being used widely in the medical and industrial fields. In this situation, a common big issue is to monitor and control the radiation generated by these facilities so as to minimize to the extent possible the effect of radiation on the workers at those facilities, on residents in the surrounding areas, and on the environment. In particular, based upon the unique context of Japan, as the only country ever exposed to radiation from atomic bombings, radiation has been strictly controlled in Japan out of respect for its citizens and the environment. Under these conditions, Fuji Electric supplies the following types of radiation control systems using sensing measuring technology, radiation control and data processing technology.

○ Personal dose monitoring systems
○ Environmental radiation monitoring systems
○ Radioactive contamination monitoring systems
○ Nuclear facility radiation monitoring systems

In Japan, Fuji Electric has been advancing and cultivating these technologies suit for the needs of the user in the field of nuclear facility radiation monitor and radiation protection. Now Fuji Electric is going to contribute to radiation protection in overseas countries.

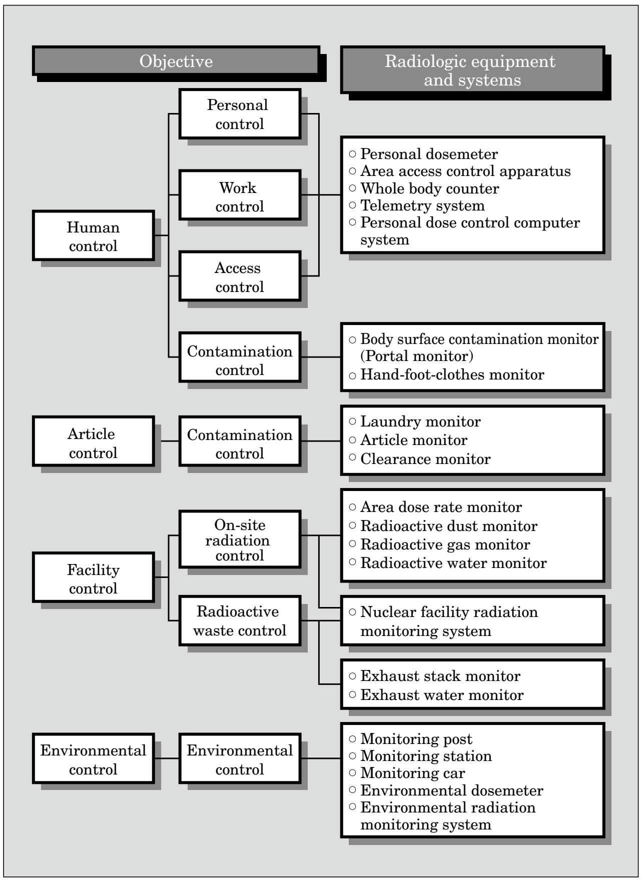
3. Radiologic Equipment and Systems

In general, radiologic equipment and systems can be broadly classified as equipment and systems used for radiation protection in radiation handling facilities, and applied equipment that utilizes exposed radiation from radioisotopes.

The field of radiation protection can be classified, as shown in Fig. 1, into the categories of "human control", "article control", "facility control" and "environmental control."

The purpose of "human control" is to reduce the radiation exposure to workers in radiation controlled areas in radiation handling facilities. "Human control" consists of "personal control" to measure and evaluate the external and internal radiation exposure levels of individuals, "work control" to control exposure of every permitted works in radiation controlled areas, and "access control" to control worker access to radiation controlled areas. Fuji Electric's equipment and systems for "human control" include personal dosemeters, area access control apparatuses, body surface contamination monitors (portal monitors), whole body counters, personal dose control computer systems, and the like.

Fig.1 Radiation control objectives and radiologic equipment and systems



The purpose of "article control" is "contamination control". This control inspects contamination monitoring before and after the washing of clothes that were worn inside a radiation controlled area, and also inspects contamination monitoring of the articles and tools used inside a radiation controlled area. Fuji Electric's "contamination monitoring" equipment includes laundry monitors, article monitors, clearance monitors and the like.

The purpose of "facility control" is to ascertain and to lower the radiation exposure dose levels in work environments in a radiation handling facility. "Facility control" consists of "radiation control" that measures the radiation (radioactivity) being processed in the facility and the area dose rate and the concentration of airborne radioactive material in a work environment, and "radioactive waste control" that controls the exhaused air and water from the facility. Fuji Electric's equipment and systems for "facility control" use include area dose rate monitors, radioactive dust monitors, radioactive gas monitors, radioactive water monitors and the like.

The purpose of "environmental control" is to ascertain and to lower the radiation exposure dose levels around radiation handling facilities "environmental control" measures the ambient dose rate and the concentration of airborne radioactive material. Fuji Electric's equipment and systems for "environmental control" include monitoring posts, monitoring stations, monitoring cars, environmental dosemeters, environmental radiation monitoring systems, and the like.

On the other hand, "applied equipment" which measure the penetration ratio from radiation of radioisotopes through an object, includes thickness meters that measure the thickness of steel plates and pipes, paper and film, densimeters that measure the concentration of liquid inside a pipe, aquameters, level meters, and the like.

4. Technological Trends

Overseas radiologic equipment and systems differ according to the country, but the general technological trends are moving toward maintenance free operation, longer life, higher reliability, durability, lower cost and so on.

Relatively inexpensive gaseous detectors such as GM counters are being used overseas for radiation sensors, but these have a short service life and high running costs. The demand is trending toward solid state detectors such as scintillation detectors and semiconductor detectors which have a high initial cost but longer service life and inexpensive running costs. Some examples of distinctive technological trends are described below.

For overseas "personal control", the thermoluminescence dosemeter (TLD) has been used widely as a personal dosemeter. Recently, an audible alarming personal dosemeter (APD) with a real-time alarm function, real-time accumulated dose, and working time and the like has realized higher reliability, lower cost, more compact size and lighter weight. The trend is shifting from TLDs toward electronic personal dosemeters. In particular, since the audible APD will be often placed in the same pocket as a cell phone or PHS, technical development has been advanced to strengthen anti-electromagnetic interference. Also the audible APD is available for several consecutive months, so technical development has been advanced to reduce the consumption current of the electronic circuitry to enable longer usage times with commercially available dry-cell batteries. Moreover, the ability to withstand more severe conditions, such as operation in a dry atmosphere or usage by firefighters or police officers, is increasingly requested. On the other hand, for systems using personal dosemeters, telemetry systems with wireless communication functions are being developed and adopted for use in high dose areas in order to control exposure dose in real-time. The form of wireless communication must be suit to the various output power and frequency requirements regulated by the different radio laws of each country.

For body surface contamination monitors, the beta-ray gas flow proportional detector with a high running cost predominates in the world market. But in the near future, maintenance-free body surface contamination monitors with beta-ray plastic scintillation detectors are expected to be standard models. Body surface contamination monitors in Japan are equipped with detectors on six planes, which cover all surfaces of a human body, so as to measure the whole body at once. Overseas body surface contamination monitors are equipped with detectors on only a portion of the surfaces, i.e. three to four planes, in order to reduce cost, and they require that the whole human body be measured twice. So body surface contamination monitors using beta-ray plastic scintillation detectors (half-face surface, long-life, maintenance-free and low-cost) are developed and installed for overseas plants.

In many cases of overseas "radiation control", measurement data are directly transferred to personal computers from each radiologic equipment without central monitoring panels or recorder panels such as in Japan. The transferred measurement data are converted to radioactive concentrations, and are output as trend graphs and tables on displays and as recording sheets and are saved in storage media. The standardization of these software packages measurement data is strongly required as there is not many requests for software customization.

5. Postscript

Fuji Electric's radiologic equipment and systems have a history of development based on Japanese laws and standard regulations. Thus, Fuji Electric is developing products for overseas markets based on recommendations from the IEC (International Electrotechnical Commission) and other standards, and the ICRP (International Commission on Radiological Protection). Fuji Electric intends also to continue to develop products that conform to the individual laws and needs of each country. Fuji Electric considers that the most important thing is to ensure the reliability and traceability of radiological equipment.

Personal Dose Monitoring System (Wireless Monitoring System)

Kei Aoyama
Takeshi Kawamura
Yuji Matsuzoe

1. Introduction

Personnel working in radiation controlled areas of facilities that utilize radiation, such as at a nuclear power plant or the like, are required to carry a personal dosemeter. Figure 1 shows the configuration of a personal dose monitoring system employed at an area access control gate. An area access control gate is installed at the entrance and exit of the radiation controlled area, and information, such as a worker's ID number and dose data, stored in the memory of a personal dosemeter is transmitted from the personal dosemeter to the area access control gate. In a conventional system, dose data is obtained in a radiation controlled area by verifying the dosage display on a dosemeter, or by sounding an alarm buzzer when a certain dosage warning level has been reached. A drawback of the conventional system, however, is that the controller obtains dose data for each worker only at the entrance and exit of the radiation controlled area several times a day. Therefore, it is desired to continuously monitor a worker's dosage in order to protect against radiation. Especially for work performed in a high dose area, the real-time acquisition of personal dose data is desired.

2. System Overview and System Specifications

Usually, a worker only carries their own personal dosemeter, and a reading system that has been installed at the entrance or exit of a controlled radiation area reads the accumulated data of the dosemeter whenever the worker enters or exits the controlled area. However, dose monitoring of workers that work in a high dose area must be performed in that controlled area within a short amount of time. So as to support this requirement, a wireless attachment is mounted onto the personal dosemeters in use, thereby configuring a system capable of dosage monitoring. In cycles lasting from several seconds to several minutes, this system is able to monitor dose data of a few or several tens of workers in a controlled radiation area. Furthermore, departure orders and other warning information can be transmitted in real-time from the monitoring system to the personal dosemeters. This system is suitable for such applications as: ① monitoring dose data during normal operation (monitoring many workers with a cycle time of several minutes), ② real-time monitoring of the individual data of workers working in a high radiation area (monitoring a few workers with a cycle time of several seconds), and ③ simple area monitoring using personal dosemeters.

As shown in Fig. 2, a personal dose monitoring system is configured from a wireless attachment for personal dosemeters (hereafter referred to a wireless attachment), a personal dosemeter, a relay station and a data processing unit. The wireless attachment, as shown in Fig. 3, consists of an attachment mountable

Fig.1 Dose monitoring system with area access control gate

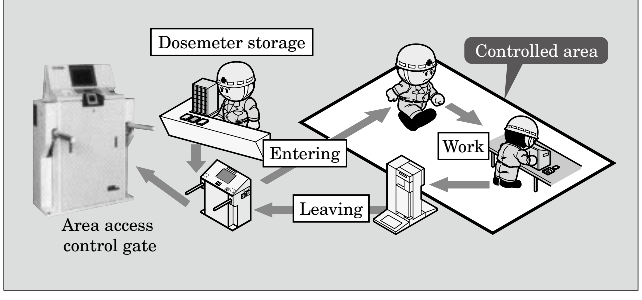


Fig.2 Personal dose monitoring system

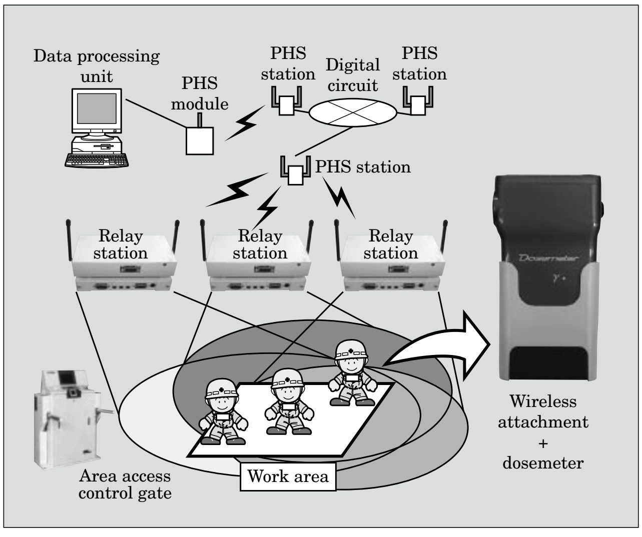


Fig.3 Wireless attachment + dosemeter

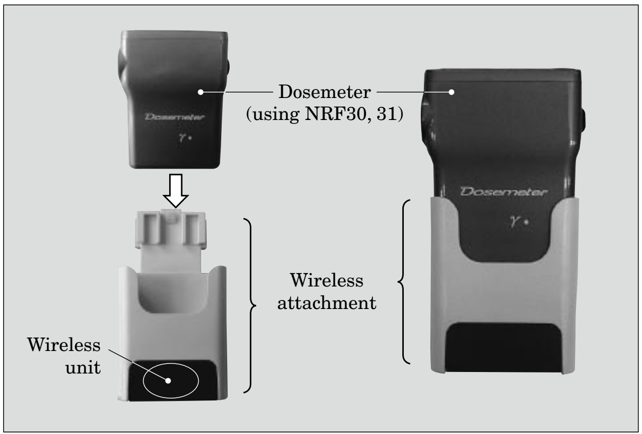
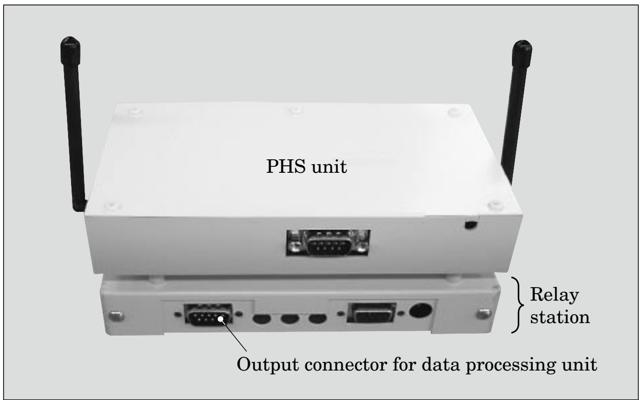


Fig.4 Relay station

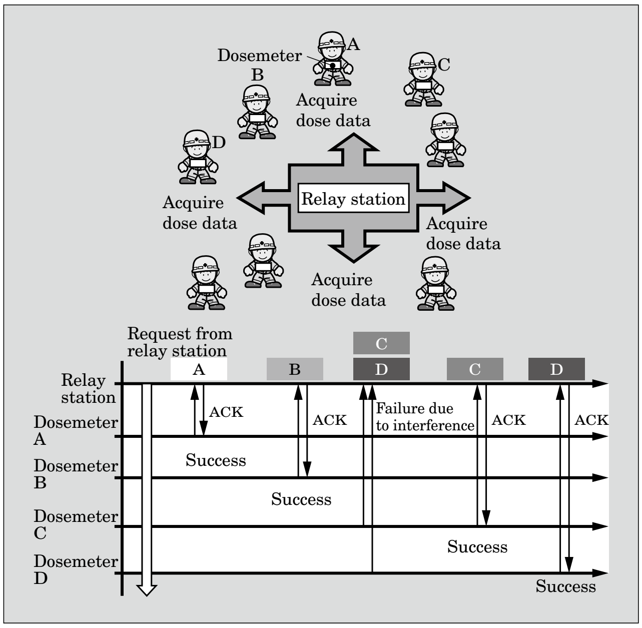


to the personal dosemeter containing a built-in radiation sensor, and a wireless unit for implementing the wireless transmission of dose data from the dosemeter to a relay station. Moreover, the personal dosemeter is also provided with an infrared communication function so as to be able to transmit dose data externally. The wireless attachment is also provided with an infrared communication function which is used to transmit dose data and so on between the personal dosemeter and the wireless unit. The relay station shown in Fig. 4 is provided with a function for temporarily storing dose data from multiple wireless attachments and a mechanism for transmitting data to a data processing unit. The mechanism for transmitting data to the upper-level data processing unit can be selected from among: ① a PHS-based communication method (local area circuit), ② an Ethernet*1-based communication method, or ③ a RS-232C-based communication method (for uploading data directly to a data processing unit). The relay stations shown in Figs. 2 and 4 are an example of a PHS-based communication method.

