# Optimization of Individual Monitoring for β Radiation Dose at BWR Plants in Japan

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## INTRODUCTION

Japanese radiation protection regulations set annual dose limits for radiation workers (hereafter referred to as "workers") and specify radiation measurement requirements. Current Japanese regulations are principally based on the International Commission on Radiological Protection (ICRP) 1977 recommendations (Publ.26)(1). To comply with them, individual monitoring for external exposure is carried out for all workers using personal monitors such as film badges to measure γ-rays and β-rays at nuclear power plants.

It is known that major portion of external radiation exposures at BWR plants is due to γ-rays from Co-58 and Co-60 in corrosion products (CPs) and cases of measurable β-ray exposures are quite few. It is suggested from the above operational experiences that individual β-ray monitoring may be necessary only under unusual circumstances. Taking the past β-ray dose records into consideration, we have carried out a survey of β-ray dose distribution inside BWR plants during their periodical inspection outage.

This report describes the results of our study on an optimization of individual monitoring for β-ray dose.

## METHOD

### (1) Plants and Equipment surveyed

a. Plants

The β-ray exposure is thought to be caused mainly by relatively high-energy β-rays emitted from fission products (FPs). With reference to past fuel damage records and current operational conditions of each plant (for example, nuclide composition and concentration in the reactor coolant, noble release rate), we have selected three plants to be surveyed from the following characteristic of TEPCO's BWR plants. In 1970s, fuel damages occurred many times and measurable β-ray exposures were frequently experienced. But on and after 1980, the number of damaged fuel assemblies decreased drastically and β-ray exposures has hardly been found.

| Name of plant | Characteristic |
|---|---|
| Fukushima-daiichi Unit-1<br>Fukushima-daiichi Unit-5 | Influenced by fuel damages |
| Kashiwazaki-Kariwa Unit-1* | Without fuel damage record and/or influences of fuel damages |

*Almost all of the 17 units of TEPCO's BWR units belong to the same group of Kashiwazaki-Kariwa Unit-1.

b. Equipment

According to the survey data obtained from past periodical inspections, it turned out that β-rays are distributed in overall plants. We, therefore, selected equipment to be surveyed from each system of overall plants to grasp the β-ray dose distribution. A typical equipment has been selected from each system with consideration of physical phase of cooling water (water, steam, gas), as follows:

| System | Equipment |
|---|---|

| | |
|---|---|
| Reactor primary cooling system | Primary loop recirculation pump (PLR)<br>Reactor water clean-up pump (CUW), etc. |
| Main steam system | Main steam isolation valve (MSIV)<br>Safety relief valve (SRV), etc. |
| Feedwater and Condensate system | Low pressure condensate pump (LPCP)<br>Hotwell, Feedwater heater, etc. |
| Off-gas system | Steam jet air ejector (SJAE)<br>Valves of off-gas system, etc. |
| Other systems<br>(Radwaste treatment system, etc.) | Concentrated waste storage tank, etc. |

c. Period

| Name of plant | Inspection Outage | Period |
|---|---|---|
| Fukushima-daiichi Unit-1 | 20th | April 2 - May 18, 1998 |
| Fukushima-daiichi Unit-5 | 16th | Sep. 18 – Nov. 13, 1998 |
| Kashiwazaki-Kariwa Unit-1 | 10th | Oct. 7 – Dec. 25, 1998 |

## (2) Monitoring method

a. Instrumentation and calibration

A thin-window type ionization chamber survey meter (Aloka ICS-313) was used for β-ray measurement. This survey meter is used in working environments at nuclear power plants. Calibration was performed by using a standard extrapolation chamber and a standard β-ray irradiation system having traceability for 70 µm dose equivalent and β-ray emitter, in accordance with JIS Z 4323 "Universal film badges"(2).

It was ensured from the calibration that the survey meter has satisfactory energy characteristics and direction characteristics. Moreover, it was shown that the instrument can measure residual maximum β particle energy with the accuracy of ± 5 % to a β-ray standard extrapolation chamber with the traceability.

b. Measurement method

It is said in general that the energy of β-rays ranges from 0.3 MeV to 2.3 MeV at nuclear power plants. β-ray exposure dose is strongly dependent on its energy, and so β-ray energy was measured as well as dose equivalent rate. β-ray energy was evaluated by calculating residual maximum β particle energy ($E_{Res}$) from the β-ray absorption curve fitted by the data measured, based on ISO 6980 as shown in Figure-1(3). Residual maximum β particle range ($R_{Res}$) was defined as the intersection of the extrapolated linear portion of β-ray absorption curve with γ background level. The calculation formula of residual maximum β particle energy is shown as follows:

$$E_{Res}=[\{(9.1R_{Res}+1)^2-1\}/22.4]^{1/2}$$

where, $E_{Res}$ = Residual maximum β particle energy (MeV)
$R_{Res}$ = Residual maximum β particle range (g/cm$^2$)

