# Green-emitting polystyrene scintillators for plastic scintillation dosimetry

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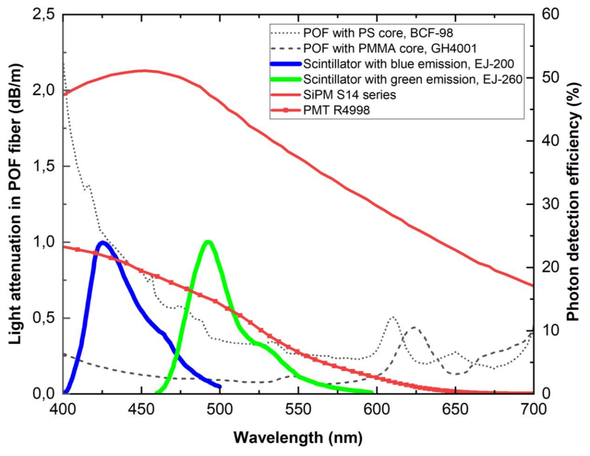
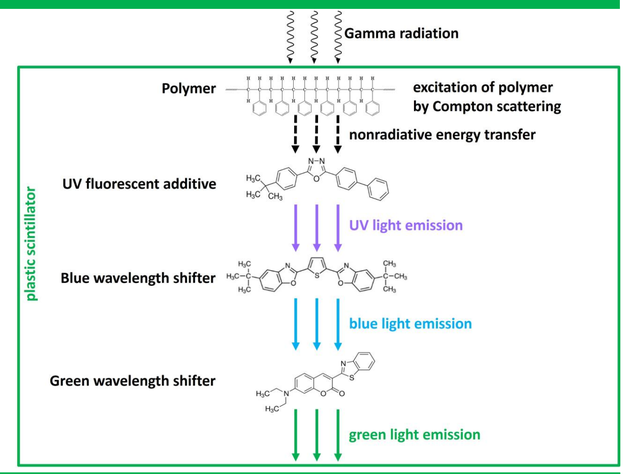
## Introduction and objectives




Plastic scintillators are used in many applications connected with medical devices, for example in time-of-flight positron emission tomography [1, 2], long-axial field of view positron emission tomography scanners [3] and in plastic scintillation dosimetry [4]. Green-emitting plastic scintillators have several advantages over blue-emitting scintillators for dosimetry applications. Firstly, green light is less attenuated by polystyrene matrix and yellow compounds resulting from radiation damage. Secondly, the longer the wavelength of scintillators light, the smaller portion of Cerenkov light is emitted in this green bandwidth in plastic dosimeter and subtraction of this stem signal is easier. Thirdly, green light around 500 nm is the least attenuated in plastic optical fibers (POF) usually glued to plastic scintillators forming scintillation dosimeter. Polymer scintillators were synthesized from styrene monomer in bulk radical polymerization [5]. Polystyrene was selected as a base of scintillators due to its water equivalent needed in dosimetry [6]. In this research one the best fluorescent compound emitting ultraviolet light, BPBD, is combined with a few blue [7] and green fluorescent dyes (anthracene, coumarin and perylene derivatives) shifting scintillators emission to the green light.

The purpose of this research is to:

- find optimal blue and green emitting fluorescent dyes combination dissolved in polystyrene matrix for dosimetry applications;
- optimize concentration of ultraviolet light-emitting BPBD fluorescent dye;
- shift plastic scintillators emission to the green light range.