The operation is described below. Figure 5 depicts the principles of a monitoring operation in the case where an unspecified large number of personal are present in a controlled area and dose data must be

*1: Ethernet is a registered trademark of Xerox Corp., USA.

Fig.5 Principles of monitoring operation



acquired. At prescribed cycle times, the relay station requests dose data from the wireless attachments carried by the workers. The dose data request signal received by a wireless attachment is converted from an electrical signal to an infrared optical signal and transmitted to the personal dosemeter. In response to the request for data, the personal dosemeter uses a built-in infrared communication function to transmit dose data as an optical signal to the wireless attachment. The wireless attachment receives the dose data and then transmits the dose data to the relay station at a random timing so there is little risk of interfering with a wireless signal from a wireless attachment carried by another worker. If there is no interference, the dose date is transmitted to the relay station and the wireless attachment receives an ACK signal from the relay station acknowledging that reception was successful to complete the communication. If there is interference, however, an ACK signal is not received from the relay station and the transmission will be attempted again at a random timing to avoid interference. By repeating this type of communication at prescribed cycle times, this communication method achieves a success rate of nearly 100 %.

The dose data from multiple wireless attachments is first stored in a memory inside the relay station. Then, at predetermined cycles, in response to data requests from the data processing unit that reads signals, the relay station transmits the dose data stored in the memory to the data processing unit. The data communication method used at this time may be any of the three methods described above. The main system specifications are listed below.

(1) Monitoring cycles: 15 s to 1 min
(2) Wireless attachments to be monitored: 10 to 50 units

Table 1 Wireless attachment specifications

Item	Details
Wireless specification	Specified low power wireless communication (Japanese standards)
Wireless frequency	429.500 MHz (tunable to other frequency bands)
Transmit power	0.01 W
Transmission rate	4,800 bps
Continuous operation time	Approx. 30 h (When communicating once per minute)
Current consumption	Approx. 17 mA

(3) Monitoring area: Several tens of meters (The area differs according the environment, and in the case of 50 units, is 10 × 10 m or less)

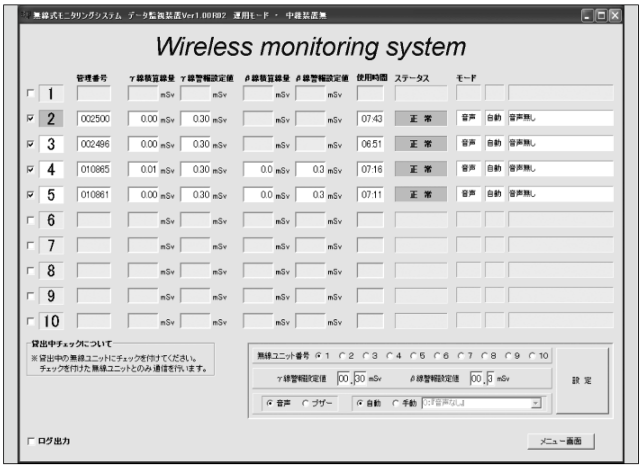
The monitoring interval can be set to approximately 15 seconds for a small number of people, or to approximately 1 minute for a large number of people. As an example, in the case where there are 50 wireless attachments to be sampled, the sampling interval will be approximately 1 minute.

3. Device Features and Specifications

3.1 Wireless attachment

The wireless attachment is provided with an attachment function capable of encapsulating the personal dosemeter (and is suitable for use with NRF30 and NRF31 dosemeters. Refer to the next chapter.) The wireless attachment is also provided with a function for converting the infrared optical signal from the personal dosemeter into an electrical signal. The wireless communication between relay stations is implemented using a type of specified low power wireless communication, and the frequency of this specified low power wireless communication can be changed to a setting that enables use overseas. Since the wireless attachment and the personal dosemeter are electrically isolated, the wireless attachment is equipped with a rechargeable AAA-size battery (nickel hydride). At the bottom of the wireless attachment is provided a terminal for connecting a charging device, and the battery can be recharged via this terminal. Or, a commercially available ordinary AAA battery may also be used. The main specifications of the wireless attachment are listed in Table 1.

Fig.6 Example display screen of data processing unit



3.2 Relay station

The relay station acquires dose data via wireless transmissions from multiple wireless attachments, and temporarily stores the dose data received. The relay station can be connected via a D-SUB connector to a PHS, to an Ethernet or to a data processing unit, and uses these communication methods to transmit the dose data to the data processing unit.

3.3 Data processing unit

The data processing unit is capable of displaying the cumulative dose value of the personal dosemeters and also displaying the status of the wireless attachment. Figure 6 shows an example of the operating mode screen for the case in which ten wireless attachments are used.

4. Postscript

The use of this system to monitor radiation dosages in controlled radiation areas such as at a nuclear power plant and the like will enable the real-time monitoring of personal dose levels, thereby helping to reduce exposure and streamline the task of worker monitoring. In the future, Fuji Electric intends to deploy this system both domestically and abroad, and to continue to supply technologically advanced and highly reliable products.

Electronic Personal Dosemeter

Tomoya Nunomia
Hideshi Yamauchi
Tetsuo Shibata

1. Introduction

Since developing an electronic personal dosemeter that uses a semiconductor detector in 1983, Fuji Electric has continued to make improvements and has developed the first electronic personal dosemeter in Japan capable of neutron measurement. Fuji Electric presently holds a 70 % share of the Japanese market for electronic personal dosemeters used for personal dose control in nuclear power plants. Fuji is eyeing future development for overseas nuclear power plants[(2),(3)] and is also moving ahead with development in compliance with Japanese Standard JISZ4312 (2002) "Direct reading personal dose equivalent (rate) meters and monitors for X, γ, β and neutron radiations" and International Standard IEC61526 (1998).

2. Overview and Characteristics

The electronic personal dosemeter is a device carried in a worker's breast pocket that measures and displays in real-time the radiation dose received while working. If the dose exceeds a preset working dose warning level, an alarm is issued and the worker can be notified immediately with a high-frequency sound. Electronic personal dosemeters have continued to be improved, and in recent years, noise-tolerance and shock-resistance characteristics have been enhanced, and reliability has been increased dramatically. When electronic personal dosemeters capable of multi-radia-

Fig.1 Exterior view of electronic personal dosemeter

Fig.2 Radiation characteristics of the electronic personal dosemeter

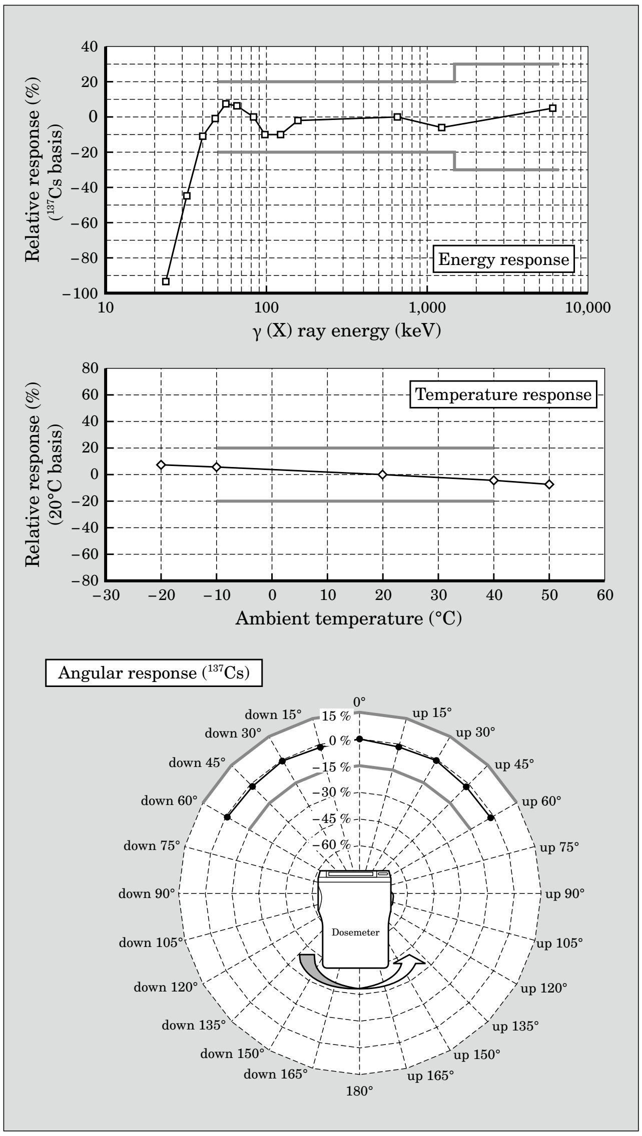


Table 1 Specifications of electronic personal dosemeter (γ (X) ray)

Item \ Model	NRF30021	NRF40021
Radiation detected	γ (X) ray	
Energy range	50 to 6 MeV	
Energy response	Within ±20 % (50 keV to 1.5 MeV), Within ±30 % (1.5 to 6 MeV)	
Angular response	Within ±20 % (up to ±60° in horizontal and vertical directions, ^{137}Cs)	
	Within ±50 % (up to ±60° in horizontal and vertical directions, ^{241}Am)	
	Within ±30 % (360° all around horizontal direction, ^{137}Cs)	
Accuracy (dose)	Within ±10% (0.02 mSv or above)	
Linearity	Within ±10% (0.1 mSvh^{-1} or above)	
Response time	Within 5 s (5 mSvh^{-1} or above)	
Static electric noise	Contact discharge ±8 kV, Gaseous discharge ±15 kV	
Alarm function	Buzzer volume : greater than 85 dB (at 20 cm), greater than 80 dB (at 30 cm), Display lamp: flashing red LED	
Power source	Battery : CR123A, 1 cell, (2,880 hours of continuous use)	
Temperature response	Within ±20 % (−10 to +40°C)	Within ±10 % (−20 to +50°C)
Shock resistance	1.5 m fall (onto wooden panel)	2.0 m fall (onto 20 mm-thick iron panel)
Resistance to electromagnetic noise	100 V/m, 60 A/m, PHS, cell phone contact	100 V/m, 400 A/m, PHS, cell phone contact
Splash-proof	JIS protection class 4	JIS protection class 4, submersion-tolerant, resistant to salt water spray
Case material	Plastic	Magnesium alloy + protective rubber
Mass	Approx. 100 g (including battery, clip)	Approx. 115 g (including battery, clip)
Size	60 (W) × 78 (H) × 27 (D) (mm)	62 (W) × 82 (H) × 27 (D) (mm)

tion measurement in real-time were first developed, external noise often resulted in counting errors, and more precise measurement was needed.

So that external noise does not affect the radiation response of the electronic personal dosemeter, the shielding of the case interior has been improved to provide noise-tolerance characteristics of 100 V/m at 100 kHz to 500 MHz, and 400 V/m at 50 Hz/60 Hz, and to prevent interference from electromagnet noise even if a PHS, cell phone or the like comes into contact with the case. Furthermore, a water-resistant construction enables trouble-free operation even while withstanding water spray at a rate of 10 liters/m for more than 5 minutes. In the past, accidently dropping an electronic personal dosemeter, during it was taken along, could lead to incorrect operation or malfunction, but the internal construction has also been improved so as to enable the dosemeter to withstand a 1.5 m vertical drop onto a hard wood surface in any direction.

Developed as an electronic personal dosemeter having enhanced environmental-resistance, the NRF40021 uses a case made of a magnesium alloy and incorporates shockproof parts so as to be capable of withstanding a 2.0 m vertical drop onto a 20 mm-thick iron plate in any direction, and also features improved noise-tolerance characteristics and is water resistant to a depth of 30 cm for 20 seconds. Figure 1 shows the exterior view of two of Fuji Electric's electronic personal dosemeters.

These dosemeters satisfy the representative radiation characteristics for energy response, temperature response and angular response, as specified by JIS and IEC standards (Fig. 2). The energy response and temperature response indicate the energy dependence and temperature dependence of the sensitivity to γ (X) rays, and the dose measurement accuracy is within ±20 % or ±30 % over a wide energy range or a wide temperature range, respectively. Similarly, the measurement accuracy with respect to the angle of incidence of radiation rays is within ±15 %.

Fig.3 Exterior view of dosemeter reader

Characteristics of the electronic personal dosemeter are listed below. Specifications are also listed in Table 1.

(1) High performance : Compliance with JIS Z4312 (2002) and IEC61526 (1998)
(2) Low power consumption : 1 primary battery cell, usable for 1 year
(3) Anti-static : Contact discharge ±8 kV, gaseous discharge ±15 kV
(4) Moisture resistant : −10 to +40°C, 35 to 95 %
(5) Resistance to electromagnetic waves : 100 V/m
(6) Vertical drop shock resistance : 2.0 m drop, NRF40021
(7) Waterproof : IP64 (IEC60529) compliant
(8) CE marking acquired

Having measured dose data in real-time, the electronic personal dosemeter is easily linked to external data processing equipment via an infrared communication interface to realize a highly functional personal dose control system. In this personal dose control system, data is transmitted from the main device of an electronic personal dosemeter, via a dosemeter reader for data communication (see the external view in Fig. 3), to an upper-level computer server, so as to implement efficient safety control of the workers.

3. Types of Electronic Personal Dosemeters

Electronic personal dosemeters mainly measure γ (X) rays which have a large affect on personal dose control, and are also capable of measuring β-rays and neutrons. Fuji Electric's product line is based on electronic personal dosemeters that measure γ-rays, but also includes units that measure "γ-rays + β-rays" and "γ-rays + neutrons".

Table 2 shows the measurement functions for β-rays and neutrons.

Additionally, an electronic personal dosemeter for use in Japan is capable of measuring three types of radiation simultaneously : γ-rays + β-rays + neutrons. This unit was developed as the world's first 3-type dosemeter, and is currently being utilized in nuclear power plants in Japan. In particular, the ability to measure neutrons distinguishes our electronic personal dosemeter from those made by other companies.

