Muon Imaging Applications for Nuclear Waste Management and Decommissioning

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National Nuclear Laboratory

Muographers 2021

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Overview

- Intro
  - NNL/Lynkeos Industrial Collaboration.
- Muon imaging of waste
  - Some examples of different waste forms.
  - Condition Monitoring and Inspection.
- Challenges of deploying on a nuclear site.
  - Detector safety.
  - Radiation environment.
  - Engineering constraints.
- Summary

NNL/Lynkeos Muon Tomography Industrial Collaboration

- Collaboration begun in 2009 with University of Glasgow.
  - *Feasibility studies.*
  - *Small Scale Proof of concept.*
- 2015: Large scale industrial demonstrator.
- 2016: Lynkeos Technology Ltd.
- 2017 – 2018: £1.6M Innovate UK grant for deployment at Sellafield.

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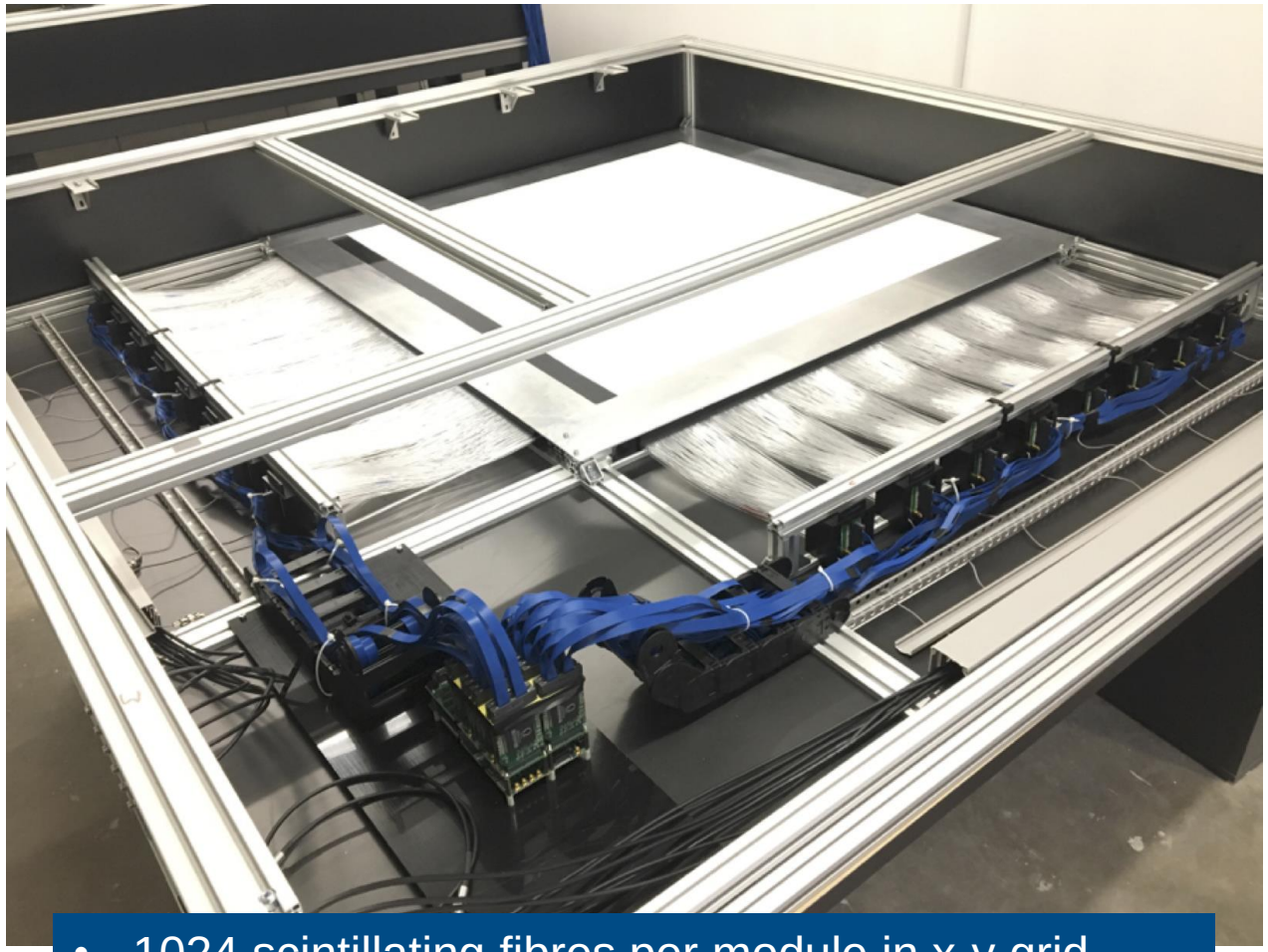
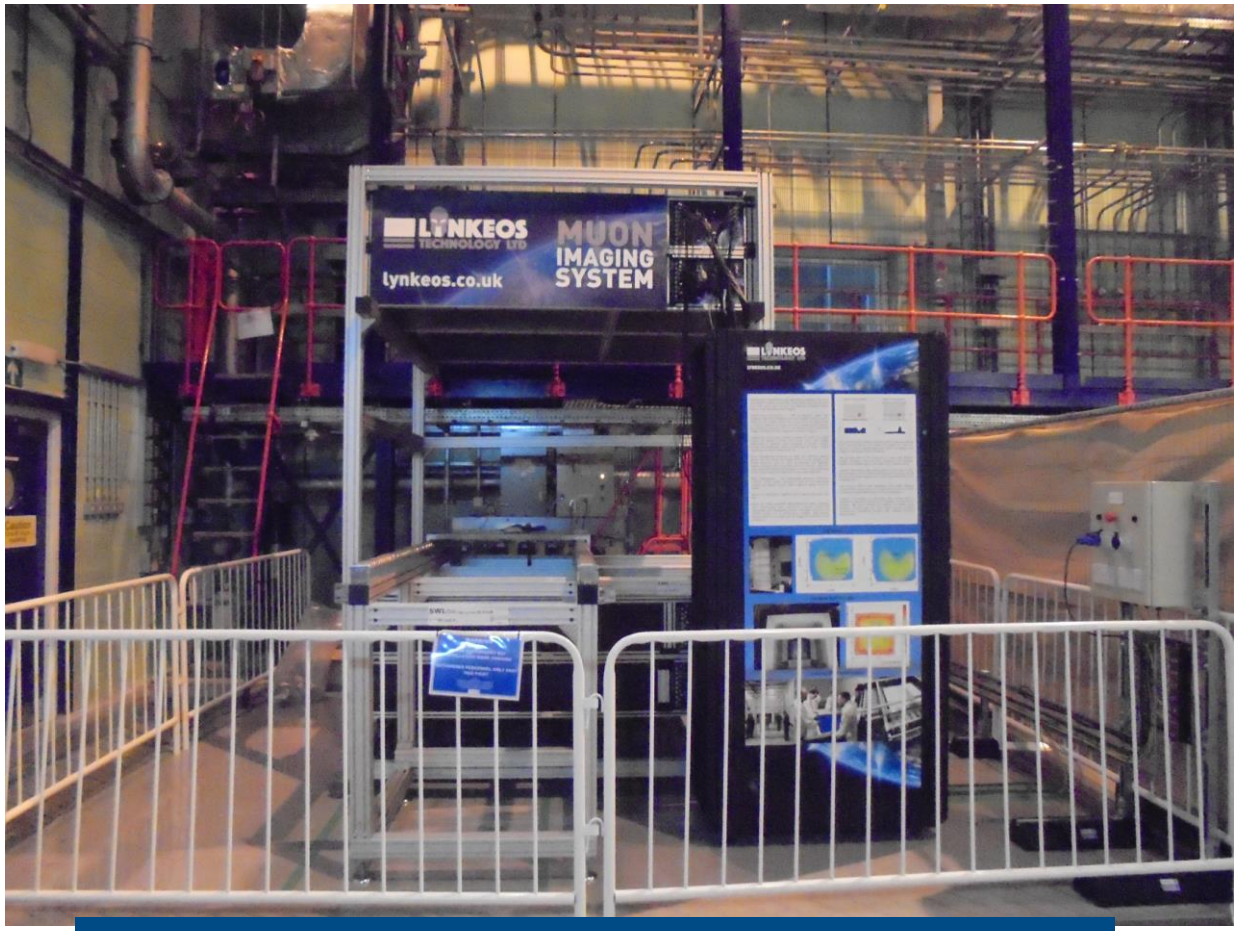
Lynkeos Muon Imaging System



