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# 論　文

# トリチウム流路変更システムへの制動X線計測装置の適用性

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# Applicability of Bremsstrahlung Counting Device to a Changeover System of Tritium Flow Channel

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## Abstract

Aapplicability of the bremsstrahlung counting device to a changeover system of a tritium flow channel has been examined. To simulate a tritium stream, a tritium flow simulator was fabricated. It consists of a radiation detector, low energy X-ray source and its reciprocative motion system. The performance of the tritium flow simulator was examined at first. It was revealed that the simulator could produce preferable peak profiles. In addition, it was observed that the products of a given total count and moving velocity of the X-ray source were almost constant, and also that the simulator performed very well. However, to evaluate the feasibility of an automatic control for the changeover system of a flow channel by a signal from the simulator, the simulator needed to be electrically connected with two valves through a comparator, and the opening and closing action of the two valves have been examined by changing the moving velocity of the radiation source and the

accumulation time of the scaler. The preferable action of the two valves could be confirmed, and it was revealed that the bremsstrahlung counting device would be applicable to a changeover system of a tritium flow channel.

## 1. Introduction

In D-T thermonuclear fusion devices, it is indispensable to control safely a large amount of tritium in a fuel circulation loop consisting of several unit systems for storage, supply, recovery, purification and isotope separation. To ensure safe tritium control in each process, the loop should be equipped with various kinds of tritium monitors. A tritium monitor in the fuel circulation loop is very important as a generator of feedback signals to control tritium concentration, flow rate and flow passage of tritium stream. For example, changeover valves of tritium flow channel will work in connection with a sequential procedure of hydrogen isotope separation process. Namely, the changeover valves will be automatically operated by feedback signals from a tritium monitor.

Some kinds of tritium monitors will be applicable to such purposes. A conventional ionization chamber is one of them. It has several advantages such as simple structure, high durability against long term use, wide working range and so on. However, since the measuring principle of this kind of monitors is based on the detection of the ionization current induced by $\beta$-rays in an ambient gas, the sensitivity is directly affected by changes in the total pressure of the ambient gas and chemical composition of the gas phase[1]. Such behavior will impede the precise measurement/control of tritium in a fuel circulation loop.

The present authors proposed the bremsstrahlung counting method as one of useful methods for in-situ measurements of high level tritium[2]. This method has many advantages : namely, (1) applicability to in-situ and real-time measurements of tritium concentration, (2) no contamination of a radiation detector, (3) independence of the chemical form of tritium species, (4) insensitivity to coexisting impurity gases and their partial pressure changes, (5) simple and small structure, (6) high durability and ease in maintenance, and (7) wide working range.

The bremsstrahlung counting device mainly consisted of a radiation window and a X-ray detector[3]. The former acts as a generator and transmitter of the bremsstrahlung X-rays, and also plays a role of confinement wall of gaseous tritium. The spectrum of bremsstrahlung X-rays which is induced by interactions between $\beta$-rays and a radiation window material showed a continuous energy distribution below 18.6

keV. To improve the transmittance of low energy X-rays, a thin beryllium disk was employed as a radiation window. Recently, Matsuyama et al. reported that the lower detection limit of the counting device could be improved to the order of $10^{-7}$Ci/cm$^3$ by using a thin beryllium disk coated with a thin gold film[4]. It will be possible to apply the bremsstrahlung counting device to the flow control of tritium gas in a fuel circulation loop.

From this viewpoint, preliminary examinations were carried out on the feasibility of the bremsstrahlung counting device as a in-line sensor of a tritium flow control system by fabricating a tritium flow simulator. This paper describes the performance of the tritium flow simulator and the response of changeover valves linked to the simulator.