4. Accessories

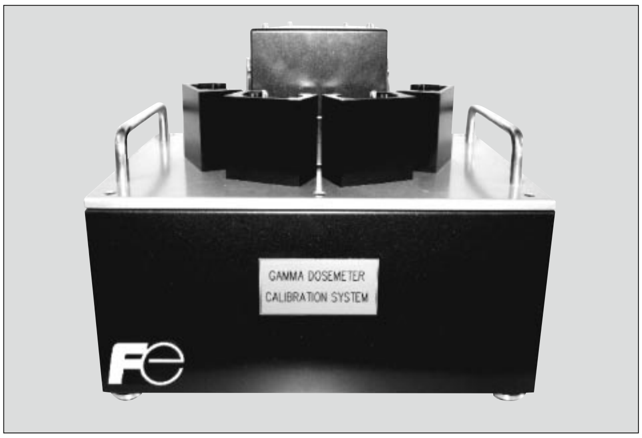
Available accessories for the electronic personal dosemeters include a setting device (Fig. 4) for setting a preset alarm value for the dose and cumulative time during operation, and a dosemeter calibrator (Fig. 5) for calibrating the measurement function of the electronic personal dosemeter.

Table 2 β-ray and neutron measurement ability of electronic personal dosemeter

Item / Radiation detected	β-ray	Neutron
Energy range	300 keV to 2.4 MeV	0.025 eV to 15 MeV
Energy response	Within ±30 % (500 keV to 2.4 MeV)	Within ±50 % (100 keV to 4.5 MeV)
Angular response	Within ±30 % (up to ±60° in horizontal and vertical directions, $^{90}Sr^{90}Y$)	Within ±30 % (up to ±60° in horizontal and vertical directions, ^{241}Am-Be)
Accuracy (dose)	Within ±15 % (0.02 mSv or above)	Within ±15 % (0.5 mSv or above)
Linearity	Within ±20 % (0.1 $mSvh^{-1}$ or above)	Within ±20 % (0.5 $mSvh^{-1}$ or above)
Response time	Within 5 s (5 $mSvh^{-1}$ or above)	Within 5 s (100 $mSvh^{-1}$ or above)

Fig.4 Exterior view of setting device

Fig.5 Exterior view of portable dosemeter calibrator



5. Postscript

As for the future electronic personal dosemeters, higher performance and functionality including product development that conforms with the international standard IEC61526 (2005) are being requested and further improvements are needed.

To implement these improvements, Fuji Electric intends to continue to commercialize competitive devices that will not only maintain our market share in Japan, but that can also be deployed in overseas markets.

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Radioactive Contamination Monitor

Toru Hasegawa
Tadao Hashimoto
Manabu Hashimoto

1. Introduction

At nuclear power plants, surface contamination inspection monitors are installed at the boundaries of radiation controlled areas in order to prevent radioactive contamination from spreading outside those radiation controlled areas, and all people exiting and all articles transported out of a radiation controlled area are monitored for surface contamination. The main types of surface contamination monitors include body surface contamination monitors that measure the surface contamination on a worker's body, article monitors that measure the surface contamination of tools and other articles carried by the workers, and laundry monitors that measure the surface contamination of worker's clothes and the like that have been worn in a radiation controlled area.

Additionally, there is also a hand-foot-clothes monitor that is used primarily at hospitals and the like to measure the surface contamination on hands, feet and clothes.

Using large-area radiation detectors, signal processing units capable of high-speed computational processing, mechanical devices capable of taking measurements under optimal conditions, and man-machine interfaces that utilize voice prompts and large-screen color LCDs to enable the measurement of radioactive matter with high sensitivity and at high-speed, Fuji Electric is delivering these systems to nuclear power plants and the like.

These systems are equipped with a self-diagnostic function and when connected to a data processing unit, enable the integrated control of contamination inspection and measurement data.

This paper presents an overview and describes the features of these surface contamination inspection systems.

2. Overview

In the past, gas flow proportional detectors were used in radiation contamination inspection systems, but in recent years, the various types of plastic scintillation detectors listed below have been developed in accordance with each system application.

Plastic scintillation detectors have significant advantages for use and differ from the gas flow proportional detectors in that gas supply equipment is unnecessary, the safety of workers carrying gas canisters into a controlled area does not have to be ensured, and running costs are eliminated since no maintenance is required.

Fuji Electric has actively developed and commercialized larger sized plastic scintillation detectors for measuring people and articles in their entirety, without a decrease in detection sensitivity.

3. Body Surface Contamination Monitors

3.1 Overview

Installed at the exits from radiation controlled areas, surface contamination monitors inspect for the presence of contamination on the body surface of a person leaving a radiation controlled area. There are two types of body surface contamination monitors, a 1-step type that measures the main body surface areas in a single step, and a 2-step type that measures the front and back body surfaces in two steps. In Japan, the 1-step type is used in order to lessen the burden on the subject to be measured and out of consideration of the processing capability, and Fuji Electric has manufactured the 1-step type in response to this domestic need.

The 2-step type, having fewer detectors than the 1-step type and not requiring a driving unit, is in demand overseas since it can be manufactured at lower cost, and Fuji Electric will actively manufacture the 2-step type in the future.

3.2 Features

(1) Detection sensitivity

Beta-rays can be measured with a sensitivity of 0.4 Bq/cm^2.

(2) Detector

Large-size plastic scintillation detectors are used for beta-rays.

(3) Measurement locations

Head: In order to measure with good sensitivity, the measurement location is raised from

1,300 mm to 2,000 mm automatically according to the height of the subject.

Hands and feet:

Right hand, left hand, back of right foot, and back of left foot can be measured individually.

Sensors are located at the measurement areas, and the measurement starts automatically when the subject sets their hand or foot in the measurement location.

Front and back surfaces:

3 large area detectors are positioned at the front and back, and provide coverage of heights of up to 2,000 mm.

Side surfaces:

2 large area detectors are positioned on the left and right sides, and provide coverage of up to the subject's shoulders.

Moreover, the detectors on either side have doors that open and close automatically and function as gates which, in the case of contamination, prevent a subject from leaving the radiation controlled area and entering a non-radiation controlled area.

(4) Operation functions

Usually, the measuring process is performed for a certain amount of time (settable according to the operation), but the measurement time may be computed automatically according to the monitor type so that the measurement is performed in a shorter amount of time.

Fig.1 Transportable body surface contamination monitor

Table 1 Specifications of the transportable body surface contamination monitor

Item	Specification
Detector	Plastic scintillation detector
Detector positioning	Front and back surfaces (top, middle, bottom) Left and right side surfaces (top, middle, bottom) Head, right hand, left hand, right foot, left foot ; Total 17 surfaces
Detector sensitivity <Measurement conditions> BG Measurement time Radiation source Measurement distance	0.4 Bq/cm^2 0.1 μSv/h 10 s ^{90}Sr 100 mm × 100 mm Hands and feet : Close contact Head : 50 mm Other : 100 mm
Processing capacity	Approx. 20 s
Size (W) × (D) × (H)	860 × 1,000 × 2,250 (mm)
Mass	780 kg

3.3 Transportable body surface contamination monitor

Surface contamination monitors are usually stationary monitors that are affixed to the floor, but a type that may be transported easily for disassembly and assembly is introduced below.

This transportable monitor is provided with detectors to cover the same entire body surface as the stationary type and also has the same functions and performance as the stationary type. Figure 1 shows the external appearance and Table 1 lists the specifications of the transportable body surface contamination monitor.

3.4 Convenient body surface contamination monitor

The number of detectors installed can be customized according to the status of radiation contamination of the facility. The monitor shown in Fig. 2 is installed inside a radiation controlled area, and detectors are positioned at the hands and feet, and body sides and front surfaces where there is a high frequency of contamination, so that preliminary measurements can be carried

Fig.2 Convenient body surface contamination monitor

out within a short amount of time. A worker enters the monitor from the backside of the monitor, and sets his/her hands and feet at the measurement location to start the measurement easily and automatically.

4. Article Surface Contamination Monitors

4.1 Overview

Article transfer monitors inspect for contamination on the surface and interior of articles transferred out from a radiation controlled area. These monitors are capable of measuring many articles at once and can operate while a worker is being measured by a body surface contamination monitor so as to reduce the amount of labor required. A small article transfer monitor and a transportable small article monitor (types 1 and 2) are available according to the dimensions and weight of the articles to be measured. Figures 3 to 5 show the appearance of each.

Fig.3 Small article transfer monitor

4.2 Common characteristics

(1) Detection sensitivity

Beta-rays and gamma-rays are measurable with sensitivities of 0.4 Bq/cm^2 and 1.1 Bq/cm^2, respectively. The measurement conditions are listed in Table 2.

(2) Positioning of detectors

To measure the contamination of articles having different shapes, monitors are produced as a type having detectors attached on all sides (above, below, front, back, left and right) of the article to be measured, and a type having detectors attached on two surfaces, either above and below or left and right of the article to be measured.

(3) Safety measures

The moveable doors on a monitor are provided with a safety switch that, when touched, stops the gate operation so as to prevent the subject's fingers or arm from being pinched.

4.3 Features of the small article transfer monitor

The small article transfer monitor is installed near the entrance and exit access of the control room, and operates so as to measure efficiently the contamination of small articles such as writing instruments or tools that have been hand-carried into a radiation controlled area by a worker.

(1) Use of a beta + gamma-ray detector

A detector that combines scintillators for beta-ray and gamma-ray use is installed in the small article transfer monitor, enabling measurement of interior surface contamination (gamma-rays).

(2) Moveable upper detector

According to the shape of the subject article, the upper detector may be lowered to measure contamination at a closer distance and to implement highly efficient measurement regardless of the shape of the subject article.

(3) Storage of subject articles

Fig.4 Transportable small article monitor (type 1)

Fig.5 Transportable small article monitor (type 2)

Table 2 Specifications of the article monitor

Item \ Monitor name	Small article transfer monitor	Transportable small article monitor (type 1)	Transportable small article monitor (type 2)
Detector	β+γ-ray detector	Same as on the left	Same as on the left
Detector positioning	Above, below, left, right, front, back of article to be measured	Above and below article to be measured	Left and right of article to be measured
Detection sensitivity (beta-rays) <Measurement conditions> BG Moving speed or measurement time Radiation source Measurement distance	0.4 Bq/cm^2 0.1 μSv/h 10 s ^{90}Sr 100 mm × 100 mm 30 mm	0.4 Bq/cm^2 0.1 μSv/h 10 s ^{90}Sr 100 mm × 100 mm 30 mm	0.4 Bq/cm^2 0.1 μSv/h 10 s ^{90}Sr 100 mm × 100 mm 30 mm
Detection sensitivity (gamma-rays) <Measurement conditions> BG Moving speed or measurement time Radiation source Measurement distance	1.1 Bq/cm^2 0.1 μSv/h 10 s ^{60}Co 100 mm × 100 mm 30 mm		
Size of article to be measured (W) × (D) × (H)	500 × 500 × 300 (mm)	420 × 300 × 120 (mm)	250 × 350 × 350 (mm)
Mass of article to be measured	20 kg	5 kg	5 kg
Example of article to be measured	○ Paper documents ○ Tools ○ Writing instruments ○ Small measuring instruments	○ Paper documents ○ Tools ○ Writing instruments	○ Helmets ○ Tools ○ Personal computers ○ Survey meters
Size (W) × (D) × (H)	1,000 × 1,900 × 1,600 (mm)	550 × 450 × 600 (mm)	460 × 600 × 600 (mm)
Mass	1,800 kg	50 kg	36 kg

After being measured, non-contaminated articles are transferred to a non-radiation controlled area conveyor. A stocker for storing these measured articles may be connected. The number of storage shelves in the stocker can be selected as, for example, eight shelves for 100 mm-tall measured articles or four shelves for 300 mm-tall measured articles.

4.4 Transportable small article monitor (type 1)

The transportable small article monitor is limited to use with notebooks and paper documents to be measured. Since a driving mechanism is not attached, the monitor is small and has a mass of approximately 50 kg. Moreover, since only a small installation space is needed, this monitor may be installed temporarily when many articles are being transferred.

The height at which the upper detector is attached can be selected from four levels: 40, 70, 100 and 130 mm, and can be set manually.

4.5 Transportable small article monitor (type 2)

This monitor is used to measure helmets and survey meters, which are relatively high (350 mm) compared to the articles measured with the abovementioned transportable small article monitor.

5. Laundry Monitors

5.1 Overview

Laundry monitors are used prior to washing to inspect efficiently whether clothes and the like used in a radiation controlled area are contaminated, and are also used after washing to inspect the surface of the clothes. The articles measured are small, and include overalls, undergarments and other clothes, hats, gloves, socks, chin straps, etc. A small article pre-monitor or the like is used to measure the contamination of clothes prior to washing, and to separate articles having high levels of contamination. A clothing monitor or the like is used to inspect whether contamination remains on clothes that have been washed.

Typical examples of a small article monitor and a clothing monitor are presented below.

5.2 Features

(1) Each monitor has an inspection sensitivity that adequately detects the legally prescribed contamination levels for articles that may be transferred outside of a radiation controlled area.
(2) A clothes monitor having high processing capability can inspect approximately 250 pairs of overalls in one hour.
(3) A low-noise, long-life plastic belt is used in the clothes conveyer part of a clothes monitor.
(4) A static eliminator is provided to protect the workers from static electric shocks from charge that has accumulated on the clothes.
(5) Various self-diagnostic functions are provided and the integrity of the measuring system is constantly being checked automatically.

5.3 Functions

(1) Small article pre-monitor

This monitor measures contamination from small articles prior to washing. The subject articles that have been inputted into the monitor are transported

Fig.6 Small article pre-monitor

Table 3 Specifications of the small article pre-monitor

Item	Details
Type of radiation detected	Gamma rays
Detector	Plastic scintillation detector
Detection sensitivity	1.0 Bq/cm^2 or less (Radiation source used : ^{60}Co)
Processing capability	Approx. 250 pairs/h (undergarments)
Size (W) × (D) × (H)	Approx. 950 × 2,500 × 1,420 (mm) or less
Mass	Approx. 1,600 kg

Fig.7 Clothing monitor

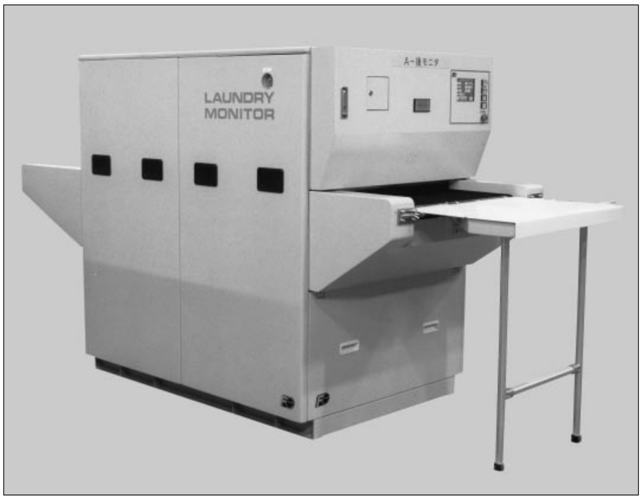


Table 4 Specifications of the clothing monitor

Item	Details
Type of radiation detected	Beta rays
Detector	Plastic scintillation detector
Detection sensitivity	1.0 Bq/cm^2 or less (Radiation source used : ^{60}Co) 0.37 Bq/cm^2 or less (Radiation source used : ^{90}Sr)
Processing capability	Approx. 250 pairs/h (overalls)
Size (W) × (D) × (H)	Approx. 1,000 × 2,500 × 1,350 (mm)
Mass	Approx. 3,000 kg

by a belt conveyor and pass underneath a detector that inspects for contamination. Also, a sorting mechanism mounted at the rear of this monitor separates non-contaminated articles from contaminated articles. Furthermore, the operating method can be selected so as to return contaminated articles to the input side. The belt conveyor is made from a highly water-resistant material so that wet small articles can also be measured. Figure 6 shows the exterior appearance of a small article pre-monitor and Table 3 lists its specifications.

