Reactor Monitoring through Anti-Neutrinos

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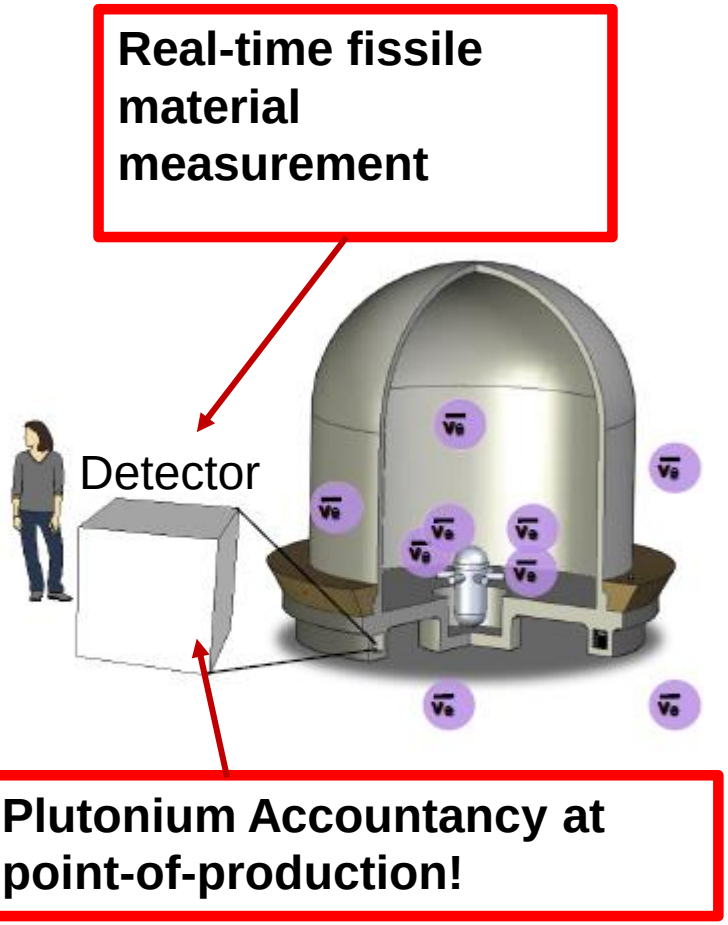
Nuclear Proliferation – A Global Challenge

- The IAEA applies safeguards in line with the Non-Proliferation Treaty
- Nuclear energy is on the rise
  - 400 new reactors in next 15 years
- IAEA is seeking innovation

