Development of low cost per unit area plastic scintillator materials for radiation detection and monitoring applications

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Outline

- Collaborative R&D between University of Sheffield and LabLogic Systems.
- Motivation and context for PS 'Tile' development.
- Design, prototyping, development and production.
- Initial test data: scaled-up muon trigger.
- Next stages and conclusions.

Collaborative R&D

- Established relationship between Experimental Particle Physics Group at **UoS** and **LabLogic** since 2009.
- LabLogic established in 1980 and based in Sheffield.
- Expertise in LSC and RN detection/analysis.
- KTP project, joint-funded research, support of H2020 research.

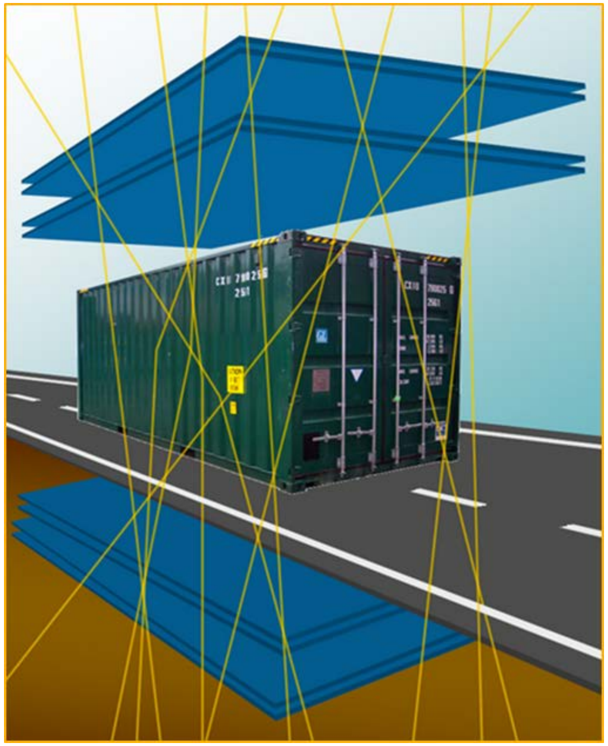
Development of PS Tiles

- Initial design specification in context of **muon scattering tomography** for security applications.
- Detection of SNM [1] where passive rates are close to background with drift chamber.
- Complement portal monitors.
- Large area permits sensitivity.
- Other applications for imaging reactors [2] and volcanoes [3,4].
- **Supply chain of suitable low cost/unit area PS limited.**

[1] MORRIS C.L., et al., Analysis of muon radiography of the Toshiba nuclear critical assembly reactor, Appl. Phys. Lett. 104 (2014) 024110.
[2] MIYADERA, H., et. al., Imaging Fukushima Daiichi reactor with muons, AIP Advances 3, (2013) 052133.
[3] TANAKA H.K.M., et al., High resolution imaging in the inhomogeneous crust with cosmic-ray muon radiography: The density structure below the volcanic crater floor of Mt. Asama, Japan, Earth and Planetary Science Letters, 263 (2007) 103-114.
[4] TANAKA H.K.M., et al., Radiographic visualization of magma dynamics in an erupting volcano, Nature Communications 5 (2014) 3381.

Design

- Scalable format to optimise tooling, raw material and production costs.
- Ability to **tile in x, y, and z planes** and scale-up.
- Channels for optical fibres to couple to detector(s).
- Rugged and cost-effective base material.
- Choice and concentration of primary and secondary fluors.



Specification

- Dimensions: 200 x 200 x 5 mm.
- Four 1.5 mm x 1.5 mm cross-section grooves for addition of optical fibres.
- PS base polymer.
- Scintillation fluors: p-Terphenyl, **pTP** and 1,4-bis(5-phenyloxazol-2-yl) benzene, **POPOP**.

Steps to Production

- Custom tooling manufactured locally (Sheffield).
- Polymerisation undertaken locally (Manchester).
- Injection moulding performed locally (Sheffield).
- Control over design and development phases.
- Min 10 kg batch (200 g/tile).

