

# Personal Dose Monitoring System

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## 1. Introduction

The level of radiation safety control in the nuclear power field and at facilities that utilize radiation has become stricter with the revision of the radiation protection regulations in April 2001 which incorporate the recommendations of the International Commission on Radiological Protection (ICRP Pub. 60) and the stipulation of a maximum exposure of 100 mSv/ 5 years in addition to the existing personal exposure dose limit of 50 mSv/year.

Since 2001, fluoroglass dosimeters and OSL (optically stimulated luminescence) dosimeters have replaced the conventional film badge as the personal dosimeters used in dose control. However, since the values measured by these dosimeters cannot be read directly, electronic dosimeters which permit the direct read-out of dose values and are equipped with an alarm function are recently being utilized for dose control.

Overseas, the usage of electronic personal dosimeters is also increasing, and an IEC standard has been established for electronic dosimeters capable of measuring gamma rays, beta rays and neutrons.

The Japanese domestic standard for electronic personal dosimeters achieved conformance with the IEC standard in 2002, and JIS Z 4312 "electronic personal dose (rate) meter for X-rays, gamma rays, beta rays and neutrons" was revised.

In 1980, Fuji Electric developed an alarm-equipped dosimeter that uses a semiconductor detector, and since then has continued to improve its dosimeter technology. Fuji Electric's personal dose control system, which increases the functionality of this electronic dosimeter and incorporates an area access control apparatus, has garnered an approximate 70 % share of the market among Japanese domestic nuclear power facilities.

## 2. System Overview

With Fuji Electric's personal dose monitoring system, a worker carries an electronic dosimeter when entering a controlled area for radiation such as a

nuclear power plant, and the radiation dose received while the worker performs his or her task is measured. Upon leaving the controlled area, an area access control apparatus reads the dose data and a computer system manages the dose per worker and dose per task. Figure 1 shows an overview of this system. In the figure, the term "dosimeter" is used as an abbreviation for "electronic dosimeter."

## 3. Electronic Dosimeter

An electronic dosimeter carried in a worker's pocket measures and displays in real time the amount of radiation received while the worker performs his or her task. This dosimeter is also equipped with a function that issues an alarm in cases where the exposure dosage exceeds a preset value. A silicon semiconductor detector that features a small size and low power consumption is used as the sensor.

Passive dosimeters such as film badges, which are characterized by a simple construction, and high durability and reliability, have previously been used widely as personal dosimeters. However, these passive dosimeters were disadvantageous because they did not permit the dose data to be read directly and because the process of obtaining monthly cumulative dose data was time consuming. Consequently, in nuclear power plants in Japan, concurrent with the usage of passive dosimeters, electronic dosimeters (equipped with an alarm function) were also used to monitor the dosage during work.

The development of electronic dosimeters has made progress in recent years, noise immunity and mechanical shock resistance have been enhanced, reliability improved, and the capability of measuring not only X-rays and gamma rays, but also beta rays and neutrons, has been realized. Additionally, the data communication capability provided with an electronic dosimeter enables easy connection to an external data processing system by means of infrared or wireless communications, enabling the configuration of a highly functional system for implementing rapid measurement archiving control, area access control, trend data measurement, and the like.