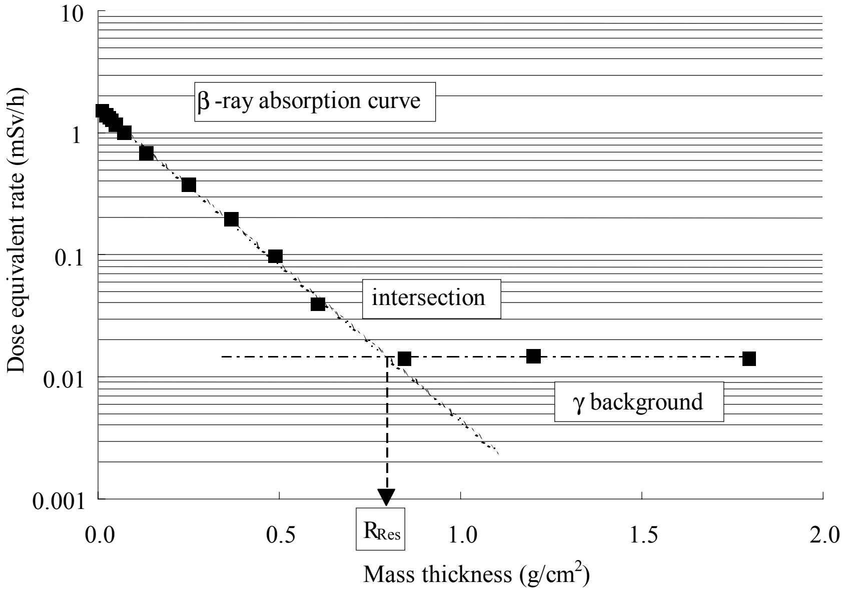


Figure.1 Calculation method of the residual maximum range and energy for β paticles from β-ray absorption curve.

β-rays and γ-rays have to be measured separately since both β-rays and γ-rays are existing simultaneously in actual working environments of the nuclear power plants. We have applied an absorption board for β-rays, like aluminum plate enabling to absorb β-rays, to separate β-rays from γ-rays.

We used a low density acrylic board with 0.01 cm - 1.5 cm thick for β-ray absorption. Measuring distance was set at 30 cm equivalent to a distance from a radiation source to an elbow from the actual working environments point of view as shown in Figure-2.

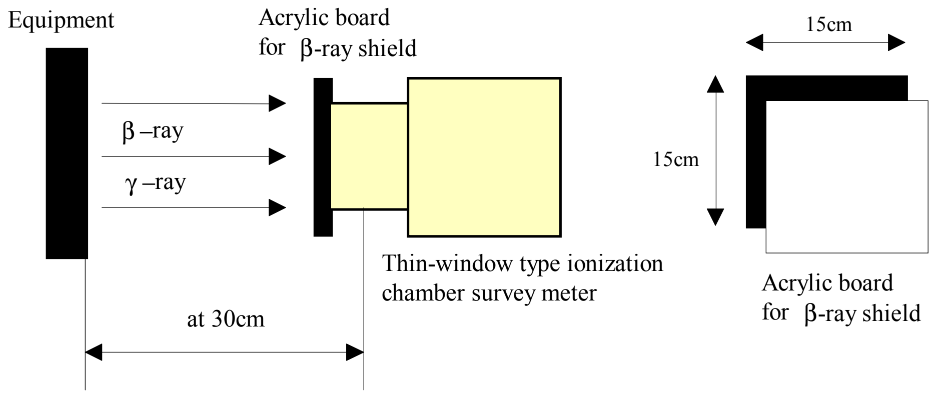


Figure.2 Measurment of β-ray dose equivalent rate by a thin-window type ionization chamber survey meter equipped with the β-ray absorption

c. Measuring method

β-ray and γ-ray dose equivalent rates were measured with a thin-window type ionization chamber survey meter equipped with an acrylic board for β-ray shielding, in each working environments, for the equipment of reactor primary cooling system, main steam system, feedwater and condensate system and off-gas system, during periodical inspection outages.

Moreover, shielding effect of the protective clothing to β-rays was evaluated, and also γ-ray emitters were surveyed by analysis of smear samples taken from surfaces of the equipment by a Ge semiconductor detector.

## RESULTS

(1) Dose equivalent rates and residual maximum β particle energy

Figure-3 shows a sample of the measurement results for β-rays. High dose equivalent rates was observed at valves of reactor water clean-up pump (CUW) and the β / γ ratio was as low as 1.0. Dose equivalent rate was low at dehumidifying cooler in off-gas system and the β / γ ratio was relatively high as 6.0 unlike CUW cases. In the case of steam jet air ejector in off-gas system, dose equivalent rates was high and also β / γ ratio was extremely high as 201. These measurement results were shown in Table-1.

