Organic scintillators for neutrons: production and characterization of detectors of interest for SPES, SPIRAL2, EURISOL

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Abstract

During these last few years a renewed interest in neutron detection has grown up. Trying to avoid liquid scintillators, which are toxic, flammable and dangerous for the environment, a study has been proposed for the production and characterization of new plastic scintillators based on silicon rubber eventually doped with Gd and B.
Results on the light output and other characteristics will be shown for several studied samples, which are important for the development of future neutron detectors and/or monitors to be used in high radiation environment. In particular this R&D is of interest for fundamental Nuclear Physics with stable and exotic beams (SPES, SPIRAL 2) where they can be coupled with new generation charged particles arrays (FAZIA).

Chemistry of scintillating silicon rubbers and neutron interactions

Samples were synthesized from two components: component A was vynil terminated polydimethyl-diphenyl siloxane and part B was hydride terminated polyphenylmethylidrosiloxane. Some fluorophores were dispersed in component A and the resin was heated at 70 °C for 12 hours. Afterwards, resin B was added and the resulting compound was kept in vacuum in order to remove all the air bubbles trapped in the viscous resin. To fasten the synthesis at low temperature Pt-divinyltetramethyldiloxane catalyst was used in different concentrations. The fluors chosen for activating the scintillation mechanism were PPO as primary fluor and, in some cases, BBOT as secondary fluor.

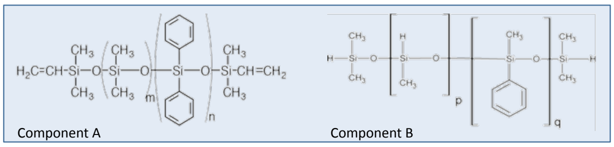


Fig.1: Molecular structure of the two main components.
n/(n+m) ratio is between 4% and 22%. p/q is fixed at about 50%.

Boron or Gadolinium are also dissolved to obtain high cross-section thermal neutron interaction:

$$\begin{aligned}
n + {}^{10}B \; &\to {}^{7}Li(1,0\ MeV) + {}^{4}He(1,8\ MeV)\ (7\%) \\
&\to {}^{7}Li(0,83\ MeV) + {}^{4}He(1,47\ MeV) \\
&\quad + \gamma(0,48\ MeV)\ (93\ \%) \qquad \sigma_{th} = 2100\ b \\
n + {}^{157}Gd \; &\to {}^{158}Gd^{*}(29-182\ keV) \to \gamma,\ X,\ el. \qquad \sigma_{th} = 70000\ b \\
n + {}^{155}Gd \; &\to {}^{156}Gd^{*}(30-199\ keV) \to \gamma,\ X,\ el. \qquad \sigma_{th} = 17000\ b
\end{aligned}$$

Realized Samples

Several series were realized varying relative concentrations of A and B components, PPO and BBOT ad of the neutron-interactive dopant elements. Two or three identical samples were produced to test reproducibility. Sample thickness is of few millimiters, only few of them are 2,5 cm high.

Series	Cat.	λ-shifter	Neutr. Abs.
K	3,0% Pt	PPO	
GD	3,0% Pt	PPO	Gd
MT*	1,8% Pt	PPO	
SB*	1,8% Pt	PPO	
BBOT	2,0% Pt	PPO+BBOT	

Tab.1:Summary of realized series.
(*PPO heated before mixing)

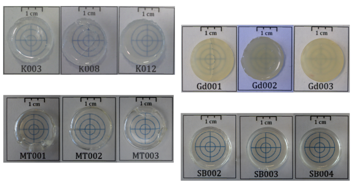


Fig.2: Some of the produced samples.

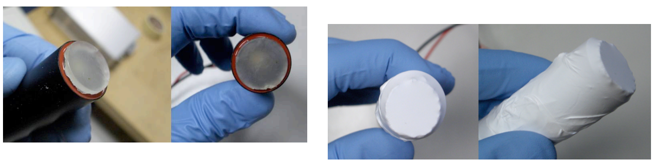


Fig.3: Coupling with Hamamatsu H6524 PMT.

Light Yield measurement

Several measures have been performed in order to obtain light yield informations about the produced scintillators. In particular, for each sample, tests with ^{241}Am α source and ^{60}Co or ^{241}Am γ sources provided the spectra showed below.
All results were obtained at atm pressure, using an Hamamatsu H6524 PMT coupled to the scintillator sample as shown on left panel (working voltage is -1450 V). A Camberra 2024 Spectroscopy Amplifier (gain = 150; shaping time = 0,25 μs) and a multichannel digitizer.
Results are compared to a commercial plastic scintillator (ELJEN Technology: EJ-212).

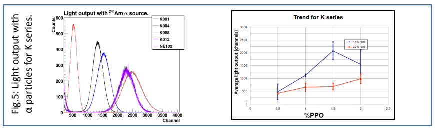


Fig.5: Light output with α particles for K series.