## 2 . Experimental

### 2. 1. Fabrication of a tritium flow simulator

To simulate a tritium stream, the device as shown in Fig. 1 was fabricated at first. It consisted of a silicon avalanche photo diode (Si-APD) to detect X-rays, glass tube, solid radioactive source fixed to the surface of cylindrical plastics and its reciprocative motion system. A $^{57}$Co source was selected as an emitter of X-rays, because $^{57}$Co radiates low energy X-rays (6.39, 6.40, 7.06 keV) which are close to an energy range of the maximum intensity of a bremsstrahlung X-ray spectrum induced by $\beta$-rays from tritium. The radioactivity of the $^{57}$Co source was about 5 $\mu$Ci. The

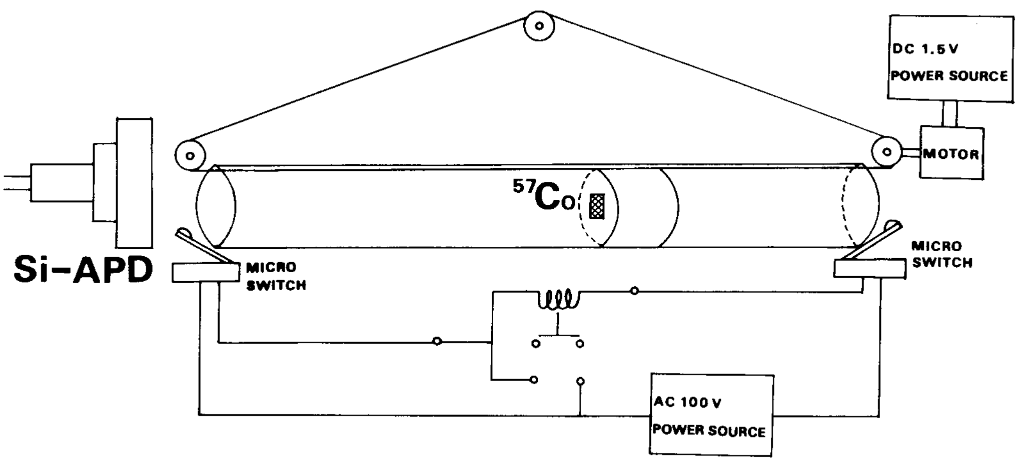


Fig. 1 A schematic diagram of tritium flow simulator.

radioactive source set in a glass tube could be reciprocated back and forth at a given constant velocity, which was controlled by a DC motor and two micro switches.

The moving velocity of the source was varied in a range from 0.8 to 6 cm/s, which corresponds to the flow rate of tritium gas in a range from 7.2 to 54 $cm^3$/min, assuming that the tritium gas was flowing in a tube with 1/4 inch in outer diameter.

## 2. 2. Electrical system

The signal from the Si-APD detector was accumulated by a conventional scaler for a given time. The accumulated counts were converted to an electrical signal, and it was sent to a comparator which is described later. The accumulation time by the scaler was changed in a range from 0.5 to 2.0 s in order to examine the response of the valves which were designed for automatic operation by the electrical signal from