(2) Clothing monitor

This monitor measures contamination from clothing and small articles after washing. The subject articles that have been inputted into the monitor are squeezed by vertical conveyors, and are moved between vertically positioned detectors so as to inspect for contamination. A beta-ray detector having a wide range of sensitivity is used to enable measurement across the entire conveyor without any dead spots. Figure 7 shows the exterior appearance of a clothing monitor, and Table 4 lists its specifications.

6. Hand-foot-clothes Monitor

6.1 Overview

Hand-foot-clothes monitors are installed mainly in hospitals and in contamination inspection rooms at facilities which handle radioactive matter. The monitors detect surface contamination from radioactive matter adhered to workers' hands, feet, clothes and so on. The monitors detect beta-rays from among the radiation emitted by the radioactive matter, sound an alarm if a preset alarm level is exceeded, and display the locations of contamination on the workers' hands, feet and clothes.

Figure 8 shows the exterior appearance of a hand-foot-clothes monitor, and Table 5 lists its specifications.

6.2 Features

(1) Automatically measures radiation contamination on hands and feet placed on the measuring location, and evaluates and displays the contamination locations.

(2) Automatically measures the background (BG) level at regular intervals, subtracts the latest BG value, and minimizes the effect of fluctuations in the BG to perform accurate contamination measurement.

(3) When contamination occurs, displays the contaminated location graphically on a color display, so that the measurement results can be verified easily.

(4) The plastic scintillation detector used does not require replacement, unlike the case in which a

Fig.8 Hand-foot-clothes monitor

Table 5 Specifications of the hand-foot-clothes monitor

Item	Details
Type of radiation detected	Beta rays
Detector	Plastic scintillation detector
Detection sensitivity	1.0 Bq/cm^2 or less (Radiation source used: ^{36}Cl, ^{60}Co) 0.2 Bq/cm^2 or less (Radiation source used: U_3O_8)
Measurement time	15 s (can be set within range of 1 to 999 s)
Size (W) × (D) × (H)	630 × 725 × 1,356 (mm) or less
Mass	Approx. 80 kg

limited-service-life GM tube is used.

(5) The detector used to measure clothing contamination is made out of plastic and is lightweight so as not to burden the measuring worker.

(6) The foot stand is low to enable easy placement of one's foot on the stand.

(7) Wheels are utilized on the back surface side so that the monitor can be moved by one person.

(8) The monitor is separable into three parts so delivery and installation are easy.

(9) Film to prevent contamination can be reeled up and replaced easily.

(10) A printer may be used optionally.

6.3 Functions

The BG and contamination measurements are performed repeatedly. If the BG level has not yet been measured, the BG level is measured first, and after the completion of a preset number of BG measurements, the contamination is measured. Usually, the BG measurement is performed to update the stored value to the latest BG value.

There are two types of contamination measurements, hands and feet contamination measurement and clothing contamination measurement, each of which is performed independently. The hands and feet contamination measurement begins after full detection by the hand and foot detection sensor, and after completion of the measurement, the evaluation results are displayed on a screen. The clothing contamination measurement uses a probe-shaped detector attachment and measures while surveying the clothing surface. The results are displayed in real-time on a screen. The BG measurement is resumed after the contamination measurement is completed, and if the measurement results are abnormal, the background setting can be verified to determine whether there is contamination from the measurer or a monitor abnormality.

7. Postscript

Fuji Electric has been developing and delivering radiation contamination monitors to nuclear power plants throughout Japan in response to customer needs. In order to expand sales overseas, Fuji Electric intends to develop model varieties that support IEC standards.

Environmental Radiation Monitoring System

Tsutomu Kato
Masatoshi Shioiri
Tsuyoshi Sakamaki

1. Introduction

An environmental radiation monitoring system (hereafter referred to as the system) is a significant system for measuring environmental radiation levels at the boundaries of monitoring areas surrounding a nuclear facility and in the surrounding regions, and for monitoring the radiation exposure to residents in the surrounding regions.

This paper presents an overview of the system and describes new functions that have been developed to improve the reliability of measurement data.

2. Overview of the System

The system is configured from a dose rate measurement device, a dust monitor, and an iodine monitor. Weather observation facilities, a telemeter, and an environmental monitor panel and computer installed in a central control room may also be connected to the system. Figure 1 shows an example system configuration and Fig. 2 shows an example installation for dose rate measurement.

Additionally, in order to supplement the measurement of the dose rate and to respond to emergencies, a mobile monitoring car equipped with a dose rate measuring system can also be provided as a part of the system, and Fig. 3 shows an example of the monitoring car.

Fig.1 System configuration example

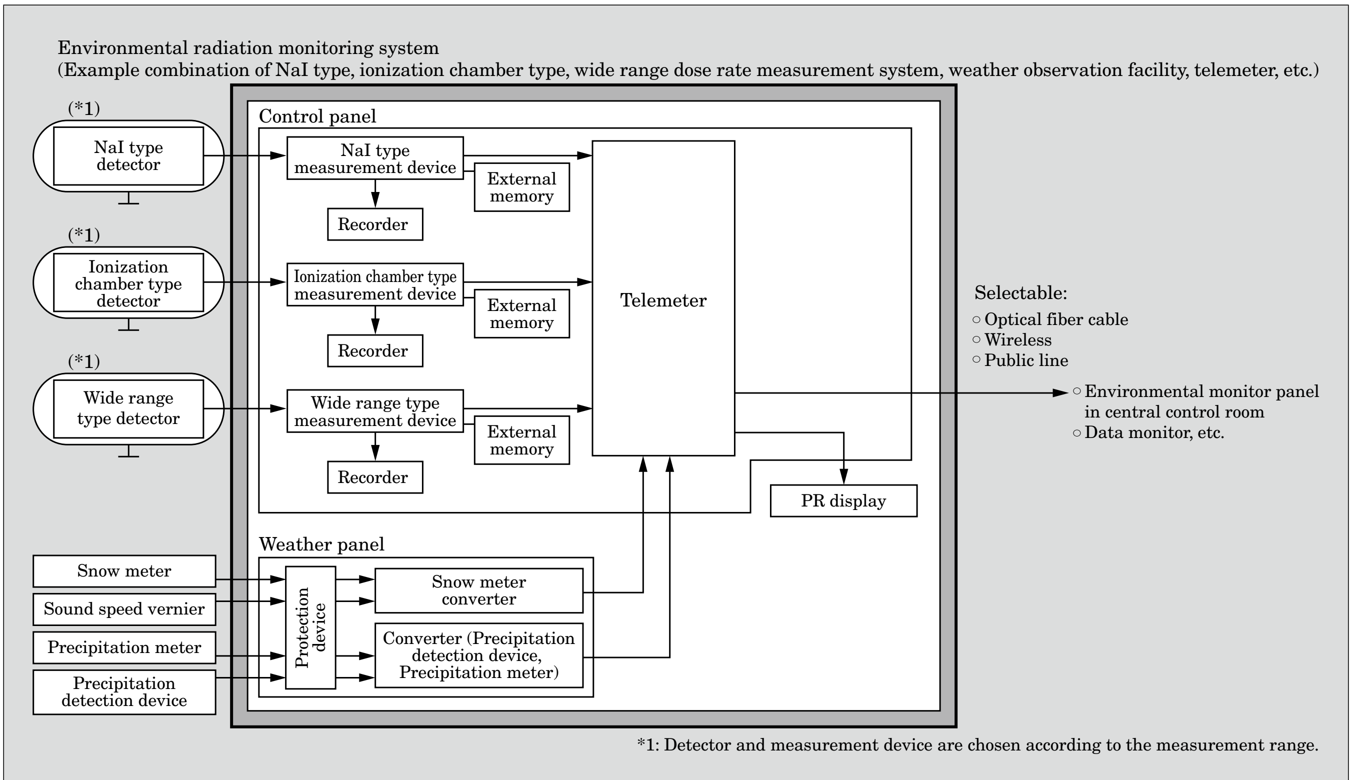


Fig.2 Example of installation for dose rate measurement device

Fig.3 Example of the monitoring car

Table 1 Specification table of dose rate measurement systems

Item	NaI type radiation dose rate measuring system	Ionization chamber type dose rate measurement system	Wide range radiation dose rate measurement system
Detector	NaI (T*l*) scintillation detector	Ionization chamber detector	NaI (T*l*) scintillation detector (with lead filter)
Detector size	2 "dia. × 2"	Approx. 14.5 L	2 "dia. × 2"
Measurement range	BG level to 10^5 nGy/h	BG level to 10^8 nGy/h	BG level to 10^8 nGy/h
Display error	Within ±10 %	Within ±10 %	Within ±20 %
Energy characteristic	50 keV to 3 MeV : Within ±10 %	50 keV to 400 keV : Within ±15 % 0.4 to 3 MeV : Within ±10 %	50 keV to 100 keV : Within ±20 % 50 keV to 3 MeV : Within ±10 %
Direction characteristic	Within ±10 %	Within ±3 %	Within ±10 %
Temperature characteristic (20°C reference)	Within ±5 %	Within ±5 %	Within ±5 %

2.1 Dose rate measuring system

The dose rate measuring system is configured from a detector and measuring device. Three types of dose rate measuring systems exist according to the dose rate range to be measured: the NaI type, the ionization chamber type and the wide range type.

(1) NaI-type of dose rate measuring system

The NaI-type of dose rate measuring system is capable of measuring the region from 10 to 10^5 nGy/h. The detector is equipped with a NaI (T*l*) scintillator, a photomultiplier, an amplifier, a high voltage power supply and a temperature compensation circuit, and outputs standardized pulse signals without any temperature dependence. The measurement device is equipped with an approximate 6-inch TFT color LCD display, a CPU for measurement-use with an energy compensation circuit, and a CPU for displaying, transmitting and storing the measurement data. Moreover, the energy compensation method employs a DWM (digital weighting method) that uses a G (E) function so that measurement data is counted with a high degree of accuracy and converted into the dose rate, and a spectral data aggregation function simultaneously enables the radioisotope to be identified from the gamma-ray energy data.

(2) Ionization chamber type dose rate measurement system

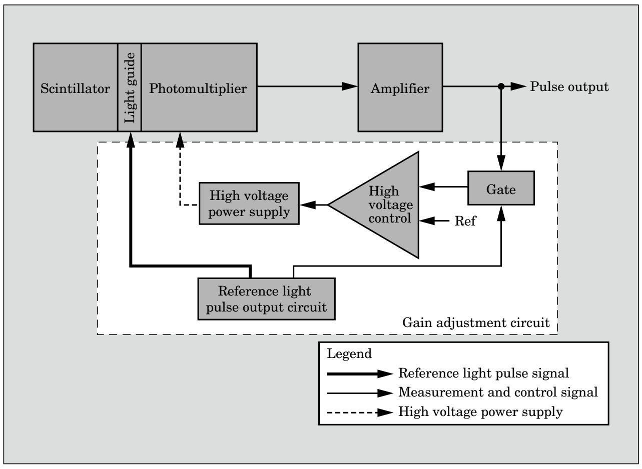
The ionization chamber type dose rate measurement system is capable of measuring the region from the BG (background dose rate) level to 10^8 nGy/h. The detector is equipped with an ionization chamber, an amplifier, a voltage-frequency conversion circuit and a high voltage power supply, and the measurement device counts frequency pulses from the detector and displays the dose rate data. Also available is a type in which the material used for the case of the spherical ionization chamber has been changed from the conventional stainless steel to aluminum, which has a smaller specific gravity, and that measures gamma rays with improved accuracy in the low energy region of 400 keV and below.

(3) Wide range dose rate measurement system

The wide range dose rate measurement system adds to the NaI-type dose rate measurement system an auxiliary measurement function for measuring the high dose rate region assumed in the case of an accident, and is capable of measuring the region from the BG (background dose rate) level to 10^8 nGy/h with the combination of a single detector and a measurement device. With the combination of a detector and a measurement device, the low dose rate region of the BG level to 10^5 nGy/h is measured and processed with pulse signals from the detector, and for the high dose

Fig.4 Portable iodine monitor

Fig.5 Schematic diagram of automatic gain adjustment



rate region of 10^5 nGy/h and above, for which pulse measurement is not possible, a method is adopted in which a current signal proportional to the dose rate is measured and processed.

Main specifications of the NaI type dose rate measurement system, the ionization chamber type dose rate measurement system, and the wide range dose rate measurement system are listed in Table 1.

2.2 Dust monitor, iodine monitor

The dust monitor continuously measures the concentration of radioactive dust in the air. The dust monitor is integrated with a dust sampler. The detector uses an alpha-beta coincidence counting method that combines a plastic scintillator for measuring beta-rays, and a ZnS scintillator for measuring alpha-rays. Moreover, a function for automatically sampling radioactive iodine in a charcoal cartridge is added for cases where the dose rate of environmental gamma-rays exceeds a preset warning level. Furthermore, a portable radioactive iodine monitor is also available for sampling and measuring the radioactive iodine. (See Fig. 4.)

2.3 Telemeter

The transfer of data from a monitoring post to a monitor panel in a central control room can be implemented with a transmission system adopting a telemeter using a programmable controller having high reliability and a successful track record for 24-hour continuous operation. The transmission pathway can be selected as a fiber optic cable, wireless transmission such as with a cell phone, or a public line.

3. New Functions

(1) NaI type dose rate measurement system

(a) Spectral data output function
The measurement device is provided with a function for setting four predetermined energy regions for the aggregated spectral data to enable the radiation dose of each region to be assessed. For example, by setting these energy regions to the natural radiation region, the man-made radiation region, and the energy region of radiation used for radiotherapy, it is possible to assess which region's radiation has caused a rise in the measured value.

