

Phoswich Detector for Simultaneous Counting of Alpha- and Beta-ray in a Pipe during Decommissioning

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ABSTRACT

A great quantity of waste has been generated during the decommissioning of nuclear facilities. These wastes are contaminated with various types of alpha, beta, and gamma nuclides. The contamination level of the decommissioning wastes must be surveyed for free release, but it is very difficult to monitor the radioactive contamination level of the pipe inside using conventional counting methods because of the small diameter. In this study a phoswich detector for simultaneous counting of alpha- and beta-rays in a pipe was developed. The phoswich detector is convenient for monitoring of alpha and beta contamination using only a single detector, which was composed of thin cylindrical ZnS(Ag) and plastic scintillator. The scintillator for counting an alpha particle has been applied a cylindrical polymer composite sheet, having a double layer structure of an inorganic scintillator ZnS(Ag) layer adhered onto a polymer sub-layer. The sub-layer in an alpha particle counting sheet is made of polysulfone, working as a mechanical and optical support. The ZnS(Ag) layer is formed by coating a ternary mixture of ZnS(Ag), cyano resin as a binder and solvent onto the top of a sub-layer via the screen printing method. The other layer for counting a beta particle used a commercially available plastic scintillator. The plastic scintillator was simulated by using the Monte Carlo simulation method for detection of beta radiation emitted from internal surfaces of small diameter pipe. Simulation results predicted the optimum thickness and geometry of plastic scintillator at which energy absorption for beta radiation was maximized. Characteristics of the detector fabricated were also estimated. As a result, it was confirmed that detector capability was suitable for counting the beta ray. The overall counting results reveal that the developed phoswich detector is efficient for simultaneous counting of alpha and beta ray in a pipe.

INTRODUCTION

There are two decommissioning sites in Korea, Korea Research Reactor 1&2 (KRR-1&2) and Uranium Conversion Plant (UCP). Generally a great quantity of waste was generated during the decommissioning of nuclear facilities. These wastes are contaminated with various types of alpha, beta, and gamma emitting nuclides. The contamination level of the decommissioning wastes must be surveyed for free release. A surface contamination is divided into removable and fixed contamination. Fixed contamination is measured by a direct method with a portable

contamination monitor and removable contamination is measured by an indirect method using smear paper and a low background proportional counter. However it is very difficult to count the radioactive contamination level of the pipe inside using conventional counting methods because of the small diameter.

In this study a phoswich detector for simultaneous counting of alpha and beta ray in a pipe was developed. The phoswich detector is convenient for monitoring alpha and beta contamination using only a single detector, composed of a thin cylindrical ZnS(Ag) scintillator and a plastic detector. The scintillator for counting an alpha particle has been applied to a cylindrical polymer composite sheet having a double layer structure of an inorganic scintillator ZnS(Ag) layer adhered onto a polymer sub-layer. The sub-layer in an alpha particle counting sheet made of polysulfone which works as a mechanical and optical support. The ZnS(Ag) layer is formed by coating a ternary mixture of ZnS(Ag), cyano resin as a binder and solvent onto the top of a sub-layer via the screen printing method.

The scintillator for counting a beta particle used a commercially available plastic scintillator, which was widely used in nuclear field [1-3]. The plastic scintillator was simulated by using Monte Carlo simulation method for detection of beta radiation emitted from internal surfaces of small diameter pipe. Simulation results predicted the optimum thickness and geometry of plastic scintillator at which energy absorption for beta radiation was maximized. The characteristic of detector fabricated was also estimated. As a result, it was confirmed that detector capability was suitable for counting the beta-ray. The overall counting results reveal that the developed phoswich detector is efficient for simultaneous counting of alpha and beta ray in a pipe.

EXPERIMENTAL DESIGN AND METHODS

Preparation of the ZnS(Ag) scintillator counting medium for alpha-ray detection

The preparation procedure for a thin film type ZnS(Ag) scintillator counting medium is shown in Fig. 1. The medium preparation is divided into two process : a casting method to prepare a polymer sheet and a screen printing method to prepare a ZnS(Ag) layer.

The ZnS(Ag) scintillator sheet for measuring the alpha-particle, consisting of polysulfone(PSf) and styrene as a polymer matrix and ZnS(Ag) as a scintillator, were prepared through the solidification of polymeric solutions and an application of ZnS(Ag) onto the polymer sheet. To formulate a base sheet, polymers were dissolved in methylene chloride(MC) and cast onto the glass plate with a doctor blade. Then, a scintillator solution, prepared by dissolving cyano resin into dimethylformamide(DMF) and adding the scintillator ZnS(Ag), was coated onto a solidified base sheet via the screen printing method.

