The development of new generation electronic personal dosimeters

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1. INTRODUCTION

We have developed two new types of small, light, electronic personal dosimeters (EPDs) using semiconductor radiation detectors for dose management of workers at nuclear power plants in place of film badges.

One is an easy-to-wear, credit-card-size dosimeter to measure the personal dose equivalents $H_{1\ cm}$, from X and gamma radiation. The other is a multi-function dosimeter capable of measuring gamma, beta and neutron doses simultaneously, which covers gamma-radiation , neutron in Hp(10) and beta-radiation in Hp(0,07)

Both dosimeters contain a rechargeable Ni-Cd battery and are stored in an exclusive charging rack. With direct readout, alarm and instant readout functions, these EPDs are rugged and if a failure happens, by external memory readout apparatus , it is able to read the dose data in the dosimeter. These dosimeters offer sufficient performance and reliability for use as dose record dosimeters. They also have a wireless data communication function, which is used for various tasks such as automatic calibration of radiation sources and transmission of measured data.

2. SENSORS

2.1 Gamma-radiation sensor

The gamma-radiation sensor uses a p-type high resistivity silicon wafer on which amorphous silicon is deposited by DC plasma CVD as shown in Fig. 2.1. In the direction of gamma-radiation incidence, multiple layers of an energy filter are provided to secure an energy response to Hp(10) .

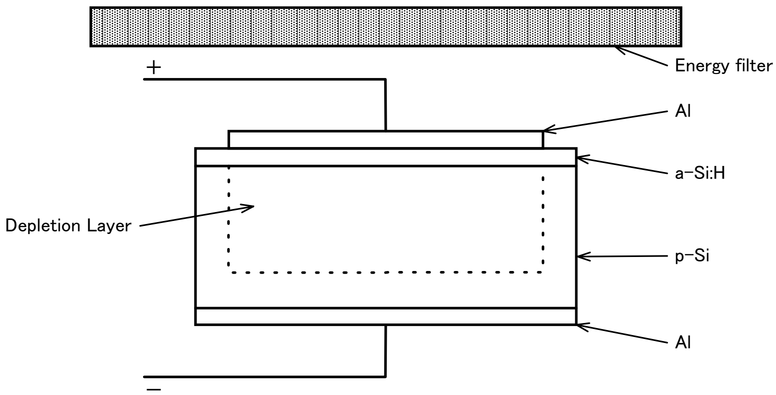

Fig.2-1 Cross-sectional view of gamma/beta-ray sensor

2.2 Beta-radiation sensor

The beta-radiation sensor has the same basic structure as the gamma-radiation sensor, but uses a plastic film of 5 mg/cm^2 for the entrance window so that beta-radiations beyond 300 keV can be measured.

Also, in order to compensate for the energy response to beta-radiations, a discriminator is provided in two stages, upper and lower. For high-energy components to which sensitivity would be larger, the count value of the upper-limit discriminator is multiplied by a constant value “C” to reduce it.

As is evident from the structure, this beta-radiation sensor is sensitive to both gamma- and beta-radiations. Hence, for indicating a beta-radiation dose, a count for beta-radiation sensor compensation is taken from the gamma-radiation sensor by an exclusive discriminator and the gamma-radiation component is compensated by subtraction using the following formula:

In a field where both beta- and gamma-radiations coexist, a difference in the energy response to gamma-radiations between the beta-radiation sensor and the gamma-radiation sensor (on counts above the discriminator level for beta-radiation compensation) appears as an arithmetic error, causing excessive or poor compensation. Therefore, the discriminator level for beta-radiation sensor compensation in the gamma-radiation sensor and the "E" value in the following formula were set so as to minimize the influence of the energy response:

$B \times [(\beta_1 - C \times \beta_2) - E \times \gamma]$

where,

B: Value determined by beta-radiation calibration (sensitivity constant as beta-radiation sensor)

C: Constant level of beta-radiation sensor to compensate for beta-radiation energy response

E: Count ratio (beta-radiation compensation coefficient) between gamma and beta-radiation sensors with respect to gamma-radiations

β_1: Count value beyond the lower-limit discriminator of beta-radiation sensor

β_2: Count value beyond the upper-limit discriminator of beta-radiation sensor

γ: Count value of gamma-radiation sensor beyond the discriminator for beta-radiation sensor compensation

2.3 Neutron sensor

The neutron sensor is composed of a fast neutron sensor and a thermal neutron sensor, and has a p-type low-resistivity silicon wafer on which amorphous silicon was deposited as in the gamma-radiation sensor (see Fig. 2.2). Low-resistivity silicon is used to reduce the gamma-radiation sensitivity by reducing the thickness of the depletion layer.

