Geometric Effects of $YAlO_3$:Ce Scintillator to Autonomous Radiation Monitoring Performance in the Marine Environment

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1. Introduction

Scintillation detector has wide-range application to in-situ environmental radiation monitoring thanks to its advantages such as rapid analysis, low sensitivity to temperature change, and so on. However, there have been limited attempts [1] to measure marine environmental radiation in the depth up to few kilometers on site, while $YAlO_3$:Ce is seen to be suitable material having chemical and mechanical stability. Also, an improved radiation detection system can be developed if combined with autonomous underwater vehicles, which provide ability to survey wide-range area. In this paper, therefore, we suggest a new marine radiation monitoring system based on a $YAlO_3$:Ce scintillation detector and autonomous underwater vehicle. Especially, geometric effects of the scintillator to hydrodynamic performance and detection efficiency are analyzed computationally.

2. Experimental methods

2.1 Description of detection system

Among various autonomous underwater vehicles, autonomous underwater glider having body length and diameter of 150 cm and 20 cm, respectively, was assumed. The forward section of the glider was supposed to be replaced with $YAlO_3$:Ce scintillator of semispherical and conical geometry with specific thickness (Fig. 1). The surface area (S) of both shapes was set to be same.

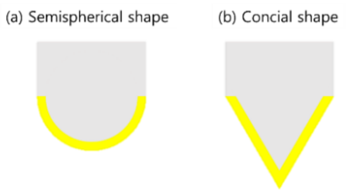

Fig. 1. Assumed geometry of $YAlO_3$:Ce scintillator adopted to an autonomous underwater glider.

2.2 Hydrodynamic performance calculation

Stress and drag coefficient on the scintillator were calculated to optimize thickness and analyze shape effect, respectively. Submerging seawater depth of the detection system was set as 2 km, and minimum thickness ($t_{semisphere}$ and t_{cone}) to resist relevant hydrostatic pressure (p) is calculated as Equations 1 and 2 with safety margin (f) of 3.

$$t_{semisphere} = \frac{p \cdot d \cdot f}{4\sigma_{max}} \tag{1}$$

$$t_{cone} = \frac{p \cdot d \cdot f}{2\sigma_{max}\cos(0.5\theta)}, \tag{2}$$

where d is body diameter, σ_{max} is flexural stress, and θ is cone angle.

In order to calculate drag coefficient, velocity of seawater flow (v) was assumed to be 0.3, 0.6, 0.9, 1.2, and 1.5 m/s through Φ2×10 meters open enclosure. Drag force (F_d) calculated by using ANSYS code was converted to the drag coefficient (c_d) by Equation 3, where ρ is density of water.

$$c_d = \frac{2 \cdot F_d}{\rho \cdot v^2 \cdot S}, \tag{3}$$

2.3 Detection efficiency calculation

After determining the minimum thickness required to resist high pressure of surrounding seawater, detection efficiency was calculated by F8 tally of MCNP6 code. Maximum thickness was set as 2.5 cm [2]. Detection efficiency (ϵ) was converted to volumetric efficiency (ϵ_v), defined as Equation 4, where effective surrounding volume (v_{eff}) of radioactive sources was calculated from effective range (R_γ) experiencing 99.7% attenuation (Equation 5, where μ is attenuation coefficient).

$$\epsilon_v = \epsilon \cdot v_{eff}, \tag{4}$$

$$R_\gamma = -\frac{\ln 0.003}{\mu \cdot \rho} \tag{5}$$

3. Results and discussion

Minimum thickness required for semispherical and conical shape is 1.1 cm and 2.4 cm, respectively. Calculated drag coefficient of each shape is represented in Fig. 2, which is in the range around 0.1. Conical shape has lower drag coefficient because of its relatively sharp and streamlined geometry toward seawater flow.

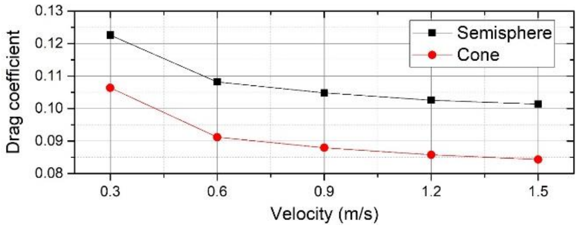

Fig. 2. Drag coefficient of semispherical and conical shape for different flow velocity.

Volumetric efficiency according to $YAlO_3$:Ce thickness in case of semispherical shape is described in Fig. 3. As energy increases, the efficiency difference among different thickness becomes significantly larger, while the efficiency of 2.5 cm thickness reduces smaller than 50% at 2.0 MeV.

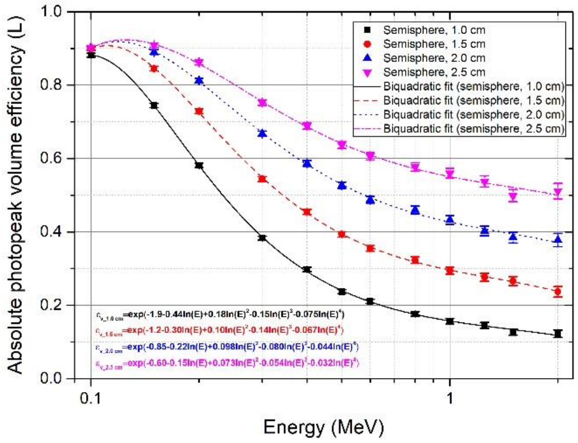

Fig. 3. Volumetric efficiency for different thickness of semispherical $YAlO_3$:Ce scintillator.

Difference of volumetric efficiency with 2.5 cm thickness between semispherical and conical shape is shown in Fig. 4. Both shapes have similar tendency, where the difference of efficiency values are within 10 % throughout the entire range of 0.1-2.0 MeV. They have much higher efficiency (> 0.3 L) than general Φ3×3 inches NaI scintillator.

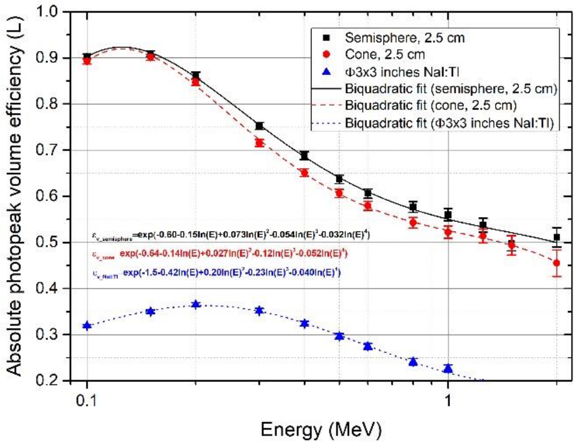

Fig. 4. Volumetric efficiency for different shapes of $YAlO_3$:Ce scintillator.

4. Conclusion

In order to suggest and optimize a new autonomous radiation monitoring system, geometric effects of $YAlO_3$:Ce scintillator were computationally analyzed. If proper thickness is provided, conical shape is beneficial to minimize drag force about 20% less than that of semispherical one. In contrast, semispherical shape is advantageous having detection efficiency higher than about 10% than conical one. For further optimization, the other streamlined shape (e.g., Myring shape) should be analyzed.

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