- 1024 scintillating fibres per module in x-y grid
- MAPMT Readout



Imaging systems operational at Glasgow University and NNL Central Laboratory

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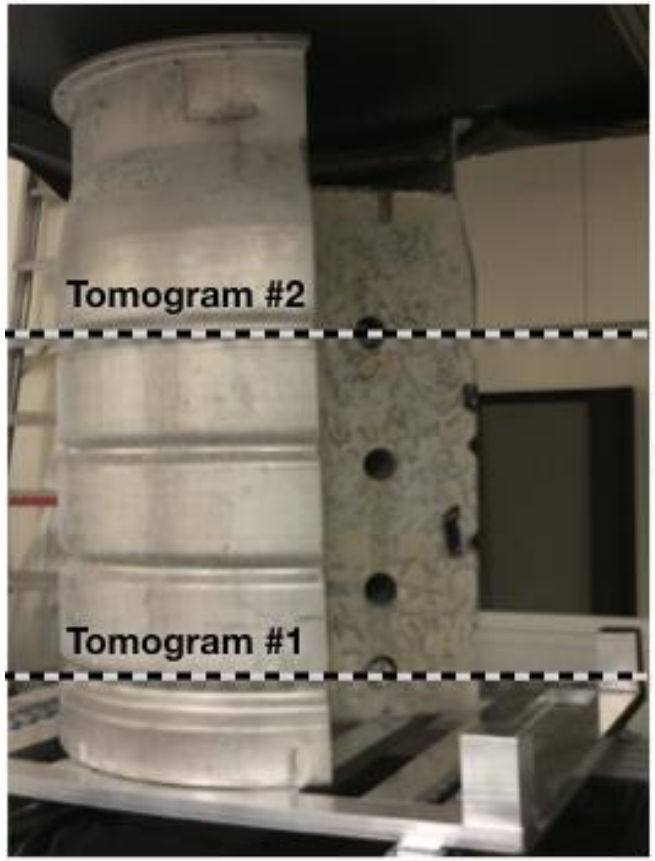
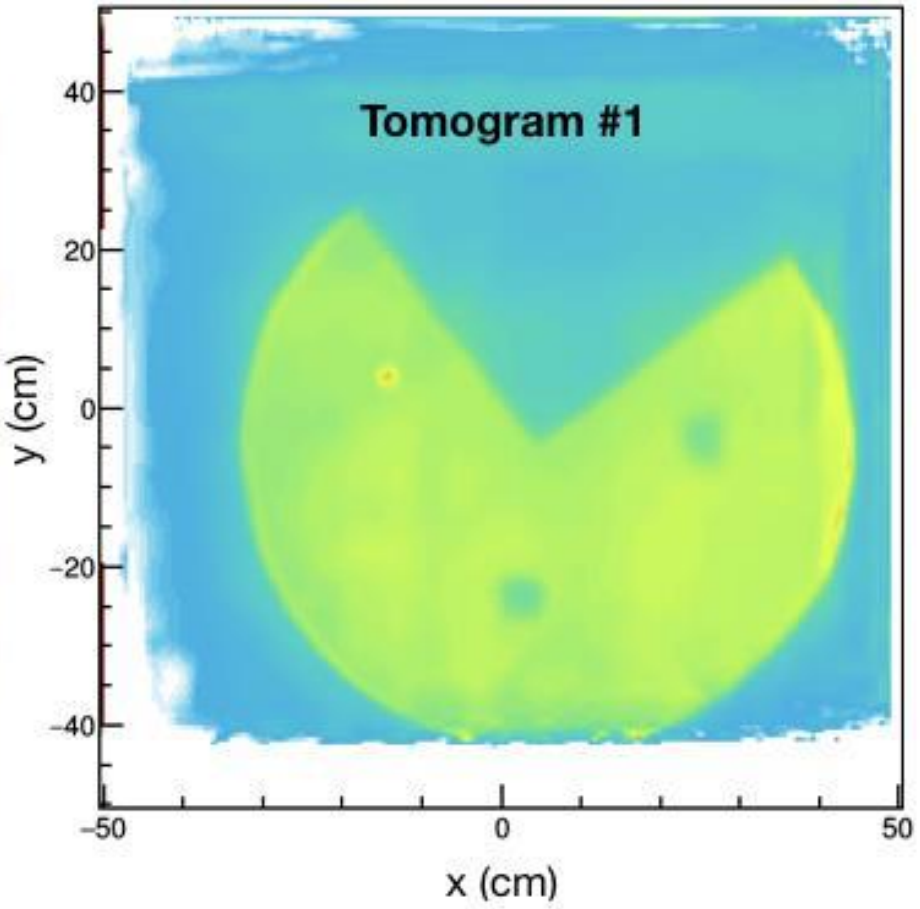
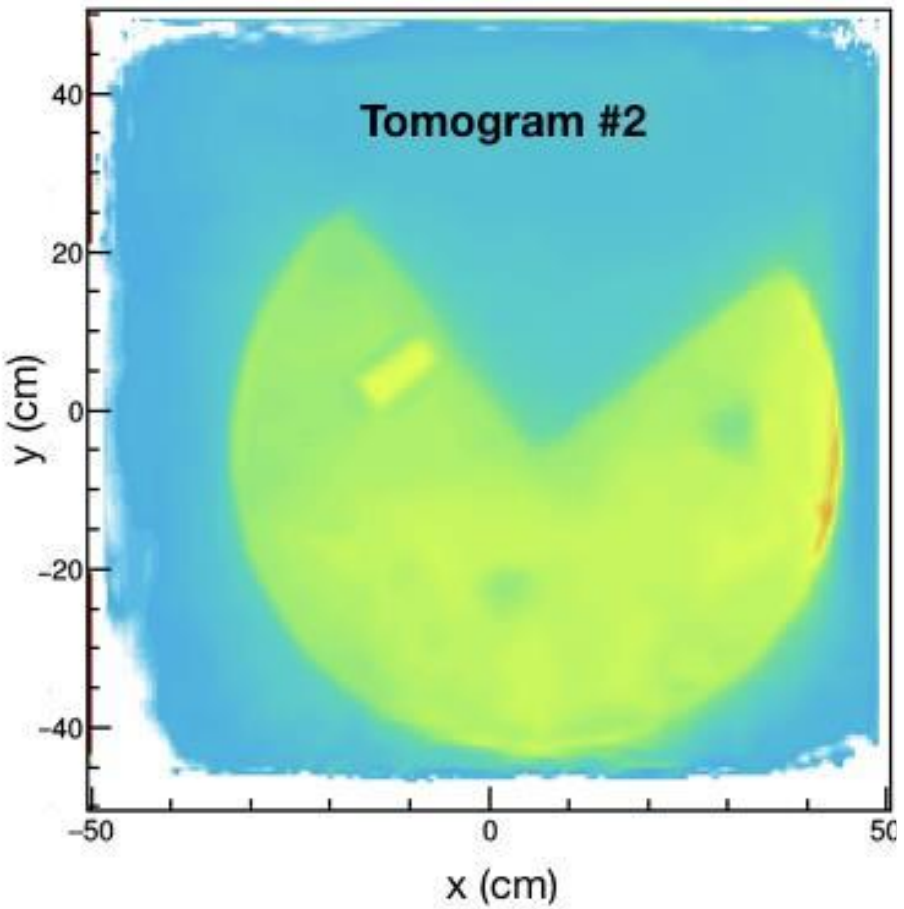
Intermediate Level Waste (ILW) Drum