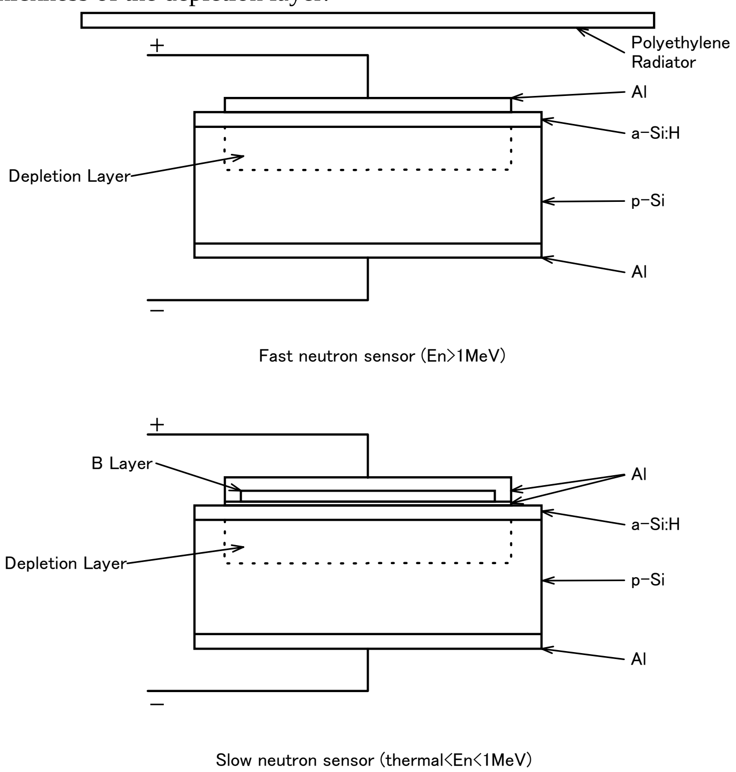

Fig.2-2 Cross-sectional view of the slow and fast neutron sensors

For the fast neutron sensor, a polyethylene radiator of about 0.8 mm is inserted in the direction of neutron incidence, so this sensor acts as a recoil proton detector. The thermal neutron sensor consists of amorphous silicon on which a boron (B) film is formed in order to detect thermal neutrons by utilizing the B(n,α)Li reaction.

Neutron dose is determined by totaling the count values from the above sensors according to the formula:

$(Nth \times nth + NF \times nf)$

where,

Nth: Sensitivity constant of thermal neutron sensor

nth: Count value of thermal neutron sensor

Nf: Sensitivity constant of fast neutron sensor

nf: Count value of fast neutron sensor

Each discriminator level of the above sensors is determined in consideration of the influence of gamma-radiations. However, the fast neutron sensor does not have a Q value due to its nuclear reaction and its sensitivity is about one-hundredth that of the thermal neutron sensor. Therefore, in the high-energy gamma-radiation field of ^{16}N, etc., gamma-radiation entry of about 10% (in terms of gamma-radiation dose) is unavoidable.

3. CREDIT-CARD-SIZE GAMMA-RADIATION EPD

This dosimeter indicates the personal dose equivalents Hp(10) from gamma-radiations through integration. When the present dose value or operation time is reached, an alarm is issued by a buzzer and red LED. Cumulative dose and elapsed time are indicated on the LCD and a maximum of 600 points can be memorized in time series. The obtained data can be transmitted to exclusive equipment by wireless serial communication at 9,600 bps.

Table 1 lists specification of EPDs

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	card-size γ -EPD	Multifunctional EPD		
radiation	photon	photon	beta	neutron
radiation energy	±20% 60Kev～6MeV、 for ^{137}Cs	same as left	±30% 500KeV～2.3MeV、 for ^{90}Sr／^{90}Y	^{252}Cf :+30% ^{241}Am-Be:+300% 0.025eV～15MeV for thermal neutron
dose display range	0.01～999.999 mSv	same as left	0.1～999.99 mSv	0.1～999.99 mSv
Accuracy	±10% 0.01～999.99 mSv	same as left	±20% 0.1～999.9 mSv	±20% 0.1～999.9 mSv
dose rate linearity	0.1mSv/h～1Sv/h	same as left	0.1mSv/h～100mSv/h	0.1mSv/h～100mSv/h
Alarm	means:buzzer and LED levels alarmed at:preset dose or preset time			
diagnostic function	automatic check on count operation			

Fig 3.1 card-size γ radiation-EPD(NRX)

This dosimeter measures 91 × 55 × 8.5 mm and weighs approximately 60 g as shown in Fig. 3.1.