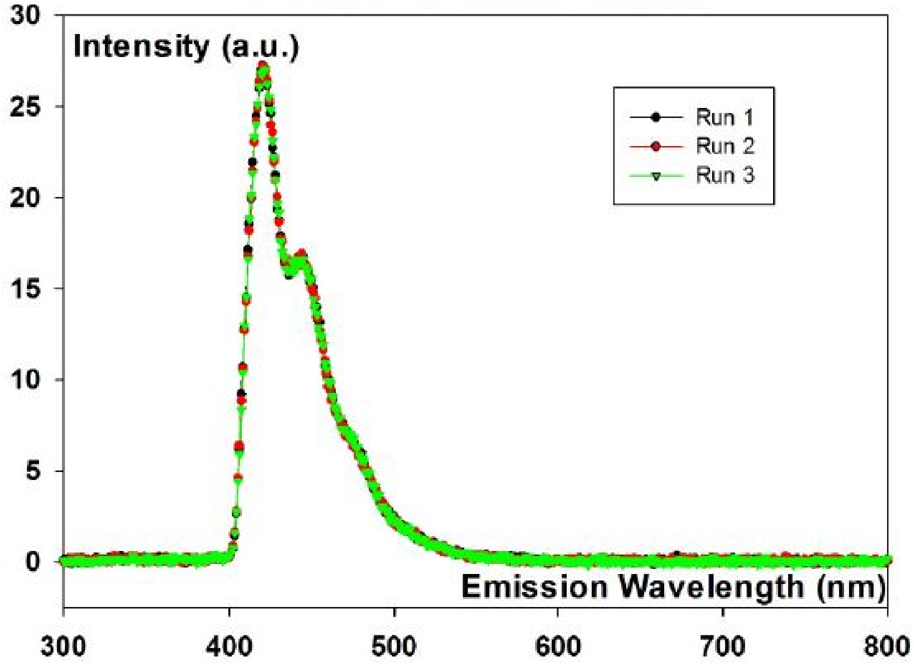
Synthesis and production of scintillator ‘pellets’ → IM barrel strip down and clean → Barrel purge → Injection moulding

Development

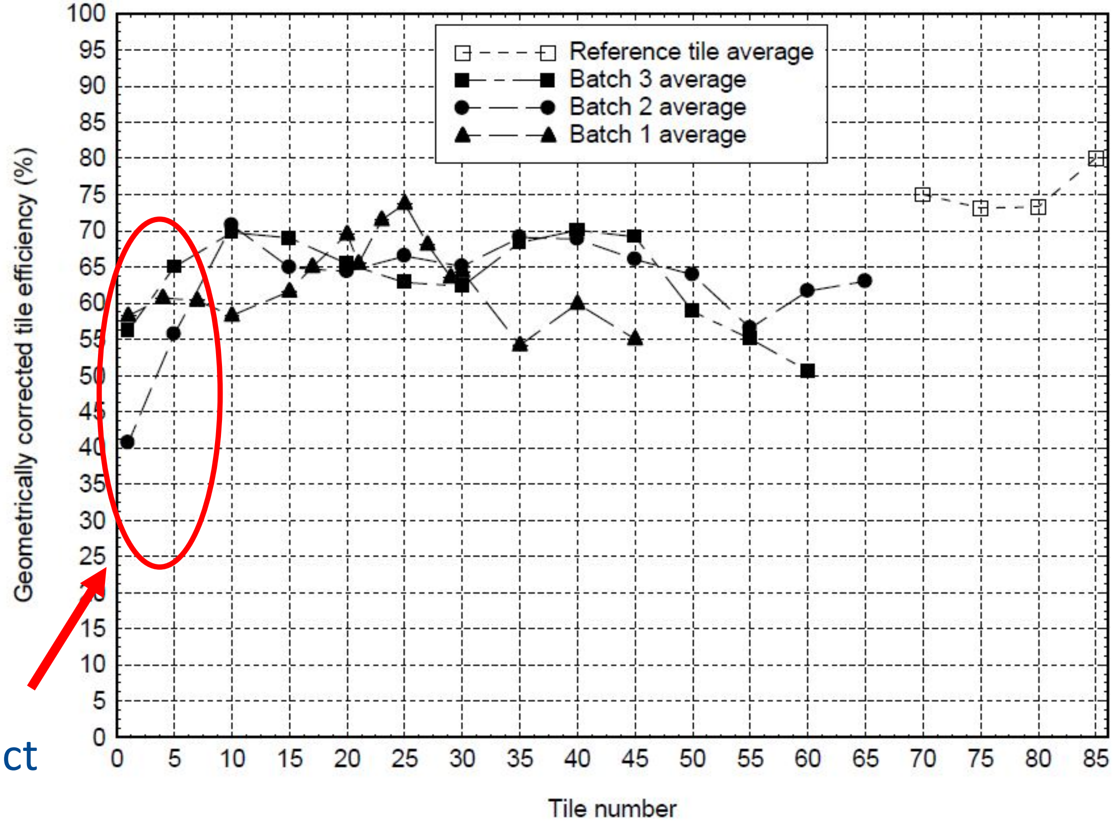
- First batches showed variation in performance for different primary/secondary concentrations.
- Optimisation from trial batches.
- Injection moulding process limitations (**timing, contaminants**).
- Refinement of production process.

