A new nuclear imaging detection technology for total body, flexible and fast SPECT diagnoses

After a long work of R&D we synthesised new organic molecules as fluorophores with very promising performances in terms of timing response and transparency, with concentration up to 30%.

Tests with charged particles (mip, electron and ion beams) shown that we can produce samples that allow to reach a time resolution better than the fast commercial plastic scintillators (EJ232).

<table>
<thead>
<tr>
<th>Samples</th>
<th>Primary dopant %</th>
<th>Wavelength Max emission [nm]</th>
<th>Light output % EJ232</th>
<th>Rise-time [ns]</th>
<th>Width [ns]</th>
<th>Time resolution [ps]</th>
</tr>
</thead>
<tbody>
<tr>
<td>EJ-232</td>
<td>-</td>
<td>370</td>
<td>100</td>
<td>2</td>
<td>9</td>
<td>123</td>
</tr>
<tr>
<td>EJ-204</td>
<td>-</td>
<td>408</td>
<td>220</td>
<td>2.5</td>
<td>11</td>
<td>211</td>
</tr>
<tr>
<td>2N</td>
<td>14</td>
<td>405</td>
<td>118</td>
<td>2</td>
<td>12</td>
<td>81</td>
</tr>
<tr>
<td>2T</td>
<td>14</td>
<td>-</td>
<td>245</td>
<td>3</td>
<td>18</td>
<td>97</td>
</tr>
<tr>
<td>1N</td>
<td>14</td>
<td>414</td>
<td>157</td>
<td>3</td>
<td>17</td>
<td>102</td>
</tr>
<tr>
<td>2B</td>
<td>14</td>
<td>420</td>
<td>160</td>
<td>2.5</td>
<td>14</td>
<td>110</td>
</tr>
</tbody>
</table>

Results obtained with mips

It is also possible to incorporate those new scintillators in the resin material and polymerise the samples by UV. Thin samples are the final target of the study.
Organic Scintillators for Imaging

Photons interactions with matter are defined by their energy and the Z of the absorber material, driving the choice of the detection strategy for each specific application.

There are applications where the interaction mechanism plays a crucial role in the detection technique.
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Photoelectric interactions give specific energy depositions allowing for an ‘interesting photons selection’.

~ NaI(Tl) most exploited scintillator

Those events are not pointing to the right position.
While in organic plastic scintillators the dominant interaction is Compton scattering, we decide to add a high Z element in order to increase the photoelectric effect probability.

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Organic Scintillators for Imaging

Photons interactions with matter are defined by their energy and the Z of the absorber material, driving the choice of the detection strategy for each specific application.
ReSPECT: system geometry concept

1. Modular structure

2. Collimator: 3D printed in tungsten

3. Enriched plastic scintillator, polymerisation in the collimator

4. Readout segmentation

Collimator: 3D printed in tungsten

Enriched plastic scintillator, polymerisation in the collimator

Readout segmentation
The granularity of the active material is crucial in order to keep a good space resolution. The same pixel size has been maintained for the readout.

**MODULE Top View**

- **50 mm**
- **50 mm**

**Readout Tile top View**

- **SPAD Based chip**
- **Sept thickness 250 µm**
- **Active material 2 mm**
- **2 mm**
- **active pixel**

The readout system is under study.
ReSPECT simulation study

The high-Z organic scintillator is simulated with a concentration of 10%.

Collimator in Tungsten, high Z and allows to realise very precise geometry (3D printed).

The high-Z organic scintillator is simulated with a concentration of 10%.

About 300 Modules organised in blocks

6 blocks
ReSPECT simulation study

FLUKA

- About 300 Modules organised in blocks
- six rotating blocks
- 120 projections => “reconstruction team” in Lyon (FR)

Collimator in Tungsten, high Z and allows to realise very precise geometry (3D printed)

The high-Z organic scintillator is simulated with a concentration of 10%
ReSPECT simulation study

- MC study: a $^{99m}$Tc point source at 10 cm
- The absorbed energy in the front module

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Michela Marafini

iWoRID 25 - 29 June 2023

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FLUKA
Photons directly coming from the source can be selected applying an energy cut, requiring an energy release consistent with the photoelectric interaction hypothesis. The resolution on the source position that can be obtained, depends on the details of the chosen geometry (pixel size, collimator length).

- MC study: a $^{99m}$Tc point source at 10 cm
- The absorbed energy in the front module
ReSPECT simulation study

FLUKA

MC study: a $^{99m}$Tc point source in a Patient CT at 30 cm from the block.