Mahon *et al.* Philosophical Transactions of the Royal Society A Volume 377, Issue 2137







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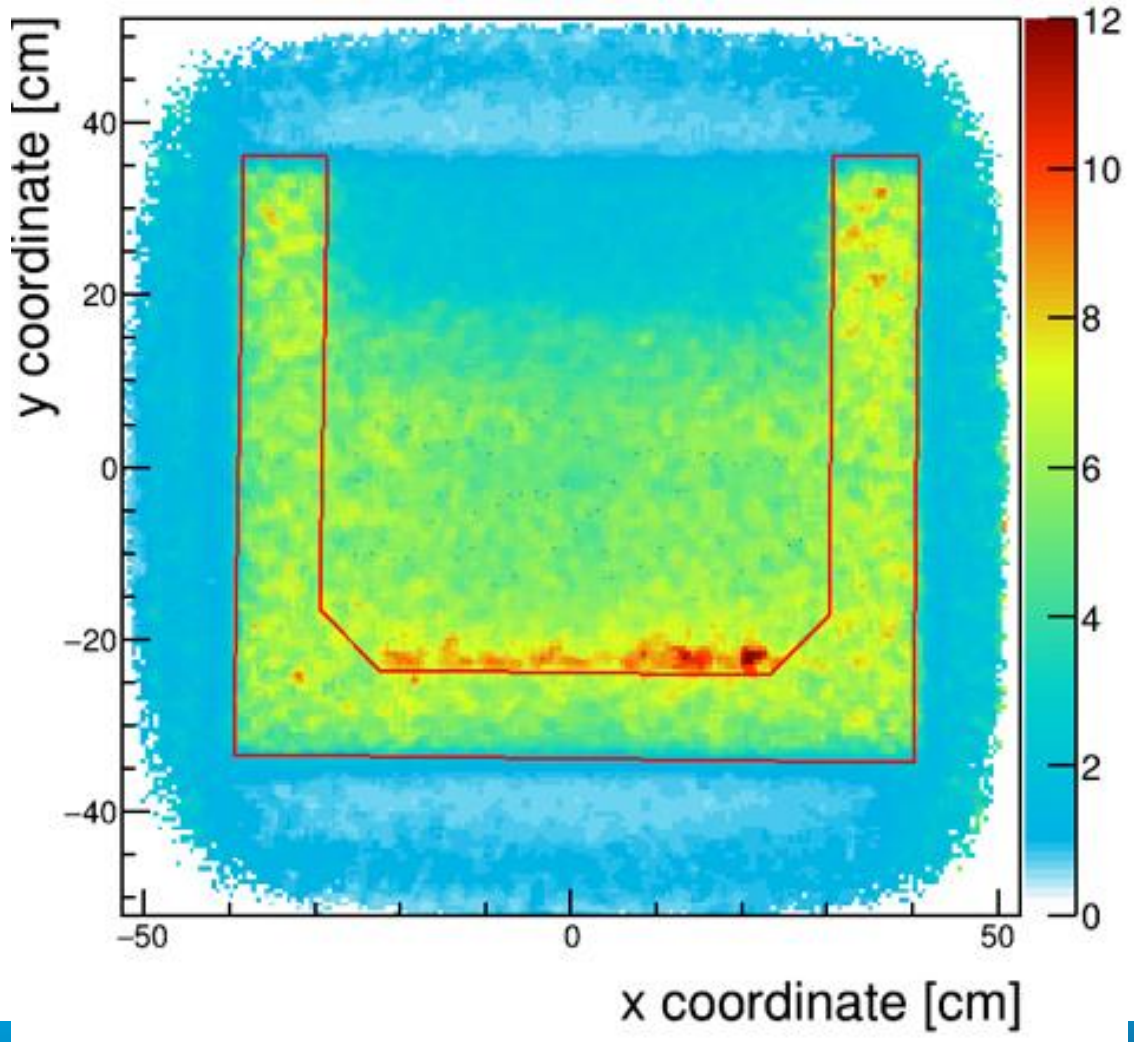
Vitrified Wastes – GeoMelt QA

Steel cannister

Uranium pennies



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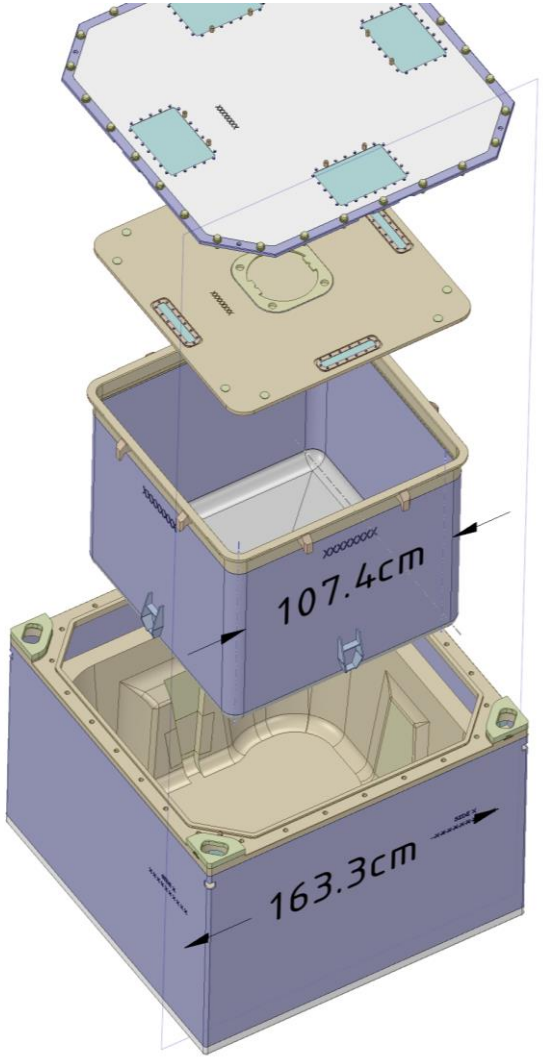
Magnox Swarf Storage Silo (MSSS)

