The utilization of YAP Scintillation Detector for Soft Gamma Radiation Measurement in Backscatter Thickness Gauge

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Abstract
Interesting properties of a YAP(Ce) scintillator make it an alternative solution for low energy gamma measurement in high counting rates that previously employed GM counter tubes and/or NaI(Tl) scintillators. Some characteristics of the YAP(Ce) crystal combined with a photomultiplier tube have been successfully demonstrated in a backscatter mode of thickness gauging with 241Am gamma-source.

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Introduction

Application of nuclear techniques in thickness gauging is based on phenomena of radiation interaction with matters. For example in paper or plastic thickness gauging, having relatively small mass-thickness (a quantity of mass per unit area), beta-ray transmission and/or low energy (soft) gamma backscattering would be usable to resolve the mass-thickness differences. To be used in such application, the detector should generally have high efficiency and fast response for high counting rate so as making measurement in a short time with high precision possible.

GM counter, one of the classical gas-filled detectors, can detect the radiation but its efficiency is low particularly for gamma rays, and the response is not adequately fast. While to utilize the most popular scintillation detector, NaI(Tl), it needs a moisture-proof protection for its hygroscopic properties.

The requirements described above could be satisfied by Yttrium Aluminum Perovskite (Cerium activated) (YAP(Ce)) scintillation detector. This paper discusses some characteristics of YAP(Ce) detector combined with a photomultiplier tube that are used in backscatter mode of thickness gauging using 241Am gamma source.

This work has been accomplished as one of activities of Annex V:BATAN JAERI Arrangement :Cooperation in Nuclear Human Resources Development

YAP(Ce) Detector- Main Features

• Highly stable scintillator

The YAP(Ce) crystal, having chemical formula of $YAlO_3$:Ce, is a non-hygroscopic, glasslike, high density inorganic scintillator. This stable nature makes it easily applicable with a very small temperature dependence of -0.01%/C in scintillation light output (C. Rozsa, et al, IEEE NSS, N20-21, 1999). This means naturally a welcome and important feature as a sensor in industrial gauging.

• High counting-rate capability

The decay time of the scintillation light is so short as 27 ns (8.5 times faster than that of NaI(Tl)). Therefore, a high

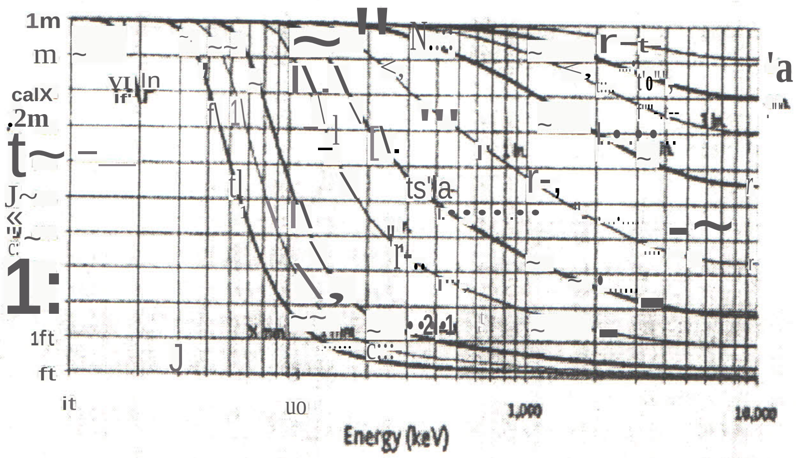


Figure 1. Detection Efficiencies of YAP(Ce) Scintillators with Different Thicknesses

counting-rate of several MHz would be feasible at maximum.

- High signal-to-noise ratio

The effective atomic number (about 36) is considerably lower than that of NaI(Tl) (about 50). On the other hand, considering the mechanical hardness of the crystal and the easiness of polishing it in optical quality, use of a thin plate of around 1mm thick or less is recommended. Figure 1 shows characteristics of YAP(Ce) detectors with different thicknesses.