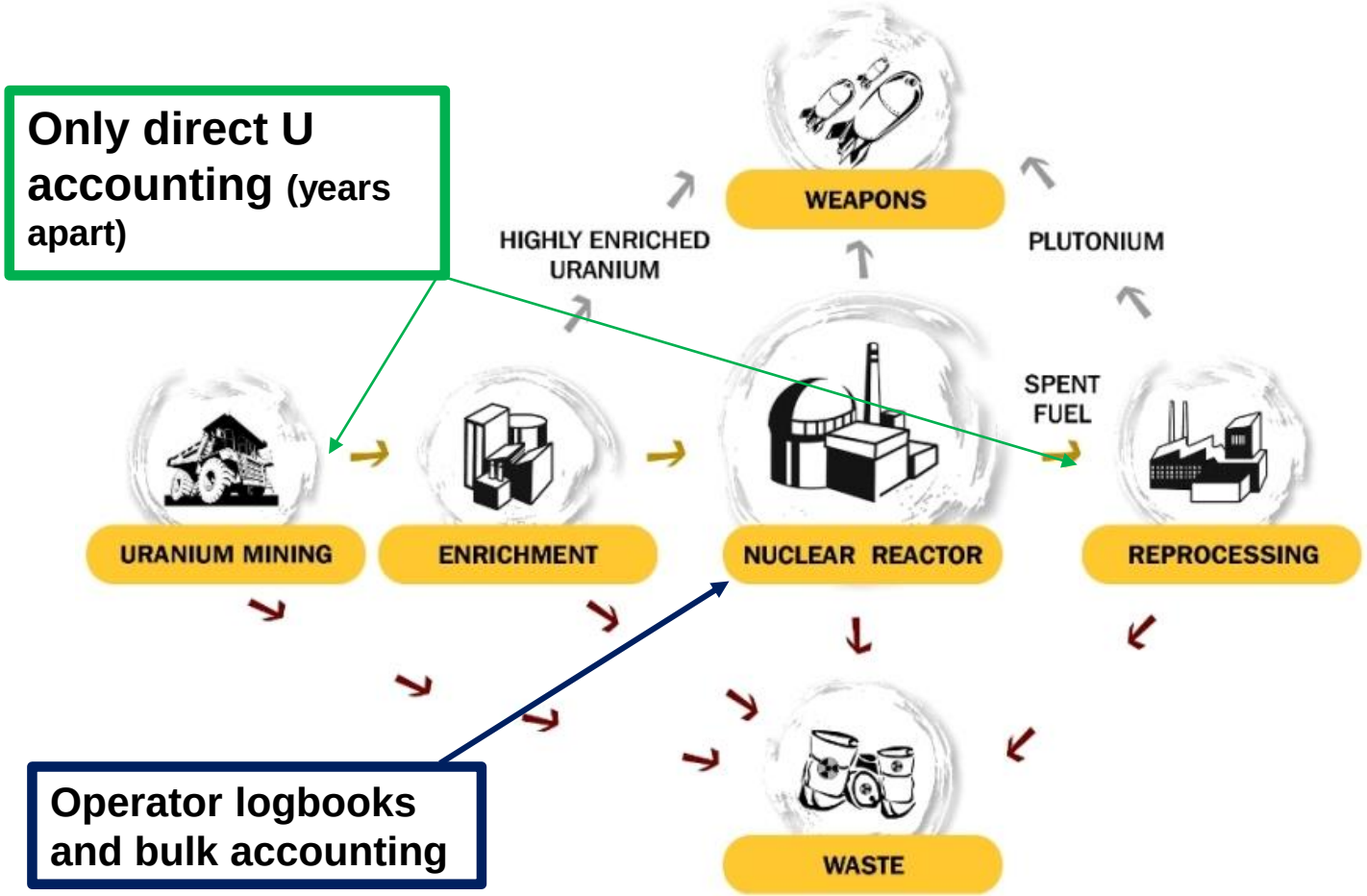
States known to posses nuclear weapons

Anti-neutrinos and Nuclear Non-Proliferation

- Accounting at production
- Non-intrusive
- Neutrinos cannot be Shielded



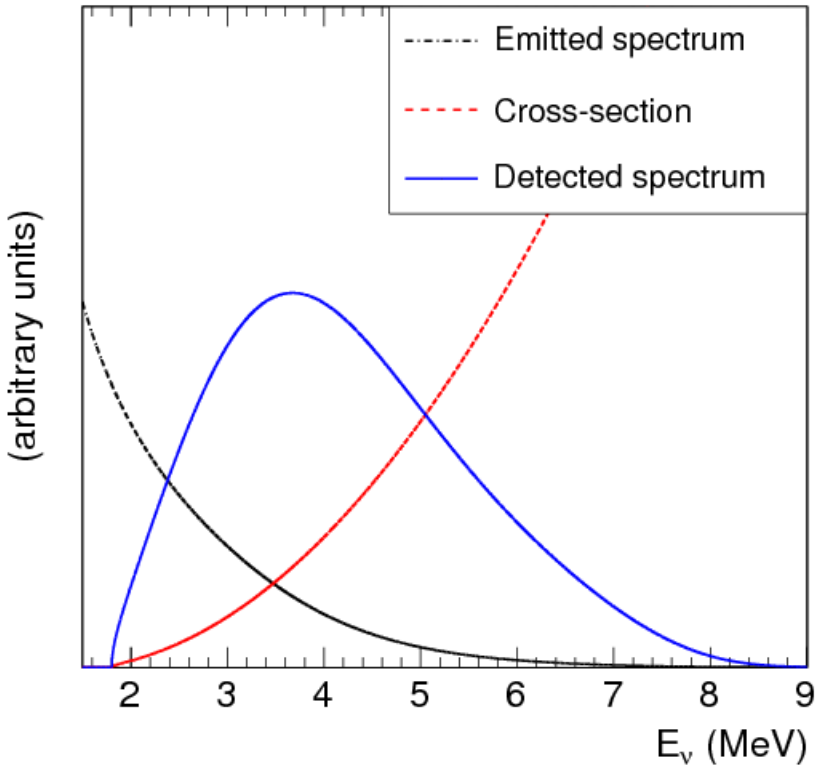
Anti-neutrinos and Nuclear Non-Proliferation