Fig.1 Overview of personal dose monitoring system

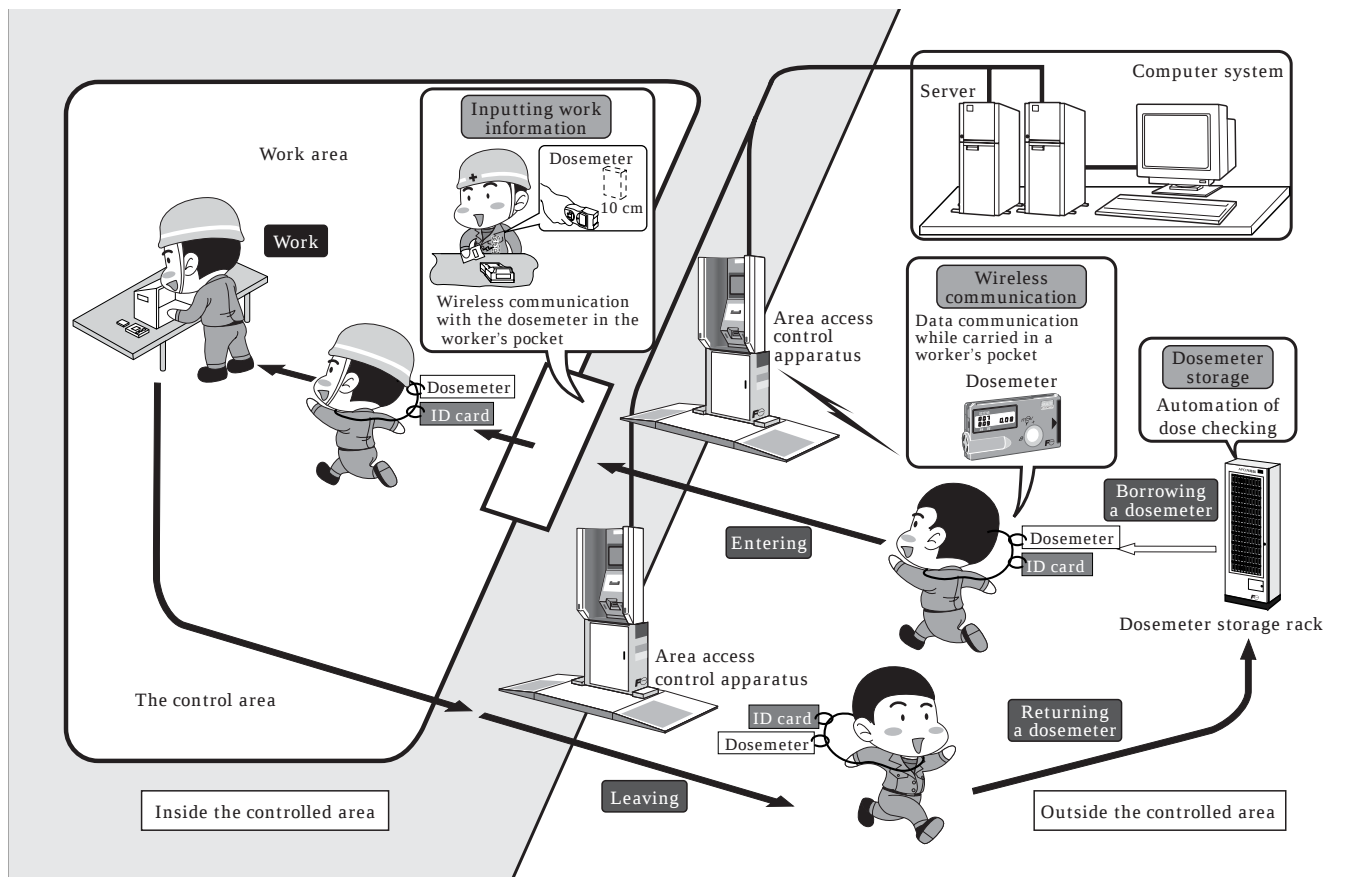


Fig.2 Gamma-beta dosimeter



Main features of electronic dosimeters are summarized below.

- (1) Simultaneous measurement of multiple types of rays

X-rays, gamma rays, beta rays and neutrons can all be measured simultaneously (for the first time in the world).

- (2) Good data reliability

Performance is equivalent to that of a conventional statutory dosimeter (passive dosimeter). Data reliability was confirmed by evaluating measurement data during concurrent use at actual nuclear power plants.

- (3) Conformance with international standards

The International Electrotechnical Commission

Table 1 Specifications of the gamma-beta dosimeter

| Dosimeter model        | NRN64311                                                                                 |                                                                                           |
|------------------------|------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| Detector               | Semiconductor                                                                            |                                                                                           |
| Radiation detected     | Gamma (X) rays                                                                           | Beta rays                                                                                 |
| Energy range           | 50 keV to 6 MeV                                                                          | 300 keV to 2.3 MeV                                                                        |
| Energy response        | ±20 %, <sup>137</sup> Cs standard                                                        | ±30 %, <sup>90</sup> Sr/ <sup>90</sup> Y standard                                         |
| Angular response       | ±15 %, Up to 60° vertically and horizontally, <sup>137</sup> Cs standard                 | ±30 %, Up to 60° vertically and horizontally, <sup>90</sup> Sr / <sup>90</sup> Y standard |
| Indication range       | 0 to 999.99 mSv                                                                          | 0 to 999.9 mSv                                                                            |
| Accuracy of indication | ±10 %, 0.1 to 999.9 mSv                                                                  | ±15 %, 0.1 to 999.9 mSv                                                                   |
| Alarm                  | Sound level: 100 dB or greater, Display lamp: flashing LED (red)                         |                                                                                           |
| Communication method   | Wireless (LF) and point contact                                                          |                                                                                           |
| Power supplies         | NiCd rechargeable battery (providing power for 12 or more hours of continuous operation) |                                                                                           |
| Ambient temperature    | 0 to 50°C                                                                                |                                                                                           |
| Size                   | 110×57×17 (mm)                                                                           |                                                                                           |
| Mass                   | 120 g                                                                                    |                                                                                           |

(IEC) standard (IEC 61526) and the Japanese domestic standard (JIS Z 4312) for electronic dosimeters are both satisfied.

