Investigation of thin YAP and YAG scintillator characteristics for Alpha radiation spectrometry

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Abstract. The characteristic of the thin plate (Ø38x0.25mm) of scintillation detectors YAP:Ce (YAlO\textsubscript{3} doped Ce) and YAG (Y\textsubscript{3}Al\textsubscript{5}O\textsubscript{12} doped Ce) were tested by using the etalons of alpha, beta and gamma radiation with low energies (\textsuperscript{241}Am, \textsuperscript{90}Sr, \textsuperscript{55}Fe...) and a standard \textsuperscript{222}Rn. Those detectors have been developed in Crytur Ltd. For the measurement was used a specially built test assembly comprising encapsulated scintillation detector with calibrated photomultiplier fixed in a black, variable-volume test chamber. All measurements were conducted under precisely defined geometry. The MC 1256 analyzer was used in 256 channel configuration. The focus was on measurement and assessment of the tested detectors surface characteristics, in relation to the light output, spectral resolution capability and peak-background characteristics [1,2]. The tests included extended time period of monitoring related to impact absorption on the surface of detectors and energy calibration. The end result was the selection of the most suitable surface processing for the thin scintillation detectors. These detectors can be assembled into large area arrays, enabling the increase of the detection efficiency, especially for the Alpha activity measurement in radioactive aerosols. The major advantage of these scintillation detectors is their low production cost compared with semiconductor detectors.

Keywords: scintillation detector, alpha radiation, YAP, YAG

1. Introduction
The largest percentage of population irradiation is caused by natural radioactivity, where the leading cause is radon in air within buildings. Radon and its products which are in the air inside apartments, school areas and workplaces are responsible for more than 70% of the entire population dosage. The measurement of radon and radon daughters is performed mainly by devices with semiconductor detectors (with surfaces barrier). Significant disadvantages of the semiconductor detectors is their small size (max φ10 cm) and high cost. For an innovative area of research we have found new large-screen detectors for application in monitoring devices, which will be able to give continual spectrometric information about concentration of radon and its daughters in air pumped from a sufficient depth. What are the reasons for this research?

1. Because of the connection between underground gases and fluids flow and seismic activity in the crust does exists, we recommend a long-term continual radon measurement (utilizing also
meteorological parameters) not only in the spring water but also in the air or in the soil near the seismic well. Those measurements could bring many interesting information for earthquake prediction.

2. The results of continual radon measurements in the pumped soil air near buildings provide a profile of radon concentration in dependence on time (the measurements are conducted over a period of days or weeks). This type of profiles gives a possibility to judge radon concentration short-term changes and also enables analysis of radon dynamics in a room or a building in relation to the radon dynamic in soil gas. This way we could obtain many interesting information applicable for the radon occurrence investigation and for buildings remediation.

2. New scintillators

YAG:Ce
Yttrium aluminum garnet activated by cerium is a fast scintillator with excellent mechanical and chemical resistance. YAG:Ce scintillation detectors are preferred for electron microscopy, beta and X-ray counting, as well as for electron and X-ray imaging screens. The material's mechanical properties enable production of thin screens down to 0.005 mm thick.

YAP:Ce
Yttrium aluminum perovskite activated by cerium is a fast, mechanically and chemically resistant scintillation material. Its mechanical properties enable precise machining. These scintillators have very low energy secondary X-ray emission, which is of advantage in imaging applications. YAP:Ce detectors are used for gamma and X-ray counting, electron microscopy, electron and X-ray imaging screens. The materials' scintillation and mechanical properties enable their use in tomography systems.

LuAG:Ce
Lutetium Aluminum Garnet activated by cerium (chemical formula Lu₃Al₅O₁₂), is a relatively dense and fast scintillation material. The material can also be used for imaging screens, similarly to YAG:Ce. A particular advantage of LuAG:Ce is its higher density resulting in thinner screens with higher spatial resolution. The material is mechanically and chemically stable, and can be machined into a variety of shapes and sizes including prisms, spheres and very thin plates.

| Table 1: Comparison of physical and luminescence parameters of scintillators |
|------------------------|----------|----------|----------|----------|
|                       | Lu₃Al₅O₁₂ | Bi₄(GeO₄)₃ | Y₃Al₅O₁₂ | YAlO₃   |
| Chemical Formula      |          |           |          |          |
| Density (g/cm³)       | 6.73     | 7.13     | 4.57     | 5.37     |
| Index of Refraction   | 1.84     | 2.15     | 1.82     | 1.95     |
| Crystal Structure     | Cubic    | Cubic    | Cubic    | Rhombic  |
| Cleavage              | No       | No       | No       | No       |
| Integrated Light Output (% of NaI:Tl) | 20 | 15-20 | 40 | 70 |
| Wavelength of Max. Emission (nm) | 535 | 480 | 550 | 370 |
| Decay Time (ns)       | 70       | 300      | 70       | 25       |
| Photon Yield (10¹³ Ph/MeV) | 20 | 8.X | 40-50 | 25 |