Take for example the efficiency curve of 1mm thick YAP(Ce) scintillator in Fig. 1, the detection efficiency of Compton backscattered gamma-rays (around 50keV) is high enough (80%), whereas in coexisting higher energy (around 500keV) impurity gamma background from 241Am source; the detection efficiency could reduce to less than 5%. It means a high signal-to-noise ratio would be attained by using an appropriate thin plate of YAP(Ce) detector.

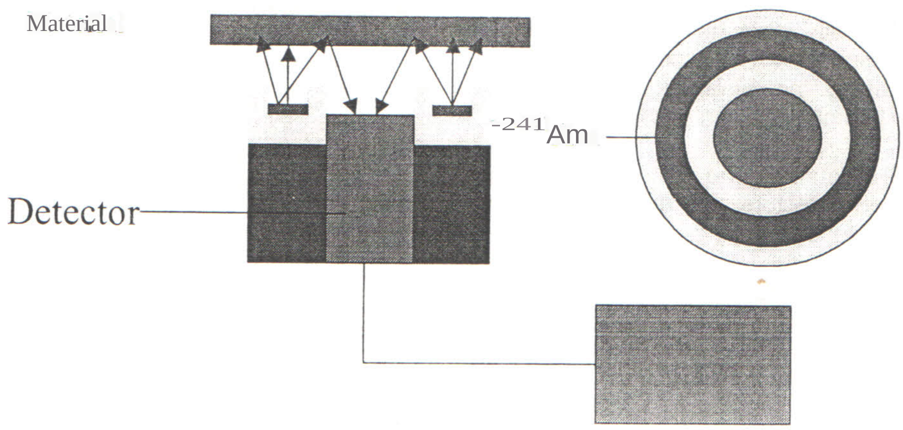


Figure 2. A Typical Backscatter Mode Gamma-ray Thickness Gauge

Backscatter Type of Gamma-Ray Thickness Gauge

Figure 2 shows an arrangement of a soft gamma source (wAm, annular-shaped), a detector, and a material to be measured, in a typical backscatter mode of gamma-ray thickness gauge.

The Interaction of the main gamma radiation from the source (nearly 60 keV) with a material consisting of elements with low atomic number (such as paper and plastic) is dominantly Compton scattering. It will generate scattered radiation with scattering angles nearly around 180°. This phenomenon is employed in backscatter mode so as the thickness of material increased; the intensity of scattered radiation is also increased until reaches its saturation. The photoelectric effects of both incident gamma and scattered gamma radiation become significant when the atomic number of material is higher than 13 (Al).

Prior to the adoption of YAP(Ce), the Center for Education and Training of BATAN used halogen gas GM-counter tube as detector for gamma backscatter thickness gauging in the same arrangement as Fig. 2.

Figure 3 shows the detailed arrangement of the newly set up measuring head which consists of the same wAm gamma-source (25 mCi), with the identical source holder/shield as one employed for the GM-counter tube. The source-YAP combination has been installed on top surface of a conventional photomu!tiplier tube.