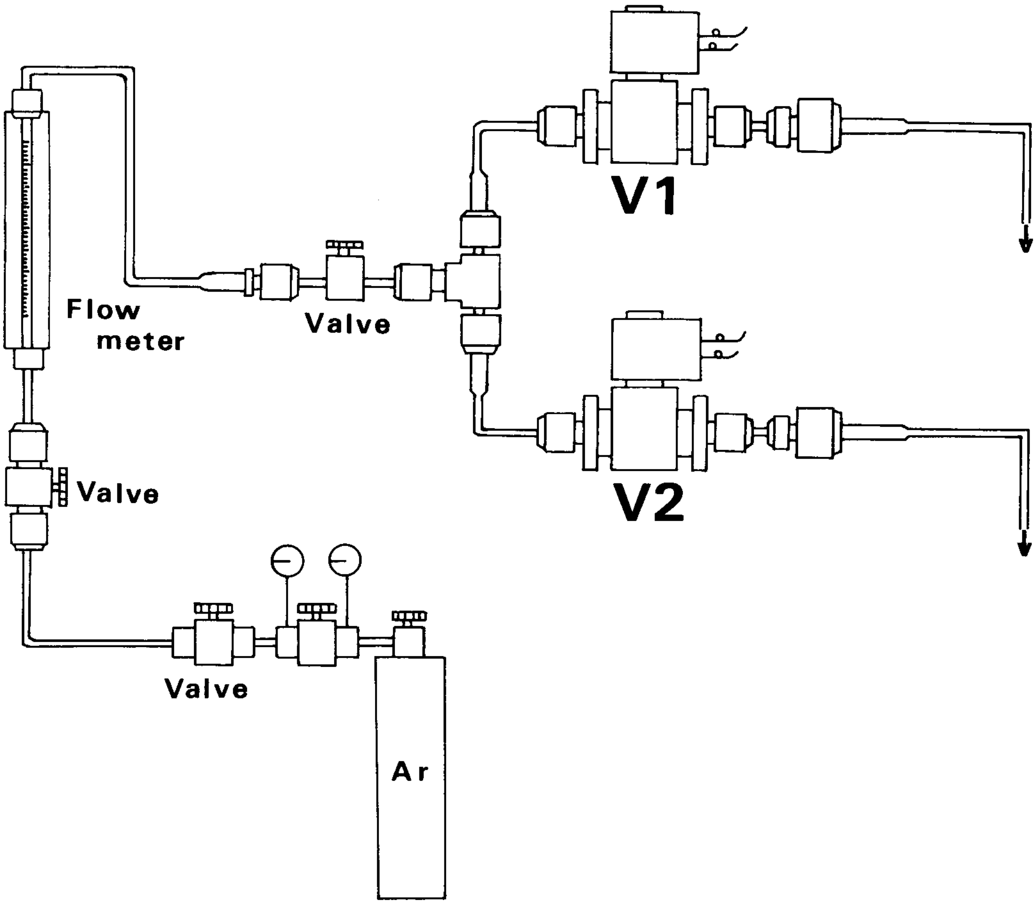


Fig. 2 A schematic illustration of the valve connection in flow system.

the scaler.

The schematic illustration of the connection of changeover valves (V 1 and V 2 ) is shown in Fig. 2 . A kind of electromagnetic valves was selected for the changeover valves. One of them will be used for the channel of tritium containing gas, and the another for the channel of tritium-free gas. They were electrically connected each other to work oppositely. In the present study, to check the opening and closing action of the changeover valves, argon gas was used instead of tritium containing gas.

The opening and closing action of those valves were controlled by a comparator equipped with a relay circuit. The comparator gave a signal to the relay circuit by comparing the signal intensity from the scaler mentioned above with the cutoff level (hereafter described as LL level) , which was set to predetermined standard levels of the opening and closing action of the valves. On receiving the signals from the relay circuit, a power source for the changeover valves would be switched on or off. The counting rate of X-rays and valve action were recorded by both a personal computer and a recorder.

## 3 . Results and discussion

### 3. 1. Performance of a tritium flow simulator

Figure 3 shows an example of an artificial tritium peak generated by using the apparatus shown in Fig.1. This peak profile was obtained by the reciprocated motion of the $^{57}Co$ source at a constant velocity of 0.8cm/s, where signal accumulation time by a scaler was set 1 second. In this peak profile, the average value of the counting rate up to 20s was about 2 cps (count per second), and the total count was 393. Such peak intensity might correspond to a very small amount of tritium, if the observed peak was caused by a tritium stream. In addition, the peak was almost symmetrical in shape.

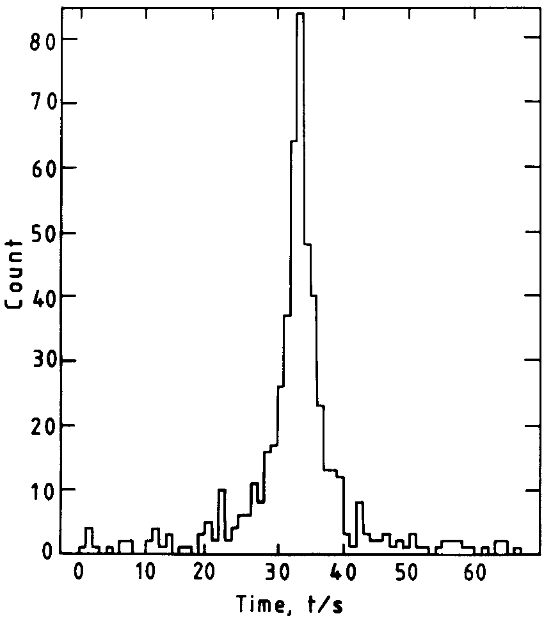


Fig. 3 An examplie of artificial tritium peak generated by the tritium flow simulator.

