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Development of a new detection system for monitoring high-level tritiated water

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ABSTRACT

To monitor high-level tritiated water in a fusion fuel circulation system, a new detection system for non-destructive measurements of tritium concentration was specially design and fabricated. A twin-type X-ray detector, which works as a detector of the low energy X-rays induced by β-rays from tritiated water, was equipped with the new detection system. Tritiated water flows in a narrow space surrounded by two X-ray detectors. Basic performance of the new detection system was examined using a poly-methylmethacrylate disk labeled with tritium and tritiated water. It was found that the present detection system satisfied the basic performance for measurements of the low energy X-rays and it is applicable to non-destructive measurements of high-level tritiated water in a flow system.

1. Introduction

In ITER a huge amount of elemental tritium is loaded as a fusion fuel, and a given amount of tritium is injected into the reactor core through a storage-delivery system in the fusion fuel circulation system during a pulse operation. However, the exhaust gases from the divertor contain various kinds of tritium species such as QT, QTO, $C_XQ_YT_Z$ (Q = H, D) as well as original fuel particles and He. From viewpoints of safety and economy of tritium, the extraction and recovery of tritium from such tritium-containing species is one of the important issues [1]. Especially, processing of tritiated water such as HTO, DTO and T_2O is of an important issue, since high-level tritiated water necessarily generated in the fusion fuel circulation system. It is necessary to track tritium concentration in the tritiated water processing system. However, if a sampling method is employed for this purpose, handling of high-level tritiated water in ambient atmosphere is very risky and a precise dilution process is required for the determination of tritium concentration. From this viewpoint, it is indispensable to develop a technique for non-destructive measurements of tritiated water in a water processing system.

Although a liquid scintillation counter is widely used for evaluation of tritium concentration in liquid samples, it is difficult to apply this technique to non-destructive measurements of high-level tritiated water. In addition to this, much organic waste containing tritium produces newly, if the liquid scintillation counter is applied. To solve such problems, utilization of β-ray-induced X-ray spectrometry (BIXS) has been recently proposed by the author as a new technique for static measurements of high-level tritiated water [2]. In this technique, a single type X-ray detector shielded with a thick lead wall and a metallic vial with a thin beryllium window in the bottom were used to reduce the effects of natural radiations and to gain a high transmittance of low energy X-rays. As a result, it was concluded that BIXS is applicable to measure non-destructively high-level tritiated water. Basic principles of this technique will be applicable to a flow system as well as a static system of tritiated water.

From this view point, a new X-ray detection system available for a flow system of tritiated water was designed and its performance was examined. To improve the detection efficiency and to lighten the detector by removing a lead shielding, the new detection system consists of two X-ray detectors without lead shielding, and they were located opposite to each other to coincidently detect X-rays generated in the tritiated water. In this paper, performance of the new detection system for non-destructive measurements of high-level tritiated water will be examined and the results will be discussed.

2. Experimental

A polymer source labeled uniformly with tritium, which is made of poly-methylmethacrylate (hereafter described as T-PMMA), was used to examine the basic performance of a newly constructed X-ray detection system. Specific activity of the polymer source was 124 MBq/g, and the size was Ø25 mm in diameter and 1 mm in thickness. Weight of the polymer source was 0.584 g [3].

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After all the examinations used T-PMMA, practical examinations were conducted using a given concentration of tritiated water. Tritium concentration of the tritiated water used was evaluated as 10.7 MBq/cm^3 by a liquid scintillation counter.

3. Results and discussion

3.1. Design and construction of the measuring device

Basic concept of a new X-ray measuring system is as follows:

(1) to reduce the electric noise and natural radiations without using a lead shielding,
(2) to improve the detection efficiency of X-rays induced by β-rays from tritium, and
(3) to be applicable for a flow system of tritiated water.

To satisfy these requirements, a twin-type X-ray detector as shown in Fig. 1 was specially designed and manufactured. Two X-ray detectors were located opposite to each other, and the tritiated water flows in a narrow space between two detectors. Volume of the narrow space was about 9 cm^3. The width of the narrow space is 5.0 mm, which was previously determined from the dependence of tritiated water volume on X-ray intensity. The details are described in the previous paper [2]. The X-rays produced in the tritiated water penetrate through a beryllium plate welded to a stainless steel flange. Thickness of the beryllium plate was 200 μm, and the surface exposed to tritiated water was coated with a thin gold film (hereafter described as Au/Be) to avoid erosion of the beryllium surface by water. The penetrated X-rays impinge on a solid NaI(Tl) scintillator enclosed in the X-ray detector, and then they are detected. The solid NaI(Tl) scintillator having the thickness of 2.0 mm was employed to reduce the effects of natural radiations.