Fig.3 Gamma (X) ray energy response

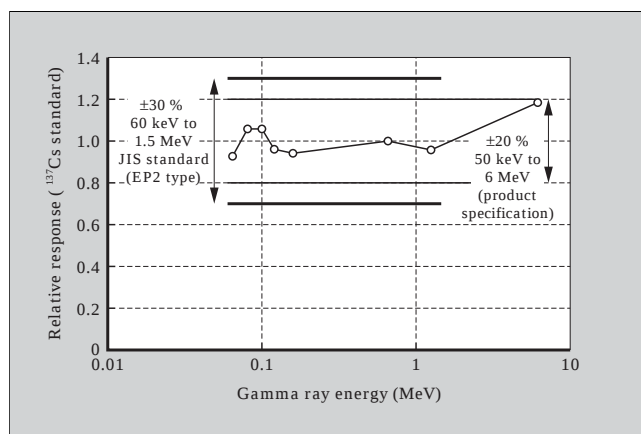
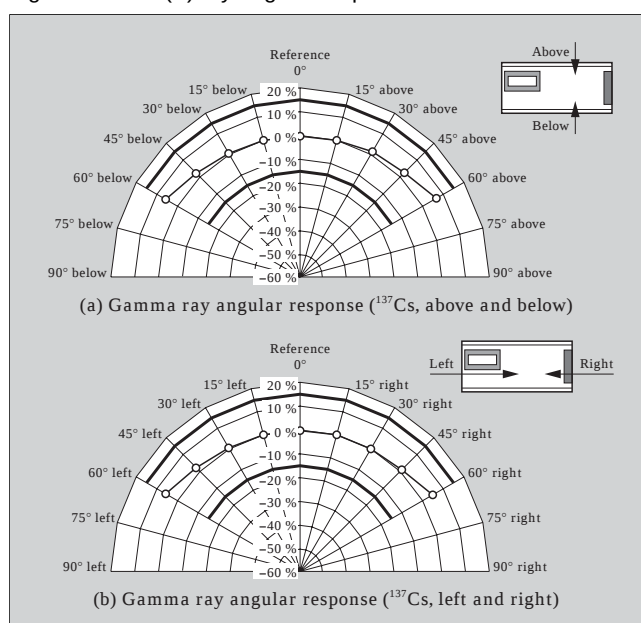


Fig.4 Gamma (X) ray angular response



(4) Wireless communication improves operability and shortens processing time

Data transfers between the electronic dosimeter and the area access control apparatus are implemented via wireless communication. Because data transfers can be implemented even while the dosimeter remains inside one's pocket, area access operability can be improved and processing time shortened.

Recently, some systems are being realized in which this wireless communication function is expanded to achieve remote wireless monitoring capability.

With the goals of streamlining dose control and reducing the burden on workers, control at many nuclear power plants in Japan is transition toward the use of only a single electronic dosimeter. The gamma (X) ray and beta ray dosimeter (hereafter referred to as the gamma-beta dosimeter) and the gamma (X) ray and neutron dosimeter (hereafter referred to as the gamma-neutron dosimeter) developed in response to these trends are described below.