- **Construction commenced in 1960s to store Magnox swarf stripped from spent fuel elements sent for reprocessing.**
- **Compartments contain heterogenous wastes and corroded sludge.**
- **High priority for decommissioning.**

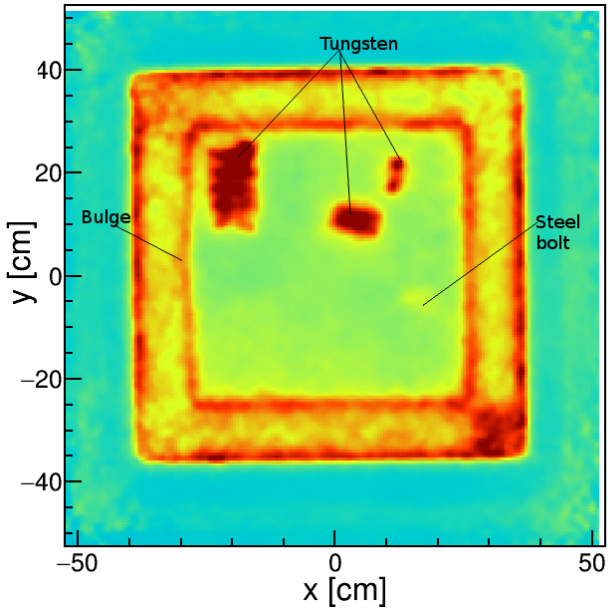
Condition Monitoring and Inspection (CM&I)

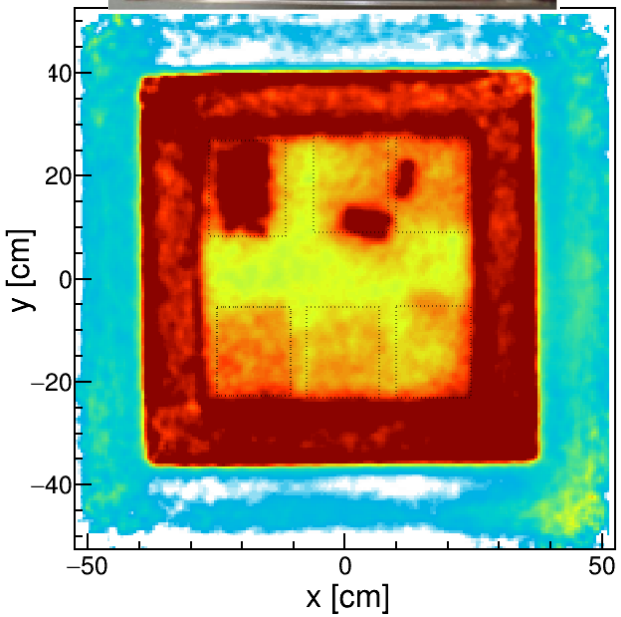


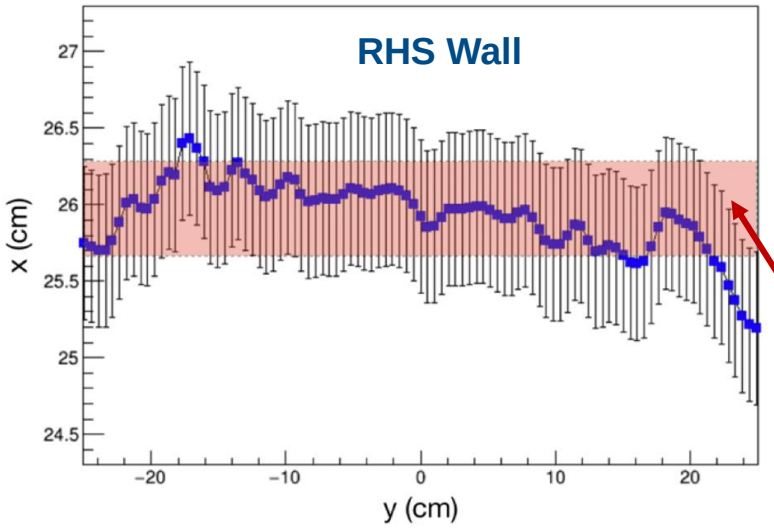
- **ONR and EA (UK regulators) want confidence that wastes are evolving as expected for safe interim surface storage and final geological disposal.**

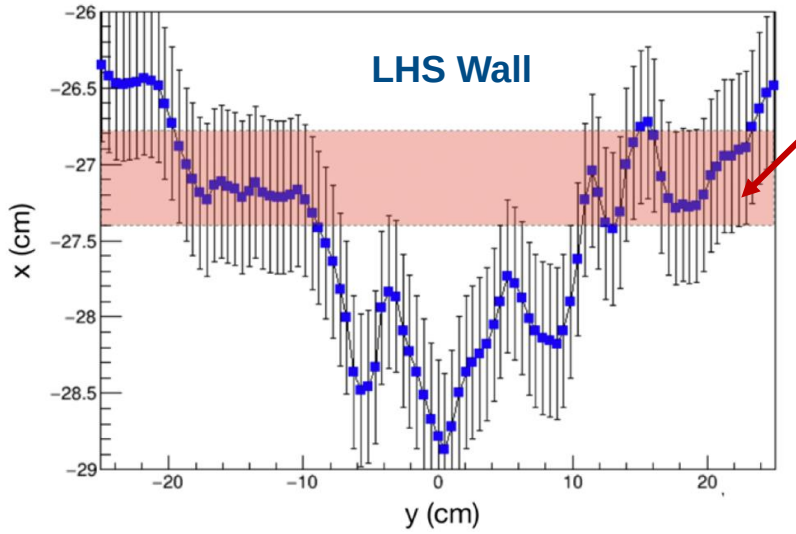
- **Periodic measurements of several parameters (CM&I), including:**
  - **Waste height**
  - **Water cover level**
  - **Inner skip integrity**