A block diagram for measurements of the counting rate and the energy spectrum of X-rays induced by β-rays is shown in Fig. 2. The measuring system was assembled using conventional NIM modules such as BIN & Power Source, High Voltage Power Source, Amplifier, Single Channel Analyzer, A/D Converter, Universal Coincidence, Scaler and Timer, and so on. The counting rate and the energy spectrum of X-rays can be separately recorded by a personal computer (PC). The Universal Coincidence module is specially added to eliminate the effects of electric noise and natural radiations. We can select either mode in single or coincidence during measurements. The effects of natural radiations are able to reduce largely by applying a coincident mode without a lead shielding.

Fig. 3 shows photographs of the new measuring system: (A) is the twin-type X-ray detector and (B) the counting system.

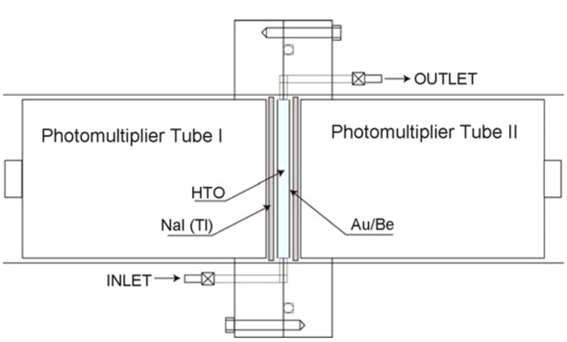

Fig. 1. A twin-type X-ray detector for measurements of tritiated water.

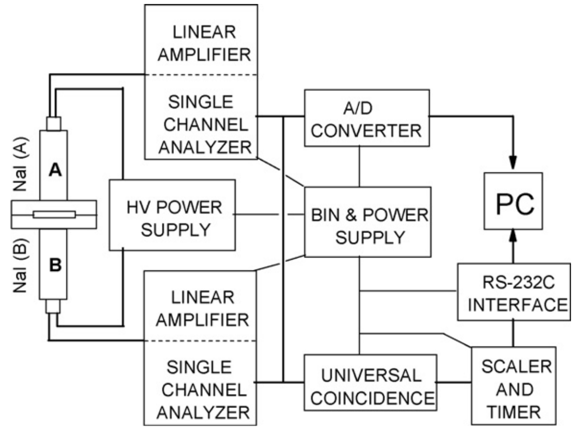

Fig. 2. Block diagram of a counting system of β-ray-induced X-ray intensity.

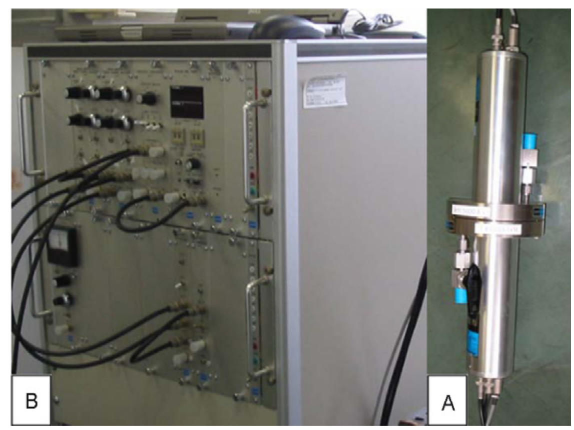

Fig. 3. Photographs of a new measuring device: A is the twin-type X-ray detector and B is the counting system.