Fig.5 Beta ray energy response

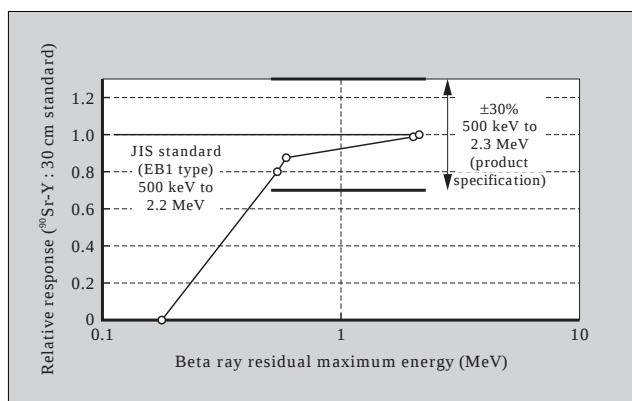
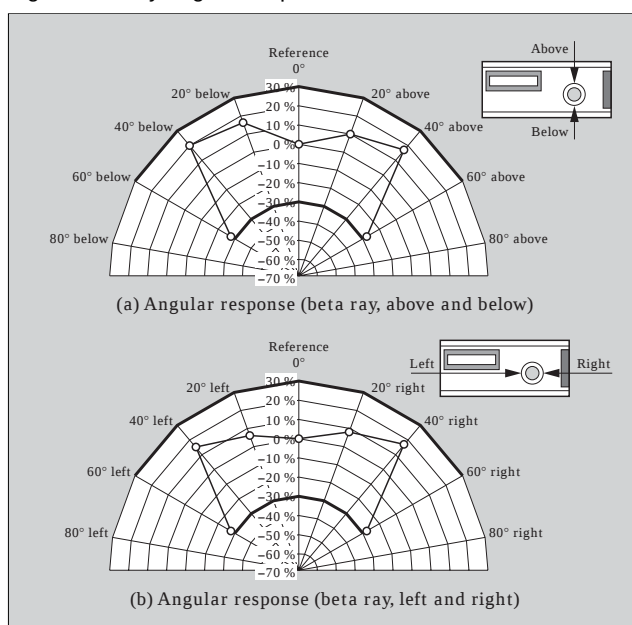


Fig.6 Beta ray angular response



### 3.1 Gamma-beta dosimeter

The gamma-beta dosimeter is equipped with two sensors, one for detecting gamma (X) rays and the other for detecting beta rays, enabling both types of radioactive rays to be counted simultaneously. The gamma-beta dosimeter is shown in Fig. 2 and its main specifications are listed in Table 1.

The gamma ray sensor is sealed in a ceramic package in order to improve the environmental immunity of its silicon sensor chip, and is provided with energy filters made of various types of metal to correct the energy response according to the direction of incidence (sensitive differs according to the gamma ray energy). Energy response is shown in Fig. 3 and angular responses are shown in Fig. 4.

Because beta rays have low penetrating power and can be stopped by a single aluminum substrate, the beta ray sensor is housed in a ceramic package made of resin film having a thickness of several tens of microns in the direction of incidence. Energy response is shown

in Fig. 5.

In order to conform to the revised JIS Z 4312 standard, beta ray angular responses were improved as shown in Fig. 6. This improvement was achieved through widening the solid angle of beta ray incidence and enlarging the beta ray entrance window. The beta ray entrance window uses reinforcing material and is constructed so as not to be damaged under normal handling conditions.

### 3.2 Gamma-neutron dosimeter

The gamma-neutron dosimeter is equipped with two sensors, one for detecting gamma (X) rays and the other for detecting neutrons, enabling both types of radioactive rays to be counted simultaneously (Fig. 7). Main specifications of the gamma-neutron dosimeter are listed in Table 2.

Fig.7 Gamma-neutron dosimeter



Table 2 Specifications of the gamma-neutron dosimeter

|                        |                                                                                                   |                                                                                                             |
|------------------------|---------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|
| Dosimeter model        | NRY50312                                                                                          |                                                                                                             |
| Detector               | Semiconductor                                                                                     |                                                                                                             |
| Radiation detected     | Gamma (X) rays                                                                                    | Neutrons                                                                                                    |
| Energy range           | 50 keV to 6 MeV                                                                                   | 0.025 keV to 15 MeV                                                                                         |
| Energy response        | $\pm 20\%$ ,<br>$^{137}\text{Cs}$ standard                                                        | $-50$ to $+150\%$ ,<br>(thermal neutron and<br>$^{241}\text{Am}$ -Be source:<br>$^{252}\text{Cf}$ standard) |
| Angular response       | $\pm 15\%$ ,<br>Up to $60^\circ$<br>vertically and<br>horizontally,<br>$^{137}\text{Cs}$ standard | $\pm 50\%$ ,<br>Up to $60^\circ$<br>vertically and<br>horizontally,<br>$^{252}\text{Cf}$ standard           |
| Indication range       | 0 to 999.99 mSv                                                                                   | 0 to 999.99 mSv                                                                                             |
| Accuracy of indication | $\pm 10\%$ ,<br>0.1 to 999.9 mSv                                                                  | $\pm 20\%$ ,<br>0.3 to 999.9 mSv                                                                            |
| Alarm                  | Sound level: 100 dB or greater,<br>Display lamp: flashing LED (red)                               |                                                                                                             |
| Communication method   | Wireless (LF) and point contact                                                                   |                                                                                                             |
| Power supplies         | NiCd rechargeable battery<br>(providing power for 12 or more<br>hours of continuous operation)    |                                                                                                             |
| Ambient temperature    | 0 to $50^\circ\text{C}$                                                                           |                                                                                                             |
| Size                   | 110×57×17 (mm)                                                                                    |                                                                                                             |
| Mass                   | 120 g                                                                                             |                                                                                                             |

The gamma (X) ray sensor is similar to the gamma-beta dosimeter and its description is omitted here.