CM&I – Container Integrity









Nominal wall positions

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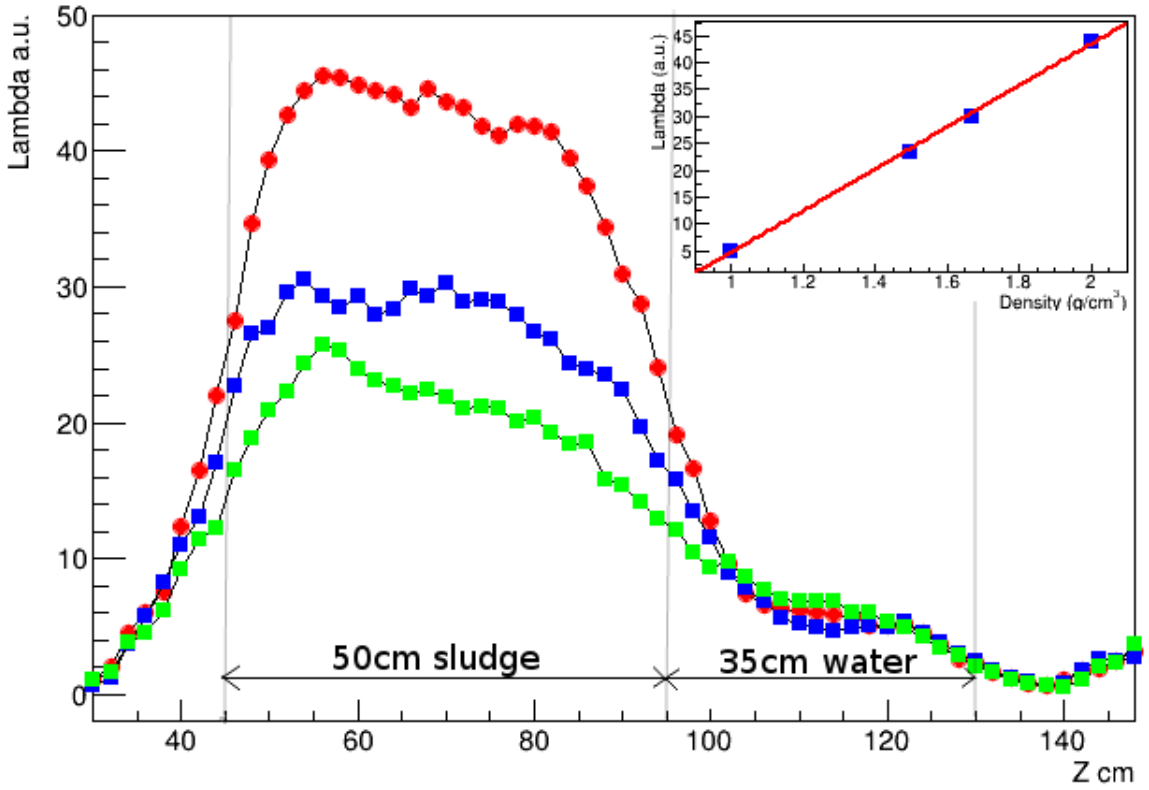
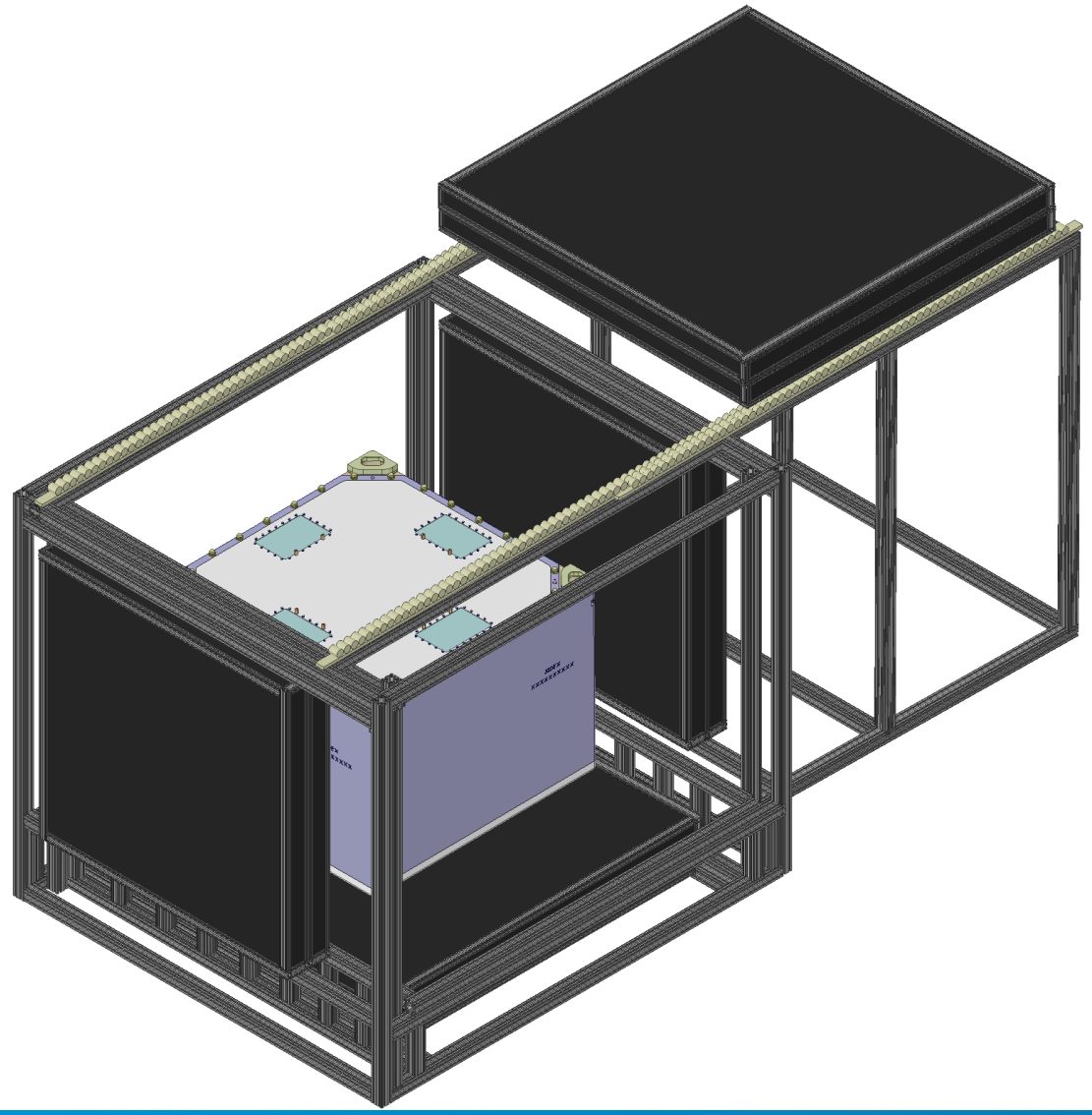
CM&I– Fill level measurements.