- MC Truth, all detected photons
- MC, direct photons from source (first interaction in scintillator)
- MC, photons from Compton interactions in the patient

<table>
<thead>
<tr>
<th>Energy absorbed in pixel [keV]</th>
<th>Counts / 2.00 [kEv]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>~ 30 cm</td>
</tr>
<tr>
<td>50</td>
<td>~ 30 cm</td>
</tr>
<tr>
<td>100</td>
<td>~ 30 cm</td>
</tr>
<tr>
<td>150</td>
<td>~ 30 cm</td>
</tr>
<tr>
<td>200</td>
<td>~ 30 cm</td>
</tr>
<tr>
<td>250</td>
<td>~ 30 cm</td>
</tr>
<tr>
<td>300</td>
<td>~ 30 cm</td>
</tr>
<tr>
<td>350</td>
<td>~ 30 cm</td>
</tr>
<tr>
<td>400</td>
<td>~ 30 cm</td>
</tr>
<tr>
<td>450</td>
<td>~ 30 cm</td>
</tr>
</tbody>
</table>
## ReSPECT expected performances

<table>
<thead>
<tr>
<th>SPECT SYSTEM</th>
<th>Sensitivity per module [cpm/µCu]</th>
<th>System Spatial Resolution [FWHM] [mm]</th>
<th>Decay Time</th>
<th>Rate Capability</th>
<th>COST scintillator/ FoV</th>
<th>COST full geometry</th>
<th>COMPLIANCE</th>
<th>MRI</th>
<th>Radiometabolic Dosimetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>@140 keV</td>
<td>@10 cm</td>
<td>[ns]</td>
<td>[cps/cm²]</td>
<td>[€/cm²]</td>
<td>[€]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPECT (NaI)</td>
<td>FoV 53 x 39 cm²</td>
<td>170</td>
<td>7.4</td>
<td>250</td>
<td>0.25-3k</td>
<td>4</td>
<td>400k</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>SPECT CZT</td>
<td>FoV 39 x 51 cm²</td>
<td>190</td>
<td>7.6</td>
<td>350</td>
<td>30-700k</td>
<td>35</td>
<td>-</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>reSPECT 6 rotating Modules: 35 x 35 cm²</td>
<td>184*</td>
<td>[8.9 (pixel 2 mm)]</td>
<td>2-5</td>
<td>50-200M</td>
<td>4</td>
<td>180k</td>
<td>yes</td>
<td>yes</td>
<td></td>
</tr>
</tbody>
</table>

*energy cut at 80 keV
Scintillators R&D

Preliminary samples irradiated by a $^{133}$Ba source:

- DATA: 2N 14% + Bi 2%
- DATA: Plastic Scintillator EJ200
- MC: Plastic Scintillator + Pb 2%
- MC: Plastic Scintillator

Scintillator mixtures:

- PVT based scintillator (2N 10%) + Bi 2%
- PVT based scintillator (2T 14%) + Bi 4%
- PVT based scintillator (2N 10%) + Bi 10%
- EJ + Pb 1.5%
- EJ + Pb 5%

133Ba gamma at 80 keV
Scintillators R&D

- We are producing samples of high-Z organic scintillators
- Transparency is good up to very high concentrations
- Test with laboratory sources and different readout systems

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<table>
<thead>
<tr>
<th>Scintillator</th>
<th>Light Output [a.u.]</th>
<th>Ph.el</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial pure</td>
<td>100%</td>
<td>-</td>
<td>reference</td>
</tr>
<tr>
<td>Commercial 1.5% Pb</td>
<td>80%</td>
<td>+</td>
<td>lower</td>
</tr>
<tr>
<td>Commercial 5% Pb</td>
<td>60%</td>
<td>++</td>
<td>ongoing</td>
</tr>
<tr>
<td>New pure</td>
<td>80%</td>
<td>-</td>
<td>faster</td>
</tr>
<tr>
<td>New 2% Bi</td>
<td>ongoing</td>
<td>+</td>
<td>ongoing</td>
</tr>
<tr>
<td>New 4% Bi</td>
<td>ongoing</td>
<td>++</td>
<td>ongoing</td>
</tr>
<tr>
<td>New 10% Bi</td>
<td>ongoing</td>
<td>+++</td>
<td>ongoing</td>
</tr>
</tbody>
</table>

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1. Waveform of our scintillator (2N)
2. Readout with a PMT
3. Readout with a SiPM
Take home messages

- Organic scintillators are fast, cheap and easy to manipulate
- With reSPECT project we are targeting a total body SPECT, accessible to National Healthy System in terms of cost, space and diagnose
- The goal is to reduce diagnosis time and dose to the patient
- Radio-metabolic dosimetry is also possible with the same reSPECT system

- We are producing and characterising samples of hi-Z organic scintillators at different concentrations
- Transparency is good up to very high concentrations => Light Output is important to keep a good energy resolution!
- Test with laboratory sources and different readout systems

- Polymerisation in metal is ongoing
- Test with $^{99m}$Tc at Policlinico => Fall 2023
- Realisation of the first module in 2024/2025

National Funding Summer 2023 - Summer 2025

PRIN: PROGETTI DI RICERCA DI RILEVANTE INTERESSE NAZIONALE – Bando 2022 Prot. 2022Z72Y3K

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  - Medical physics school: Hospital Policlinico Umberto I Università Sapienza di Roma

GRAZIE