(b) Automatic gain adjustment function
The automatic gain adjustment method was developed to improve the reliability of measured data. As a method to prevent gain drift, an LED light source is inserted into the detector, a reference pulse is inputted continuously, and a function is provided that checks the peak channel position on a minute-by-minute basis. Figure 5 shows an overview of the automatic gain adjustment function. In the case where the measured peak channel position has drifted from the reference channel to a value greater than the standard value, the amplifier gain is adjusted automatically so that data can be acquired without being affected by gain drift.

(2) Dust monitor

The naturally occurring radionuclides of the uranium and thorium series exist in nature as background radiation. The radiation emitted from these radionuclides are nuclides that interfere with counting by the dust monitor, and if the measurement data fluctuates, whether that fluctuation is due to a fluctuation in natural radiation or due to an increase in radiation levels from the facility cannot be determined. Previously, many methods for removing these interfering nuclides have been tried, and introduced here is the alpha-beta coincidence count method that has been commercialized by Fuji Electric. This method is applicable to a wide range of products, including monitoring posts. The principles of this method are described below.

Fig.6 Decay scheme of radon (Rn) series

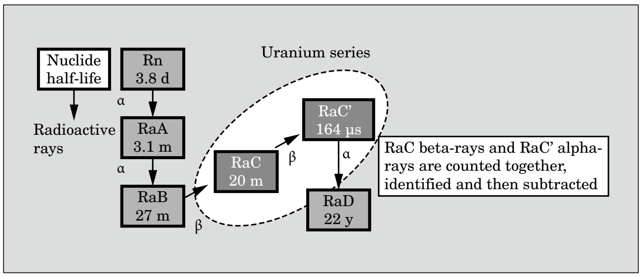
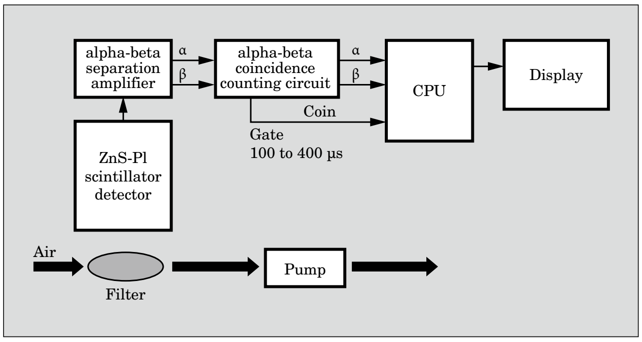


Fig.7 Schematic diagram of the alpha-beta coincidence counting circuit

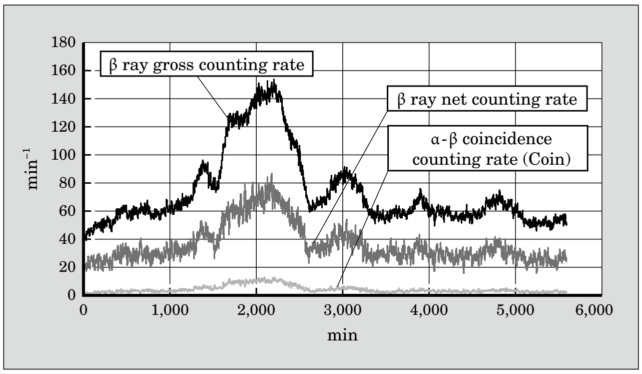


(Principle of subtraction by alpha-beta coincidence counting)

Each radionuclide emits a certain type of radiation for a certain time duration and then changes into another atomic nucleus, and the halfway point for that change is known as the half-life. Figure 6 shows the decay scheme of the radon series of natural radiation.

In consideration of the half-life of RaC and RaC' shown in Fig. 6, the subtraction method counts both the beta-rays and alpha-rays emitted within the extremely short time of 164 μsec. In other words, these alpha-rays and beta-rays are regarded as an alpha-beta coincidence signal (Coin), and an CPU subtracts them from all counted values, so that the effect of natural radiation emitted from RaC and RaC' can be eliminated. Figure 7 shows a schematic diagram of the alpha-beta coincidence counting circuit. Moreover, Fig. 8 shows the subtraction effect of the alpha-beta coincidence method. Use of this subtraction method enables the background influence to be reduced by approximately half.

Fig.8 Subtraction effect of the alpha-beta coincidence counting method



4. Postscript

Fuji Electric has been building highly reliable systems that utilize comprehensive technology including radiation measuring and data transmission techniques and the like.

In the future, based on this radiation measuring technology, Fuji Electric intends to build monitoring systems that are even more compact and have lower cost.

Nuclear Facility Radiation Monitoring System

Keiichi Ooi
Katsumi Yasutomo
Zenjiro Suzuki

1. Introduction

Radiation control at nuclear power facilities is implemented in accordance with various laws and regulations for the safety of workers in the facility and local residents. Radiation monitoring systems are critical systems that operate 24 hours a day, monitoring the radiation conditions in work environments inside the facility and the radiation concentrations in air and fluids discharged outside the facility.

In a radiation monitoring system, the data signals from radiation detectors installed at each worksite are transmitted to a central control room where radiation levels and alarm activation are monitored on a radiation monitoring panel and where a radiation control computer processes the data and outputs the data on a display or as a printout.

In conventional systems, extremely weak radiation signals had to be converted into electrical signals, amplified and then transmitted. Furthermore, the detection mechanisms differed according to the type of radiation to be measured, and as a result, the latter stage signal transmission methods also differed, and the radiation detectors installed at each worksite and the radiation monitoring panel which installed in the central control room were connected by cables in a 1-to-1 correspondence.

Applying the conventional system configuration to a monitoring system having a large number of radiation monitors distributed throughout multiple facilities would require the construction of an enormous hardware structure, and this was a limiting factor for system construction.

Recently, as radiation control at nuclear power facilities becomes more advanced, radiation monitoring systems are being required to provide improved reliability, labor saving maintenance and inspections, and enhanced monitoring functions.

Meanwhile, there has been remarkable progress in the development of IC and other semiconductor technology, transmission processing technology and data processing technology.

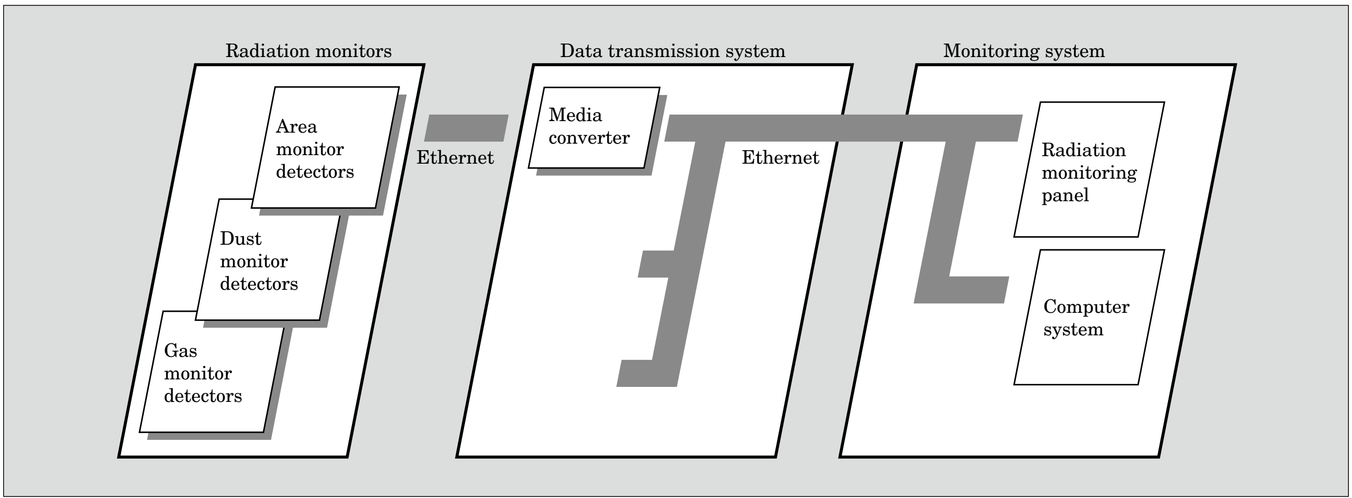
Under these conditions, Fuji Electric is providing large-scale radiation monitoring systems that incorporate the latest technology, and this paper introduces these systems.

2. Overview

Fuji Electric has developed radiation monitoring systems in accordance with the following objectives.

(1) To develop new semiconductor radiation sensors in

Fig.1 Concept of nuclear power facility radiation monitoring system



order to increase the detection sensitivity (efficiency).

(2) To make radiation detectors more intelligent and to improve their reliability and maintainability, to integrate into a radiation detector the characteristic functions for radiation measurement (configured with custom circuits for each type of radiation to be measured, α-ray, β-ray, γ-ray and so on, since signal levels vary according the type of measurement) having been distributed previously between a central control room and onsite locations, and to use a general-purpose transmission interface.

(3) To incorporate the latest data transmission technology in the transmission of signals from the radiation detectors to a central control room or to a radiation control computer, and to achieve higher reliability and faster transmission speeds for large amounts of data.

The configuration of a developed system based on these objectives is shown in Fig. 1.

All the functions required to measure radiation were successfully installed in a radiation monitor, and the signal processing results are output as digital data. The transmission interface is the IEEE-802.3 standard (Ethernet*1), regardless of the type of monitor, and an always-on self-diagnostic function and a remote automated inspection function were added to realize labor savings for maintenance and inspections. Additionally, the radiation sensor uses a newly developed large-size semiconductor sensor.

A data transmission system can be constructed flexibly according to the number of detectors to be connected and the size of the facility. Figure 1 shows a schematic diagram of a large-scale system in the case where Ethernet is used as the transmission interface. Each radiation detector's output is in Ethernet 100 BASE-TX format, transmitted through a media converter to transfer large quantities of data optically to a central radiation monitoring and control system.

3. Radiation Monitors

The functional configuration of a radiation detector is shown in Fig. 2. Previously, radiation monitors were provided with onsite sensors and pre-amps only, and the remaining functions were all housed in a radiation monitoring panel. In the past, a monitor loop was formed by assembling multiple hardware modules according to the type of each sensor, but now using a

*1: Ethernet is a registered trademark of Xerox Corp., USA.

Fig.2 Radiation detector functions and configuration

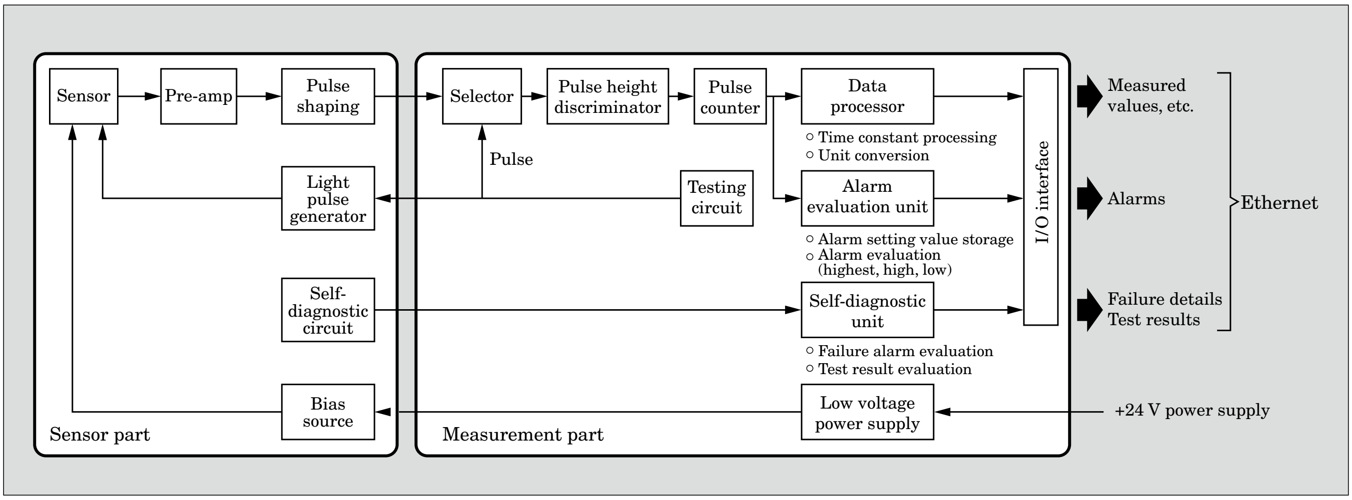


Table 1 Types and main functions of radiation detectors

Monitor types	Main specifications: Detectors	Main specifications: Measurement range
γ-ray area monitor	Ionization chamber detector	10^{-2} to 10^{4} μSv/h
	Semiconductor detector	10^{-1} to 10^{4} μSv/h
Neutron area monitor	^{3}He proportional counter tube	10^{-2} to 10^{4} μSv/h
α-ray dust monitor	Semiconductor detector	10^{-2} to 10^{4} s^{-1} (cps)
β-ray dust monitor	Semiconductor detector	10^{-1} to 10^{5} s^{-1} (cps)
β-ray gas monitor	Plastic scintillation detector	10^{-1} to 10^{5} s^{-1} (cps)
Iodine monitor	NaI (T*l*) scintillation detector	10^{-1} to 10^{5} s^{-1} (cps)

single-chip micro computer, and all these functions are incorporated into a single CPU board and housed in the detector.

A radiation detector consists of a sensor part and a measuring part. Common functions that do not depend on the type of monitor are provided in the measuring part and functions that differ according to the type of radiation to be measured are provided in the sensor part.

The radiation detector has the following always-on self-diagnostic functions, and sends an automatic transmission to the data monitoring and control system when an abnormality occurs.

(1) Continuous monitoring of discrimination level
(2) Continuous bias voltage monitoring
(3) CPU checking (RAM, ROM)
(4) Continuous DO/AO monitoring
(5) Continuous monitoring for temperature abnormalities

Additionally, the radiation detector also has a function for receiving remote commands from the central control room, implementing the following tests automatically, and notifying the central control room of the results.

(1) Light pulse test

An internal light pulse generator produces light pulses to verify the integrity of the entire monitor loop, including the sensors. The frequency of the light pulses can be set arbitrarily by the radiation monitoring system.

(2) Alarm test

This test verifies the integrity of an internal alarm circuit by incrementing and decrementing inputted data and verifying the alarm output.

(3) Maximum and minimum calibration

An internal test circuit produces electrical pulses which are counted to verify the maximum and minimum limits of the measurement range.

Table 1 lists the main specifications of radiation detectors.

Figure 3 shows a neutron area monitor detector. The energy range to be measured is 0.025 eV to 15 MeV, which sufficiently covers the range of energy of neutrons emitted from a nuclear power facility. (External dimensions: approx. 257 mm (dia.) × 388 mm (H) × 250 mm (dia.) (bottom); Mass: approx. 15 kg.)

Figure 4 shows a semiconductor γ-ray area monitor detector that is capable of measuring energy in the range from 55 to 1,500 keV. (External dimensions: 120 mm (W) × 100 mm (D) × 190 mm (H); Mass: approx 1.3 kg.)