The motion of the source with different velocities gave similar peak profiles, although the total count was different from each other. Figure 4 shows the correlation between the total count and the accumulation time at various moving velocities. The accumulation time was also varied in a range from 0.5 to 2 s. It was seen from the figure that the total count decreased with the increase in moving velocity, but it was not independent of the accumulation time within the range of experimental conditions.

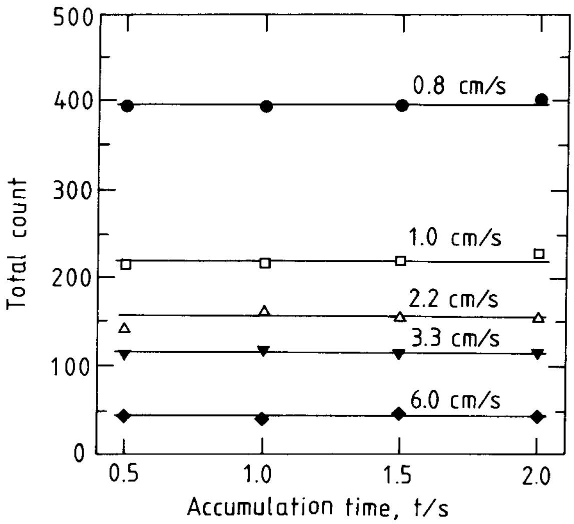


Fig. 4 Correlation between total count and accumulating time at various moving velocity of the $^{57}Co$ source.

On the other hand, the products of a given total count and moving velocity appeared to be almost constant, and th average value of them was evaluated as 306 ± 56 (counts·cm/s). It appears that the standard deviation of the products is relatively large, but this is due to a low count in each peak. It is likely that the present tritium flow simulator to generate an artificial tritium peak worked quite well. The average value of the products corresponds to about 20-30 $\mu$ Ci of tritium gas, flowing in a 1/4 inch tube. Those results suggest that it would be possible to examine the applicability of the bremsstrahlung counting device to a changeover system of tritium flow channel by using the present simulator, because the X-ray spectrum of $^{57}Co$ source is quite similar to that of the bremsstrahlung

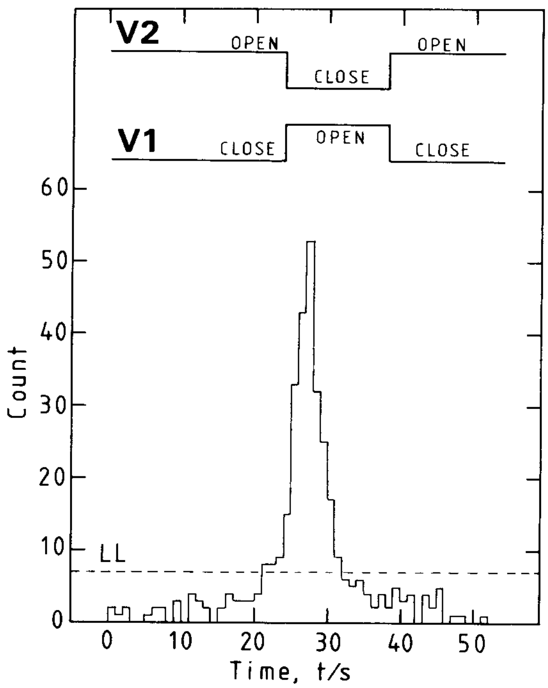


Fig. 5 An example of the valve actions caused by artificial tritium flow.

X-rays by tritium $\beta$-rays.