Emission Spectra

- Spectophotometry measurements (UV excitation).
- Peak emission response at 420 nm.



μ Efficiency – Single Thickness

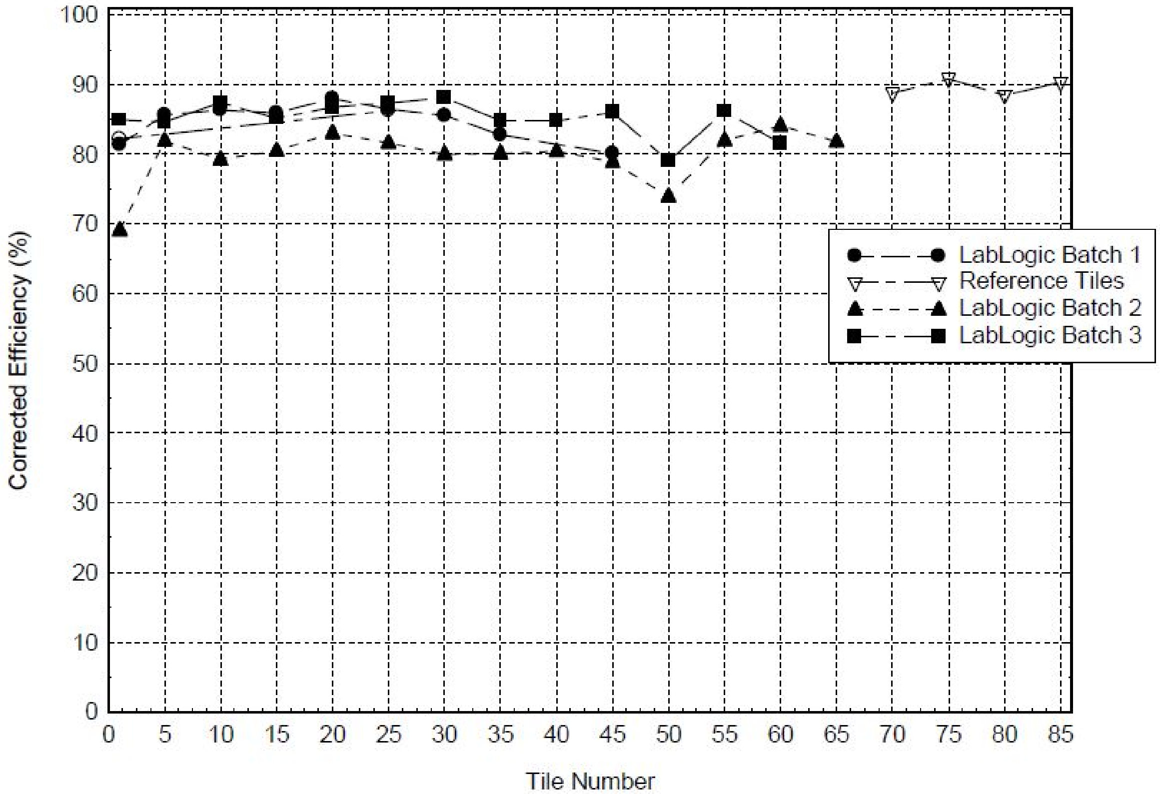


Moulding process effect

Efficiency > 60%

LSC 2017, Copenhagen

