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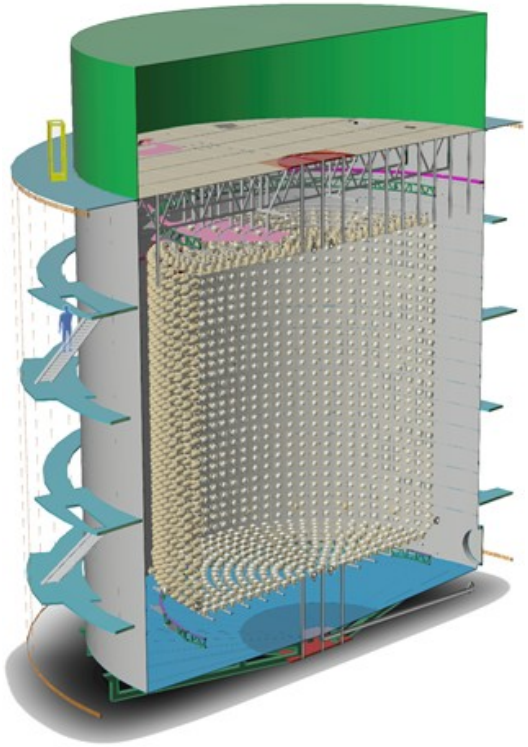
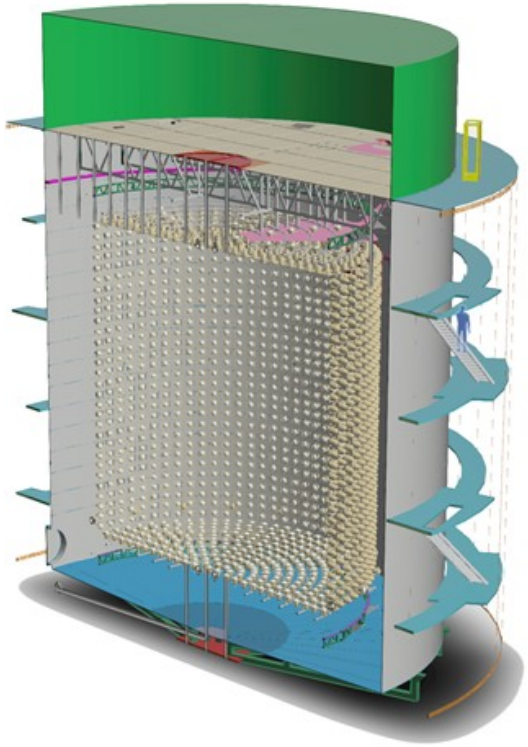
Remote Reactor Monitoring with the AIT-NEO Project





Matthew Malek
The University of Sheffield

UK-US Academic Network in
Nuclear Security & Nonproliferation Skills
27 April 2021

Motivation

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High Level Objective:

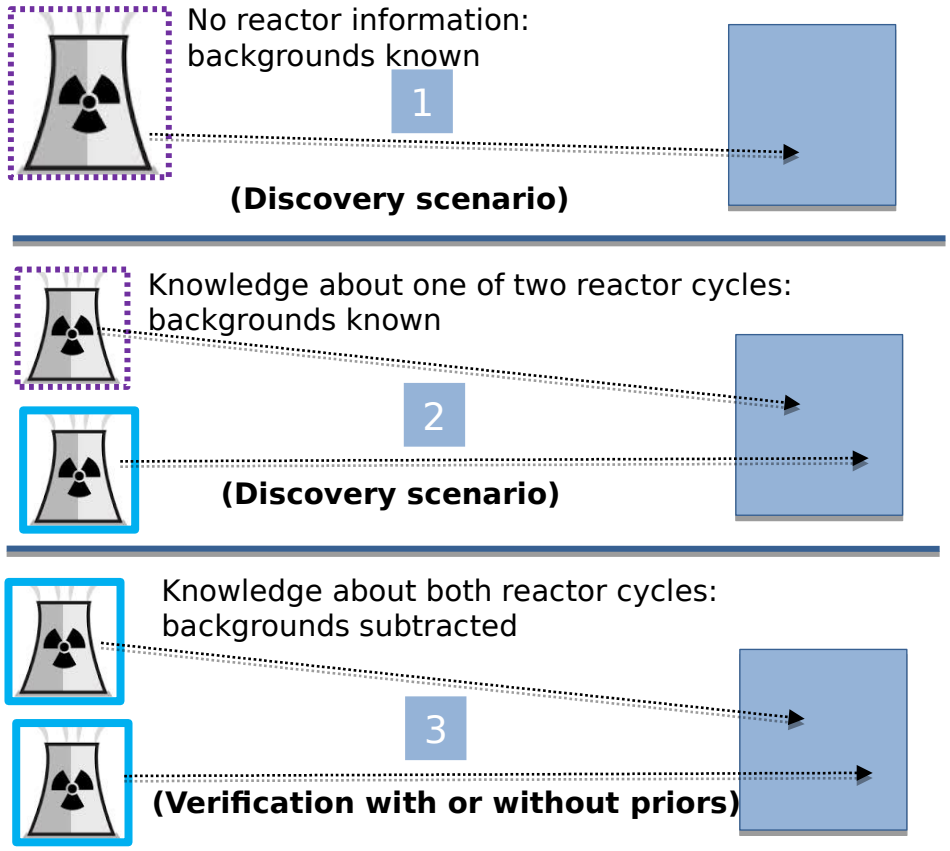
Deliver a world-class experimental facility to advance and demonstrate innovative applications of neutrino technologies for nuclear non-proliferation and science.