Because neutrons lack an ionization effect and cannot be detected directly, the neutron sensor reacts hydrogen or boron atoms with neutrons, and then detects the charged particles generated from that reaction. Moreover, due to the wide energy range (from thermal neutrons to 15 MeV) to be measured by the neutron sensor, two types of sensors are provided, a thermal neutron sensor for low energy use and a fast neutron sensor for high energy use. The silicon sensor chip of the thermal neutron sensor is formed with a boron thin film on its surface and is sealed within the sensor package.

$^{10}\text{B}$  atoms contained in the boron film have a large cross-sectional area within which to react with low energy neutrons, and alpha rays and Li nuclei generated from this reaction are detected by the silicon sensor.

In the fast neutron sensor, polyethylene ( $\text{CH}_2$ ) is

Fig.8 Neutron energy response

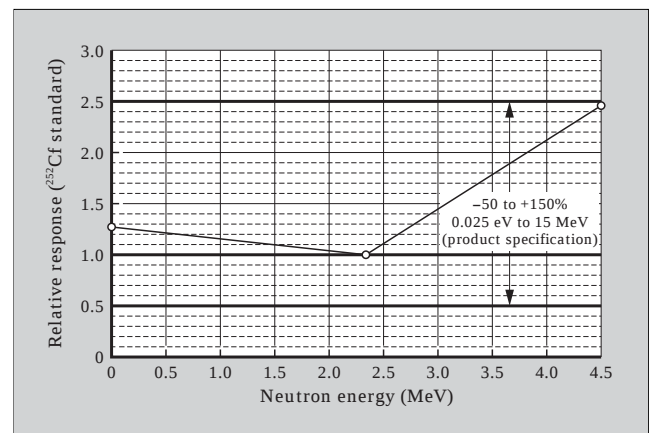
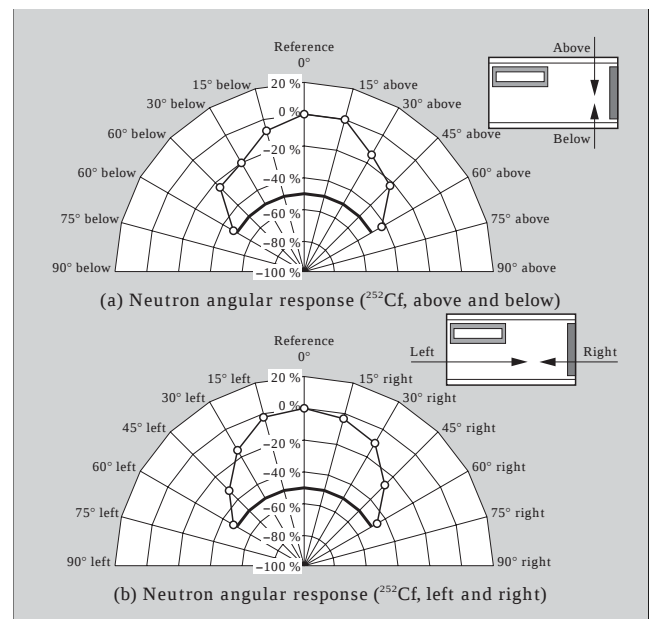


Fig.9 Neutron angular response



disposed on the silicon sensor within the sensor package, and the silicon sensor detects recoil protons which are generated in reactions between neutrons and the hydrogen atoms contained in the polyethylene.

The neutron sensor is calibrated using a  $^{252}\text{Cf}$  source (having an average energy of 2.3 MeV). In actual usage, it is important that a calibration constant, suitable for the radiation field of the work environment, be acquired in advance, and for this purpose a correction constant that allows a variable weighting of the count values of the thermal neutron

sensor and fast neutron sensor is set internally, and the weighting is calculated according to the actual work environment in order to display the correct dose value.