Figure 5 shows the measurement part combined with the detector (sensor). The front panel has an LCD display, and can display measured radiation values. Various settings and operations are controlled by a dedicated infrared ray remote controller. Changes to the alarm setting value and the like can be accomplished by remote operation via a LAN. An alarm display is installed on the upper side, and alarms can be displayed or sounded at an onsite location. (External dimensions: 190 mm (W) × 70 mm (D) × 242 mm (H), not including projections; Mass: approx. 2.7 kg.)

The interface specifications for transmitting data to the center from the measuring part are as follows.

(1) Transmission method: IEEE-802.3 standard (Ethernet)
(2) Transmission data: Radiation measurement values, alarm contents, failure contents, test results, etc.

Fig.3 Neutron area monitor detector

Fig.4 Semiconductor γ-ray area monitor detector

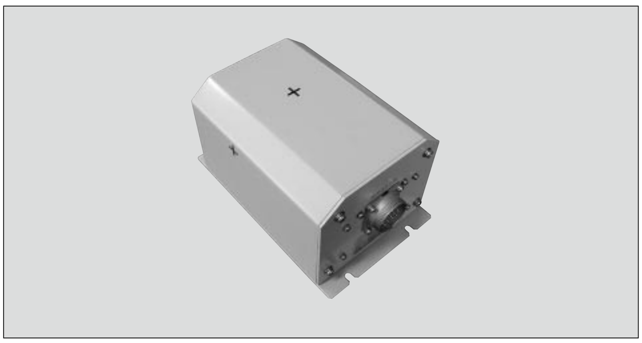


Fig.5 Measurement part

Fig.6 Configuration of nuclear power facility radiation monitoring system

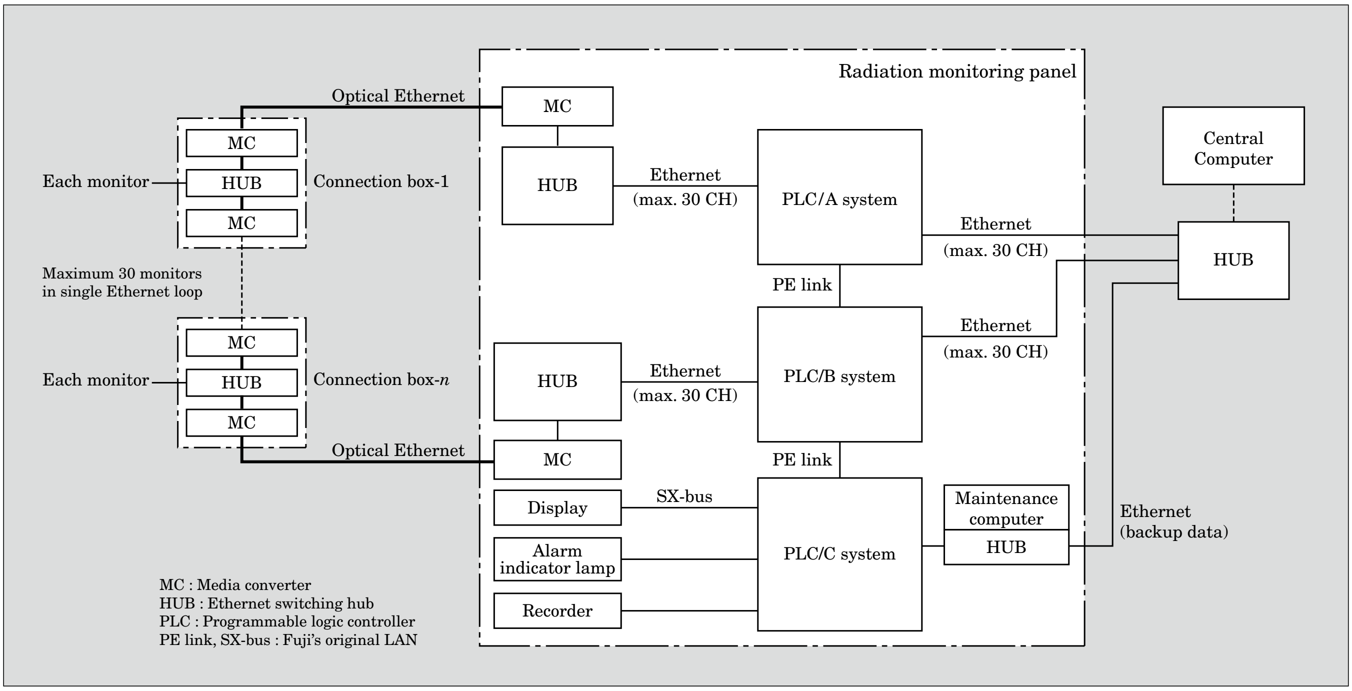
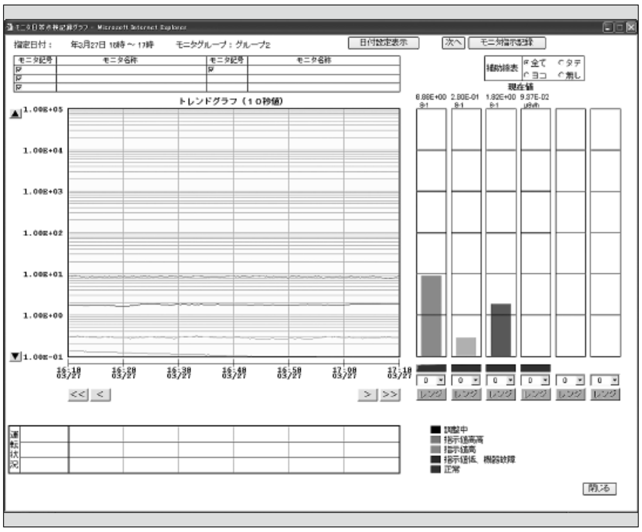


Fig.7 Example of central computer display



4. System Configuration

The development of radiation monitors having an Ethernet interface enables a radiation monitoring system to be constructed according to the size of the facility. Figure 6 shows an example configuration of a radiation monitoring system.

This system is capable of connecting a maximum of 30 radiation monitor channels in a single Ethernet loop. Multiple Ethernet loops can be combined to construct a large-scale system. The signal from each radiation monitor is input to an Ethernet switching hub (HUB), fed through a media converter (MC), and transmitted via an optical Ethernet to the radiation monitoring panel. A maximum of 3 radiation monitor channels are connected to a HUB and are installed at a suitable location according to the layout of the facility.

A pair of programmable controllers (PLC/A and PLC/B) are installed in the radiation monitoring panel, and are connected to each side of the optical Ethernet via a MC. Radiation monitoring data is transmitted every second to both of these controllers, enabling data to be acquired even when there is mechanical failure of a LAN device onsite or in the monitoring panel. Additionally, each radiation monitor is also provided with an Ethernet interface and can transmit data directly to a central computer. Figure 7 shows an example of a central computer display.

The HUB is shared by the system, and may be replaced in the case of failure. The PLC/C implements essential command, data recording and alarm functions at the radiation monitoring panel.

5. Postscript

This paper has introduced Fuji Electric's nuclear facility radiation monitoring systems. The systems and components introduced here have been designed such that all characteristic functions for radiation measurement are installed in the radiation detector, and the signal processing results are output as digital data. As a result, there are almost no restrictions on the system configuration, and future advances in data processing technology will be easy to incorporate.

Fuji Electric intends to continue its developmental efforts, aiming for higher reliability, maintainability and productivity.

Reliability and Traceability in Radiation Calibration

Sadao Nakashima
Teruo Ebato

1. Introduction

Fuji Electric has a successful history of delivering radiation measuring equipment used in the controlled areas of facilities that handle radioactive matter and nuclear fuel materials. Radiation measuring equipment is required to have high measuring accuracy, and proper calibration, using a calibrator that provides traceability to national standards, is essential in order to ensure that accuracy.

In order to calibrate radiation measuring equipment for various uses, Fuji Electric maintains and operates calibrator having different nuclides and irradiation strengths.

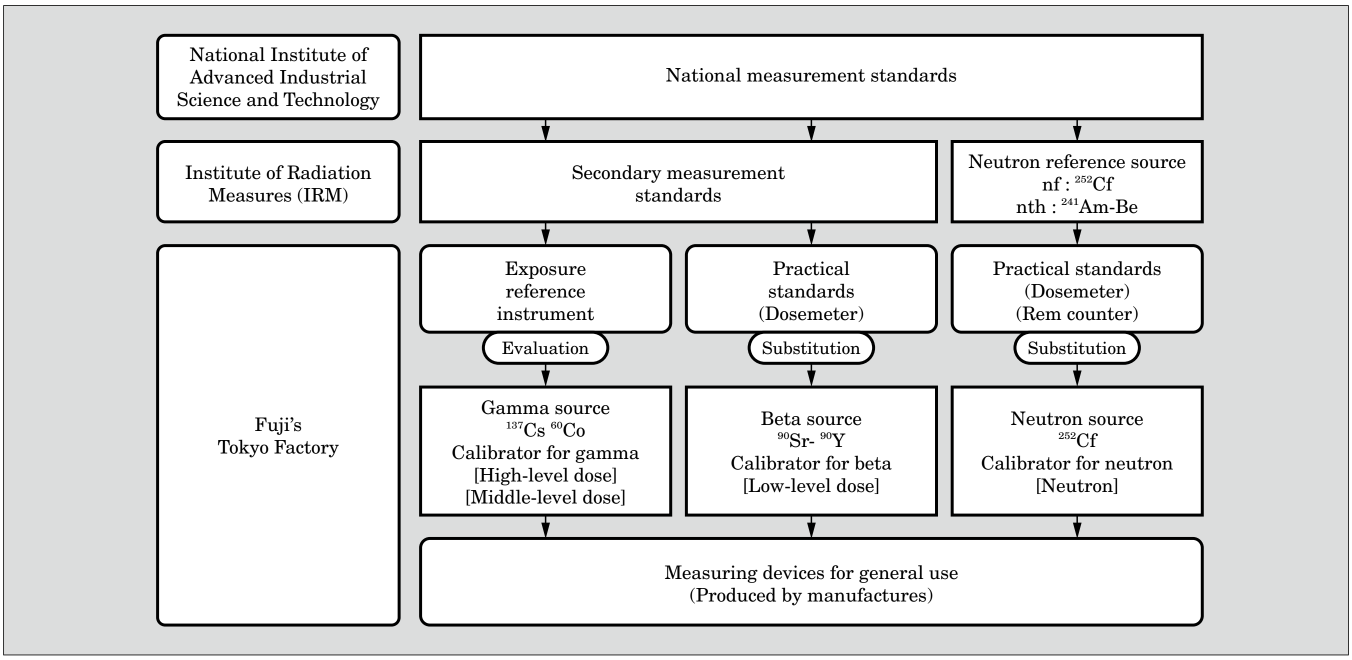
2. Traceability

For radiation measuring equipment, establishing traceability linking the national standards to products, and maintaining the calibration accuracy are extremely important. Fuji Electric's calibration equipment for radiation measurement devices is based on Japanese domestic laws and standards, and is traceable to the national standards shown in Fig. 1.

3. Calibrator

The calibrator is measured at a location an arbitrary distance from the radiation supply, with a reference measuring device traceable to national standards, and is assigned a value. The device to be calibrated is placed in the same place with the calibrator, and the calibration is performed by comparing the measured values obtained with the values measured by the reference measuring device. The calibration of the device to be calibrated is performed using a radiation source of the same nuclide, also by changing the irradiated dose equivalent rate. Moreover, the energy calibration is performed using a radiation source of different nuclide to irradiate at the same dose equivalent rate.

Fig.1 Traceability system chart



3.1 Gamma-ray calibrator

(1) Gamma-ray calibrator (high dose)

This calibrator is used for calibrating survey meters, area monitors, ionization chambers and the like. ^{137}Cs, ^{60}Co and ^{226}Ra radiation sources are used for the calibration and for energy calibration. This calibrator is configured from an irradiator that houses the radiation source, a calibration truck in which the device to be calibrated is placed, and a controller that controls the operation of these apparatuses. When an irradiated dose equivalent rate is set by the controller, the type of radiation source and distance are computed, the calibration truck moves automatically to a predetermined location, the radiation source is selected, irradiation by the radiation source is implemented, and so on. Figure 2 shows the external appearance, Fig. 3 shows the system configuration and Fig. 4 shows the calibration range of this gamma-ray calibrator.

(2) Gamma-ray calibrator (medium dose)

This calibrator uses a ^{137}Cs radiation source to calibrate personal dosemeters and environmental dosemeters. The calibrator is configured from an irradiator and a controller. This calibrator varies the strength of the radiation source and the time duration of the irradiation to change the irradiated dose and to perform the calibration. The devices to be calibrated are arranged in a circle around the radiation source, and 50 devices can be calibrated simultaneously. Figure 5

Fig.2 Photograph of gamma-ray calibrator (high range)

Fig.4 Calibration range of gamma-ray calibrator (high level)