The energy response expressed as a deviation from the Hp(10) [Sv] characteristic given in ICRP ’51 lies within ±20% with reference to ^{137}Cs (Fig. 3.2). The directional characteristic is ±15% max. within ±60° of the perpendicular to the center of calibration (Fig. 3.3), and dose rate linearity is ±10% max. between 0.1 mSv and 1 Sv/h of the value at 10 mSv/h (Fig. 3.4). The temperature characteristic is ±10% max. from 0 to 40°C with reference to 20°C.

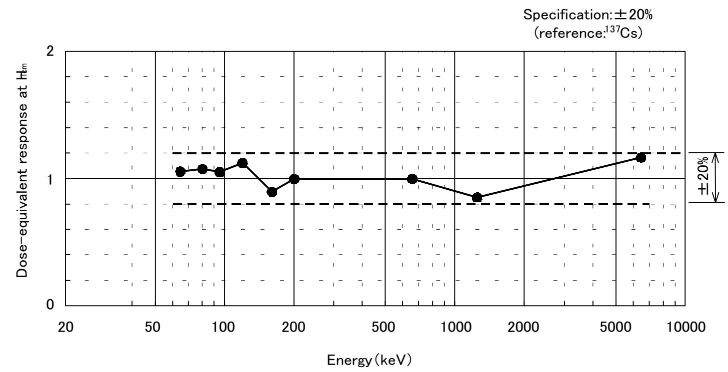

Fig.3-2 X/gamma-ray energy response (H_{1cm})

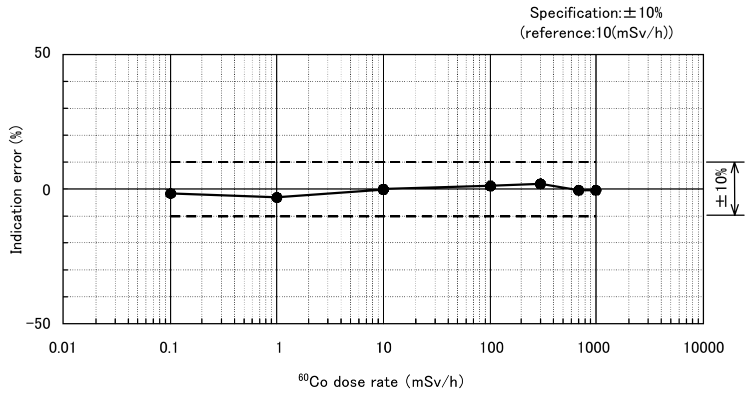

Fig.3-3 Gamma-ray dose rate characteristic (^{60}Co)

4. MULTIFUNCTIONAL EPD

This dosimeter is capable of measuring a Hp(10) of gamma-radiations and neutrons, and a Hp(0,07) of beta-radiations simultaneously. Each dose value can be displayed on the LCD through switching. All the functions are the same as those of the credit-card-size gamma-radiation dosimeter (NRX), except that the dose alarm can be set for only the gamma-radiation sensor. Also, various gamma-radiation characteristics match those of the NRX.

This dosimeter measures 102 × 55 × 14.5 mm and weighs approximately 95 g as shown in Fig. 4.1.

Fig 4.1 Multifunctional EPD(NRN)

The neutron energy response corresponding to ICRP '51 is evaluated using a monoenergetic neutron source and Ri neutron source selected with an accelerator as shown in Fig. 4.2. The dip within a range from a few hundred keV to 1 MeV in this figure is attributable to the influence of the gamma-radiation discriminator set value on the fast neutron sensor. On the other hand, the beta-radiation energy response is defined in terms of the relative sensitivity of ^{204}Tl with respect to ^{90}Sr, and is approximately -30% (Fig. 4.3).