## Materials and methods

| Polymer | UV-emitting dye |
|---|---|
| polystyrene (PS) | BPBD |

**Blue-emitting wavelength shifters**

| BBOT | DPA | LFV 570 | MDAC | TPB |
|---|---|---|---|---|

**Green-emitting wavelength shifters**

| BPEA | Coumarin 6 | LFY 083 | SG 5 |
|---|---|---|---|

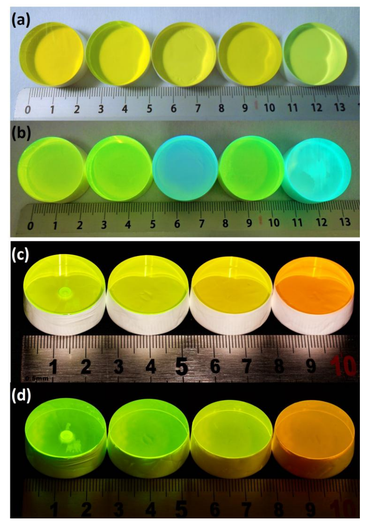
Molecular structures of polymer and fluorescent dyes with UV, blue and green emission used in this work.

Polystyrene was selected as a base of polymer scintillators due to its water equivalency needed in dosimetry. PS have density about 1.05 g/cm$^3$ and is composed of carbon and hydrogen which is similar to human tissue atomic composition. BPBD (2-(4-tert-butylphenyl)-5-(4-biphenylyl)-1,3,4-oxadiazole) was chosen as a UV-emitting fluorescent dye due to its high efficiency as first addition in plastic scintillators, very good solubility in organic solvents and high photochemical stability.

Polymer scintillators were synthesized from styrene monomer in bulk radical polymerization without use of polymerization initiators. Scintillators were polymerized in sealed glass ampoules in electric furnace with hot air circulation at maximum temperature of 140°C and duration of five days.

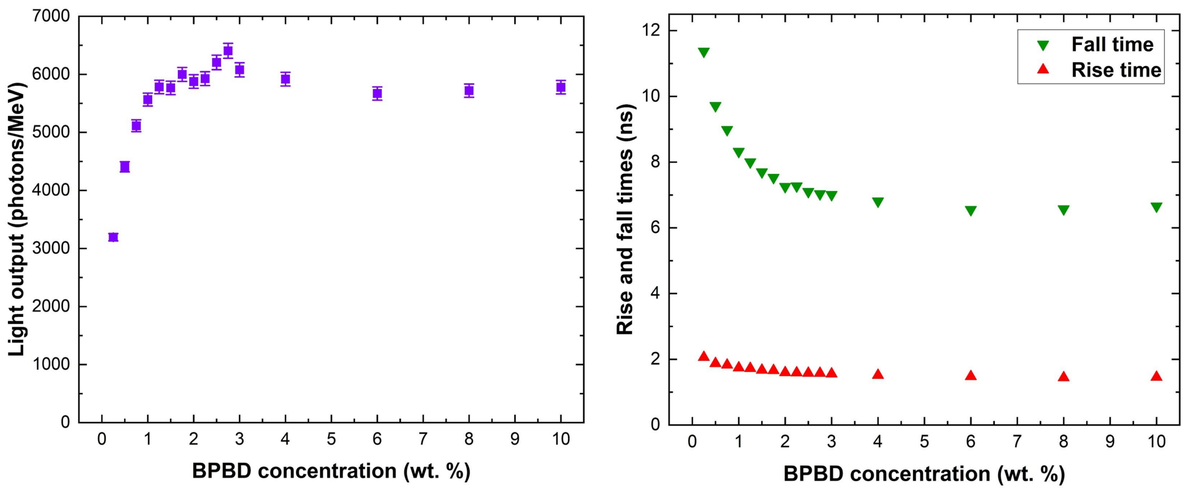
Twenty combinations of five blue-emitting and four green-emitting WLS substances were investigated. Emission spectra were measured with the use of USB4000 fiber optic spectrometer from Ocean Optics. Green scintillators were excited by laser diode with 405 nm maximum emission and blue scintillators were excited by UV lamp with 365 nm maximum emission.

Light output measurements were performed using setup consisted of R4998 photomultiplier tube (PMT) from Hamamatsu (Japan) supplied with 2350 V from CAEN N470 high voltage (HV) power supply. Signals were read out by desktop digitizer CAEN DT5743 connected with computer. Scintillators were excited by gamma rays emitted by Cs-137 radioactive source.