β / γ ratios exceeded 10 by far and residual maximum β particle energy ($E_{Res}$) exceeded 1 MeV at most of the equipment in off-gas system. Dose equivalent rates of reactor primary cooling system was relatively high, and β / γ ratio was around 1 at most of the systems including this system. The residual maximum β particle energy was less than 0.5 MeV at all of the other systems.

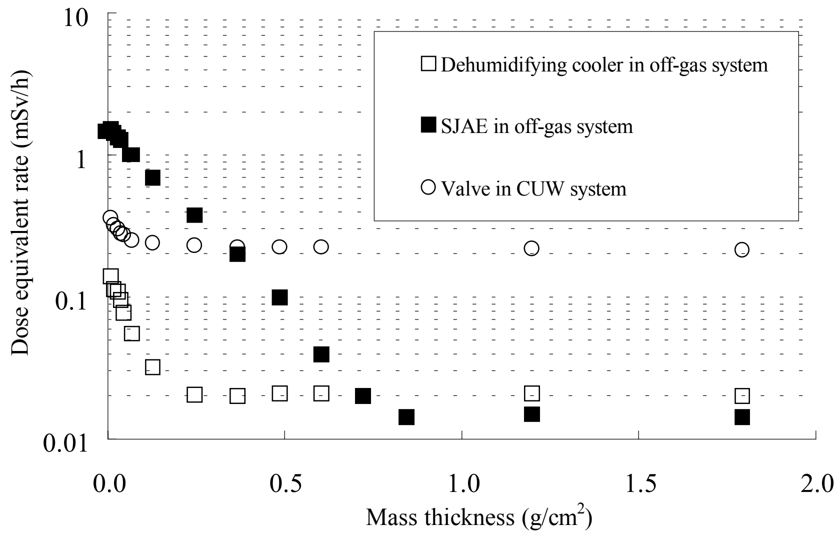


Figure.3 Measurment data of β-ray dose equivalent rate at 30cm distance

Table.1 Residual maximum β particle energy, β / γ ratio and β-ray dose equivalent rate

| System | $E_{Res}$ values (MeV) | β / γ ratio* | β-ray dose equivalent rate* (mSv/h) |
|---|---|---|---|
| Reactor primary cooling system | < 0.5 | ~ 1.0 | ~ 2.4 |
| Main steam system | < 0.5 | ~ 2.6 | ~ 0.02 |
| Feedwater and Condensate system | < 0.5 | ~ 1.3 | ~ 0.02 |
| Off-gas system | ~ 1.7 | ~ 201 | ~ 2.9 |
| Other systems | < 0.5 | ~ 0.9 | ~ 1.2 |

*β / γ ratio and β-ray dose equivalent rate with shielding by protective clothing

(2) Shielding effects by protective clothing

Protective clothing shielded more than 60 - 70 % of β-rays at almost all places where residual maximum β particle energy was less than 0.5 MeV. On the other hand, only 10 - 30 % of β-rays were shielded by the clothing in the off-gas system where residual maximum β particle energy was high.

(3) γ-emitters analysis by smear method

Almost all radioactive nuclides were activated CPs emitting low β-ray energy such as Co-60 ($E_{\beta max}$ = 0.318 MeV) at equipment in the systems other than off-gas system. On the other hand, FPs emitting relatively high β-ray energy were detected at equipment in off-gas system.

It is expected that there may exist nuclides emitting β-rays only such as Sr-Y-90 ($E_{\beta max}$ = 2.28 MeV) because very high β-ray energy was measured at equipment and FPs such as Cs-137 was detected in the smear samples.

## CONCLUSIONS

Predominant radioactive materials in most systems of BWR plants are CPs having relatively low β-ray energy, like Co-60, and β dose equivalent rates are at very low levels. Although the dose equivalent rates of reactor primary cooling system are relatively high, the β / γ ratio is as low as around 1 similar to other systems, and the residual maximum β particle energy is also at low level as less than 0.5 MeV. In addition, protective clothing being used during periodical inspection are very much effective in shielding workers from β-ray exposure. It may be concluded that external exposures at BWRs can be normally controlled by individual monitoring for γ-ray dose only.

As for the off-gas system, it has been suspected that nuclides, like Sr-Y-90 emitting β-rays only, were present, and it has been observed that β / γ ratio exceeded 10 and also residual maximum energy for β particles ($E_{Res}$) was higher than 1 MeV.

Therefore, as far as the off-gas system is concerned, an individual monitoring for not only γ -ray dose but also β-ray dose may be needed in principle.

## REFERENCES

1. ICRP Publication 26, *Recommendations of the International Commission on Radiological Protection*, (1977).
2. JIS Z 4323, *Universal film badges* (1997).
3. ISO 6980, *Reference beta radiations for calibrating dosimeters and dose-rate meters and for determining their response as a function of beta-radiation energy* (1996).