(Some) Project Goals:

1) Demonstrate the capability of remote fission reactor monitoring via detection of antineutrino emissions.

2) Prototype a scalable detector concept with eventual non-proliferation applications at both the **mid-field** (2 – 20 km) and the **far-field** (> 20 km) standoff distances.

3) Develop advanced instrumentation (*e.g.*, target materials, photosensors, etc.)



Additional non-proliferation use cases are being developed, in consultation with NNSA, STFC, and the non-proliferation community.

What Is AIT?

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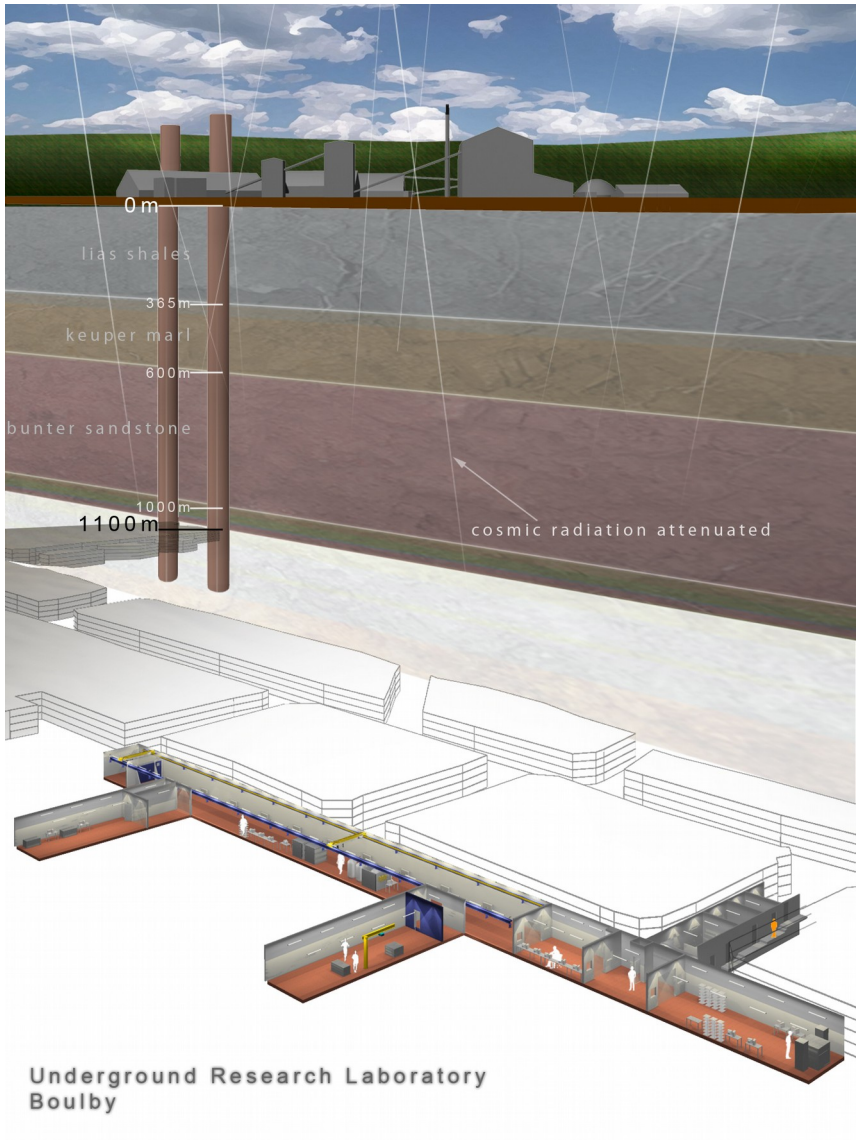
AIT = Advanced Instrumentation Testbed



AIT is being developed by NNSA (US), in partnership with STFC and MoD (UK), as a new facility that expands upon the STFC / Boulby Underground Laboratory.