### 3. 2. Opening and closing action of valves

Figure 5 shows an example of the valve action operated automatically by the artificial tritium peak. In this experiment, the radioactive source was reciprocated with 1 cm/s, where the accumulation time was 1 s and the LL level shown by a broken line in the figure was set at 7 counts. The opening and closing action of the two valves were observed as the upper inset in the figure. It is clear from the figure that two valves worked alternately quite well. Similar valve action was observed for different accumulation time in a range from 0.5 to 2 s, and also for different moving velocity in a range from 0.8 to 6 cm/s.

However, the valve action somewhat lagged behind the point of intersection of the counting curve with the LL level. It appears that this is mainly due to the time constant of a comparator. The shorter the time constant, the faster the valve response. Supposing that the time constant is too short and/or the LL level is too low, the hunting of valves may be caused by a noise-like variation of count in vicinity of the LL level. Contrarily, a part of tritium gas should pass through the valve, if the time constant is too long. The same phenomenon will result from too high LL level. Therefore, an adequate time constant and reasonable LL level should be set to avoid the hunting of valves and to cause sharp changeover of the tritium flow channel.

Figure 6 shows an example of the effect of accumulation time on the valve action. The accumulation time was changed in the range from 0.5 to 2.0 s, the moving velocity of the

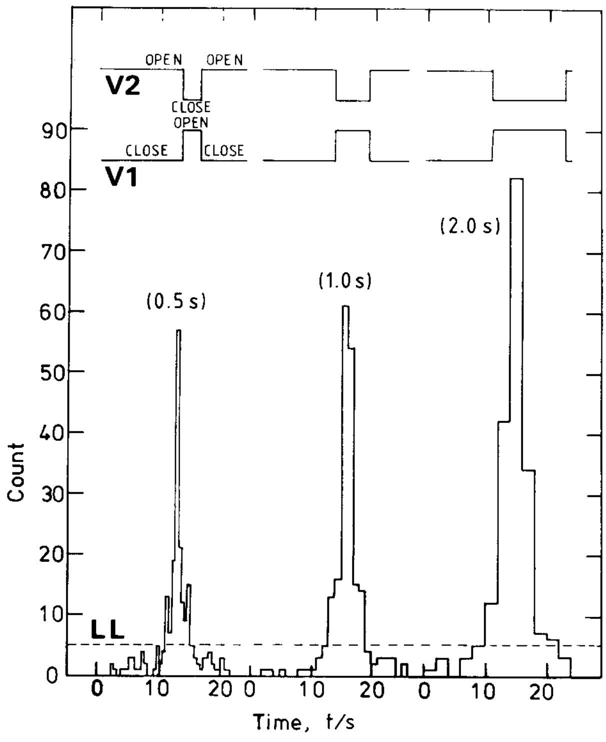


Fig. 6 Effect of accumlation time on the valve actions.

radioactive source in this run was kept at 2.2cm/s, and the LL level was set at 5 counts. The total count of each peak was almost the same irrespective to the accumulation time as shown in Fig. 4 . On the other hand, the peak width became wider with the increase in accumulation time. The difference in the accumulation time being taken into account, this tendency is reasonable.

In addition, it is evident that such tendencies will not hinder the changeover of actual tritium flow. The radioactivity of tritium corresponding to the present peaks was very low as mentioned above. For this reason, it appears that the difference of the observed peak width was merely enlarged. Namely, the such difference of peak width should be negligibly small, because the width of a peak due to a tritium flow will be much wider than that of the peak generated by the present simulator. We can be fairly certain, therefore, that the valve action caused by the variations of count is suitable for the changeover of tritium flow channel.

