Perspective liquid scintillators for spectrometry of neutron and gamma radiation

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Abstract—**This paper presents some results of the development of two new scintillation detectors usable for the detection and spectrometry of neutron and photon components of the mixed field. It is a series of liquid organic scintillators containing carbon, hydrogen, nitrogen and oxygen. Elements of individual scintillator designs are arranged in various chemical bonds defining physical and chemical properties of the scintillators. These scintillators have advantageous useful properties. They are non-hygroscopic, not poisonous and are not sensitive to contact with the outside atmosphere and can be stored in conventional laboratory containers.**

Index Terms—**scintillators, scintillation detectors, pulse shape discrimination, Figure of merit**

I. INTRODUCTION

The authors list basic properties of two types of new liquid scintillators LSB205 and LSB206 that are compared with the characteristics of the BC 501 A (NE-213) liquid scintillator, which can be considered the standard used for many years for detection and spectrometry in the mixed field of neutron and photon radiation. Characteristic data of the scintillators developed are focused on the energy range useful, e.g. reactor dosimetry, i.e., neutron energy $\leq$ 15 MeV. This paper mainly contains qualitative and quantitative data on the resolution of neutron and photon particles detected by the scintillator. The resolution of the charged particles is done by pulse shape discrimination, which is based on a variant of the integration method [1], [2]. Quantitatively, the quality of the resolution of charged particles is characterized by the generalized function of Figure of Merit - FOM [2], [3]. If FOM > 1, neutron and gamma radiation responses are perfectly separated. If FOM < 1 then the responses of both particles overlap. Besides, the article contains data on energy resolution and light output of scintillator. The interesting data were observed when investigating the relations of characteristics in a temperature range of 0 – 50 °C. In order to use these scintillators for gamma/neutron mixed field spectrometry, it is necessary to obtain light output function at least for protons. The obtained scintillator temperature dependencies described in this article will enable to refine the measurement of the amplitude resolution of the neutron spectrum measured at the collimated reactor output beam moderated by silicon. This spectrum contains several neutron lines with well-defined energies which could substitute hard to obtain mono-energetic neutron sources [4], [5]. The next step towards the usability for neutron and photon spectrometry in the mixed field is the calculation of the response functions needed for the unfolding of energy spectra.

The properties of newly developed liquid scintillators give them the potential to be used in various areas of nuclear physics, including nuclear safety.

II. DESCRIPTION OF THE MEASURING OBJECT

There are many types of scintillators for mixed neutron and gamma radiation fields. The main requirement for such a scintillator is the ability to distinguish between neutron and gamma radiation interactions. In this paper, we want to focus on comparing the temperature dependencies of the standard BC-501A scintillator and two versions of the newly developed LSB 205 to LSB 206 scintillators containing 88.3 to 91.1% C; 7.6 to 8.7% H; 0.1 to 1.9% N and 0.1 to 2.2% O in the CF^{252} source pool.

III. METHODOLOGY

We compare the thermal properties of the experimental scintillators and the standard liquid scintillator BC-501A. This scintillator has very good separation properties. However, it loses its properties when exposed to air oxygen. The composition of the liquid scintillators tested is not public - it is still protected.

IV. EXPERIMENTAL SETUP

The NGA-01 spectrometric system was used for the measurement. This two-parameter system uses

2" PMT Hamamatsu R329-02 equipped with an active tapered voltage divider as a detector. This configuration allows the device to be used even with large amplitude ranges of input signals while maintaining excellent output linearity. This configuration ensures excellent results even at high count rates per second. The device can measure up to 700,000 pulses per second.

The NGA-01 measures detector output pulses using two differently amplified branches for two 12-bit ADC inputs with a sample rate of 500 MS/s - see Fig. 1. Two channels are used for better signal-to-noise ratio, especially for smaller amplitudes. The data are digitally filtered, summed and evaluated by Field Programmable Gate Array (FPGA).
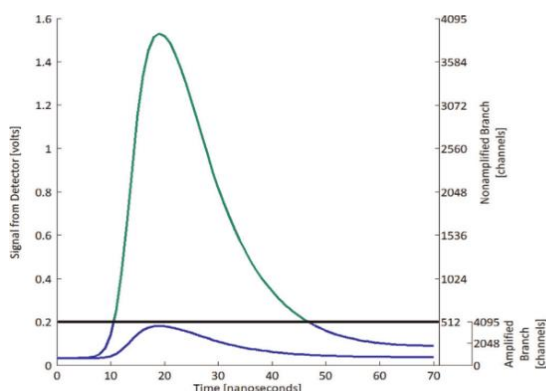

Fig. 1. Amplified and non-amplified impulse selection [3], [6]

The Cs^{137} and Co^{60} emitters were used for calibration of the measurement. The Compton edges in the photon instrument spectrum are for the Cs^{137} a 0.477 MeV energy edge and for the Co^{60} emitter a 1.17 MeV energy edge.