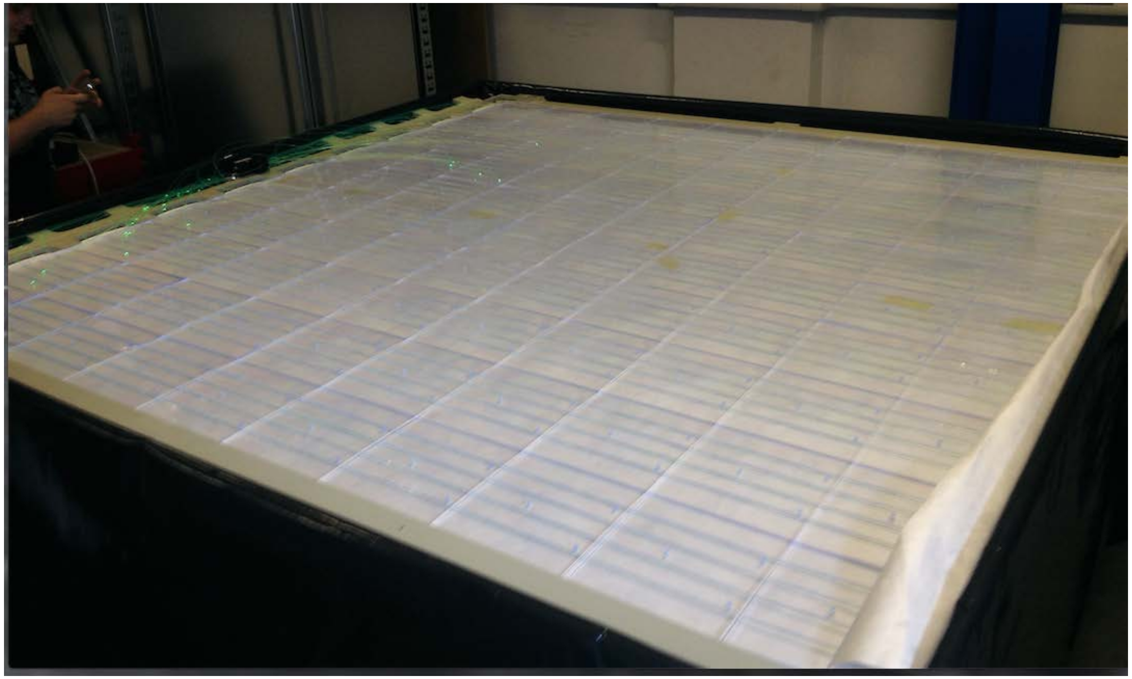
μ Efficiency – Double Thickness



Efficiency > 80%

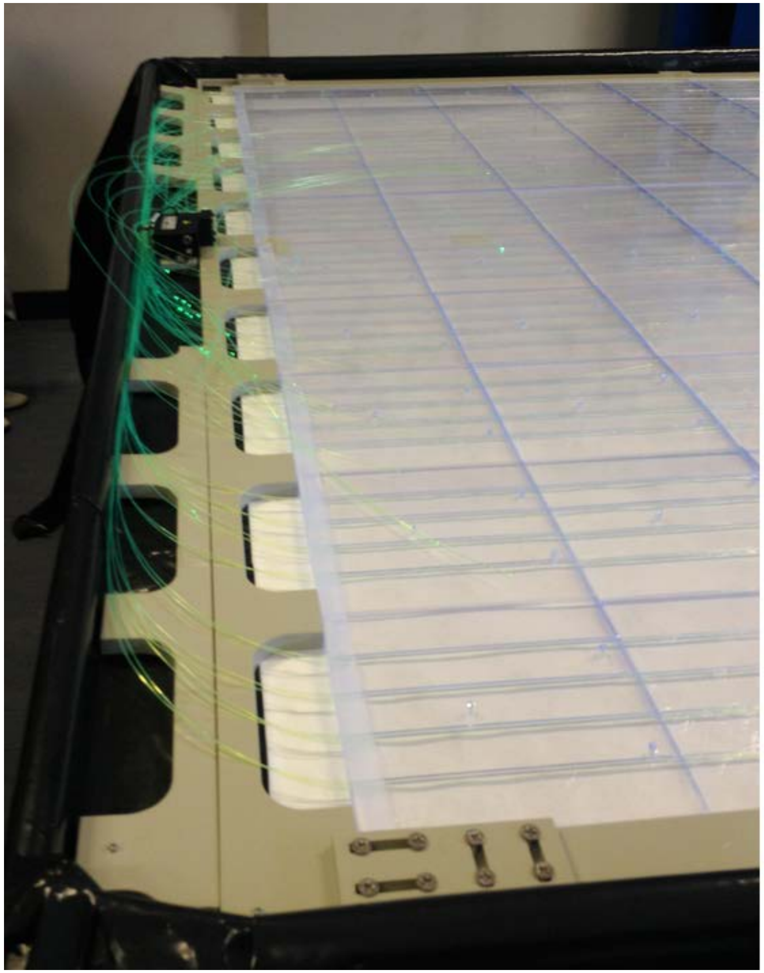
Scale-Up Tests

- Cargo scanner demonstrator (muon DAQ trigger).
- 2 m x 2 m x double-tile thickness (10 mm).