### 3. 3. Design of a changeover system of tritium flow channel

Figure 7 illustrates the schematic diagram of a simple changeover system of tritium flow channel designed on the basis of above mentioned results. In the present

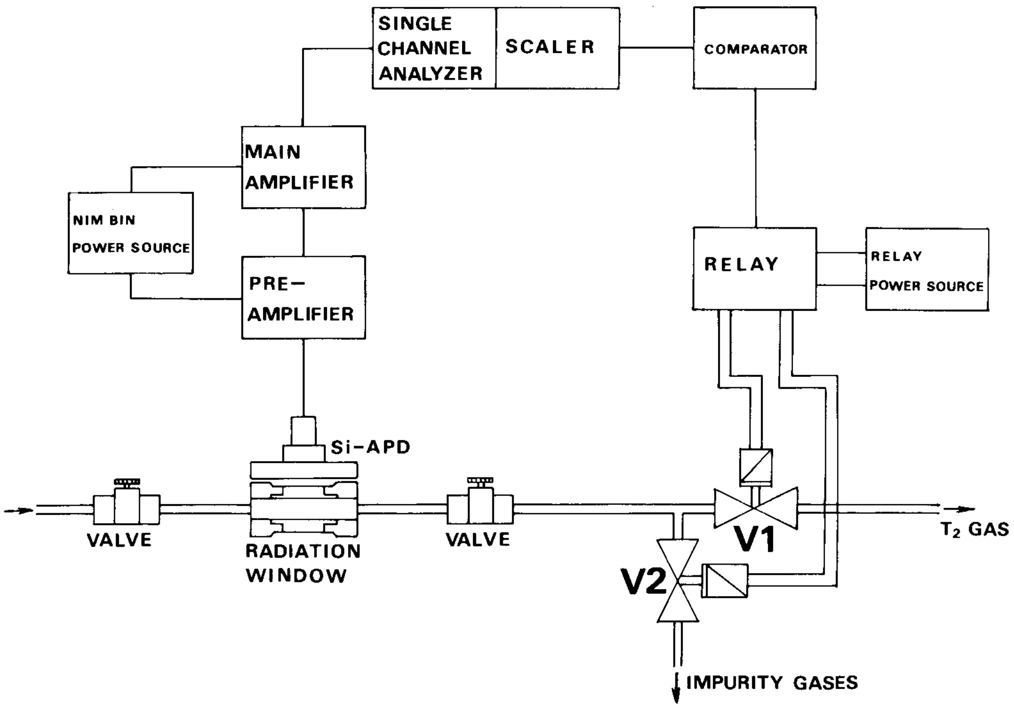


Fig. 7 A schematic diagram of a changeover system of tritium flow channel.

design, the role of the changeover system was restricted to discriminate tritium efflux and tritium-free one in tritium processing such as hydrogen isotope separation by gas chromatographic method. This is the reason that only two valves are equipped with the changeover system, and the bremsstrahlung counting device was attached to the upstream side of the two valves. The most favorable distance from the valves to the bremsstrahlung counting device must be determined by taking account of flow rate, accumulating time and the time constant of a comparator. The potentiality of this system will be evaluated by using the tritium gas in the near future.

## 4. Conclusions

To examine the applicability of the bremsstrahlung counting device to a changeover system of tritium flow channel, the tritium flow simulator was fabricated prior to examinations by use of tritium gas. The tritium flow simulator consisted of $^{57}$Co source and its reciprocative motion system. The intensity changes in the low energy X-rays emitted from $^{57}$Co source were measured by a low energy X-ray detector (Si-APD) , which was connected to a scaler. As a first step, the performance of the tritium flow simulator was tested with respect to the moving velocity of the source and the accumulation time of the scaler. It was seen that various artificial tritium peaks could be obtained by the reciprocated motion of the $^{57}$Co source. This indicates that the present simulator could work quite well.

Subsequently, to evaluate the opening and closing action of a valve, the tritium flow simulator was electrically connected with two valves through a comparator, which compares the signal inensity from the Si-APD detector with the predetermined cutoff level. The preferable opening and closing action of the valves could be confirmed by changing the moving velocity in a range from 0.8 to 6 cm/s and by doing the accumulation time in a range from 0.5 to 2 s. Namely, this indicates that the automatic control of valves is feasible by utilizing a signal from the Si-APD dete ctor which can measure bremsstrahlung X-rays caused by tritium $\beta$ -rays. It was concluded, therefore, that the bremsstrahlung counting device would be applicable to the changeover system of tritium flow channel.

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