For all scintillators, we used the same PSD (pulse shape discrimination) method based on Charge Comparison [1], [2] implemented directly in the FPGA of the spectrometer NGA-01.

The individual pulse parameters used in the relationship to quantify the PSD are 'energy delta' and 'discrimination delta' values are determined empirically for optimal delimitation of areas with maximum neutron and photon responses in the scintillator being measured.

V. DESCRIPTION OF THE TEMPERATURE CHAMBER

The Vötsch Industrietechnik GmbH VT4004 type chamber was used for temperature dependence testing. Temperatures of 0, 5, 10, 20, 30, 40 and 50 degrees Celsius were used for the experiments. A photomultiplier with an active resistor divider was placed in the chamber. The measuring apparatus was outside the air-conditioned space. The connection was made by coaxial cables. The interior of the temperature chamber was shielded from ambient light.

All tested scintillators were air-conditioned at the same time. Calibration sources and test source were mounted on scintillators from their side.

VI. TEMPERATURE TEST RESULTS

The results of the experiments were CSV matrices expressing temperature dependence of individual scintillators. The FOM temperature dependencies of each scintillator for the selected test temperature repertoire and concrete energy are shown in the following graphs for each scintillator separately.
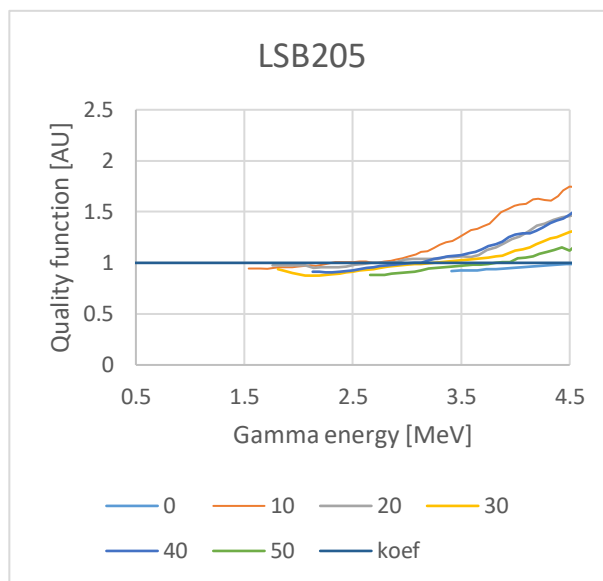

Fig. 2. FOM temperature dependencies of the LSB 205 scintillator
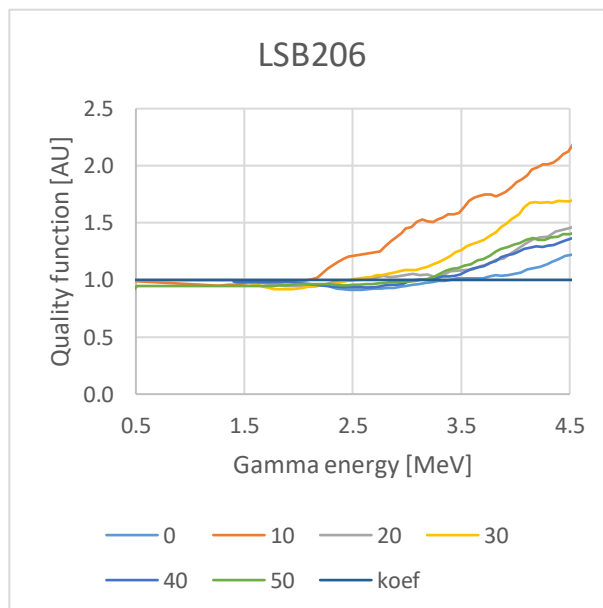

