Optimization of liquid organic scintillator composition for fast neutron spectrometry

Jaroslav Jánský[1], Jiří Janda[2], Věra Mazánková[1], František Cvachovec[1]

[1] University of Defence, Faculty of Military Technology, Department of Mathematics and Physics, Brno, Czech Republic

[2] University of Defence, NBC Defence Institute, Vyškov, Czech Republic

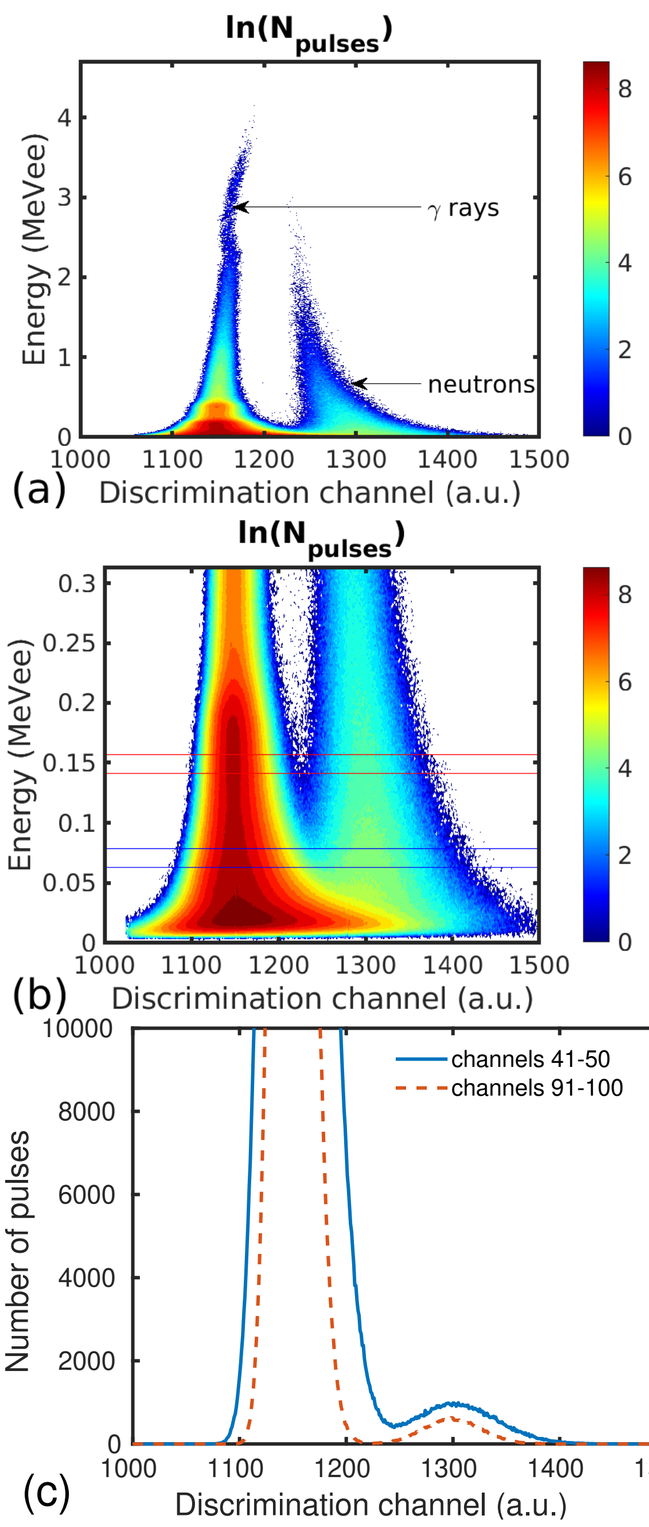
e-mail: **jaroslav.jansky@unob.cz**

Abstract

Liquid organic scintillators are important devices for measurements of neutron radiation. This work aims to develop and optimize the composition of liquid organic scintillators so it can be used for fast neutron spectrometry. As the neutron radiation is usually accompanied with γ ray radiation, this work is focused on γ/n discrimination. In our experiments, the ^{252}Cf is used as a radiation source for a mixed field of γ rays and neutrons, and ^{137}Cs is used as radiation sources for pure γ rays. The scintillators within 20 ml glass vials are placed above the photomultiplier (PM) RCA 8575. The two parameter spectrometric system NGA-01 is used to analyze the energy and discrimination characteristics. It is shown first that from six selected solvents, the DIPN and 1-Methylnaphthalene are capable of good γ/n discrimination in combination with luminophore PYR. In second stage the solvent is DIPN and the concentration of luminophores is varied. The concentration of luminophore PYR from 3 g/l to 9 g/l is shown to be best for γ/n discrimination. The energy threshold for good γ/n discrimination is 0.14 MeVee. Luminophore THIO (2,5 - Bis (5 - tert - butyl - benzoxazol - 2 - yl) thiophene) has best γ/n discrimination at concentrations from 3 g/l to 6 g/l and the energy threshold is 0.17 MeVee. Luminophore XAZ (2 - (4 - BiPhenylyl) - 6 - phenylbenzoxazole) has best γ/n discrimination at concentrations from 2.4 g/l to 3 g/l and the energy threshold is 0.20 MeVee. These scintillators at optimal concentrations have lower energy threshold for γ/n discrimination than reference liquid scintillator AquaLight AB. However the stilbene crystal scintillator is better than scintillators from this work.