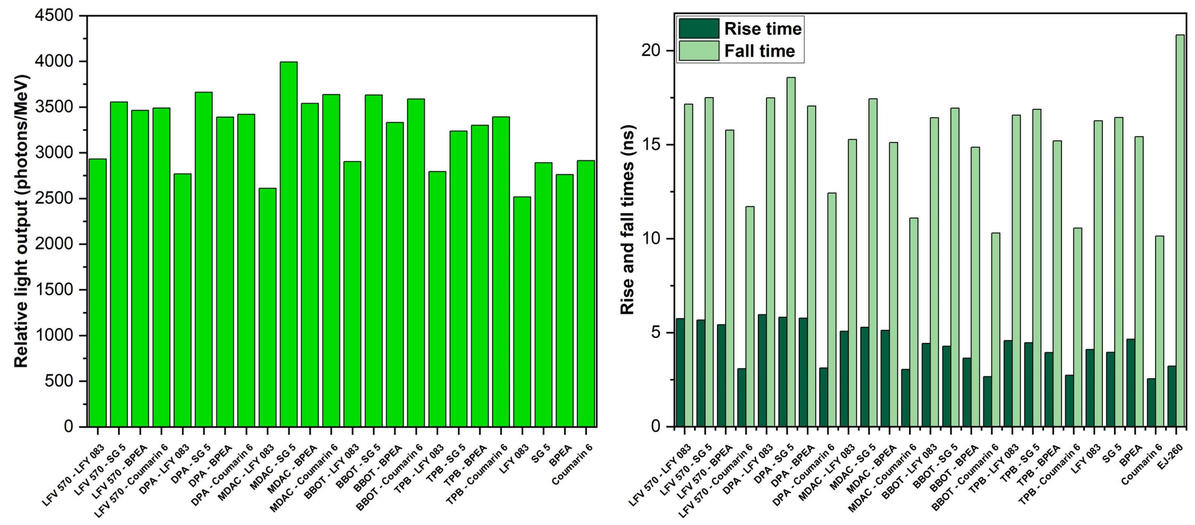



Samples with various WLS (a, b) and different SG5 concentration (c, d).