3. Materials and methods

Alpha particles have a very small range and for this reason we must minimize the distance between detector and the moving particle, in order to detect it. For the radon in air detection, it is desirable, that the scintillation detector is in a direct contact with the analyzed gas. Thin plate of scintillation material also enables to suppress influence of the other types of radiation (e.g. gamma radiation).

For the described measurement, was used a specially built test assembly, comprising encapsulated scintillation detector, with calibrated photomultiplier fixed in a black, variable-volume test chamber. All measurements were conducted under precisely defined geometry. The MC 1256 analyzer was used in 256 channel configurations, enabling the measurement of differential spectra of radioactive samples and the number of pulses in selected energy regions.
We are testing the characteristic of the thin plate (φ38x0.25mm) scintillation detectors YAP:Ce (YAlO₃ doped Ce) and YAG (Y₃Al₅O₁₂ doped Ce) by using the etalons of alpha, beta and gamma radiation with low energies (²⁴¹Am, ⁹⁰Sr, ⁵⁵Fe...) and a standard ²²⁲Rn.

**Photo 1:** Variable-volume test chamber

A  

B

**Photo 2:** Variable-volume test chamber, the MC 1256 analyzer in 256 channel configuration in the non-flow regime (A) and continual flow regime (B)

The air with radon and its decay products are sources of , , and rays that can be detected with scintillation detectors. Radon measurement based on alpha spectrometry requires good detection efficiency and energy resolution for alpha particles and minimal effects of and rays on acquired spectra. Thin YAG or YAP crystals (with a thickness of several hundreds of micrometers) absorb whole energy of alpha particles, because their ranges are lower then crystal thickness and the alpha tracks are almost straight. The good detection efficiency for alpha particles results from high crystal area and high probability of total energy absorption. The rays influence the acquired spectrum mainly in low energy region. They produce a continuous background out of peaks of alpha rays, because the spectrum of rays is continuous and the probability of total energy absorption is very low for particles of higher energies. Even rays do not disturb the alpha spectrometry thanks to very slight detection efficiency for thin scintillation crystals.

The focus was on measurement and assessment of the tested detectors surface characteristics, in relation to the light output, spectral resolution capability and peak-background characteristics [1.2]. The surface of the detectors was refined using various methods of finishing (different polishing methods, etching, deforming crystalline surface layer, etc.) The tests included extended time period of monitoring related to impact absorption on the surface of detectors and energy calibration. The end result was the selection of the most suitable surface processing for the thin scintillation detectors. These detectors can be assembled into large area arrays, enabling the increase of the detection efficiency, especially for the Alpha activity measurement in radioactive aerosols. The major advantage of these scintillation detectors is their low production cost compared with semiconductor detectors.

**Photo 3:** The thin plate (φ38x0.25mm) of scintillation detector (YAlO₃, doped Ce)

4. **Energy calibration**

For energy calibration was used etalon ²⁴¹Am. The results are shown in Table 2. The calibration equation:

\[ E (\text{MeV}) = 0.043919 \text{ channel} - 0.705 \]  

(1)

| Distance (mm) | E alpha (MeV) | Channel |
|---------------|---------------|---------|
| 2             | 4.7           | 119.8   |
| 5             | 4.07          | 111     |
| 10            | 3.263         | 91.5    |
| 20            | 1.98          | 62.5    |
| 30            | 0.905         | 35.1    |

5. **Conclusion**

15 mm  30 mm  60 mm
Theoretical position of the $^{222}$Rn peak (channel 141)
Theoretical position of the $^{218}$Po peak (channel 153)
Theoretical position of the $^{214}$Po peak (channel 191)

**Figure 1:** The spectra of radon from radon artificial source in non-flow regime by different depth of chamber (15, 30 mm and 60 mm), $t=100s$, 1$^{st}$-red - energy of $^{222}$Rn; 2$^{nd}$-yellow - $^{218}$Po; 3$^{rd}$ – blue - $^{214}$Po

The measurements confirmed the independence of thin detectors on gamma and beta rays. These detectors can be assembled into large area arrays, enabling the increase of the detection efficiency, especially for the Alpha activity measurement in radioactive aerosols. The major advantage of these scintillation detectors is their low production cost compared with semiconductor detectors.

**Literature**

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