An alpha-particle's range in a material is very short. The alpha-particle-detection efficiencies of the ZnS(Ag) layers are considerably more variable because this material is available only in the form of a microcrystalline powder that must be deposited as a thin layer (often with a binder) to form a suitable detector. Therefore, the ZnS(Ag) layers' thickness is critical for optimizing its detection efficiency. The thickness should be thick enough to react with most of the deposited alpha-particles, but also thin enough not to induce a significant absorption of the produced scintillation.

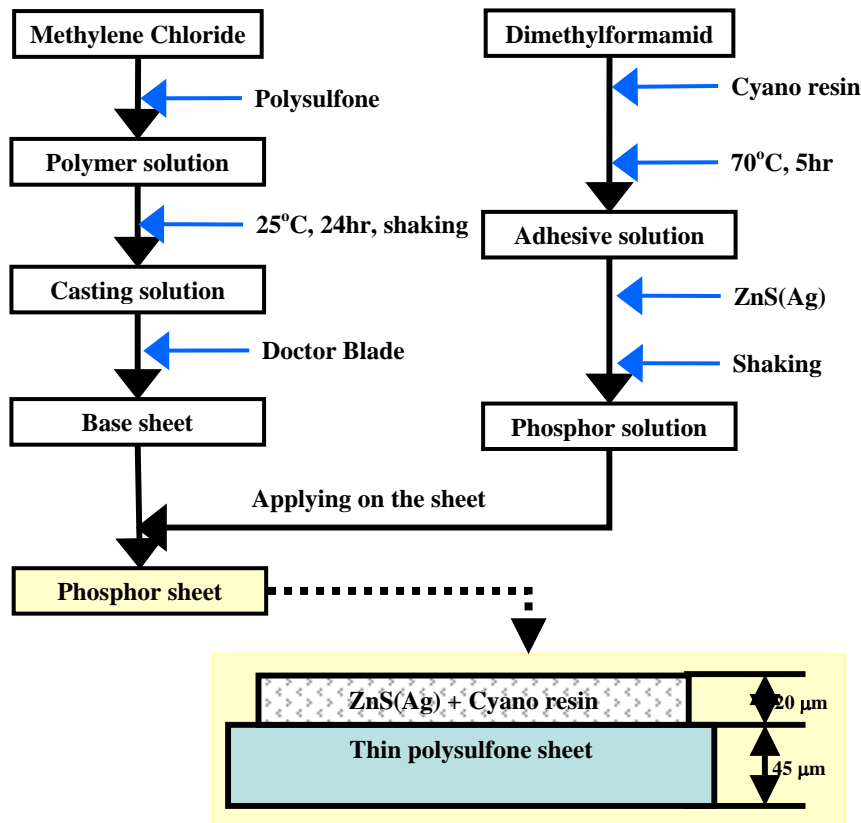


Fig. 1. Schematic diagram for the preparation processes of the thin ZnS(Ag) scintillator sheet for an alpha-particle detection

Plastic scintillation detector for beta-ray

The plastic scintillator used for beta-ray detection was BC-408(Bicron), its base polymer was a polyvinyltolunene(PVT). The density and refractive index of plastic scintillator used is 1.032g/cm^3 and 1.58, respectively. The plastic scintillator was cut into the various dimensions and polished. It was coupled to the Head-on type PMT(R1924A) manufactured by HAMAMATSU.

RESULTS AND DISCUSSION

Estimation of the ZnS(Ag) scintillator sheet for alpha-ray detection

Considering an optical and mechanical strength and a simplicity of preparation for support polymer film, PSf and estyrene as a polymer were selected. After adhering the ZnS(Ag) scintillator onto the PSf and estyrene sheet using the screen printing method, the estyrene film was cracked. Although the support film was dissolved by scintillator solution containing DMF, the polysulfone film was not effected with DMF after applying the ZnS(Ag) layer. The tensile strength of the polysulfone sheet was 5.77 and 5.75 kgf/mm^2 before and after applying the scintillator solution, respectively. As a result, PSf was most excellent as a support film.

Because the PMT measures the scintillation created in the scintillator sheet, wavelength of the scintillation must agree with the response wavelength of the PMT. The emitting wavelength of the ZnS(Ag) scintillator sheet prepared by the screen printing method was 400 to 500 nm ranges with Max. 450 nm. It was correspondent with the used PMT.