Use muons travelling at large angles to zenith



Simulated data



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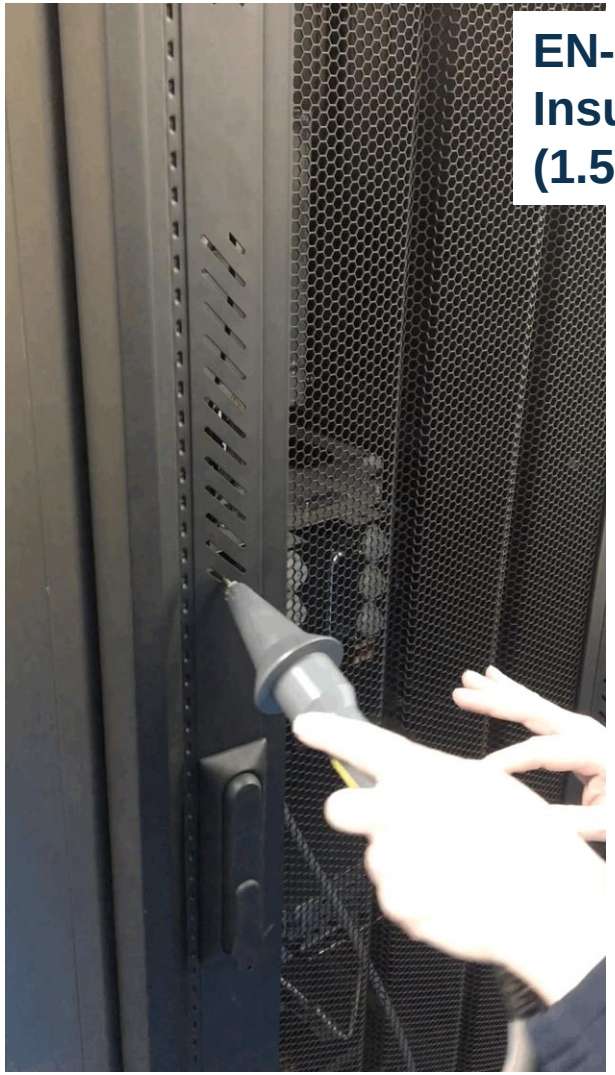
CE Marking – From University Lab to Supply Chain

- **Demonstrate compliance with EU product safety standards.**
- **Assessment against member state technical standards.**

CE + CE != CE

Physical testing of the detector system at a notified laboratory

Detector Safety



EN-61010 6.7.1.5
Insulation electric strength (1.5 – 4.1 kV)

EN-61010 8.2.2
Impact test with 1kg sphere

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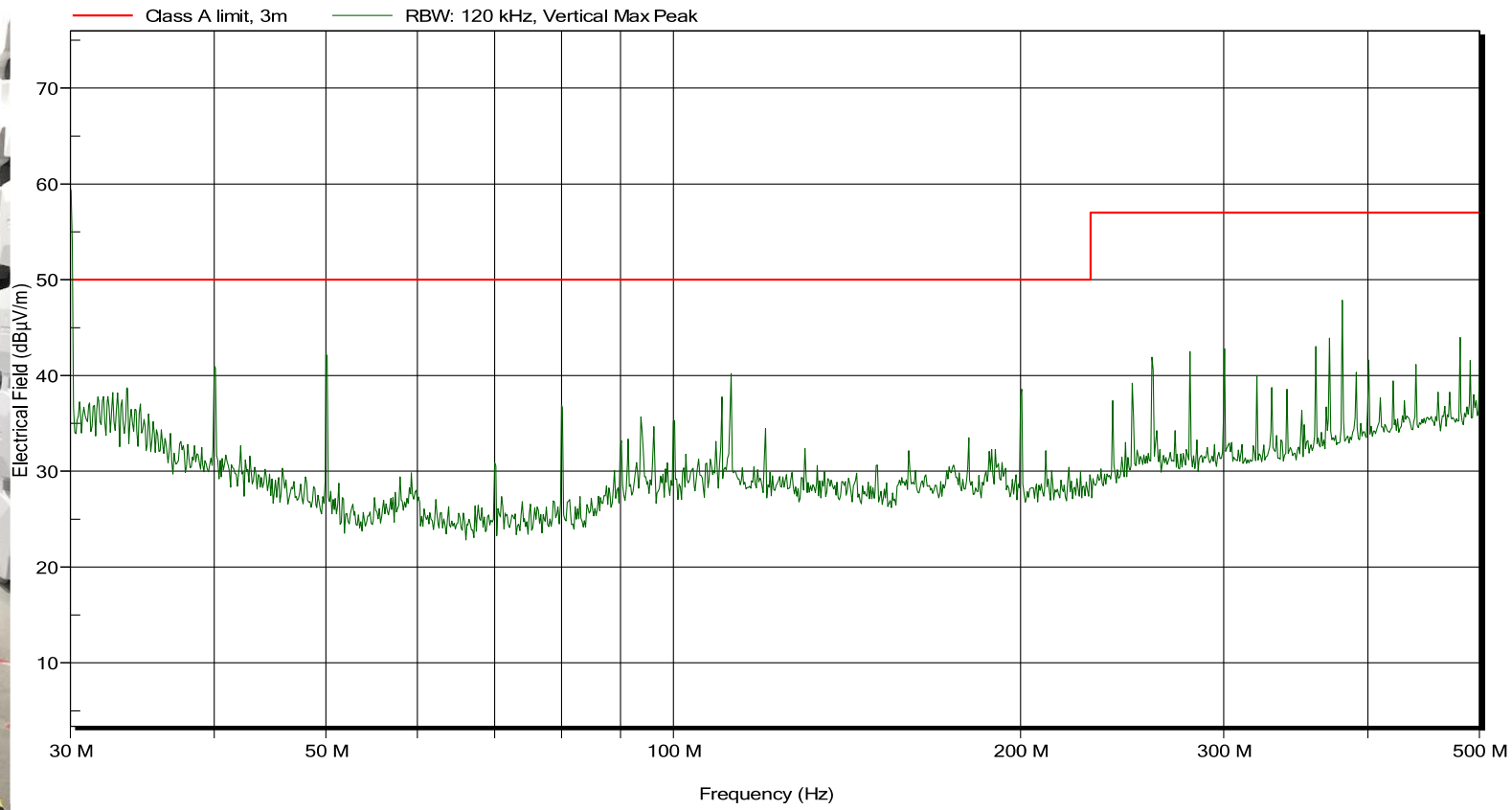
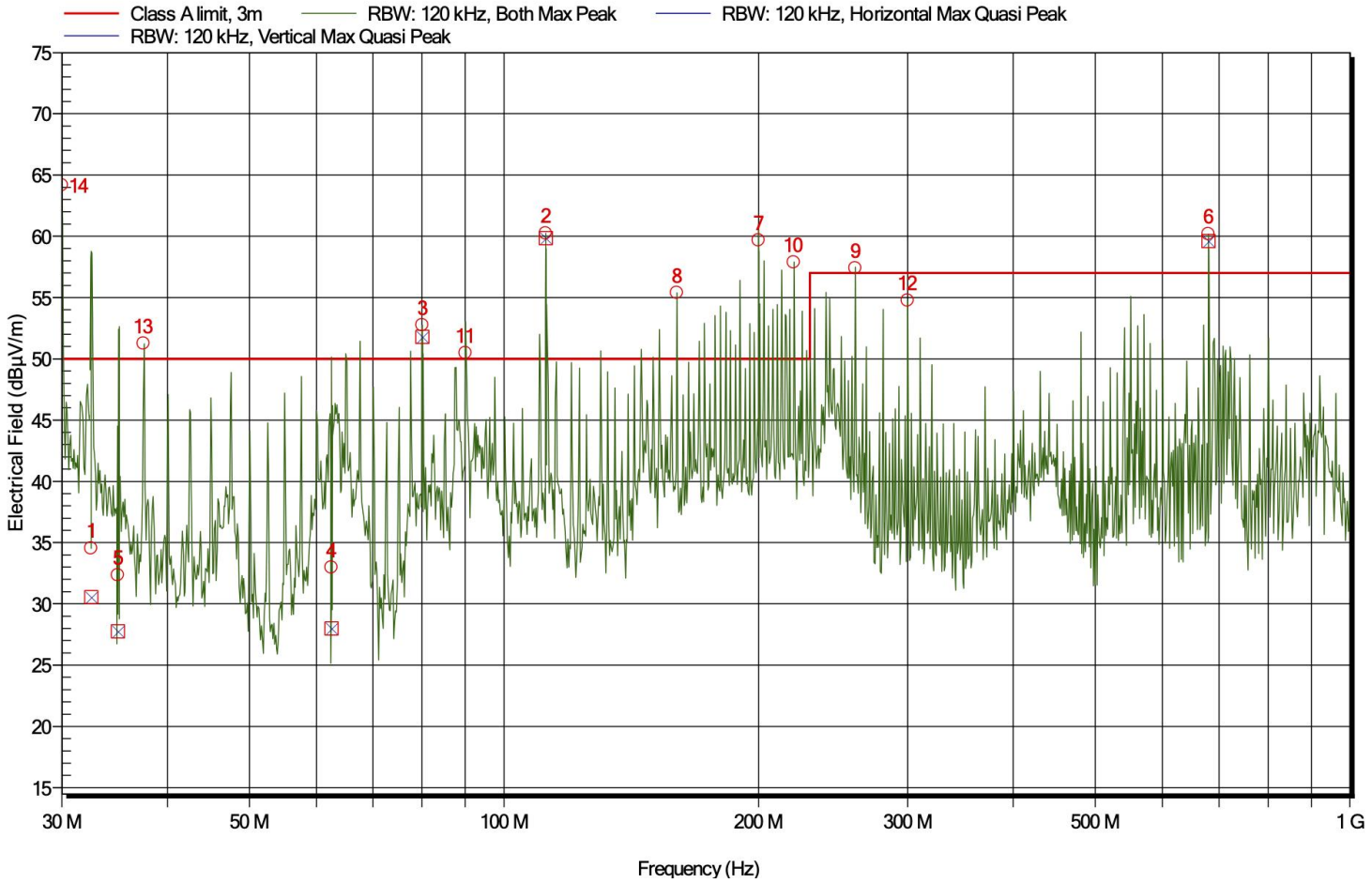
EMC Emissions