Reactor Anti-Neutrinos

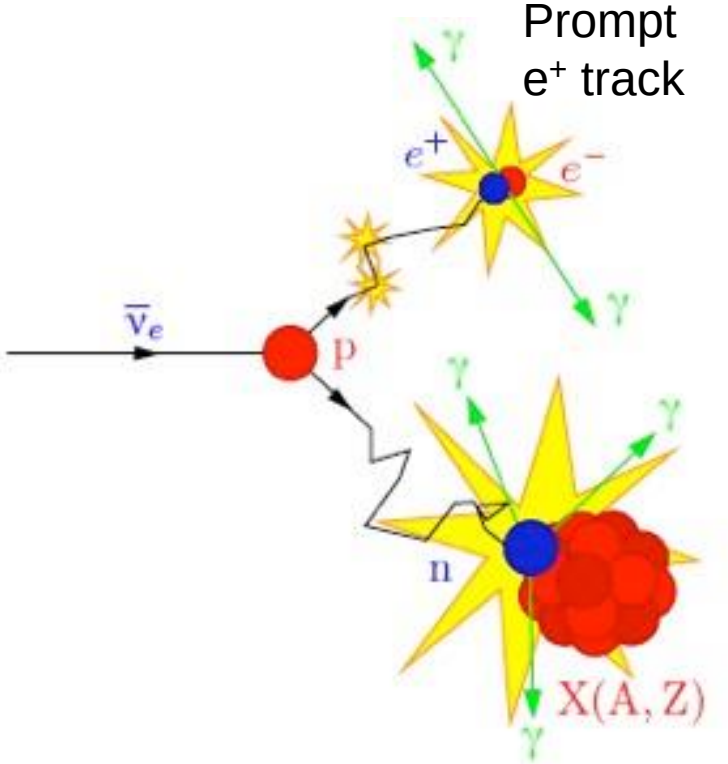
- From fission fragment β-decay
- 10^{21} ν /s
- Isotropic emission

Energy spectrum plot



Detecting Anti-Neutrinos

- Via Inverse Beta-Decay
- Rely on delayed coincidence between fast component from positron
- And a slow component from a delayed Neutron Capture



Proof-of-concept demonstrated

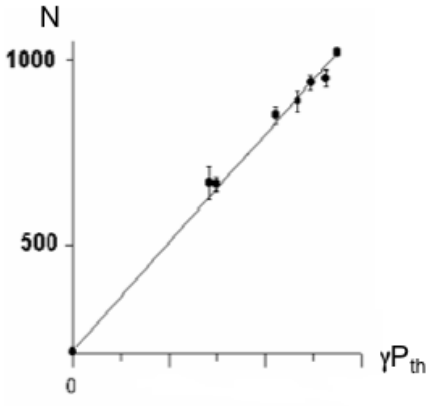
- Pioneered in Russia in the 80's
- LLNL / Sandia (US)

Remarkable monitoring of reactor operation.