In the case of ZnS(Ag) scintillator, the optimal thickness for alpha-ray detection was known as 10 mg/cm^2 [4-5]. If the thickness of ZnS(Ag) layer is greater than 25 mg/cm^2 , it is useless as a scintillation detector because the generated scintillation will not reach the PMT [6]. Also, in the case of small thicknesses, the ZnS(Ag) layer can't absorb the whole energy of the alpha-ray, so it brings about a small detection efficiency. Therefore, the thickness of the ZnS(Ag) layer plays a key roll in the detection ability, so in this study the thickness was kept for 10 mg/cm^2 . The detection ability for the alpha-ray using ZnS(Ag) sheet and PMT was satisfactory.

Estimation of the plastic scintillator for beta-ray detection

In order to confirm the effect of gamma-ray in the plastic scintillator, it was cut into the dimensions of 1.2, 3.1, 5.2 and 12 mm thickness. For the 5.2mm thickness of the plastic scintillator, it was confirmed that the efficiency for gamma rays emitted from Cs-137 and Co-60 was relatively about 0.4 and 0.18% so that gamma events attributable to beta events could be neglected. However, it was observed the beta and gamma events were overlapped about 1% in the region of low energy for the 12mm thickness of the plastic scintillator.

Phoswich detector for alpha- and beta-ray detection

A conceptual diagram of a phoswich detector for simultaneous counting of alpha and beta rays in a pipe is shown in Fig. 2. The detecting part was constructed in phoswich type for simultaneous counting of alpha and beta rays in a pipe. For a alpha counting in a pipe, ZnS(Ag) scintillator sheet prepared for alpha-ray detection was formed in cylinder type. This cylindrical ZnS(Ag) scintillator sheet would play a role of preventing a PMT and a plastic scintillator from internal contaminant in a pipe as well as counting alpha particles.

The distance between a plastic scintillator and a cylindrical ZnS(Ag) scintillator is one of the important factors for selecting the size of a phoswich detector. The count rates as a function of the distance between a plastic and a ZnS(Ag) scintillator was measured from 0 to 6 cm. The maximum count rate for alpha rays was observed when the distance was 2 cm. Therefore, when the phoswich detector was manufactured, its front space opened about 3 cm such as Fig. 2. The ZnS(Ag) scintillator sheet was covered with an aluminized mylar film to raise efficiency of collecting scintillation light into the PMT and shield external light.

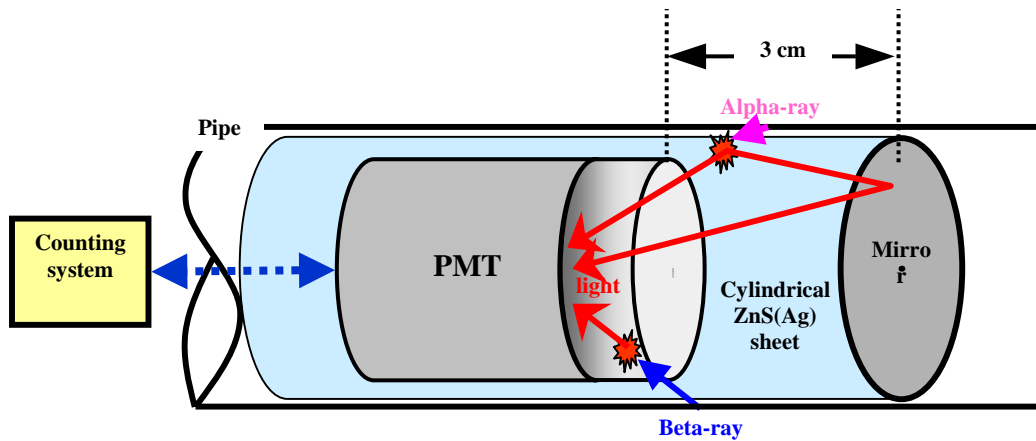


Fig. 2. Conceptual design of a phoswich detector for simultaneous detection of alpha- and beta-rays in a pipe

Fig. 3 shows the pulse height spectrum measured with the phoswich detector put into a pipe for alpha and beta-ray detection. Beta-ray events were observed in the low energy range, while alpha-rays were observed simultaneously in the higher channels.