AIT at a glance:

Depth:

1100 metres underground

2800 metres water equivalent

10^{-6} cosmic ray muon attenuation

New cavern required:

- 22m height
- 20m roof beam
- 18m diameter (lined)

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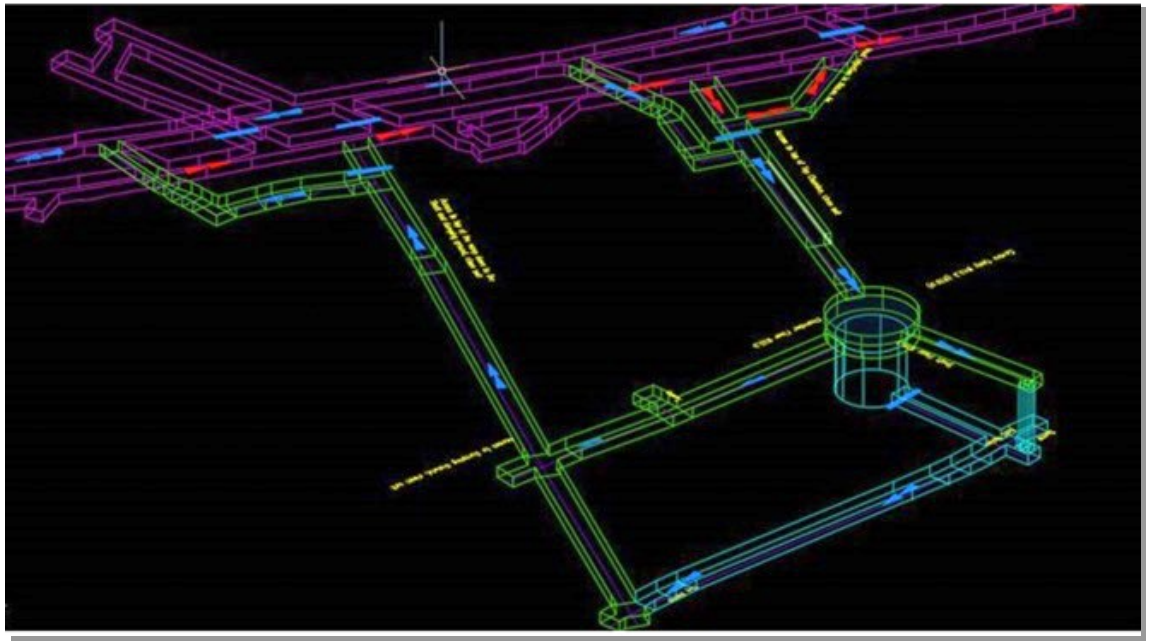
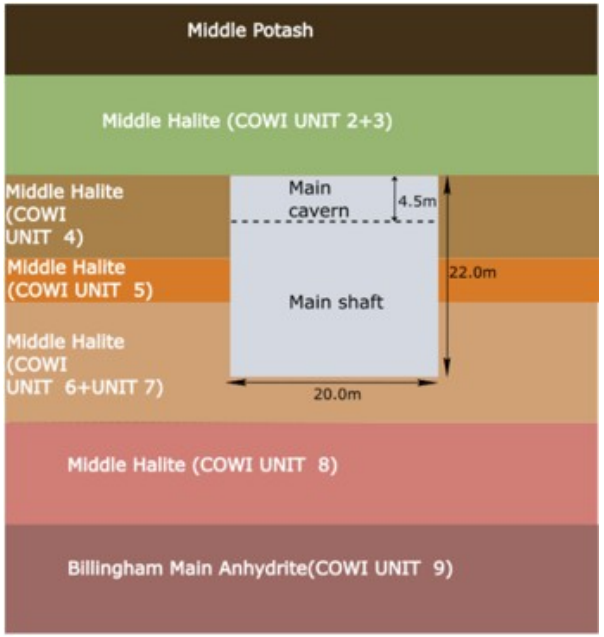
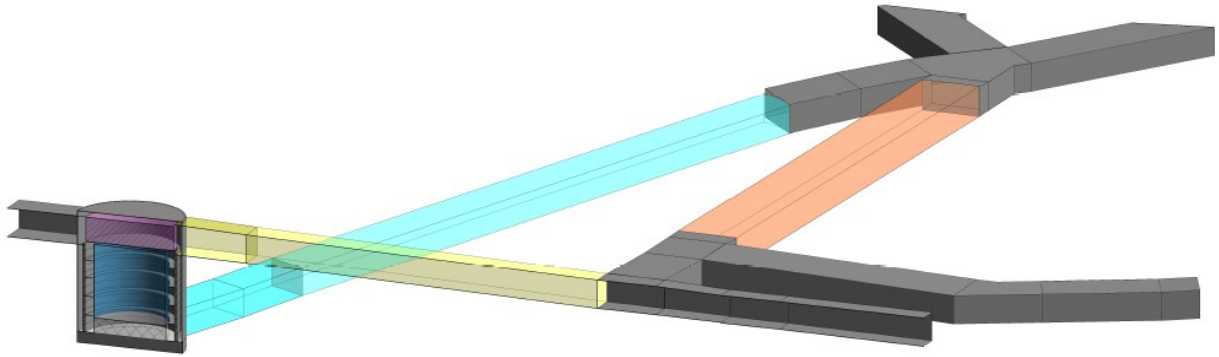