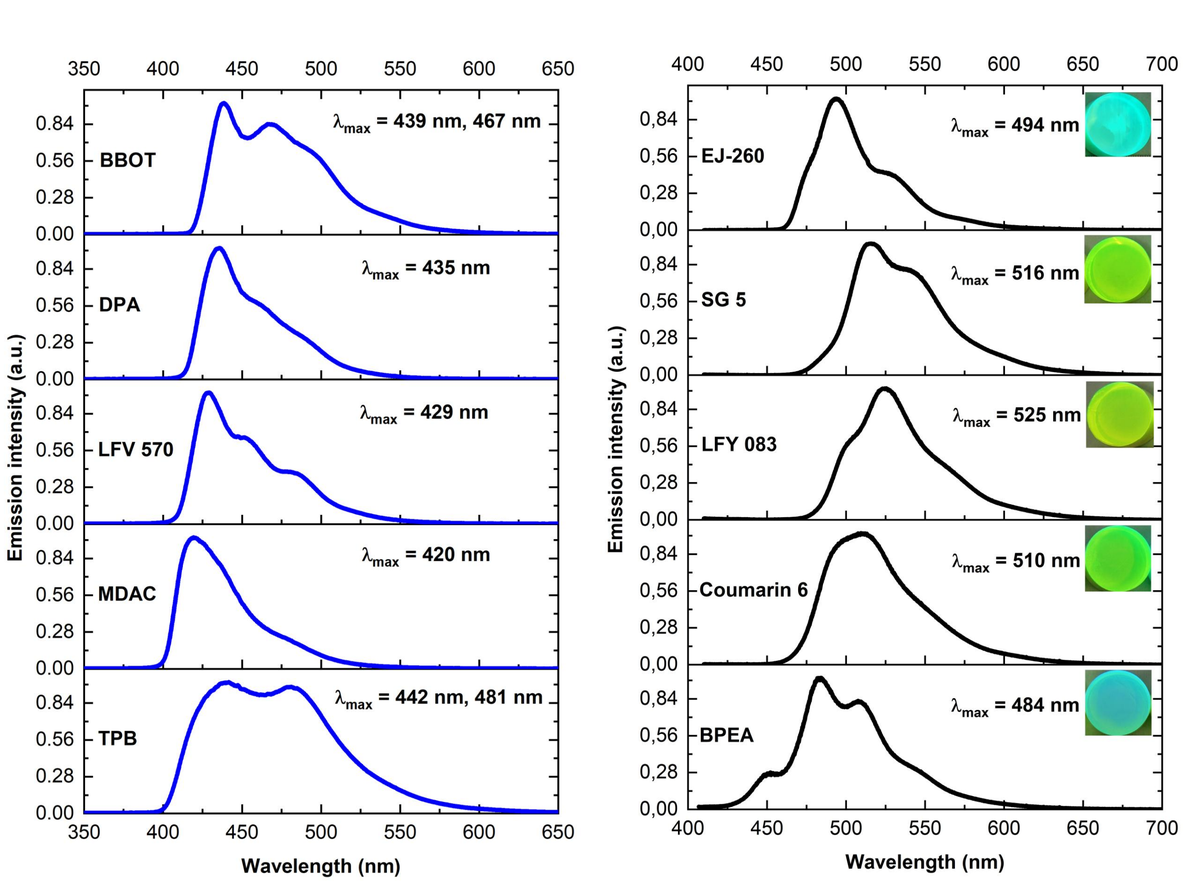
## Results



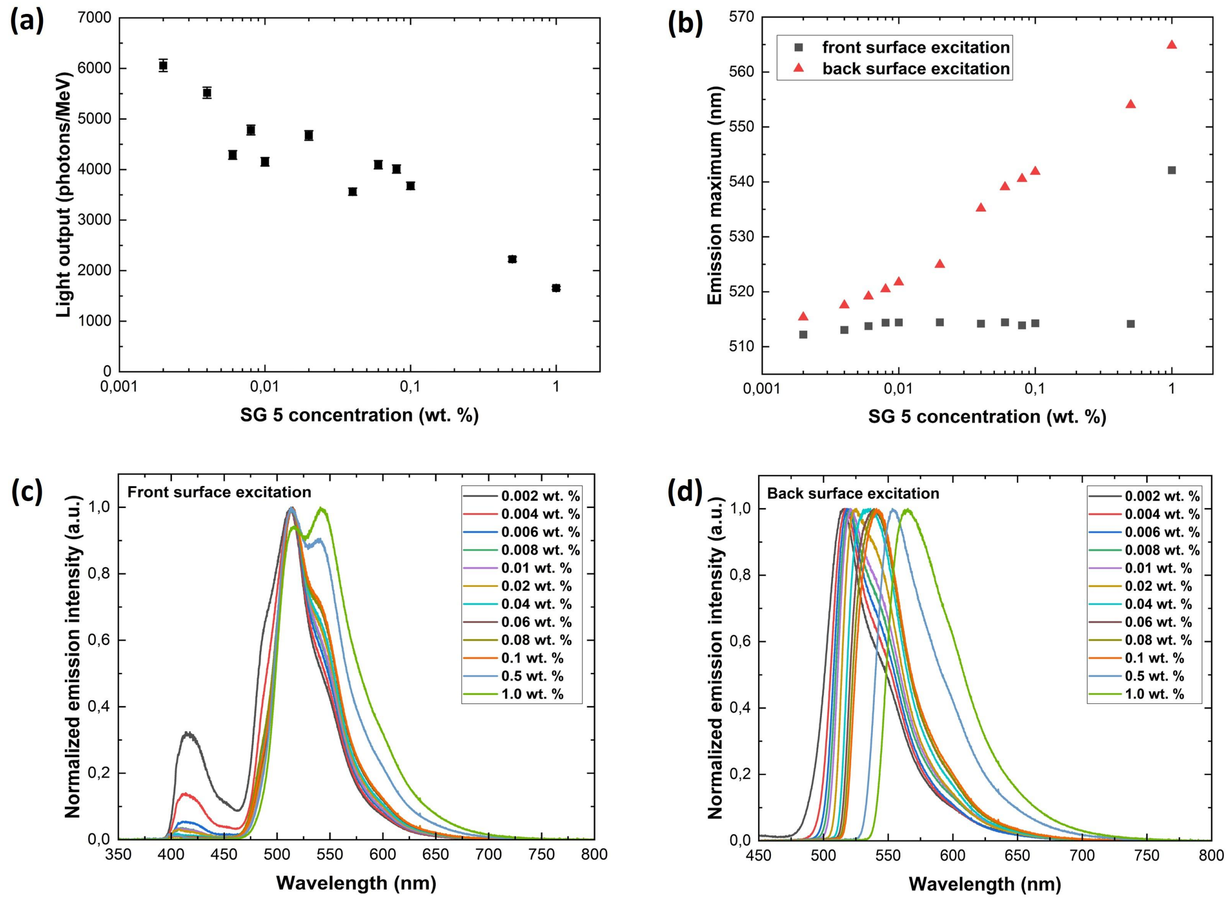

Dependence of the light output (left panel), rise time and fall time (right panel) of polystyrene scintillator on the BPBD concentration. Bis-MSB was used as blue wavelength shifter with fixed 0.05 wt. % concentration.




Light output (left panel) and timing of signals (right panel) for green polystyrene scintillators containing 2.75 wt. % BPBD and 0.05 wt. % blue and green WLS combinations.




Normalized emission spectra of commercial green scintillator EJ-260 and selected polystyrene scintillators with blue WLS (left panel) and green WLS (right panel). Excitation wavelengths were 365 nm and 405 nm for blue and green scintillators, respectively. Inserts are photos of the samples under UV light.




Influence of SG 5 concentration in polystyrene scintillator with 2.75 wt. % BPBD and 0.05 wt. % MDAC on: (a) light output, (b) emission maximum with two geometrical types of excitation at 405 nm, (c) emission spectra of the samples excited and read out from the front surface and (d) emission spectra of the samples excited in one side and read out in the other side of the sample through 25 mm thickness (back surface).

## Conclusions

- Emission maxima of manufactured polystyrene scintillators are in green region of visible light (484 – 525 nm) and are close to maximum quantum efficiency of light detectors used in plastic scintillation dosimetry.