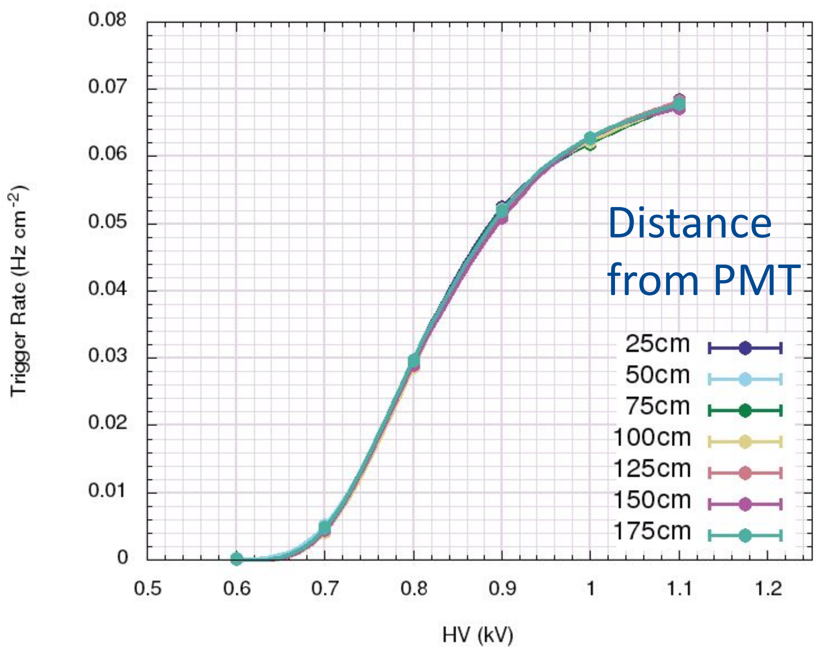
Scale-Up Tests

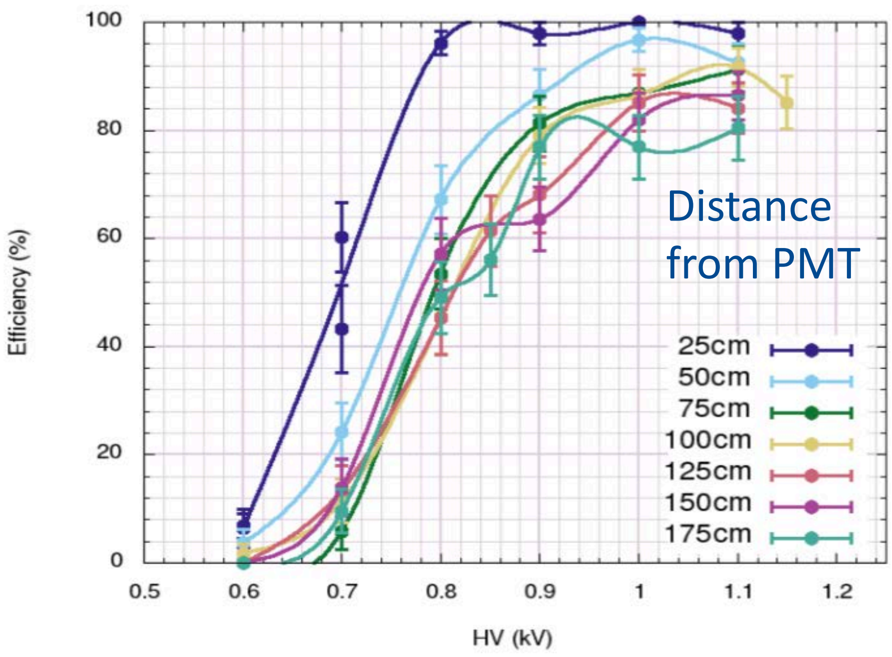
- WLS fibres used to capture scintillation light and transmit to PMT (Bicron BC91A).
- Tyvek sheet reflector.
- Black polypropylene enclosure.
- 80 fibres coupled to single PMT.