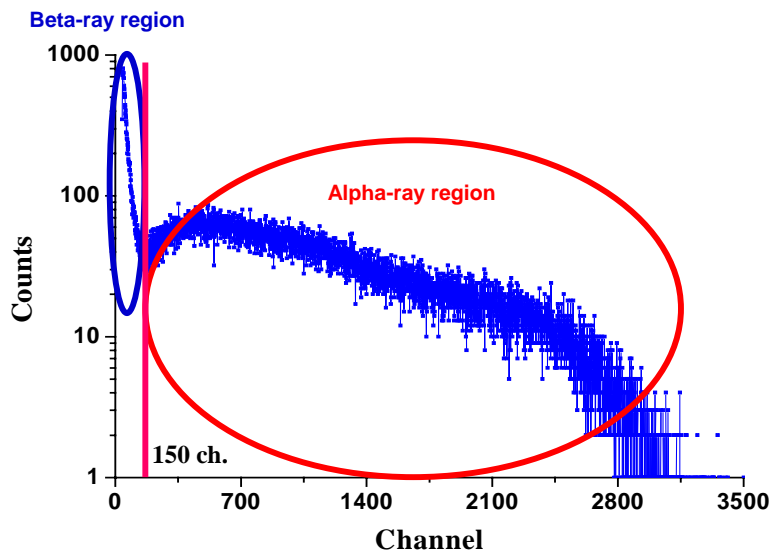


Fig. 3. The simultaneous spectrum for alpha- and beta-ray measured in a pipe using the phoswich detector

Each radiation must be discriminated in a phoswich detector to allow simultaneous measurement of different type radiations using single-detector system. The pulse-shaped discrimination and pulse-height discrimination were generally used to discriminate each radiation. Pulse heights generated by alpha- and beta-ray were discriminated using the energy level discriminator for the pulse-height discrimination method. But, the accurate measurements can't be performed because

of overlap of alpha and beta events for low level activity. Therefore, the pulse-shape discrimination method is generally used to discriminate each other. The pulse-shape discrimination is the method discriminating rise-time of scintillation formed in each scintillator. The pulse-shape distribution spectrum for alpha and beta rays was measured with the detection system as Fig. 4. As a result, a degree of overlap for alpha and beta events was less than 1%. It is possible for simultaneous counting of alpha and beta rays in pipe using the method of the pulse-shape discrimination.

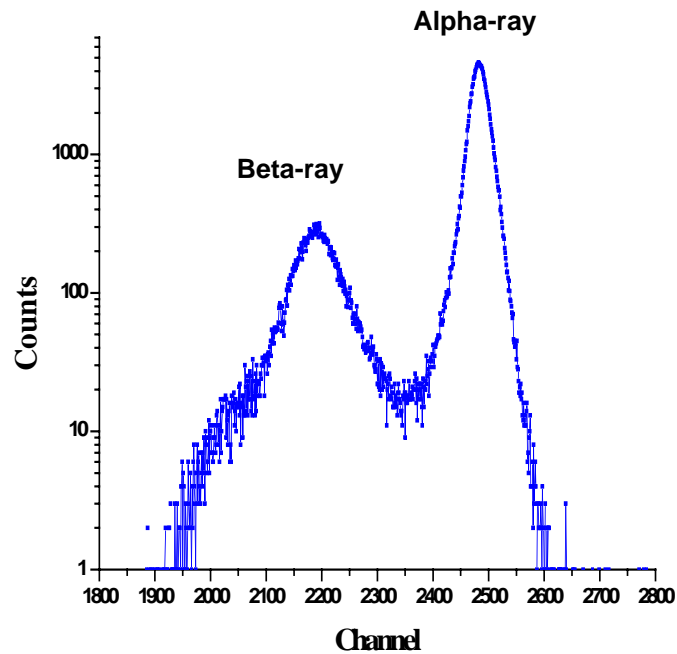


Fig. 4. Rise-time distribution of alpha- and beta-rays measured with the ZnS(Ag) and plastic scintillator in a pipe

CONCLUSION

In order to simultaneously measure the in-pipe alpha- and beta-ray contamination during decommissioning, the phoswich detector was developed and estimated. The thin film type cylindrical scintillator applicable to internal pipe for alpha-ray detection was manufactured using ZnS(Ag) powder. The prepared cylindrical ZnS(Ag) scintillator had sufficient mechanical strength, optical property, and good detection ability for alpha-rays. Also, the plastic scintillator for beta-ray detection having an optimal thickness and the optimal distance between detector and counting position, confirmed a good detection ability.

The phoswich detector to be developed in this study will be tested in the decommissioning works of the Korea Research Reactor 1&2 and Uranium Conversion Plant. And, after comparing the contamination data taken by conventional methods, it will aid in understanding the problem of the detector and improving the equipment.

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