EMC Emissions



Detector Safety

EU Declaration of Conformity

Manufacturer Contact Details
Lynkeos Technology Ltd. support@lynkeos.co.uk
No. 11 The Square www.lynkeos.co.uk
University of Glasgow
Glasgow G12 8QQ

Object of the Declaration
Type of Object: Muon Imaging System
Model Number: LYNK-MIS

The object of the declaration described above is in conformity with the following EU Directives:

- **Electromagnetic Compatibility Directive (2014/30/EU)**
- **Low Voltage Directive (2014/35/EU)**

The following harmonised standards and technical specifications have been applied:

- **EN 61326-1:2013**
- **EN 61010-1:2010**[1]

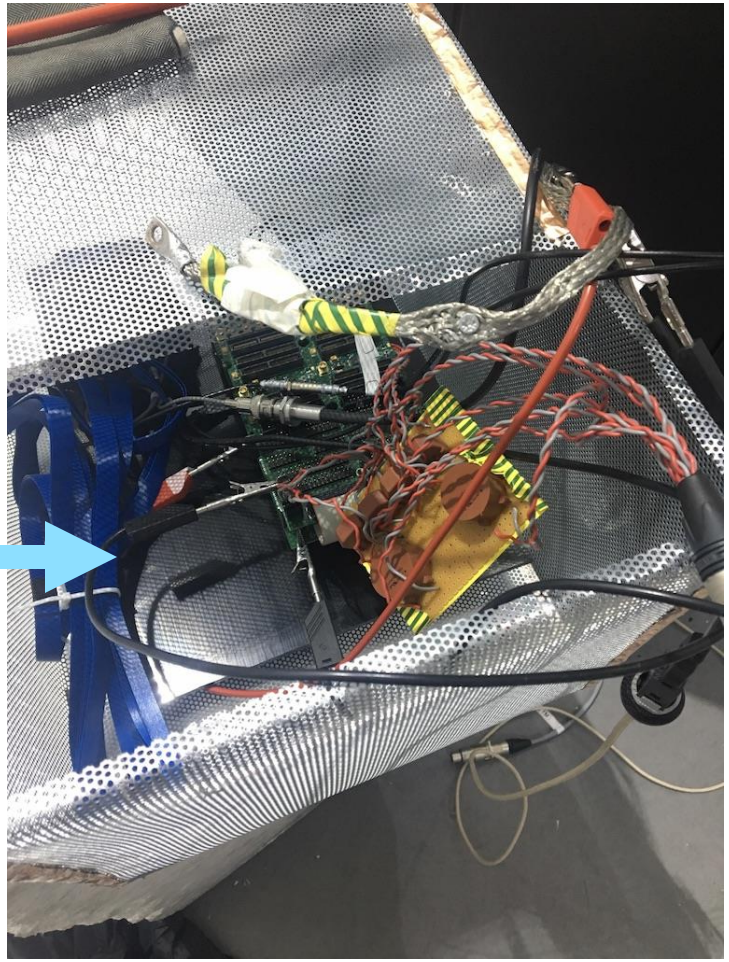
Notified Body
Eurofins York 1574
Certificate Number 4972TC1
Report Numbers 4971TR1 4988TR1

This declaration of conformity is issued under the sole responsibility of Lynkeos Technology Ltd.