Energy response is shown in Fig. 8 and angular responses are shown in Fig. 9.

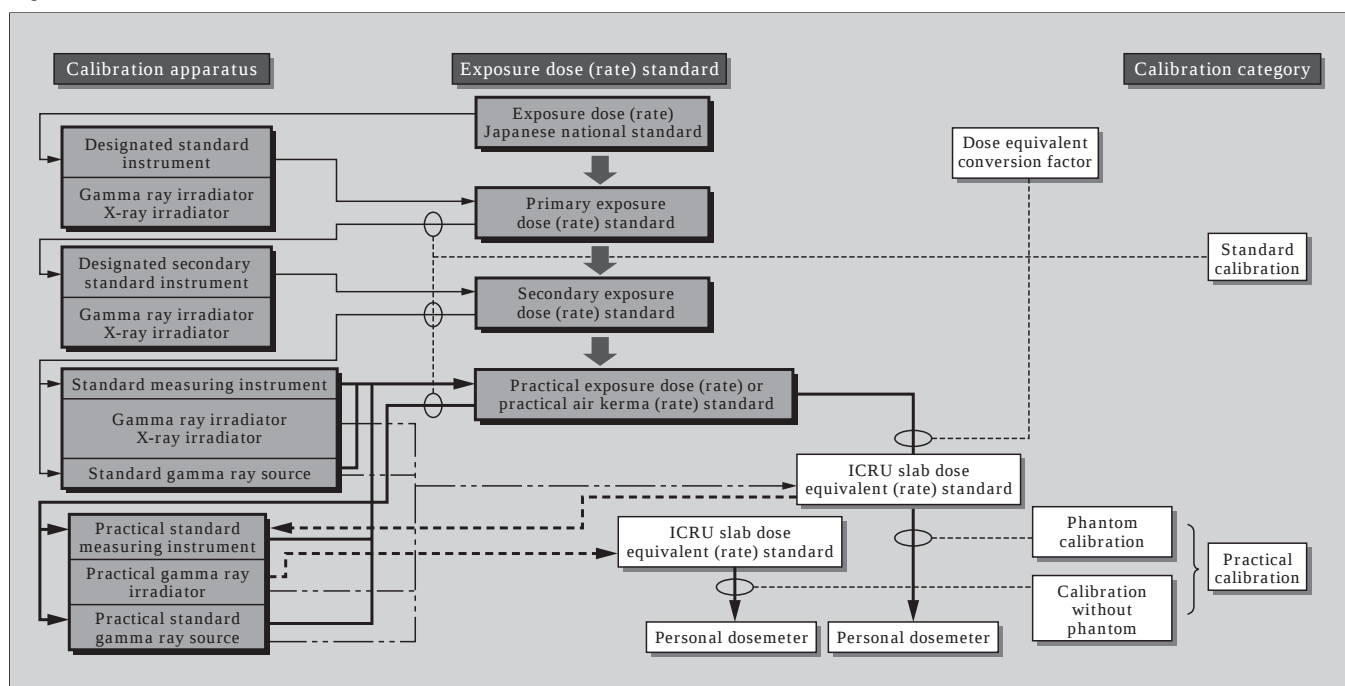
#### 4. Area Access Control Apparatus

Installed at the border of the controlled area, the area access control apparatus automatically screens

Table 3 Area access control apparatuses

| Delivery to :       | Company A                                                                                                                                                           | Company B                                                                                                                                                        | Company C                                                                                                                                                            | Company D                                                                                                                                                        |
|---------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| External appearance |                                                                                    |                                                                                 |                                                                                    |                                                                               |
| Features            | Integrated dosimeter storage rack.<br>Number of dosimeters : 150 units                                                                                              | Compact, lightweight, space-saving design                                                                                                                        | Large LED used for alarm indicator                                                                                                                                   | Wireless communication with ID card (breast pocket)                                                                                                              |
| Specifications      | Dosimeters : NRY1, NRN1<br>Transit method : flapper gate<br>Transit time : approx. 15 s<br>Size : approx. 1,440 (H)×1,350 (W)×300 (D) (mm)<br>Mass : approx. 300 kg | Dosimeter : NRY4<br>Transit method : flapper gate<br>Transit time : approx. 7 to 8 s<br>Size : approx. 1,300 (H)×1,100 (W)×300 (D) (mm)<br>Mass : approx. 160 kg | Dosimeters : NRY5, NRN5<br>Transit method : pole gate<br>Transit time : approx. 7 to 8 s<br>Size : approx. 1,700 (H)×1,120 (W)×420 (D) (mm)<br>Mass : approx. 210 kg | Dosimeters : NRY6, NRN6<br>Transit method : no gate<br>Transit time : approx. 7 to 8 s<br>Size : approx. 1,600 (H)×780 (W)×400 (D) (mm)<br>Mass : approx. 200 kg |

Fig.10 Dosimeter calibration method



access to the controlled area, and possesses the following features.