AIT is currently at a preliminary stage of design. These figures are intended for illustrative purposes only; the final facility design may look different.



Proximity to Reactors

EDF Hartlepool Nuclear Plant

EDF Hartlepool at a glance:

Dual-core advanced gas-cooled reactors (AGR); 1550 MW_{th} per core

- Can look for flux difference between 1-core & 2-core operation
- Potential for future complementary work with near-field detection

EDF Heysham complex very similar: Quad-core @ 148 km standoff

Hartlepool Signal @ Boulby

EDF Hartlepool provides 84% of total $\bar{\nu}_e$ flux @ Boulby

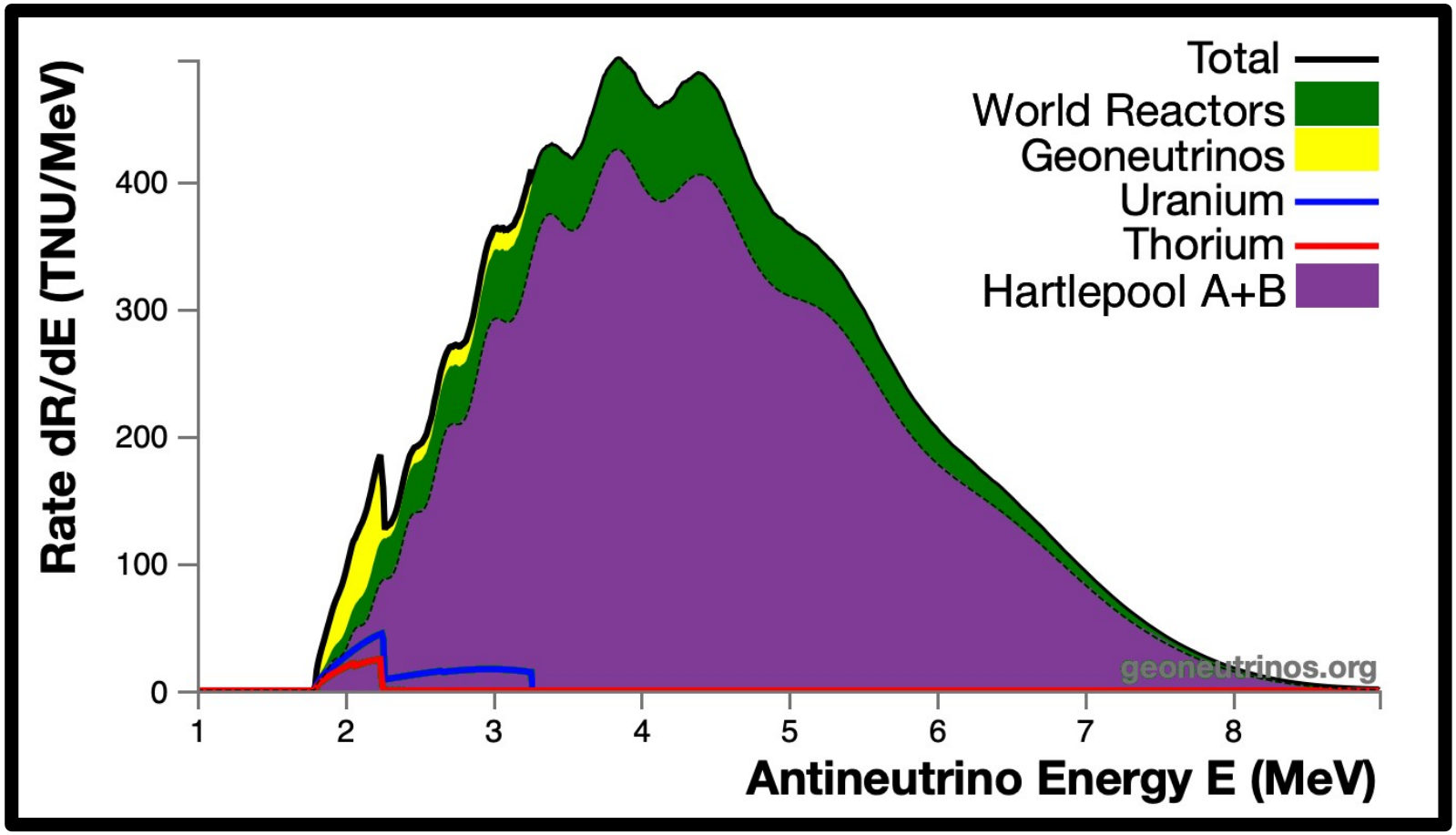


Figure produced by Geoneutrinos.org

Potential to determine reactor ranging via oscillation signature.