3.2. Background level

To examine the effects of addition of a coincident counting module on background level of the present system, a single and a coincident mode were applied to measure background level. Measurements in each mode were repeated 10 times. In addition to this, energy spectrum of noise was also measured for 100 h to clarify the background level. The result is shown in Fig. 4 as an example, which was observed by the Detector (A). Although the channel number

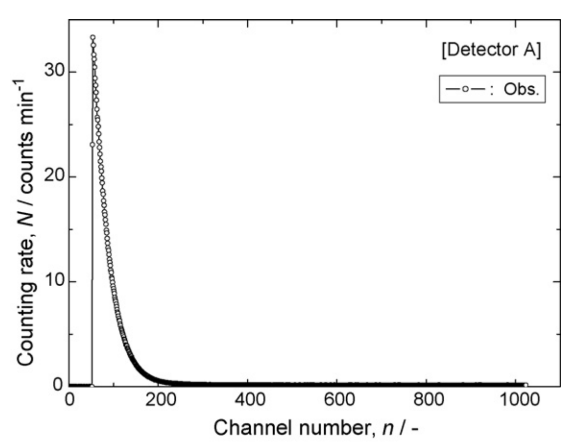

Fig. 4. An energy spectrum of background level in the present system.

of the abscissa is basically corresponding to energy of radiations, the conversion factor from channel number to the X-ray energy is strongly dependent on gain of the amplifier. This effect is described in the following Section 3.3. The intensity of noise exponentially decreased with increase in energy and the noise in a higher energy region was negligibly small. This was also true for the Detector (B). Therefore, it was suggested that the majority of noise was caused by an electric noise of the X-ray detectors and that it could be eliminated by fairly controlling a lower discrimination level of a detector as described later.

On the other hand, in the case of a single mode, background levels of Detector (A) and (B) were 963 ± 10 and 800 ± 7 counts/min, respectively. A little difference of the background level between both detectors is due to that of an amplification factor of the amplifier. In the case of a coincident mode, however, the background level largely decreased to the intensity of 1.69 ± 0.05 counts/min. These results indicate that the background level could be lowered below about 1/500 by applying the coincident mode without a lead shielding. Namely, it was seen that the coincident mode worked effectively in the present counting system.

3.3. Dependence of discrimination level and gain on X-ray measurements

The background level can be also lowered by cutting off electrically the low energy level with a lower level discriminator (LLD), although it depends on performance of the photon multiplier and pre-amplifier incorporated in the X-ray detector. Fig. 5 shows the energy spectra observed by changing LLD for the Detector (A). In this experiment, T-PMMA was used as a tritium source, and it was put on the Au/Be plate during measurements. Changes in the energy spectra indicate that it is possible to eliminate the noise in a low energy region by LLD without change in the shape of an X-ray spectrum induced by β-rays. Quite similar changes were also observed by the Detector (B).

Since the maximum energy of β-rays emitted from tritium is 18.6 keV, maximum energy of the X-rays inducing by the β-rays is also 18.6 keV. To measure only X-rays induced by the β-rays, gain of the amplifier was controlled. Fig. 6 shows the X-ray spectra observed by changing the gain of the Detector (A). In this measurement, the coarse gain was fixed to the amplification factor of 64. X-ray spectra were apparently enlarged toward to the higher energy side with increase in the gain without changes in the total intensity of X-rays. This was also true for the Detector (B). Namely, it was seen that higher energy radiations can be moved out of region of interest by controlling the gain.

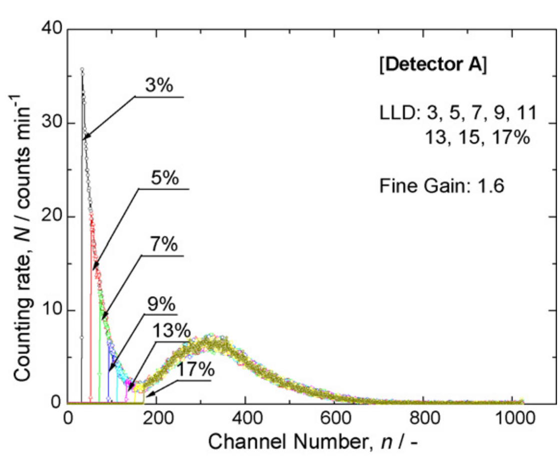

Fig. 5. Changes in energy spectra with LLD. T-PMMA was used as a tritium source.

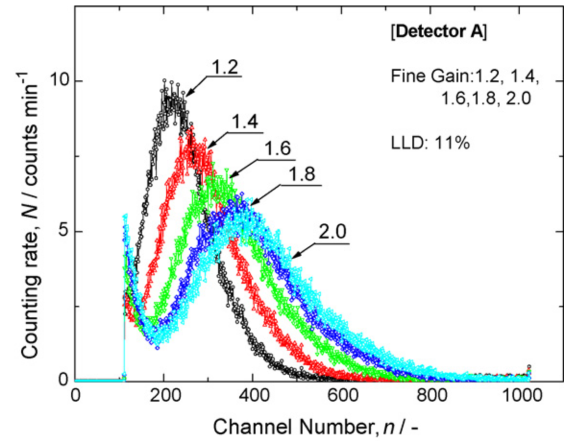

Fig. 6. Changes in energy spectra with gain. T-PMMA was used as a tritium source.