Measurements

(a) Two-parameter histogram from the measurement of liquid scintillator with PYR ($5\,\mathrm{g/l}$) dissolved in DIPN, (b) zoomed two-parameter histogram from the measurement of the liquid scintillator with PYR ($5\,\mathrm{g/l}$) with highlighted two energy channel intervals for channels 41 to 50 and channels 91 to 100, (c) number of pulses as the function of discrimination parameter for these two intervals,



$$\mathrm{FOM} = \frac{T_\mathrm{p} - T_\mathrm{e}}{(W_\mathrm{p} + W_\mathrm{e})}$$

where T_p is the discrimination channel where the proton peak is at maximum, T_e is the discrimination channel where the electron peak is at maximum, W_p is the full width at half maximum for the proton peak, and W_e is the full width at half maximum for electron peak.

Chemicals

Solvents:

- Di-iso-propylnaphthalene Mixed Isomers, CAS 38640-62-9, TCI Chemicals (labeled DIPN),
- 1-Methylnaphthalene, CAS 90-12-0, TCI Chemicals,
- Diethylbenzene, CAS 25340-17-4, Sigma-Aldrich,
- Dodecylbenzene (hard type) (a mixture of branched-chain isomers) CAS 25265-78-5, TCI Chemicals,
- Propylbenzene, CAS 103-65-1, Sigma-Aldrich,
- 1-Phenyloctane, CAS 2189-60-8, Sigma-Aldrich.

Solutes:

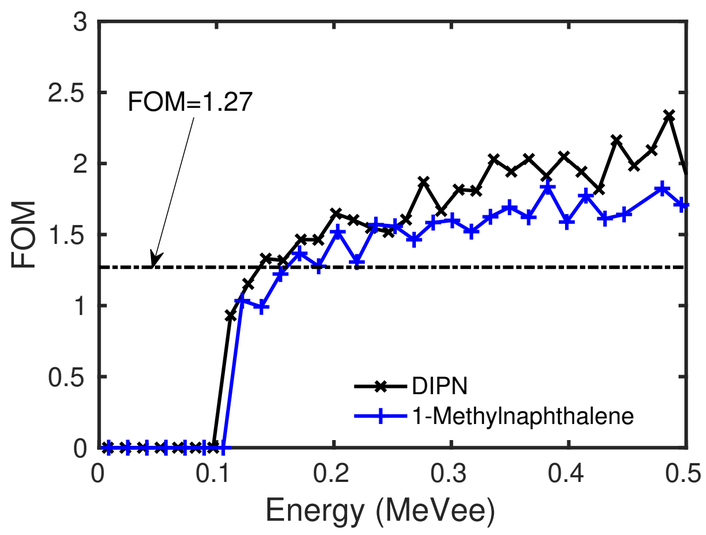
- 2-(4-BiPhenylyl)-6-phenylbenzoxazole, CAS 17064-47-0, Sigma-Aldrich (labeled XAZ)
- 2,5-Bis(5-tert-butyl-benzoxazol-2-yl)thiophene, CAS 7128-64-5, Sigma-Aldrich (labeled THIO)
- 1-Phenyl-3-(2,4,6-trimethyl-phenyl)-2-pyrazoline, CAS 60078-97-9, TCI Chemicals (labeled PYR).

Solvent comparison

Energy channel of Cs Compton line:

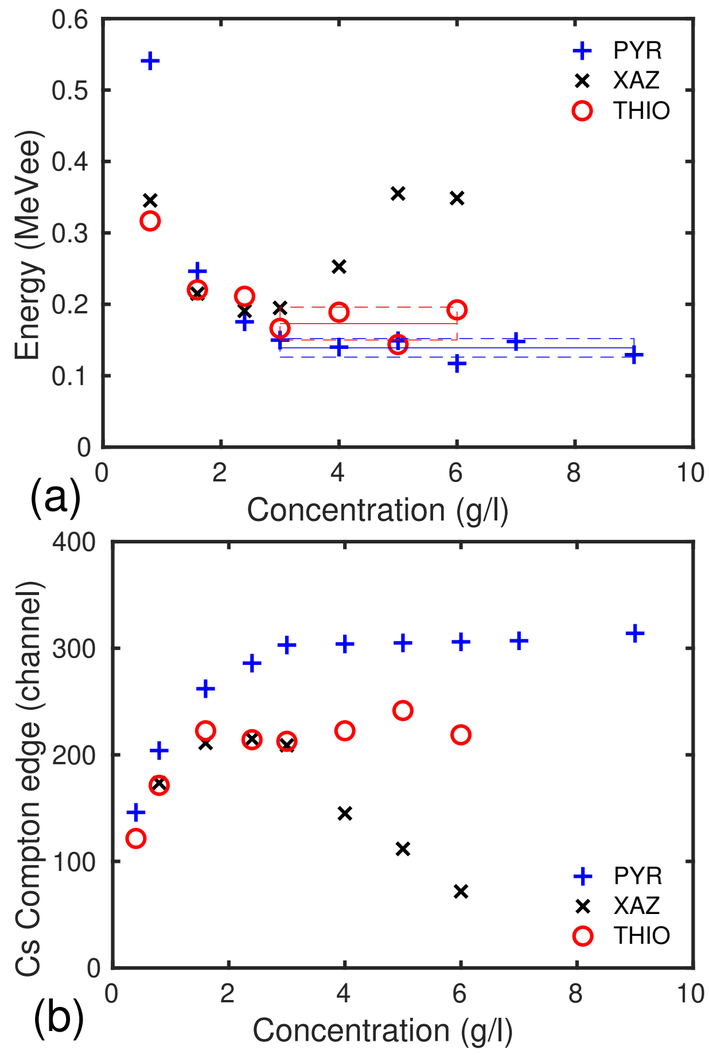
Solvent	Energy channel
DIPN	360
1-Methylnaphthalene	295
Diethylbenzene	245
Dodecylbenzene	205
Propylbenzene	215
1-Phenyloctane	160