→ Stretch goal for AIT-NEO

What is NEO?

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NEO = Neutino Experiment One

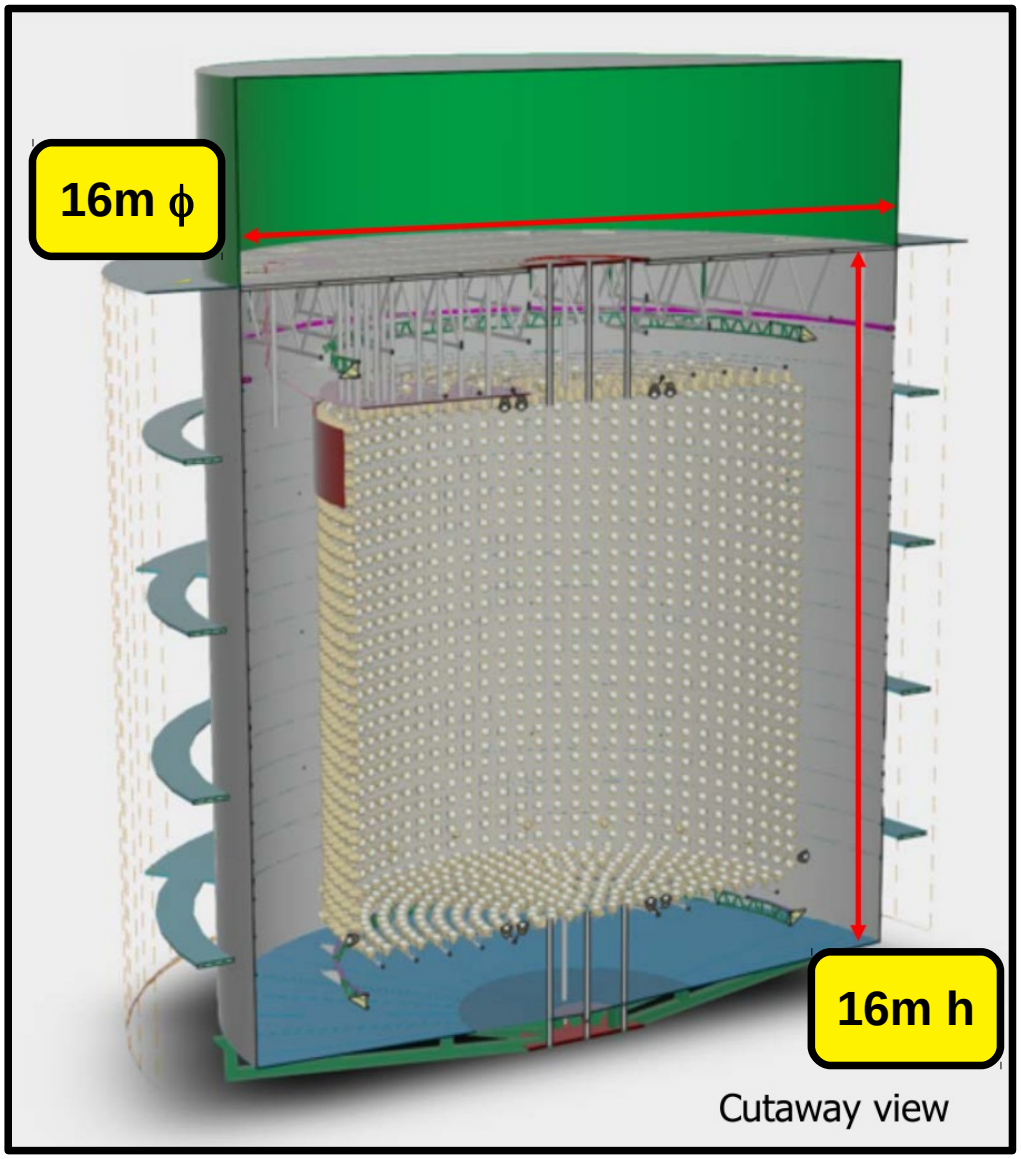
NEO at a glance:

- **Total mass:** 3.2 kilotonnes
- **Fiducial mass:** > 1 kilotonne

- **Shielding:** ~2 metres water

- **Target material:**
Gadolinium loading in a water (or water-based) liquid medium.
→ See next slide