- The concentration of the ultraviolet BPBD dye and the best green fluorescent dye Solvent Green 5, affects the light output, rise and fall times, and emission spectra of the scintillator samples.
- The best green polystyrene scintillator emits 4000 photons/MeV and have duration of signals around 15 nanoseconds.

## References

[1] P. Moskal et al., "Positronium imaging with the novel multiphoton PET scanner," Science Advances 7(42) (2021) eabh4394
[2] Ł. Kapłon et al., "Comparative studies of plastic scintillator strips with high technical attenuation length for the total-body J-PET scanner," Nuclear Instruments and Methods in Physics Research A 1051 (2023) 168186
[3] S. Vandenberghe, P. Moskal, J. Karp, "State of the art in total body PET," EJNMMI Physics 7 (2020) 35
[4] Ł. Kapłon et al., "Investigation of the light output of 3D-printed plastic scintillators for dosimetry applications," Radiation Measurements, 158 (2022) 106864
[5] Ł. Kapłon, "Synthesis and characterization of plastic scintillators for the total-body J-PET scanner," Acta Physica Polonica B, 51 (2020) 225
[6] L. Beaulieu, S. Beddar, "Review of plastic and liquid scintillation dosimetry for photon, electron, and proton therapy," Physics in Medicine and Biology, 61 (2016) R305
[7] Ł. Kapłon, G. Moskal, "Blue-emitting polystyrene scintillators for plastic scintillation dosimetry," Bio-Algorithms and Med-Systems, 17 (2021) 191

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