3.4. Measurements of X-rays from tritiated water

Fig. 7 shows an example of the X-ray spectra obtained by measuring tritiated water with the Detector (A). Maximum intensity of the X-rays induced by β-rays appeared in the channel number of 277. A quite similar X-ray spectrum was also observed by the Detector (B). It is concluded, therefore, that the present measuring system is able to measure non-destructively the low energy X-rays induced by β-rays from tritiated water. The intensity of the β-ray-induced X-rays was evaluated to be 5757 counts/min when the background denoted as BG in the figure was excluded.

Furthermore, effects of the single and coincident modes in counting were examined. In case of the single mode, the counting rates measured by the Detector (A) and (B) were 3900 and 3671 counts/min, respectively. These counting rates were lower than the intensity evaluated from the X-ray spectrum mentioned above. This is due to the difference in a lower discrimination level between both measurements of the X-ray spectra and the counting rate. On the other hand, in case of the coincident mode, the counting rate drastically decreased as 2.4 counts/min, because most of X-rays did not impinge on radiation windows of both detectors at the same time. If the X-rays produced in tritiated water simultaneously reached both radiation windows, the counting rate in the coincident mode should be almost same as that in the single mode. Namely, the large decrease indicates that the X-rays generated in tritiated water have strong directivity. It is considered, therefore, that the coincident mode which worked well for elimination of

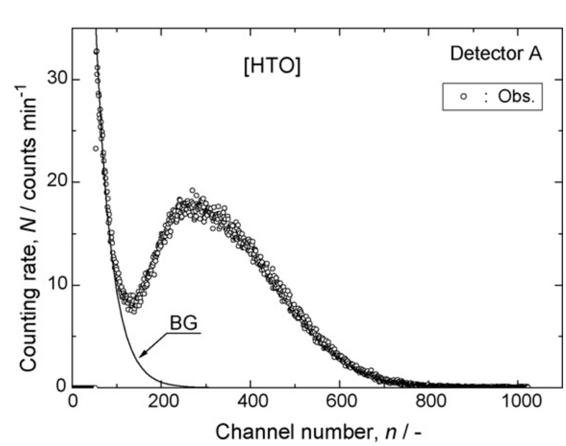

Fig. 7. The energy spectrum observed for tritiated water.

the noises oppositely acted in a detection process of X-rays. This indicates that the measurements by anti-coincident mode may be advantageous if optimum values for the lower discrimination level and gain are controlled well. In addition, a long durability test of the Au/Be plate against tritiated water will be required for a practical use.

4. Summary

A new detection system of X-rays induced by β-rays in high-level tritiated water was specially designed and assembled using conventional NIM modules, and its performance has been examined. Main features of the new detection system are as follows: An X-ray detector consists of a twin-type structure without a lead shielding, and tritiated water flows in a narrow space between both detectors. Effects of changes in lower level discriminator and gain of the amplifier were examined and dependency of them on the counting rate and energy spectrum of X-rays induced by β-rays was evaluated. As a result, it was seen that the electrical system of the present measuring system works well for the present purpose. In addition, it was found from the experiments used tritiated water that the new detection system is applicable to measure non-destructively high-level tritiated water in a flow system.

References

[1] I.R. Cristescu, I. Cristescu, L. Doerr, M. Glugla, D. Murdoch, Tritium inventories and tritium safety design principles for the fuel cycle of ITER, Nucl. Fusion 47 (2007) S458–S463.
[2] M. Matsuyama, Y. Torikai, K. Watanabe, In-situ measurement of high-level tritiated water by bremsstrahlung counting, Fusion Sci. Technol. 48 (2005) 324–331.
[3] M. Matsuyama, Y. Torikai, K. Watanabe, Analysis and simulation of β-ray-induced X-ray spectrum observed for a thick tritium source made of methylmethacrylate resin, Ann. Rep. Hydrogen Isotope Res. Center, Toyama Univ. 22 (2002) 55–64.