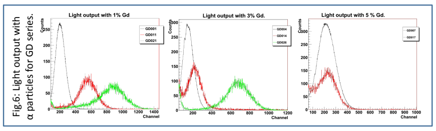


Fig.6: Light output with α particles for GD series.

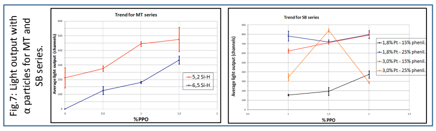


Fig.7: Light output with α particles for MT and SB series.

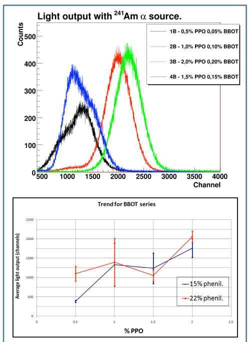


Fig. 8: Light output with α particles for BBOT series.

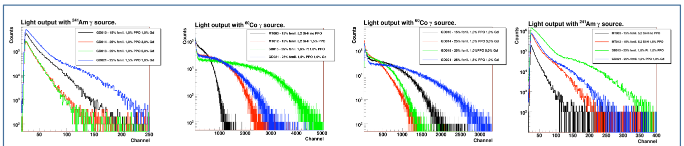


Fig. 9: Light output with various γ sources.

IBIL – Radiation Hardness

Radiation hardness of some samples was tested using a 4,5 MeV α beam with 4 nA of current. Light output intensity vs time of exposition at the emission peak wavelegnth, as well as. emission spectra before and after 80 s of dose were measured.

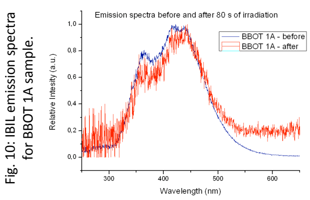


Fig. 10: IBIL emission spectra for BBOT 1A sample.

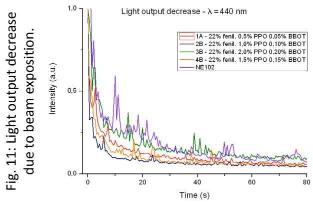


Fig. 11: Light output decrease due to beam exposition.

Results for some samples of BBOT series are shown . Emission spectra do not evidence shape deformation and exponential decay is, in some cases, comparable to EJ-212.

Tests with moderated Am-Be neutron source

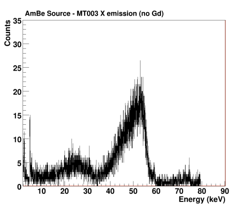
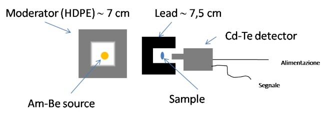


Fig. 12: X emission without Gd.



Gadolinium containing samples were irradiatied with moderated neutrons coming from AmBe source. Emission consequent to Gd neutron capture was observed using a well calibrated **Cd-Te X detector**. Comparison with non doped samples enhances the differences due to different neutron interaction.

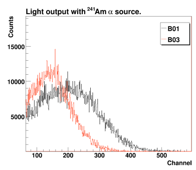


Fig. 14: Light output of B doped samples.

Very preliminar tests with **Boron doped samples** and **PMT** allowed to observe a good response to thermal neutrons, even with low light output. Same measures with GD samples did not provide good results.

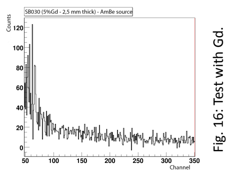


Fig. 16: Test with Gd.

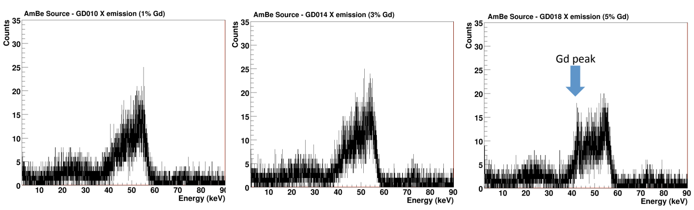


Fig. 13: Growing of 42 keV peak with increasing percentage of Gadolinium.

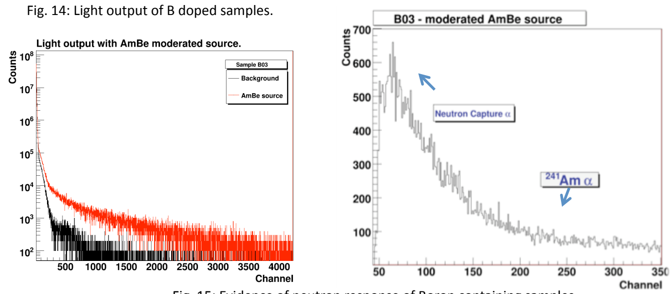


Fig. 15: Evidence of neutron response of Boron containing samples.