Comparison of FOM as the function of energy for two best solvents: DIPN and 1-Methylnaphthalene. The PYR luminophore with a concentration of $4\,\mathrm{g/l}$ is used. Note that FOM of the other measured solvents is 0 in this energy range.



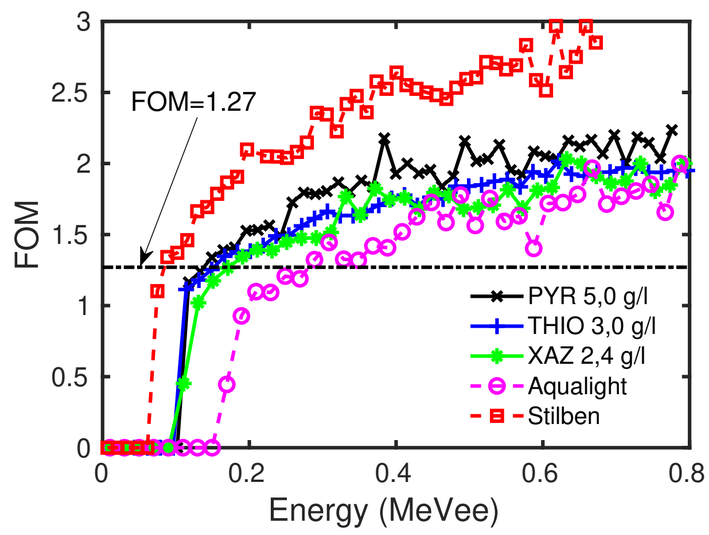
Luminophore comparison

Properties of the scintillators with the PYR, THIO and XAZ luminophores, and their variations with the concentration. (a) the energy thresholds where FOM=1.27 (PMT voltage adjusted), and (b) the energy channel of ^{137}Cs Compton edge normalized to PMT voltage $1650\,\mathrm{V}$.



Comparison with Stilbene

Comparison of FOM as the function of the deposited energy for the best liquid scintillators from this work with the PYR ($5\,\mathrm{g/l}$), THIO ($3\,\mathrm{g/l}$), and XAZ ($2.4\,\mathrm{g/l}$) luminophores with the stilbene crystal scintillator and the AquaLight AB liquid scintillator.



Conclusions

It has been demonstrated that from six preselected solvents, only Di-iso-propylnaphthalene Mixed Isomers and 1-Methylnaphthalene are capable of good γ/n discrimination in combination with the PYR luminophore. Afterwards the influence of the concentration of luminophores on the γ/n discrimination was studied. The concentration of the PYR luminophore from $3\,\mathrm{g/l}$ to $9\,\mathrm{g/l}$ is found to be the best for γ/n discrimination. The energy threshold where Figure of Merit FOM=1.27 is determined to be $0.14\,$MeVee. The THIO luminophore has the best γ/n discrimination at concentrations from $3\,\mathrm{g/l}$ to $6\,\mathrm{g/l}$ and the energy threshold where FOM=1.27 is observed to be $0.17\,$MeVee. The XAZ luminophore has the best γ/n discrimination at concentrations ranging from $2.4\,\mathrm{g/l}$ to $3\,\mathrm{g/l}$ and the energy threshold where FOM=1.27 is $0.20\,$MeVee. However, the stilbene crystal scintillator is better than the scintillators based on this work.

Acknowledgment

This research work has been carried out within the ADAR project (Accelerator Driven Advanced Reactor). The authors gratefully acknowledge the financial support from the Ministry of Education, Youth, and Sports of the Czech Republic under the INTER-ACTION research program (project No. LTAUSA18198). The authors gratefully acknowledge the financial support from the grant VAROPS (DZRO FVT 3) granted by the Ministry of Defence of the Czech Republic.