- (1) The exchange of data (such as dose data, dosimeter number, time length accessing to the controlled area, alarm value, etc.) between the electronic dosimeter and the apparatus is implemented via wireless communication.
- (2) A reduction in transit time is achieved by simplifying input of the job number and by displaying a selectable list of the latest jobs on a screen when entering the area.

- (3) The entire apparatus has a low profile form and high functionality.

Main components of the apparatus include an operation screen, a dosimeter communications unit, an ID card reader, a human presence sensor and a status indicator light. According to user needs, the apparatus may be integrated with an electronic dosimeter storage rack, and may be equipped with a gate and so on. Features and specifications of apparatuses that have been delivered to nuclear power related facilities are presented in Table 3. As can be seen from the

Fig.11 Gamma-beta calibration apparatus

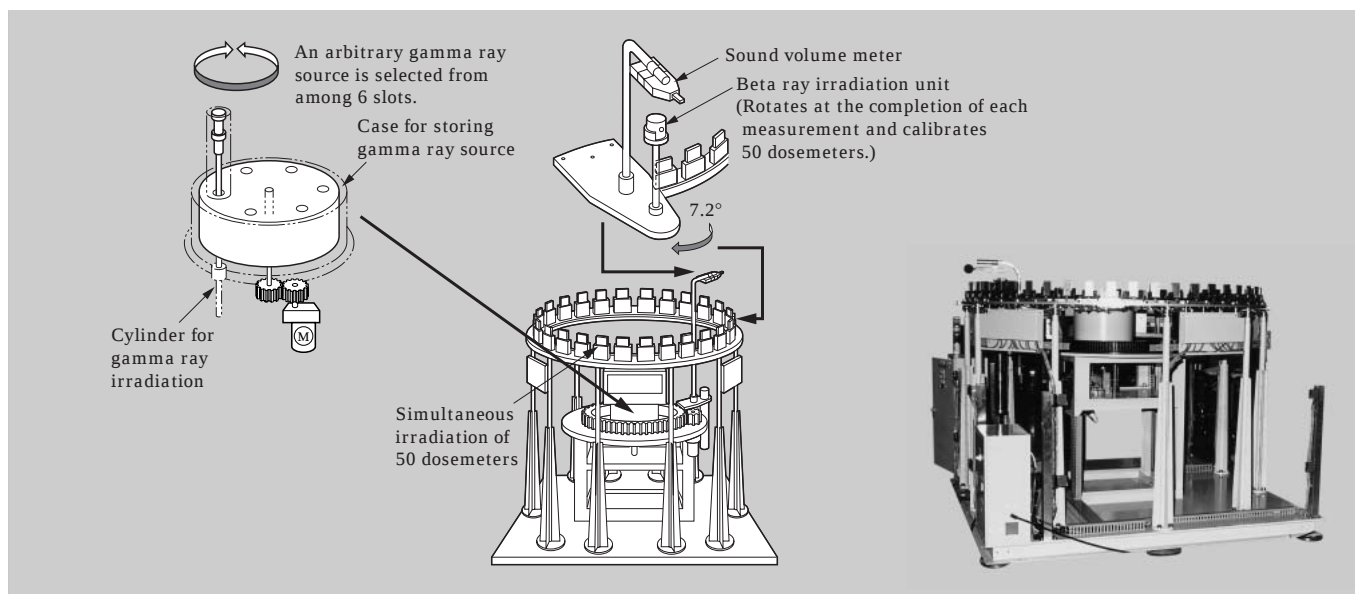
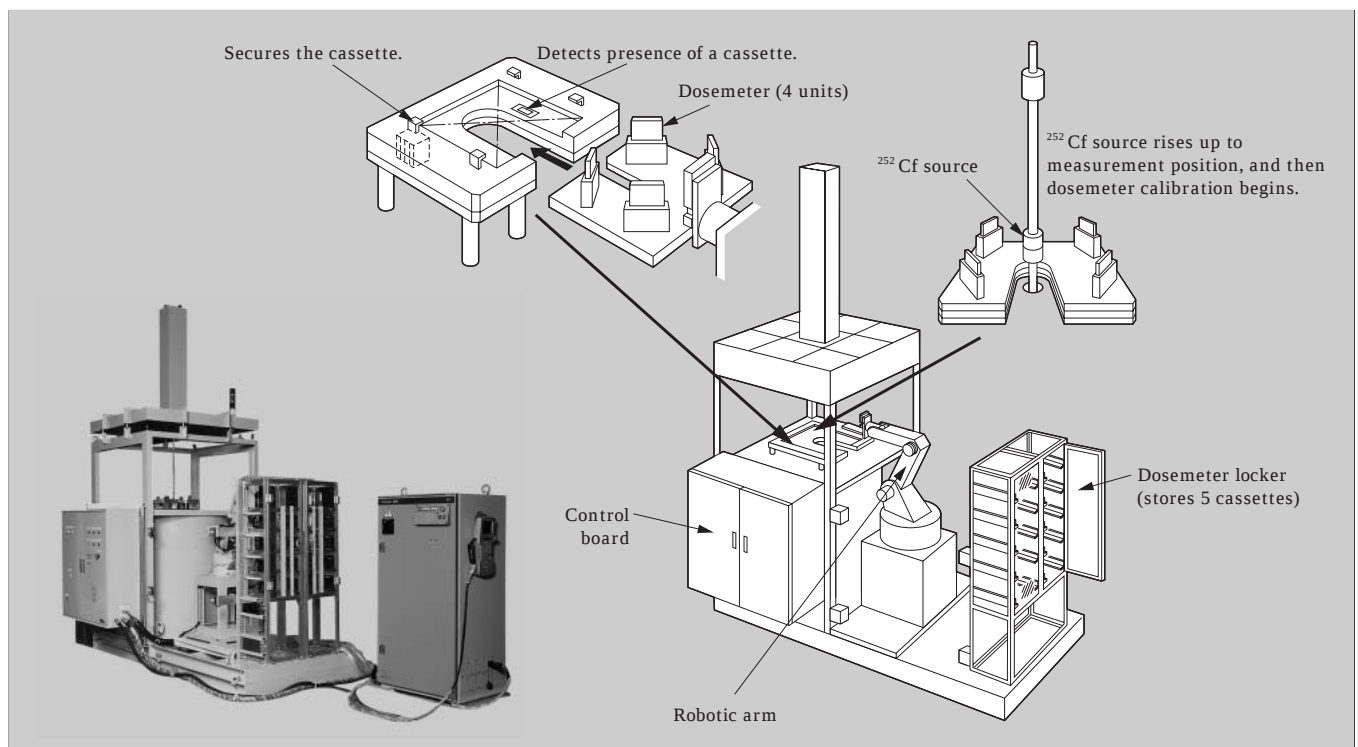