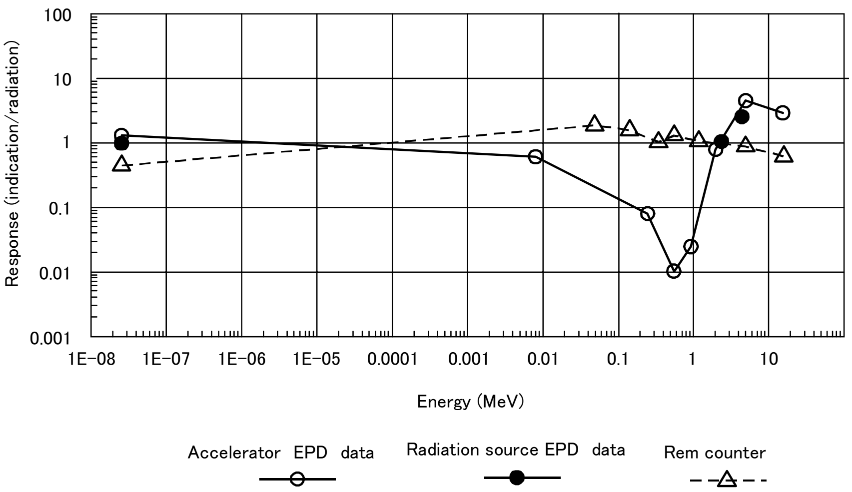

Fig.4-2 Neutron energy response (with accelerator)

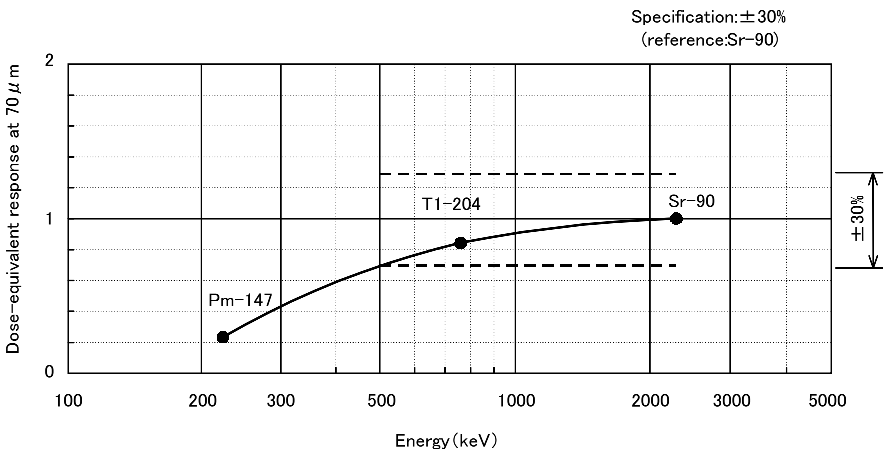

Fig. 4.3 Beta-ray energy response

The directional characteristic of each neutron sensor is evaluated on ^{252}Cf, and is ±50% max. within ±60° of the perpendicular to the center of calibration (Fig. 4.4). The directional characteristic of the beta-radiation sensor is evaluated on ^{90}Sr, and is ±50% max. within ±30° of the perpendicular to the center of calibration (Fig. 4.5).

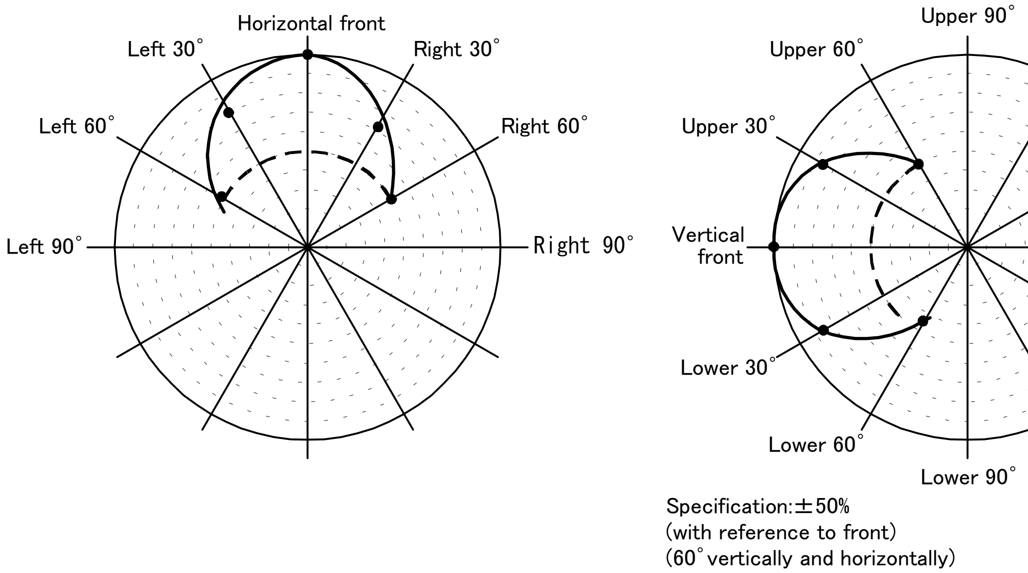

Fig.4-3 Directional characteristic of neutron (^{252}Cf)