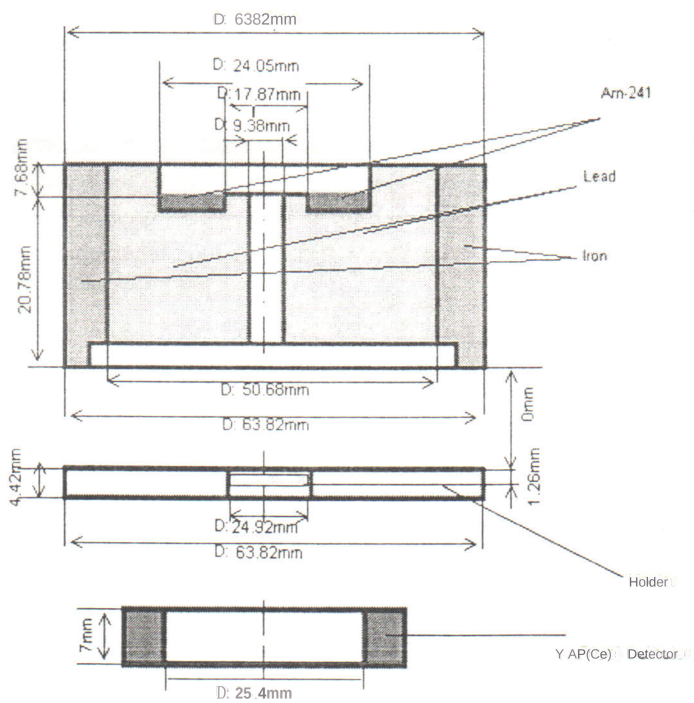


Figure 3. Detailed Arrangement of the 241Am Annular Source, Source Holder/Shield, Combined with YAP(Ce) Crystal (Net Size of About 25 mm Diameter x 1 mm Thickness).

Experimental Results

The energy of the main gamma radiation from the ^{241}Am source is 59.5 keV, the spectrum of which has been confirmed by using the YAP(Ce) detector, as shown in Fig. 4.

The energy of backscattered radiation, calculated from Compton scattering (180° angle) is 48.3 keV. Figure 5 shows the backscattered radiation peak compared with the primary radiation peak.

Calibration curves have been prepared prior to performing thickness gauging. Figure 6 shows typical calibration curves for sheets of paper, plastic, and