Signed for and on behalf of Lynkeos Technology Ltd.:

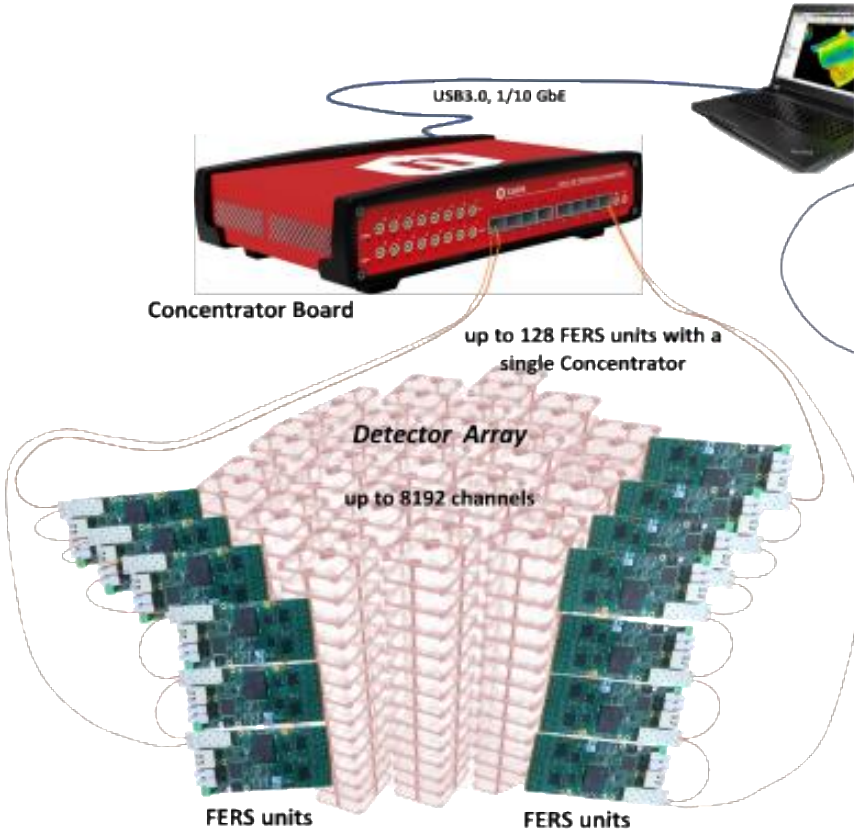
Falkirk	**6th August, 2018**	
Place of Issue	Date of Issue	Prof. Ralf Kaiser, CEO

[1] Safety test report 4988TR1 notes that the Olson 4-way mains distribution socket currently has documentation relating to an older standard.



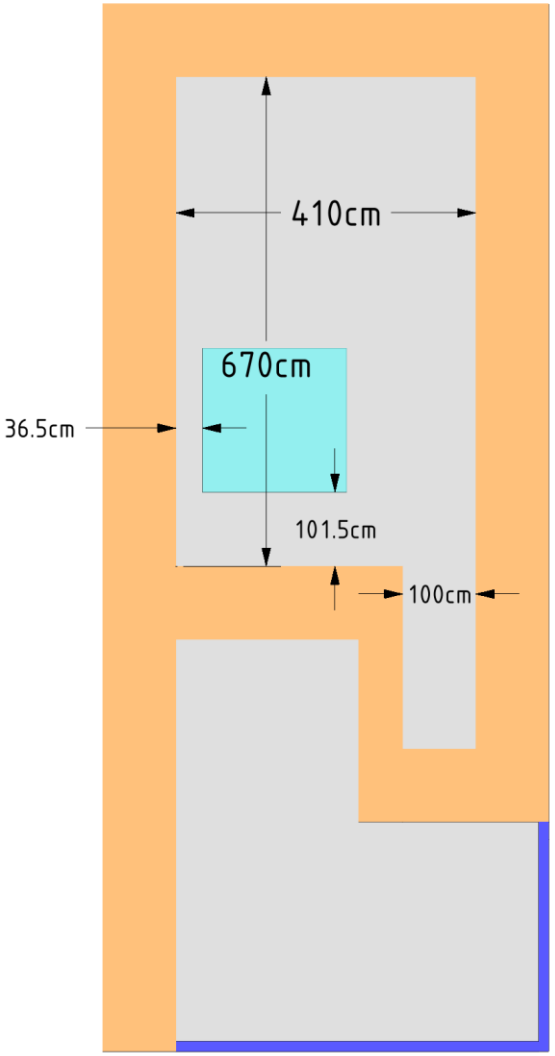
MSSS Waste - Radiation Environment

- **Significant flux of low-energy gammas.**
- **Currently evaluating detector response and methods of dealing with the background.**



CAEN FERS System
https://arxiv.org/pdf/2010.15688.pdf

Plant Requirements – Example Cell



Control system

Operator Training

Power requirements

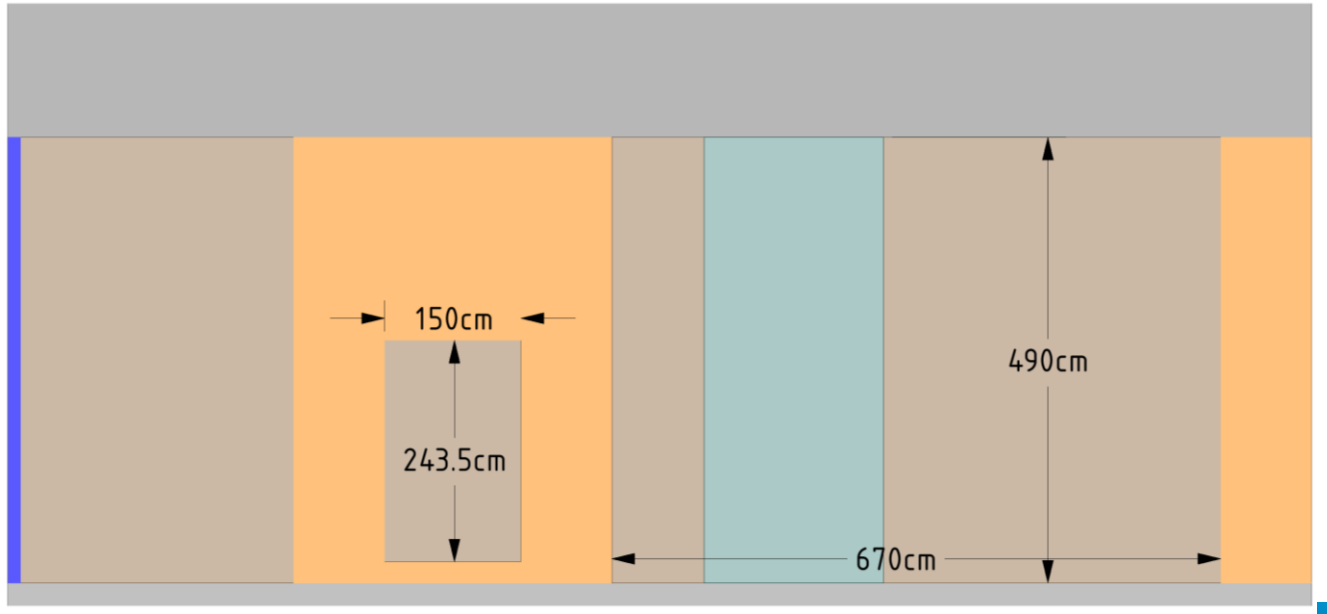
Data analysis

Cabling and wall penetrations

Maintenance

Heat load and cooling

Throughput



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Conclusions and Summary

- **Waste characterisation requirements can be more demanding than just high-Z detection and location.**
- **Muon imaging is a good candidate technology to meet some of these requirements and help underpin regulatory compliance.**
- **The engineering requirements for deployment at waste processing plants are challenging…**
- **… but passive and robust detectors can meet these challenges.**

Backup – Preliminary Muon Flux Measurements