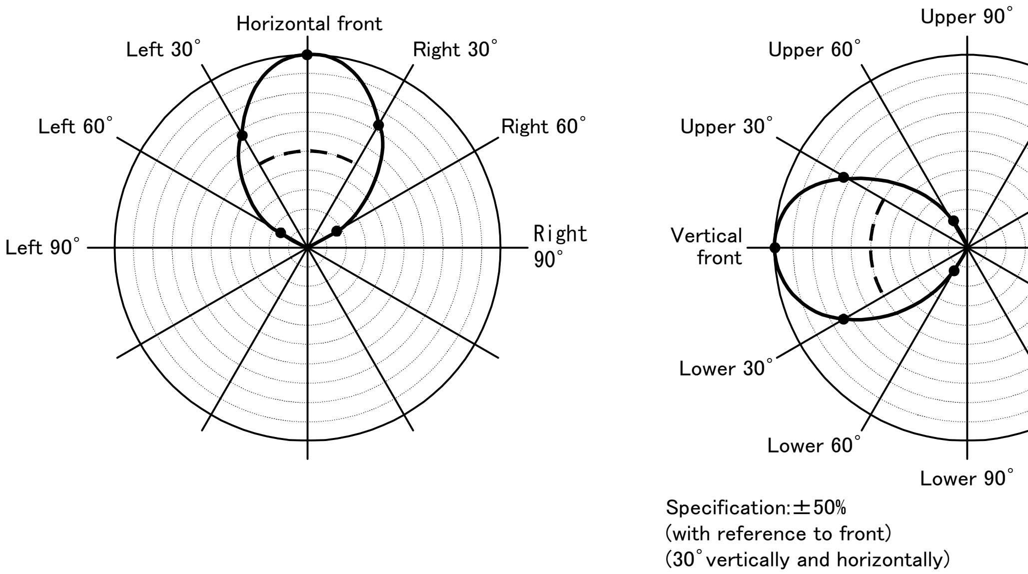

Fig.4-5 Directional characteristic of beta-ray (^{90}Sr)

For dose rate linearity, inverse-square measurement cannot be performed due to scattering, absorption, etc., so it was evaluated on both the neutron and beta-radiation sensors by using a simulated input. As a result, the indication deviation between 0.1 mSv to 1 Sv/h was within ±10% of the value at 10 mSv/h.

As an index of beta-radiation discriminating capability in a beta/gamma-radiation coexisting field, beta-radiation dose was measurable with an accuracy of ±30% when gamma-radiation dose was three times as large as beta-radiation dose. And as an index of neutron discrimination in the neutron/gamma-radiation coexisting field, about 10% of gamma-radiation dose was contained in the count of neutron dose in the 16N gamma-radiation atmosphere.

5. PERFORMANCE EVALUATION OF EPDS

These EPDs have been used in the Tokai nuclear power plant of Japan Atomic Power Company since October 1997, and in its Tsuruga nuclear power plant since December 1997.

At present, the EPDs are used as auxiliary dosimeters and their performance is being evaluated and compared with FBs to verifty that they can be used as legal dosimeters.

Actual application data with FBs and EPDs for gamma-radiation measurement in the past one year were compared. Figures 5.1 and 5.2 compare the monthly cumulative dose in the Tokai and Tsuruga plants, respectively.