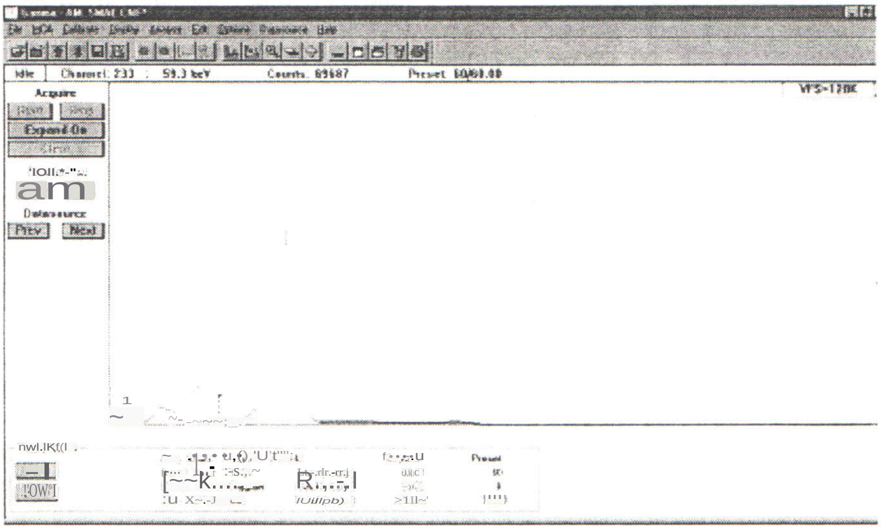


Figure 4. The Primary Incident Gamma Spectrum from the ^{241}Am Source

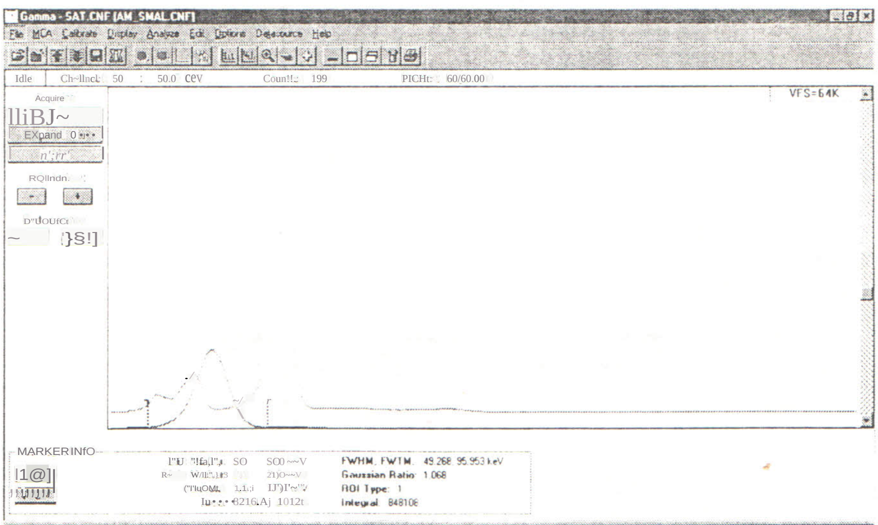


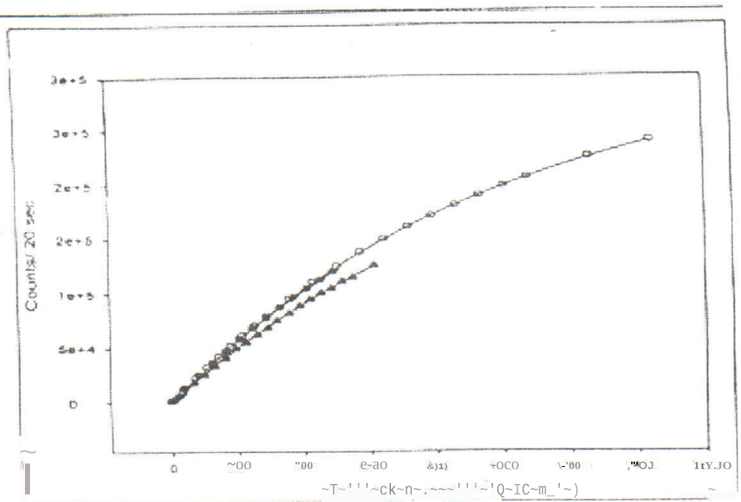
Figure 5. The Spectrum of Backscattered Radiation Peak, Compared with the Primary Radiation Peak.

aluminum, obtained by utilizing the instrument that include the YAP(Ce) detector.

As illustration, the high counting-rate measurement of around 100,000 counts per 20 seconds will provide a sufficiently high quality thickness determination with standard deviations of less than one percent.

The main reason for this improvement is due to the adoption of YAP(Ce) detector instead of the GM Tube. The following Table 1 shows clearly the differences of the gauge performance between the old and new detectors.

Important factors that contribute to the improvement of gauging performance are better detection efficiency to about 20 times, and improved signal-to-background ratio from 2.4 to 18.1, as shown in the Table 1.



• Paper
o Plastic
▲ Aluminum

Figure 6. Calibration Curves for Thickness Measurement in the Gamma Backscatter Mode Using the YAP(Ce) Detector

Table 1 Comparison of the Gauge Performance between GM Tube and YAP(Ce) Detectors

	GMTube	YAP(Ce)	YAP/ GMT
(1) Counting rate (at 100 mg/cm^2)	4,250 Counts/50 s	29,000 Counts/20 s	20.5
(2) Counting rate (at 0 mg/cm^2)	1,750 Counts/50 s	1,500 Counts/20 s	–
(3) Signal/Background Ratio=(1)/(2)	24	18.1	–

Summary

By replacing the detector from a GM counter tube to a YAP(Ce) scintillator (with a size of 25 **mm** in diameter by 1 **mm** in thickness) in the 241Am gamma backscattering mode thickness gauging, the counting-rate of a sheet of paper at 100 mg/cm^2 increased by nearly 20 times and the signal-to-background ratio was improved from 2.4 to 18.1.

References

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Saint-Gobain Crystals. *YAP(Ce) Yttrium Aluminum Perovskite Scintillation Material.*