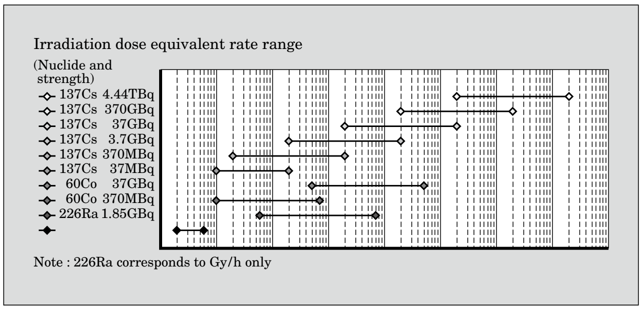
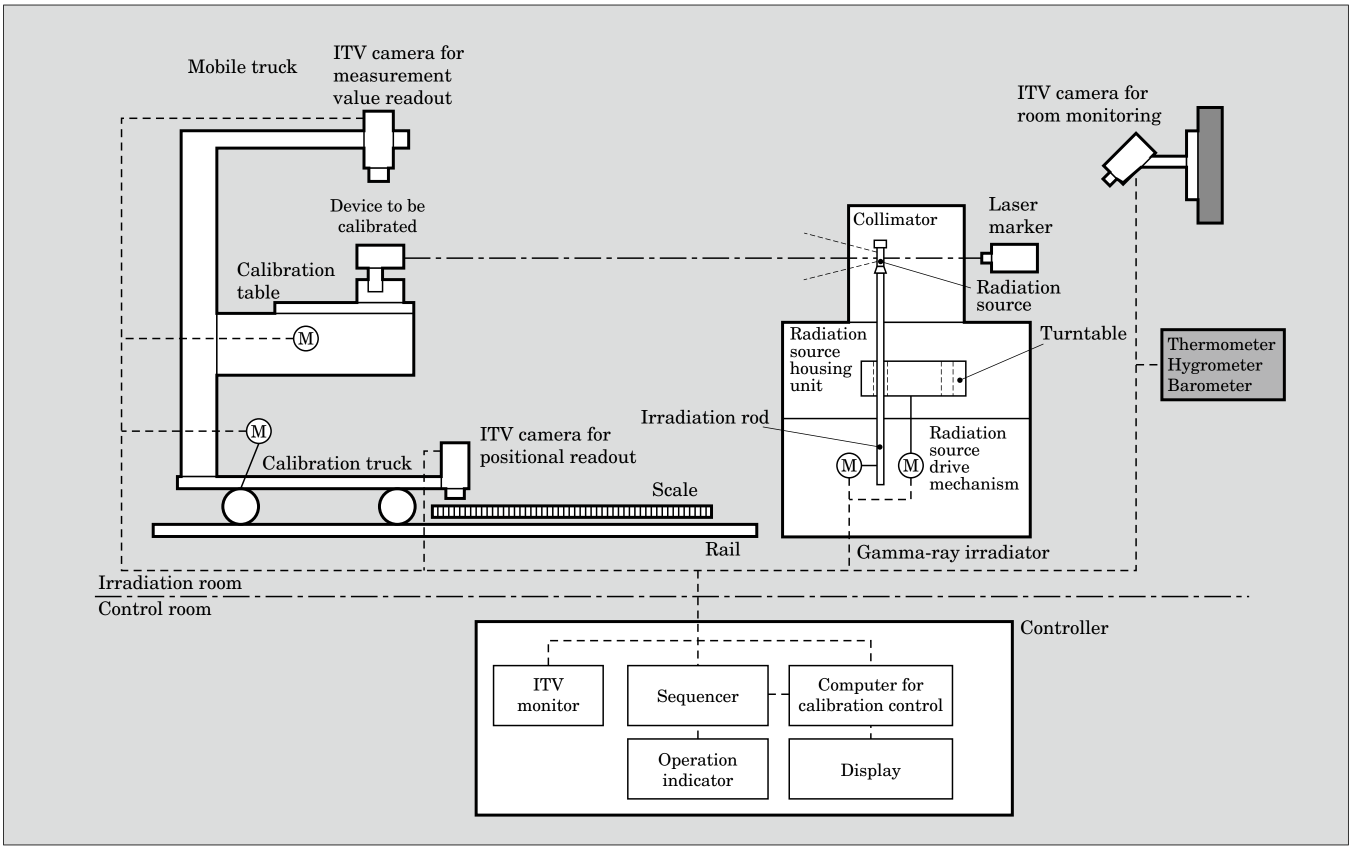


Fig.3 System configuration of gamma-ray calibrator (high level)



shows the external appearance, Fig. 6 shows the system configuration and Fig. 7 shows the calibration range of this gamma-ray calibrator.

3.2 Neutron calibrator

This calibrator uses a ^{252}Cf radiation source to calibrate neutron area monitors, rem counters, personal dosemeters and the like. This calibrator is configured from an irradiator and an apparatus (automatic conveyor) in which the device to be calibrated is placed, and calibrates with the dose equivalent of fast neutrons and thermal neutrons. Personal dosemeters are conveyed automatically by an automatic conveyor to the calibration location, and 24 personal dosemeters may be calibrated consecutively. Figure 8 shows the external appearance, Fig. 9 shows the system configuration and Fig. 10 shows the calibration range of this neutron calibrator. The apparatus shown in the front in Fig. 8 is the automatic conveyor and the rear apparatus is the irradiator that houses the radiation source.

Fig.5 Photograph of gamma-ray calibrator (middle level)

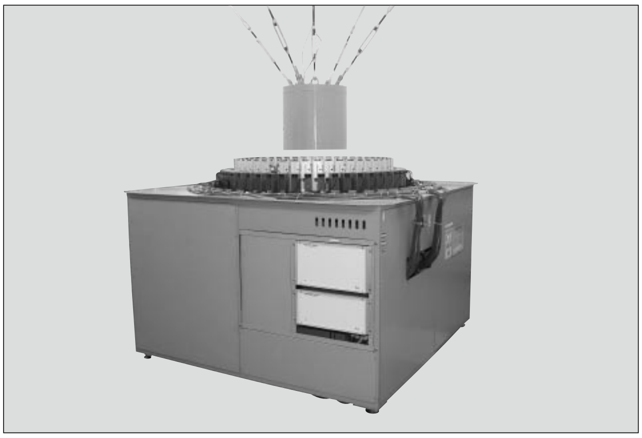


Fig.6 System configuration of gamma-ray calibrator (middle level)

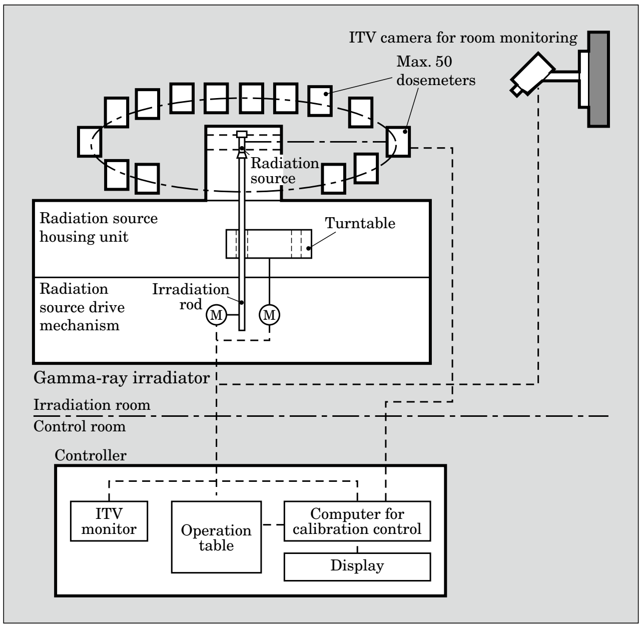


Fig.7 Calibration range of gamma-ray calibrator (middle level)

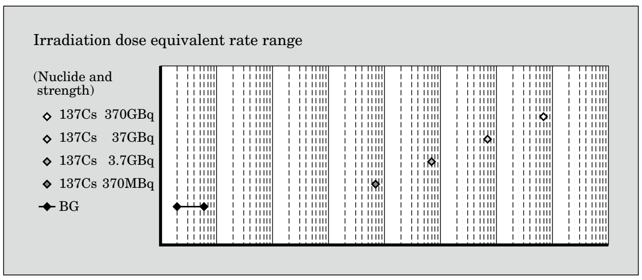


Fig.8 Photograph of neutron calibrator

Fig.9 System configuration of neutron calibrator (middle level)

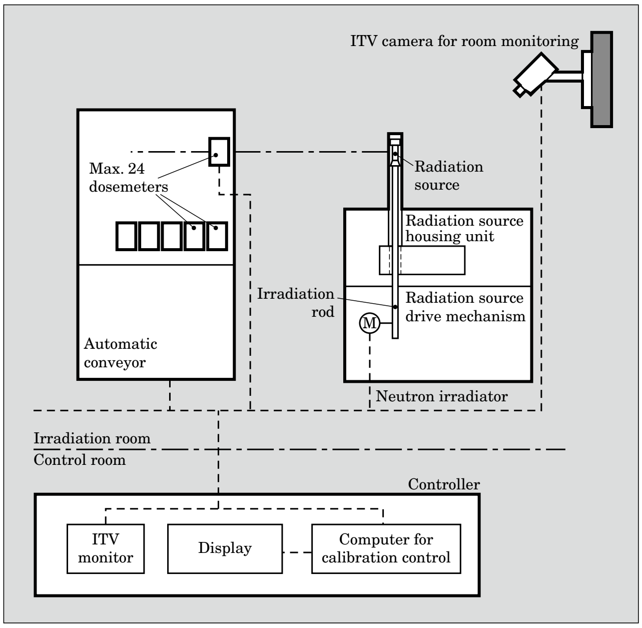


Fig.10 Calibration range of neutron calibrator (middle level)

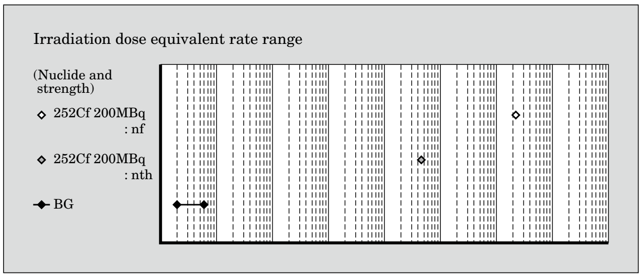


Fig.11 Photograph of beta-ray calibrator

3.3 Beta-ray calibrator

This calibrator uses a ^{90}Sr radiation source and this calibrator is dedicated for use with personal dosemeters (beta-rays). This calibrator is configured from a radiation source housing unit, a part on which to mount the device to be calibrated, an operation part and a computer. The radiation source is housed in the radiation source housing unit and the dosemeter is inserted through an inlet to the mounting part. Then, by setting the irradiation time duration from the operation part or from the computer and starting the calibration, the shutter will open and the calibration begins. After the preset irradiation time duration has elapsed, the shutter closes automatically and the calibration is completed, and personal dosemeter measurements are verified with the computer. Figure 11 shows the external appearance, Fig. 12 shows the system configuration and Fig. 13 shows the calibration range of this beta-ray calibrator.

Fig.12 System configuration of beta-ray calibrator (middle level)

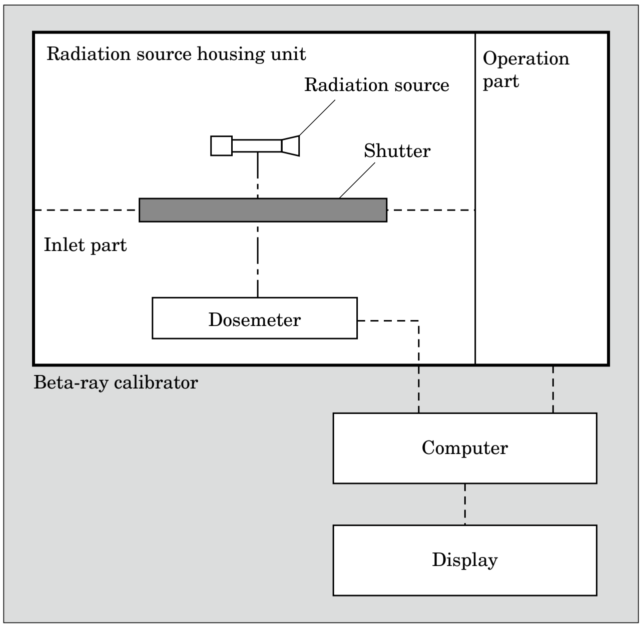
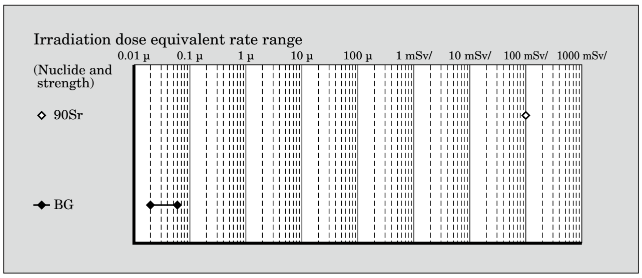


Fig.13 Calibration range of beta-ray calibrator



4. Postscript

This paper has introduced Fuji Electric's calibrators.

Monitoring by radiation measurement devices is of critical importance for ensuring the radiation safety in nuclear power plant facilities and surrounding areas, and the calibration of these devices ensures the reliability of the abovementioned monitoring and is an indispensable part of maintenance. To complement efforts to design, manufacture and sell radiation measurement devices, Fuji Electric intends to continue to maintain and improve the reliability of calibration equipment that is traceable to national standards.

Portable Radiation Monitor

Kaoru Masui
Takeshi Ishikura
Daisuke Inui

1. Introduction

At nuclear power plants, research facilities, hospitals and the like in Japan, portable radiation monitors that can be carried by workers are used commonly as simple radiation monitors for everyday use. Also outside of Japan, the increasing number of nuclear power plants and facilities that utilize radiation is expected to lead to greater demand for portable radiation monitors. This paper presents an overview of portable radiation monitors and introduces new model types that have been developed in recent years.

2. Types and Uses of Portable Radiation Monitors

Types of portable radiation monitors include survey meters, portable monitoring posts that measure γ-ray dose rates, environmental dosemeters that measure an accumulated dose at the border of a radiation controlled area, and the like. Survey meters can be classified as γ-ray survey meters that measure γ-ray dose rates, neutron rem counters that measure neutron (n) dose rates, and β-ray survey meters that measure surface contamination on people and articles. Table 1 lists the main products and their specifications.

The ionization chamber survey meter (NHA100) is able to measure 1 cm dose equivalent rates with good accuracy over a wide energy range. Moreover, this small, lightweight and easy-to-use survey meter can measure instantaneous X-ray doses, and by removing the front surface cap of the ionization chamber, is capable of detecting β-rays (Fig. 1). Main specifications of the ionization chamber survey meter are listed in Table 2.

The Geiger-Muller (GM) survey meter (NHJ110) employs a highly sensitive GM counter, and is used for simple detection of radiation leakage at nuclear facilities. Moreover, the NHJ120 of the same series is a survey meter for surface contamination measurement using an end-window type 50 mm-diameter GM counter, and is capable of measuring β-ray surface contami-

Fig.1 Ionization chamber survey meter

Table 1 Main types of portable radiation monitors

Product name	Model	Type of radiation measured: β	γ	n	X	Energy (keV) (10^0 10^1 10^2 10^3 10^4)	Measurement range (10^{-2} 10^{-1} 10^0 10^1 10^2 10^3 10^4)	Units
Ionization chamber survey meter	NHA100	○	○		○			μSv/h
Wide energy range X/γ ray survey meter	NHC510		○		○			μSv/h
GM survey meter	NHJ110		○					μSv/h
Neutron rem counter	NSN100			○				μSv/h
GM survey meter	NHJ120	○						Bq/cm²
Portable monitoring post	–		○					nGy/h
Environmental dosemeter (accumulated)	NSD2		○		○			mSv

Table 2 Specifications of ionization chamber survey meter

Item	Specifications
Detector	Ionization chamber detector
Measurable radiation	X-ray, γ-ray and β-ray
Energy range	X-ray, γ-ray: 25 keV to 3 MeV
Measurement range	Dose equivalent rate: 1 μSv/h to 30 mSv/h Instantaneous dose equivalent rate : 0.1 to 10 μSv
Measurement accuracy	Within ±10 %
Energy response	Within ±20 % (25 keV to 3 MeV)
Ambient temperature	0 to 40°C
Dimensions	Approx. 106 (W) × 200 (D) × 210 (H) (mm)
Mass	Approx. 1 kg
Continuous operation time	100 hours or more at normal temperature
Power supply	C battery × 5

Fig.2 GM survey meter

Fig.3 Neutron rem counter

nation (Fig. 2). Specifications of the GM-type survey meter are listed in Table 3.