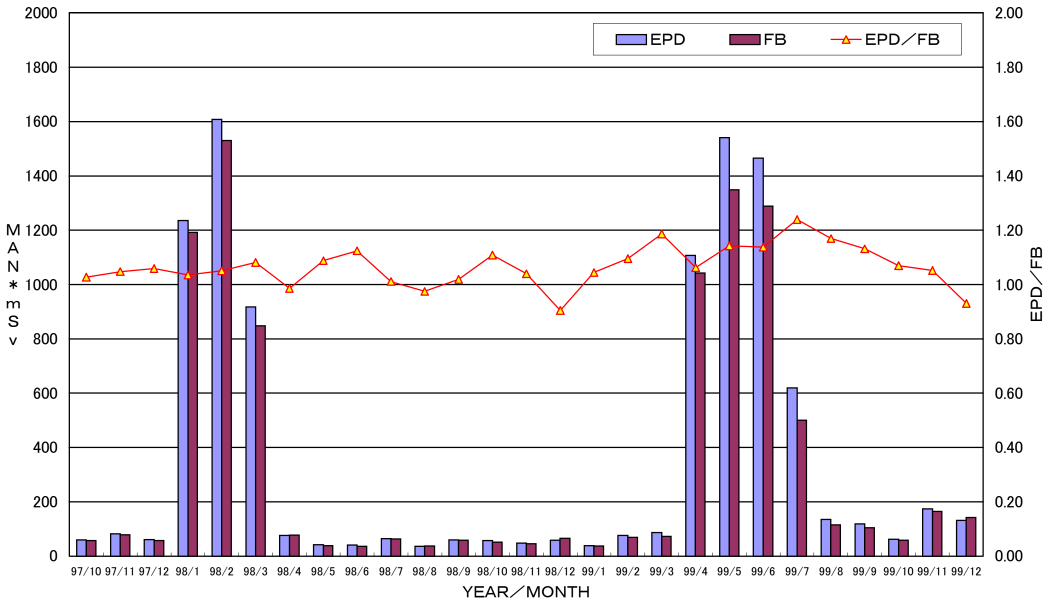

Figure 5.1.　Comparison between EPD and FB (Tokai)

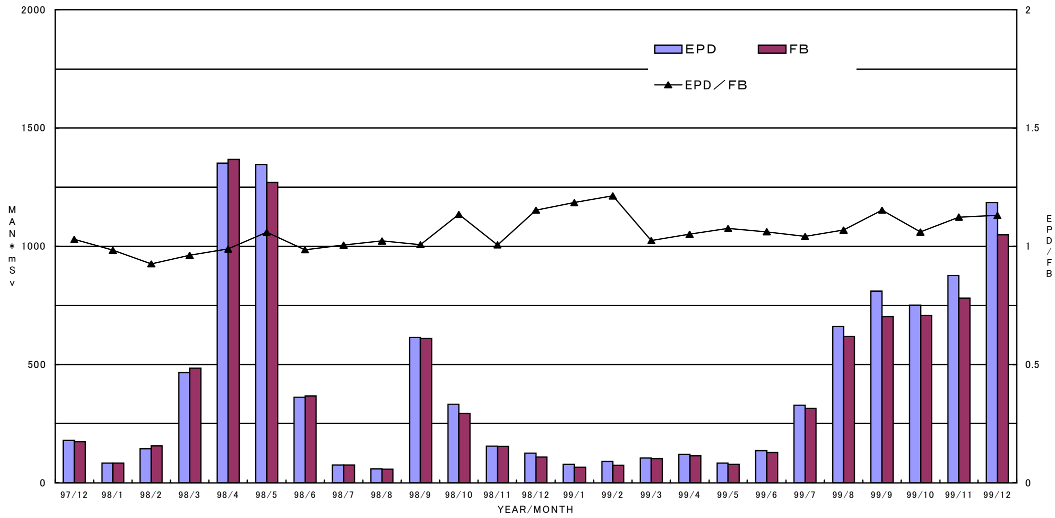

Figure 5.2.　Comparison between EPD and FB (Tsuruga)

The ratio of the monthly totaled dose indication on EPD to that on EB lies within 0.93 to 1.17 (EPD indication value/FB indication value), thus showing satisfactory coincidence.

In the monthly cumulative dose of individuals, there were only 0.02% where the indication difference between FB and EPD exceeded 20% (or 0.5 mSv).

The occurrence of troubles in using EPDs such as failure to collect data can be considered to be zero. Based on the above results, use of the EPD as a legal dosimeter for gamma-radiation measurement should not cause a problem.

When using EPDs for beta-radiation and neutron measurements, several problems have been reported, but such problems occurred primarily because the equipment was adjusted under conditions that did not match the radiation environment in the power plant, and are being solved.

6.　FUTURE　PLANS

The results of actual use of EPD are currently being evaluated.　In addition, a device for calibrating

EPDs has been introduced and is now in use. When the whole EPD system is completed, JAPC intends to switch over to using EPDs.

7. REFERENCES

1. T.Nakamura, M.Sasaki, T.Suzuki, O.Ueda,. *Nuclear Instruments and Methods in Physics Research A 418(1998)465-475*