Fig.12 Neutron calibration apparatus



photographs of the apparatuses, the absence or presence of a gate, apparatus design, color and other features will distinguish each location where such an apparatus is installed. These products are made to correspond to a diverse array of user needs.

## 5. Calibration of Electronic Dosimeters

Electronic personal dosimeters must be calibrated in accordance with the method of JIS Z 4511, illustrated in Fig. 10. In accordance with the Japanese Measurement Law, an accredited laboratory calibrates an electronic personal dosimeter to which a phantom is attached, and then by using this calibrated dosimeter as a practical standard measurement instrument, other personal dosimeters of the same type can be calibrated by the substitution method without the use of a phantom. This method complies with the JIS standard for practical calibration and practical calibration by this method is thought to be possible not only with gamma rays, but also with beta rays and neutrons. Because the practical calibration of electronic dosimeters requires the calibration of many elec-

tronic dosimeters, Fuji Electric is developing practical calibration equipment such as a panoramic irradiator and a machine automated by means of a robotic arm. Figure 11 illustrates an example of a gamma ray and beta ray calibrating apparatus, and Fig. 12 illustrates an example of a neutron calibrating apparatus.

## 6. Conclusion

Fuji Electric's efforts in the field of personal dose monitoring systems have been presented with a focus on electronic personal dosimeters. So that these devices can be used in a wider range of facilities in the future, Fuji Electric intends to develop electronic dosimeters that are easier to use and have lower cost and greater accuracy in order to expand the scope of applications.

Finally, the authors wish to express their appreciation and gratitude to all those individuals at electric companies, nuclear power facilities and various research organizations who provided considerable guidance and assistance in the development and commercialization of the electronic personal dosimeter.





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