The neutron rem counter (NSN100) is a survey meter for measuring the neutron dose equivalent rate in a nuclear facility, accelerator or other leakage neutron field. The detector response has been designed to match the rem response listed in the ICRP51 (Data for use in protection against external radiation) publication by the International Commission on Radiological Protection (ICRP), and dose equivalent values can be

Table 3 Specifications of GM survey meter

Item	Specifications	
Detector	GM detector	
Measurable radiation	γ (β)-ray	β (γ)-ray
Energy range	60 keV to 1.5 MeV	–
Measurement range	Dose rate : 0.0 to 300.0 μSv/h Count rate : 0 to 99.99 × 1000/min	Count : 0 to 9999 k counts Surface contamination density : 0 to 9999 Bq/cm² Count rate : 0 to 99.99 k/min
Measurement accuracy	Dose rate : within ±20 % Count rate : within ± 3 %	Count rate : within ±3 % Surface contamination density : depends on measurement conditions
Energy response	Within ±50 % (60 keV to 1.5 MeV) (Dose equivalent rate H*(10))	–
Angular response	Within ±20 % (0 to ±60°C)	–
Counting efficiency	–	30 % or more (U_3O_8 : 10 cm × 10 cm radiation source, distance to the detector : 5 mm)
Ambient temperature	–5 to +45°C	
Dimensions (mm)	Approx. 98 (W) × 227 (D) × 145 (H)	Approx. 98 (W) × 227 (D) × 170 (H)
Mass	Approx. 1.3 kg	
Continuous operation time	100 hours or more (alkaline AA battery), 20 hours or more (rechargeable battery)	
Power supply	Alkaline AA battery × 6 or rechargeable battery	

Table 4 Specifications of neutron rem counter

Item	Specifications
Detector	^{3}He proportional counter
Measurable radiation	Neutrons
Energy range	0.025 eV to 15 MeV
Measurement range	Dose rate : 0.01 μSv/h to 9.999 mSv/h Dose : 0.001 μSv to 9.999 mSv
Measurement accuracy	Dose rate : within ±15 % at 1 μSv/h Dose : within ±25 % at 0.005 μSv
Energy response	ICRP51 compliant
Angular response	Within ±10 % (0 to ±135°, ^{252}Cf)
Neutron sensitivity	4.5 s^{-1}/μSv/h ±20 % (^{252}Cf)
Ambient temperature	–10 to +45°C
Dimensions	Approx. 210 (dia.) × 320 (mm)
Mass	Approx. 7 kg
Continuous operation time	More than 12 hours (C battery)
Power supply	AC power, C battery × 2, rechargeable battery (option)

read directly. The neutron rem counter made by Fuji Electric features extremely high sensitivity and a light weight. A ^{3}He proportional counter is used to improve the sensitivity, and the construction of the neutron moderator that covers the detector is optimized to achieve a lighter weight (Fig. 3). Table 4 lists the specifications of the neutron rem counter.

The recently developed wide energy range X/γ survey meter (NHC510), the environmental dosemeter system, and the portable monitoring post (NAJ5) are introduced below.

3. Wide Energy Range X/γ-ray Survey Meter

3.1 Overview

X-ray generators are now used in various applications such as medical field, and at the facilities where they are used, there is a need for survey meters capable of measuring leakage doses from low energy X-rays to environmental γ-rays (γ-rays of approximately 1.5 MeV or less). The energy of X-rays emitted from an X-ray irradiator used for medical purposes is at least 8 keV, and in consideration of this range, Fuji Electric developed a survey meter capable of highly sensitive and accurate 1 cm dose equivalent measurements in the 8 keV to 1.5 MeV region (Fig. 4).

During the development stage, in order to efficiently measure low energy photons while ensuring the angular response when measuring environmental γ-rays, the dimensions of the NaI (T*l*) scintillator and the material and thickness of the storage case were optimized. Also, energy compensation and temperature compensation functions were provided to realize good performance characteristics. The energy characteristics are shown in Figs. 5 and 6. A 1 cm dose equivalent response within ±25 % was realized for the range from 10 KeV to 200 keV in the X-ray mode and for range from 50 keV to 1.5 MeV in the γ-ray mode.

3.2 Characteristics and specifications

The characteristics are listed below.

(1) Measurement with high sensitivity is possible for the wide energy range from 8 keV (X-rays) to 1.5 MeV (environmental γ-rays)

Fig.4 Wide energy range X/γ-ray survey meter

(2) An energy compensation function enables accurate measurement of 1cm dose equivalent rates.

(3) Measurement results are easily verified with a 4-digit digital display and a bar graph indicator

Fig.5 Energy response (X-ray mode)

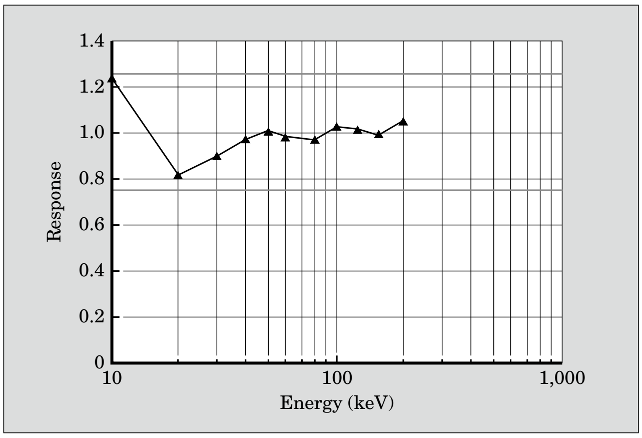


Fig.6 Energy response (γ-ray mode)

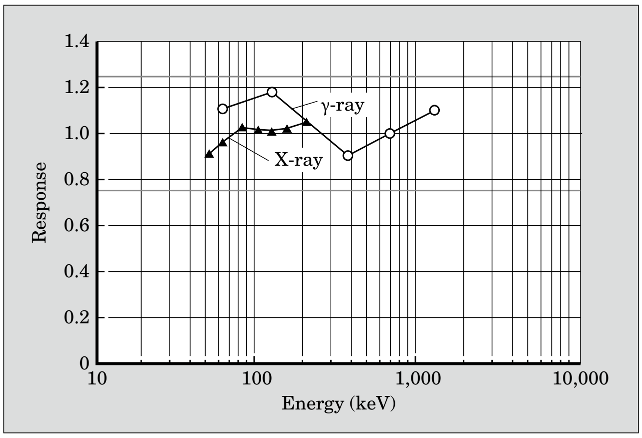


Table 5 Specifications of wide energy range X/γ-ray survey meter

Item	Specifications
Detector	NaI scintillator, 12.7 (dia.) × 12.7 (mm)
Measurable radiation	X-ray, γ-ray
Energy range	X-ray : 8 to 300 keV γ-ray : 50 keV to 1.5 MeV
Measurement range	X-ray : BG to 60 μSv/h (^{241}Am reference) γ (X)-ray : BG to 60 μSv/h (^{137}Cs reference)
Measurement accuracy	Within ±20 %
Energy response	X-ray : within ±25 % (10 keV to 200 keV) γ (X)-ray : within ±25 % (50 keV to 1.5 MeV)
Angular response	Within ±20 % (0 to ±90°)
Ambient temperature	0 to 40°C
Dimensions	Approx. 100 (W) × 215 (D) × 155 (H) (mm)
Mass	Approx. 1.3 kg
Continuous operation time	More than 8 hours (C battery)
Power supply	C battery × 6 Rechargeable battery (option) AC power (option)

display.

(4) Operation is switchable between an “X-ray mode” for low energy X-ray measurement and a “γ-ray mode” for measurement of up to 1.5 MeV.

(5) The meter has a small size and is lightweight, portable, and easy to use.

(6) A temperature compensation circuit is provided.

Table 5 lists the main specifications.

4. Environmental Dosemeter System

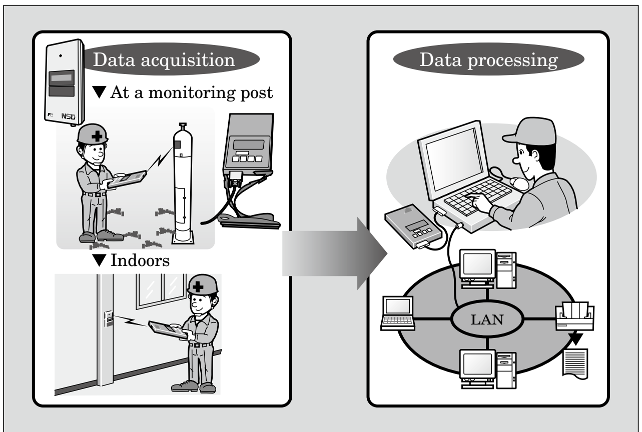
4.1 Overview

At nuclear power plants and other facilities that use radiation, the γ-ray total dose is measured and recorded at the boundaries of the controlled areas, at workplaces in radiation controlled areas, and in the surrounding areas. Previously, thermoluminescent dosemeters have been used for this purpose, but those dosemeters must be collected and relocated, dose rate trends cannot be recorded, and the read out process was complicated and required annealing.

To satisfy the abovementioned need, Fuji Electric applied its personal dosemeter technology, having been refined over many years of development, to develop an environmental dosemeter system configured from an environmental dosemeter, a data acquisition terminal and a data processing computer. Figure 7 shows an overview of the environmental dosemeter system. An environmental dosemeter system is installed at each measurement site and measures dose rate trends and accumulated doses, and the measurement data is acquired periodically using a small size, light weight and portable data acquisition terminal. The acquired data is transferred via a RS-232C cable to a data processing computer, and the data can easily be stored, referenced and processed. With this method, there is no need to collect or relocate the dosemeters, and the acquisition of data is easy to implement.

During development of the environmental dosemeter, in order to enable measurement of doses due to the normal background (BG) level (approximately 0.001 mSv or greater), the sensor was enlarged and the electrode structure was optimized to increase the sensitivity of the semiconductor detector. Accordingly, measurement accuracy of within ±10 % was realized for dose values of 0.01 mSv or greater. Additionally, a low current consumption circuit was developed so that the environmental dosemeter could be used continuously for at least one year. In order to prevent data loss due to a power failure, the environmental dosemeter continuously stores measurement data in a non-volatile memory (EEPROM). Furthermore, a battery voltage drop sensing function and a count circuit self-diagnostic function ensure good reliability. This environmental dosemeter system is widely used at present in Japanese nuclear power plants and the like as a substitute for thermoluminescent dosemeters.

Fig.7 Process flow for an environmental dosemeter system



4.2 Characteristics and specifications

Features of the environmental dosemeter (NSD2) are listed below.

(1) Sensitive to background level doses and capable of accurate measurement.

(2) Can operation continuously for at least one year.

(3) Is provided with a non-contact communication (infrared communication) function to a data acquisition terminal.

(4) Stores measurement data in a non-volatile memory so that measurement data can be read even in the case of a failure.

(5) The main unit has a moisture resistant construction that is able to withstand water droplets

Table 6 Specifications of environmental dosemeter

Item	Specifications
Measurable radiation	γ (X) ray
Energy range	50 keV to 6 MeV
Measurement range	0.001 to 999.99 mSv
Measurement accuracy	Within ±10 % (0.01 to 10 mSv/h)
Energy response	Within ±30 % (60 keV to 6 MeV)
Angular response	Within ±20 % (horizontal : ±180°, vertical : +240 to −60°)
Trend data storage capacity	1,152 data points (max)
Communication specifications	Communication method : Infrared communications Contacting party : Data acquisition terminal Read time : Less than 2 sec (without trend data) Less than 10 sec (at max. number of trend data) Communication distance : 0 to 15 cm Communication speed : 9,600 bps Communication data : Accumulated dose, trend data, etc.
Ambient temperature	−10 to 50°C
Dimensions	Approx. 65 (W) × 20 (D) × 110 (H) (mm)
Mass	Approx. 140 g
Continuous operation time	More than 13 months
Power supply	Primary cell × 2

formed by condensation or the like.

The main specifications are shown in Table 6.

5. Portable Monitoring Post

5.1 Overview

At nuclear power plants and other such facilities, there is a need for simple environmental radiation monitors in order to supplement fixed-type monitoring posts and, in the case of an emergency, to assess quickly the dose rate at the periphery of the facility. Specific requirements are for accurate dose rate measurement over the wide measurement range from a background dose rate of 10 nGy/h to a dose rate during an accident of 10^3 nGy/h, and for easy transportation and measurement.

Typically in the past, two detectors were used according the dose rate, but in order to achieve lighter weight and a more compact size, Fuji Electric has developed a portable monitoring post that is capable of measuring the abovementioned range with a single detector. The detector is a NaI (T*l*) scintillator, and both pulse measurement and current measurement methods are used. The low dose rate region is measured in a pulse measurement mode and the high dose rate region is measured in a current measurement mode. Additionally, to ensure various characteristics such as the energy response over a wide range, the radiator shielding of the detectors is optimized, and an energy compensation circuit and a temperature compensation circuit are provided. Figure 8 shows the external appearance of the portable monitoring post.

5.2 Characteristics and specifications

Features of the portable monitoring post are listed below.

(1) A single detector supports dose rate measurement from the background level to high levels during an emergency.
(2) Small size and light weight facilitate transportation and installation.
(3) An all-weather model can be installed outdoors.
(4) Can operate with an external battery in locations where there is no AC power.
(5) An internal memory can store one week of measured data (one data value per minute).
(6) An energy compensation circuit and a temperature compensation circuit are provided.
(7) Data acquisition is performed with portable data acquisition devices or via (optional) cell phone communication or the like.

The main specifications are shown in Table 7.

Fig.8 Portable monitoring post

Table 7 Specifications of portable monitoring post

Item	Specifications
Measurable radiation	γ-ray
Energy range	Low range region : 50 keV to 3 MeV High range region : 50 keV and above
Measurement range	10 to 10^8 nGy/h Low range region : 10 to 5 × 10^5 nGy/h High range region : 3 × 10^5 to 10^8 nGy/h
Measurement accuracy	±10 % (reference : for ^{137}Cs irradiation dose rate)
Angular response	±20 % (0 to ±90°)
Energy response	Low range region : ±20 % (50 keV to 100 keV) ±10 % (100 keV to 3 MeV) High range region : −50 % to +25 % (50 keV to 100 keV) −10 % to +20 % (100 keV to 400 keV) ±10 % (400 keV to 3 MeV)
Data acquisition method	With dedicated acquisition apparatus (serial communication)
Ambient temperature	−10 to +40°C
Dimensions	Approx. 440 (W) × 450 (D) × 740 (H) (mm)
Mass	Approx. 15 kg (without options)
Continuous operation time	Approx. 10 days (internal primary cell)
Power supply	100 V AC power supply, 12 V DC power supply, internal primary cell
Options	Wireless data acquisition, GPS

6. Postscript

The portable radiation monitors introduced herein are being used at various facilities for a wide variety of purposes. In the future, Fuji Electric intends to continue to improve monitor performance and functionality, and to actively deploy these systems in overseas markets.

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