Fig. 3. FOM temperature dependencies of the LSB 206 scintillator
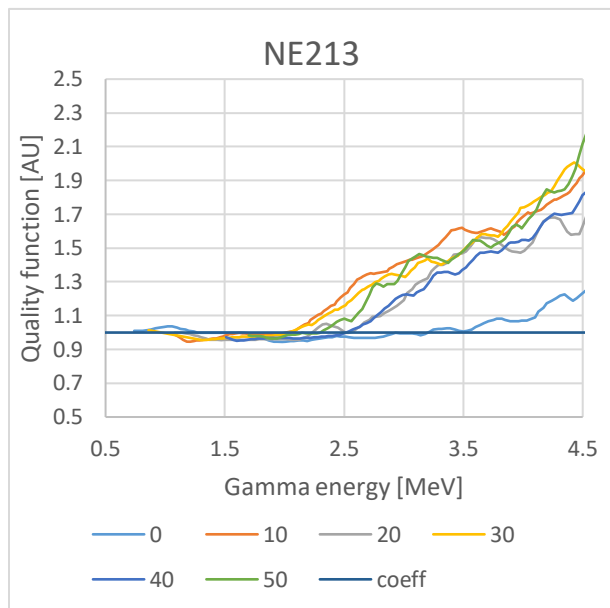
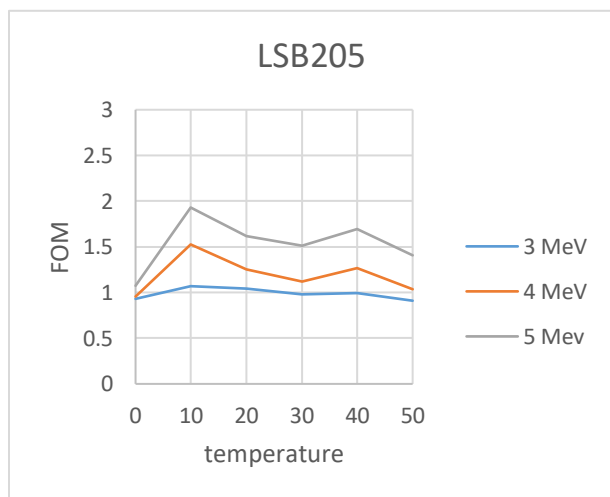Fig. 4.   FOM temperature dependencies of the NE213 scintillator

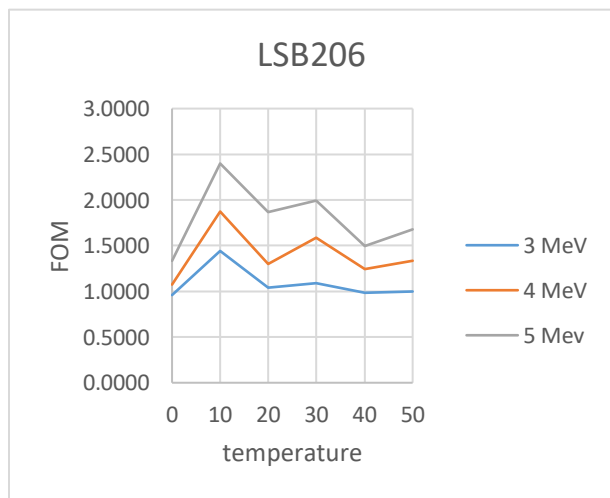Fig. 5.   FOM temperature dependence of the LSB 205 for some energy

Fig. 6.   FOM temperature dependence of the
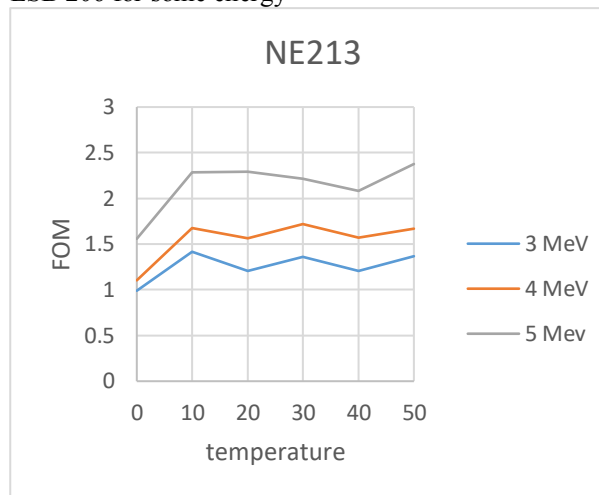
LSB 206 for some energy

Fig. 7.   FOM temperature dependence of the NE213 for some energy

VII.   CONCLUSION

It can be seen from the graphs that the FOM temperature dependence is neither linear nor monotonic. The reason for the non-linearity will be the subject of further research. Knowledge of the FOM temperature dependence of scintillators allows eliminating this dependence in calculations of energy spectra of measured neutron-gamma mixed radiation.

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