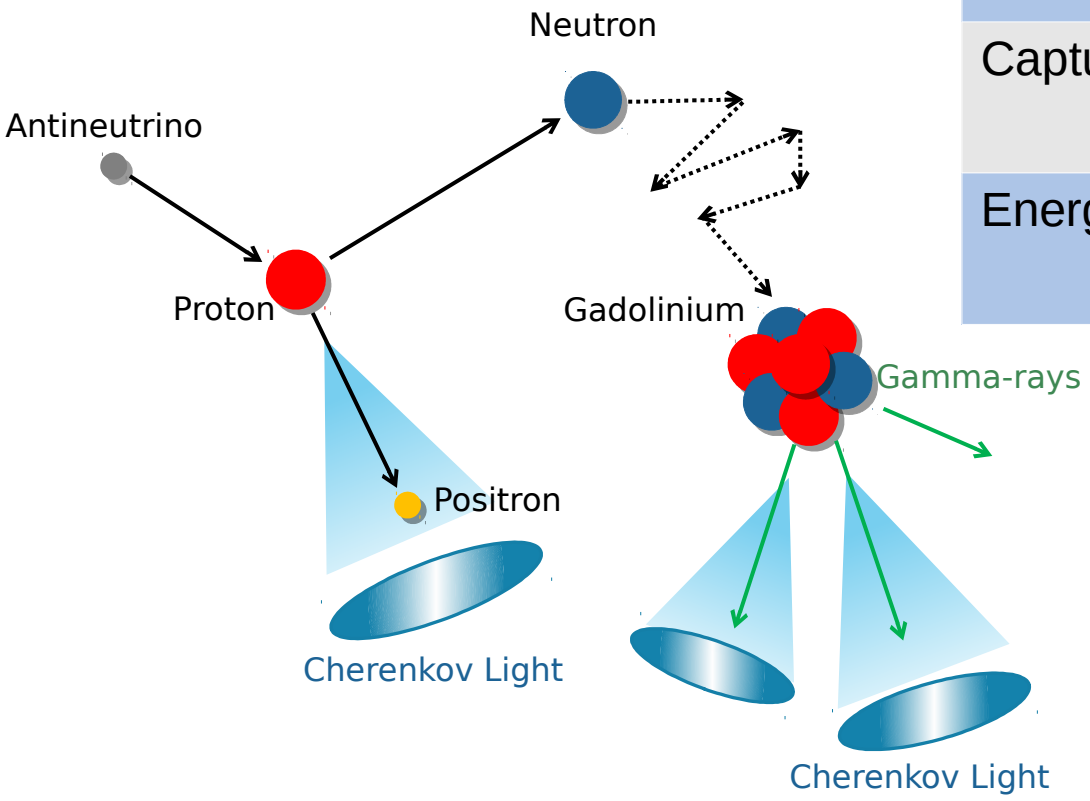
- **Instrumentation:**
10% – 15% photocoverage achieved via 10” Hamamatsu PMTs with:
  – high quantum efficiency
  – low radioactive backgrounds



Antineutrino Detection

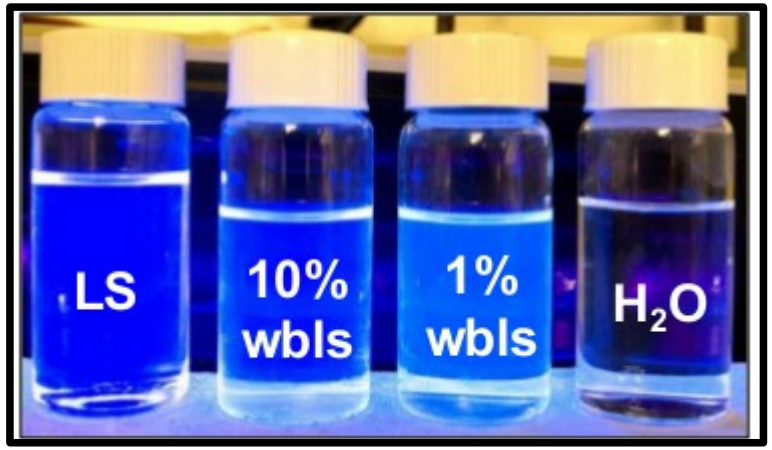
Tag antineutrinos via coincidence between positron and neutron from inverse beta decay:

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

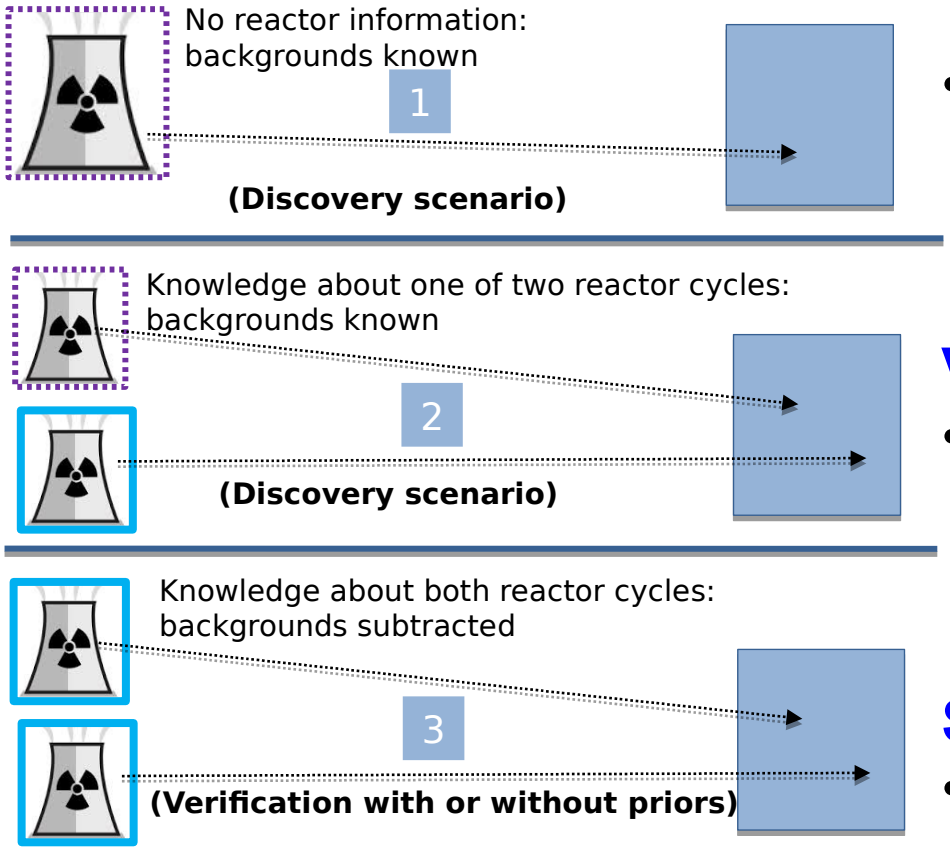


	H_2O	H_2O + 0.1% Gd
Thermal capture cross section (σ)	~ 0.3 barns	~49,000 barns
Capture time (τ)	~220 μsec	~30 μsec
Energy released	2.2 MeV (single γ)	~8 MeV (γ cascade)

Also investigating the use of water-based liquid scintillator (WbLS)



Non-Proliferation Use Cases



Discovery Scenarios (Hartlepool):

- **Case 1:** Determine whether any reactor is present.
- **Case 2:** Knowing that one reactor is operating, determine that a second reactor has turned on.

Verification Scenario (Hartlepool):

- **Case 3:** Confirm operational status with or without prior knowledge of both reactor cycles.

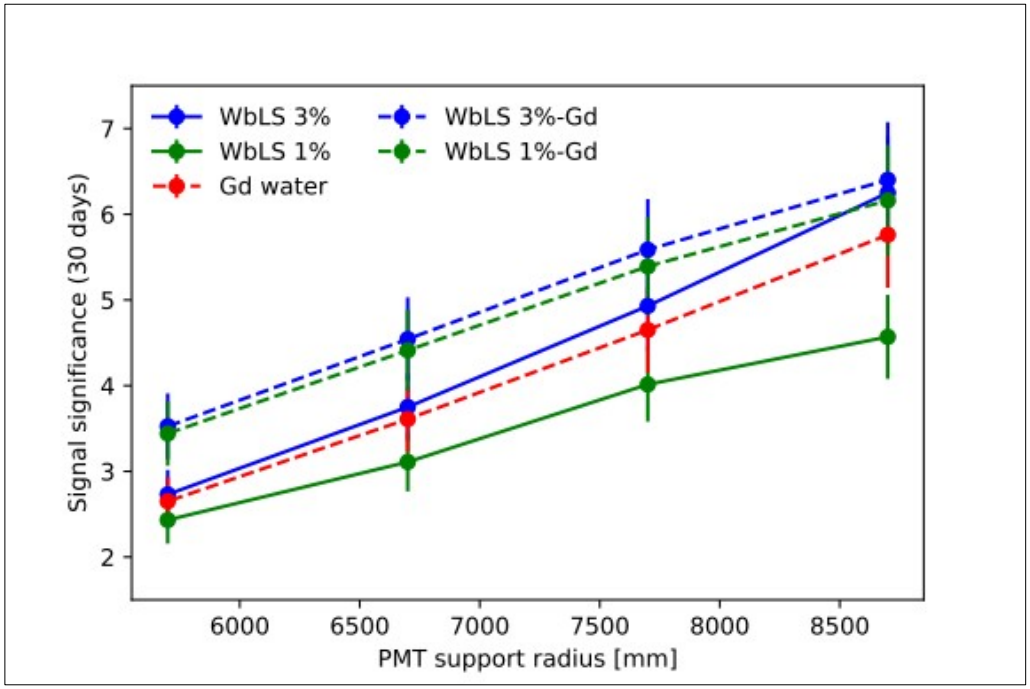
Stretch Goals:

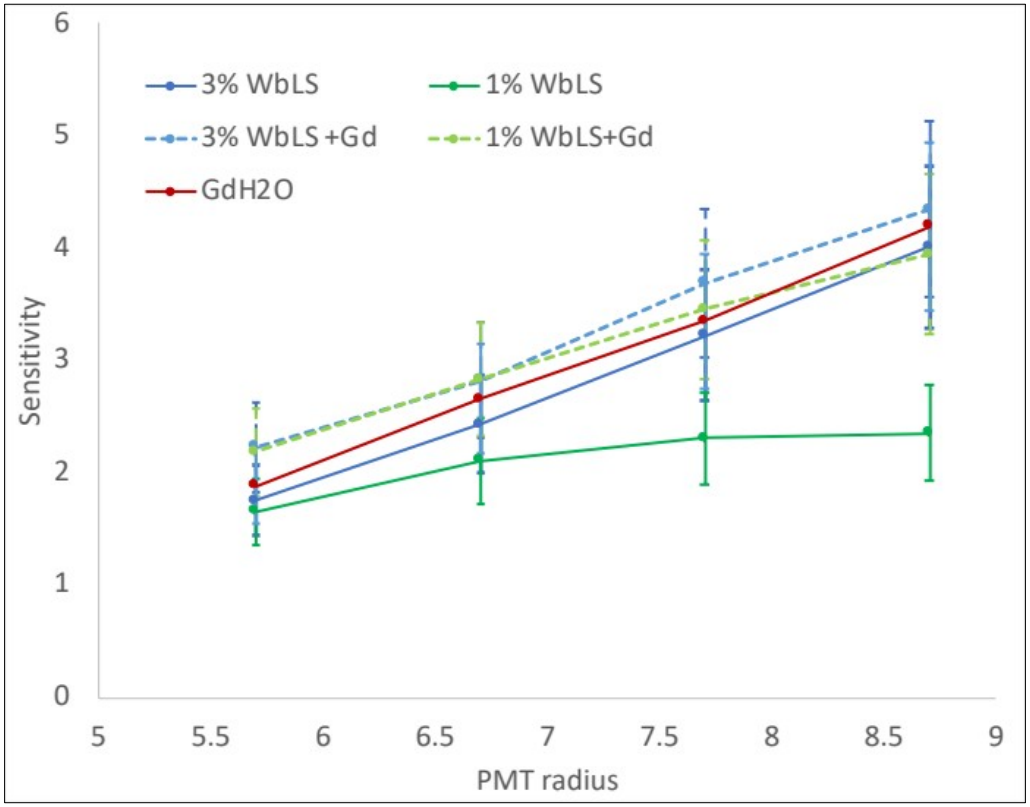
- **Reactor ranging (Hartlepool):** Use neutrino oscillation signature to determine range.
- **Distant reactors (Heysham):** Discovery Case 1 for longer standoff distances.

Reactor Discovery Sensitivity

Primary Goal: Hartlepool
26 km standoff; 2 x 1.5 GW_{th} cores

Stretch Goal: Heysham
148 km standoff; 4 x 1.5 GW_{th} core





Results:
Significance shown for 30 days; should be possible to reach 3σ within 1 – 2 months dwell time.

Results:
Significance shown for 1 year; achieving 3σ may take longer

Conclusions

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- **Antineutrino detectors may provide valuable nu tools for non-intrusive monitoring and exclusion goals at mid-field and far-field standoff distances.**
- **The Advanced Instrumentation Testbed project is a US / UK initiative to construct a new facility at the STFC Boulby Underground Laboratory.**
- **Neutrino Experiment One will be the first AIT experiment, and shall serve as a technology demonstrator for a variety of non-proliferation use cases.**
- **AIT will also be a testbed for innovation, advancing and demonstrating technologies and instrumentation for neutrino detection and analysis. Examples include:**
  - Novel target materials, such as water-based liquid scintillator,
  - Advanced photosensors, such as Large Area Picosecond Photo-Detectors and others
- **AIT-NEO will also promote engagement between the non-proliferation and fundamental physics communities, promote collaboration between the US & the UK, and attract and train early career scientists & engineers to increase scientific & non-proliferation.**

Thank you for listening!