μ Detection Efficiency

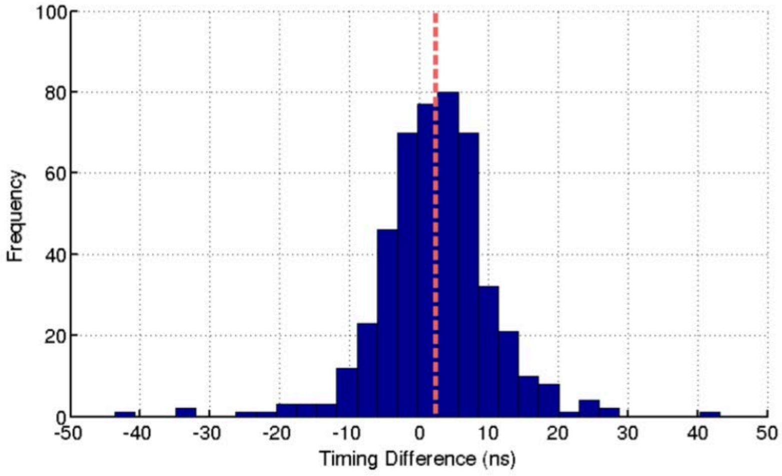
- Muon trigger rate and efficiency.
- Efficiency calculated from coincidence measurements.
- Two paddles moved from far end towards detector.

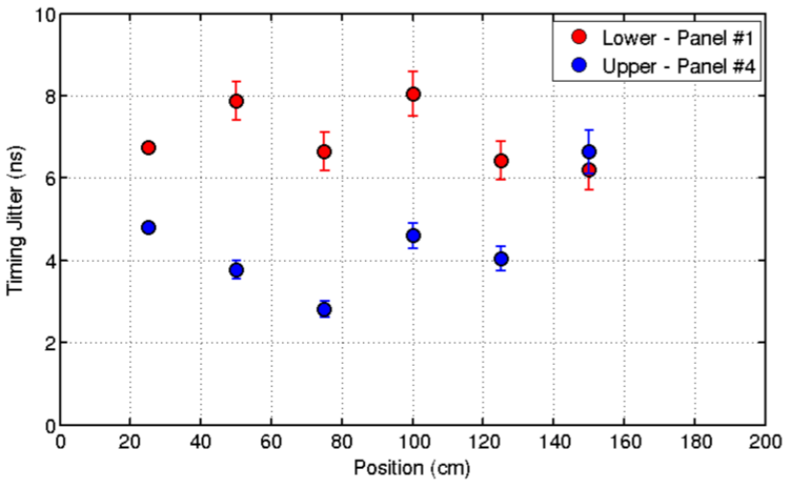




Timing

- Coincident timing resolution important for drift chamber tracking resolution.
- Output pulses digitised using 5GS/s DRS4 evaluation board (PSI).
- Mean time difference compared to muon traversal time (**2.4 ns**) .
- Panel timing jitter relative to coincident "paddle" trigger is typically **4-8ns** (includes paddle, panel and PMT jitters).





Gamma Efficiency

- Set of gamma calibration sources (Spectrum Techniques) measured relative to 1x1” NaI(Tl)/PMT.
- Avoid pulse saturation/dead-time issues, giving higher count rate for higher energy emissions.

Radionuclide	Primary Gamma Energy	Single Tile
^{54}Mn	834.85	x2.55
^{57}Co	122.06	x0.53
^{60}Co	1173.23; 1332.49	x4.46
^{65}Zn	1115.54	x2.49
^{109}Cd	88.03	x0.14
^{133}Ba	80.99; 302.85; 356.01	x0.22
^{137}Cs	661.66	x1.13

Conclusions and Future Work

- Design, development and production of PS-based scintillation tiles has been undertaken.
- Good efficiency for both cosmic ray muon and gamma detection.
- Products for scaled-up arrays of tiles.
- Different sizes and geometries (bars, blocks, etc.) to be undertaken next.
- Doping to give n, γ discrimination (e.g. Gd salt – cost??).
- 3-D printing of raw material (improve properties).

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Thank You - Any questions?

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