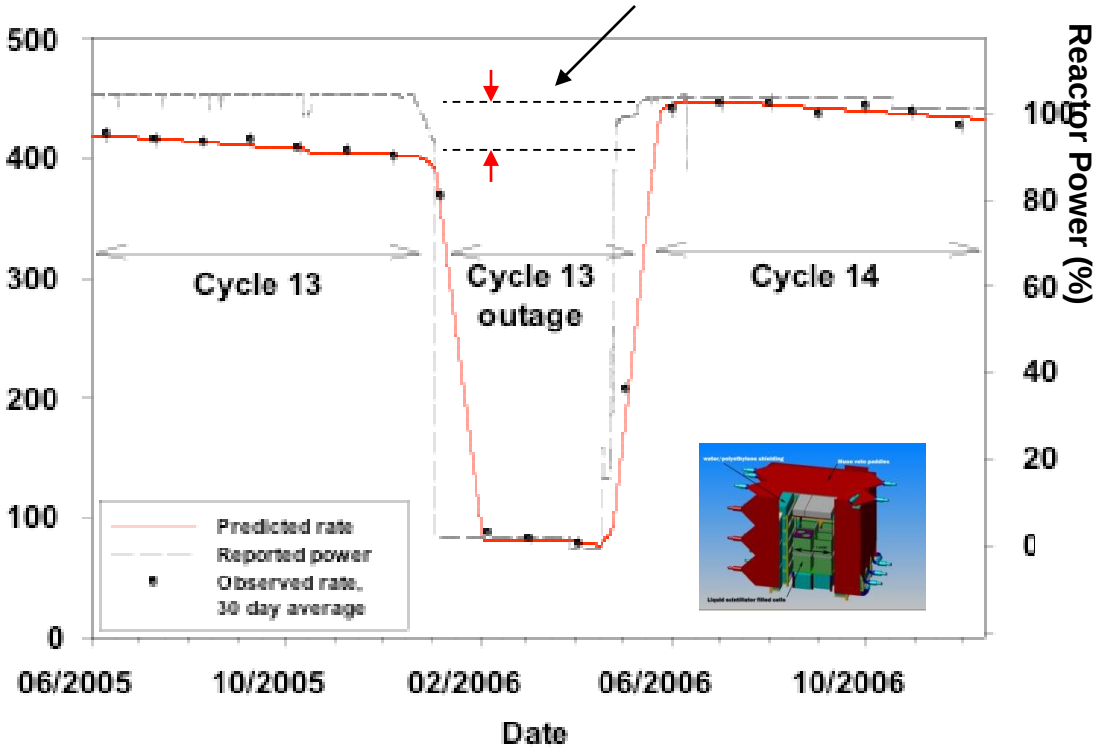
~450 evts/day after cuts

- Deployed 24m from the core
- 20 mwe overburden
- 3 GW_{th} power

Need to improve in choice of technology



Removal of 250 kg ^{239}Pu, replacement with 1.5 tons of fresh ^{235}U fuel



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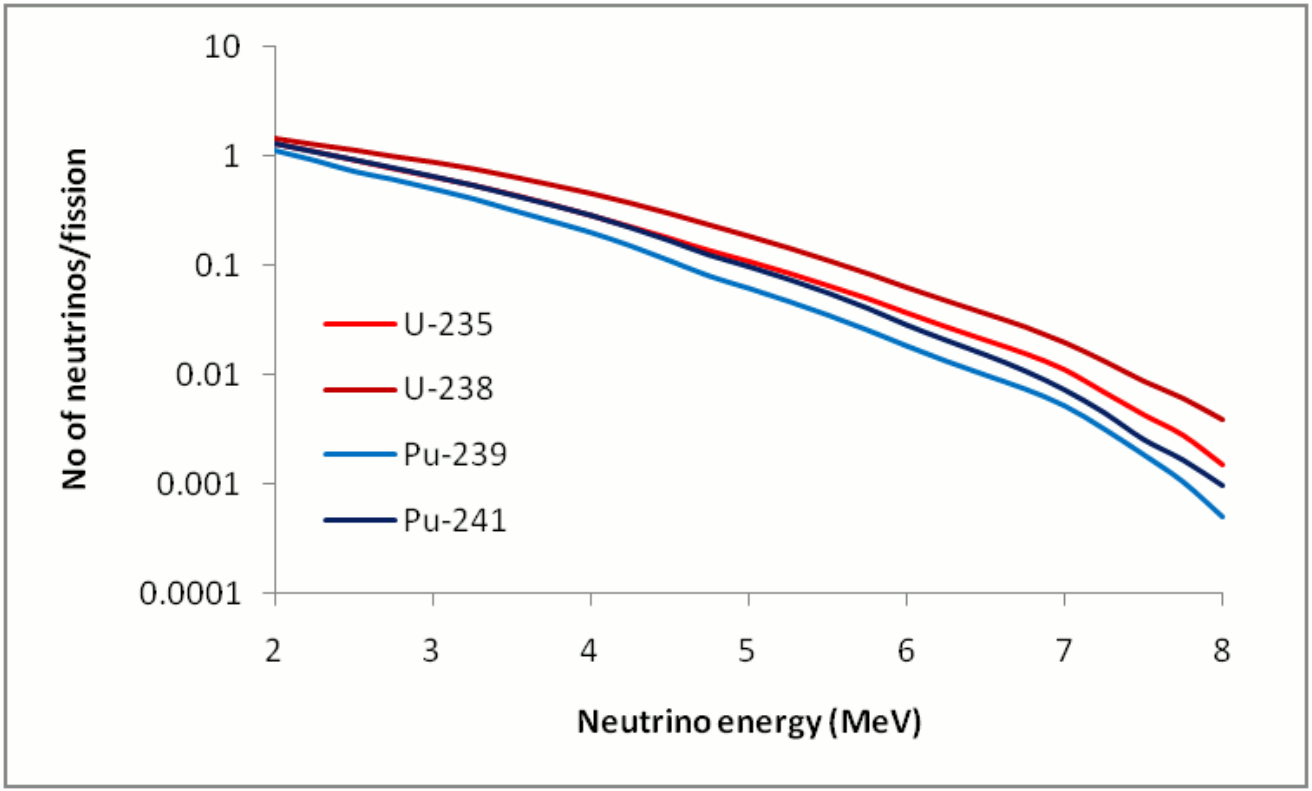
Spectrum by fission nuclei



T.A. Mueller et al., arXiv hep-ex/1101.2663v3

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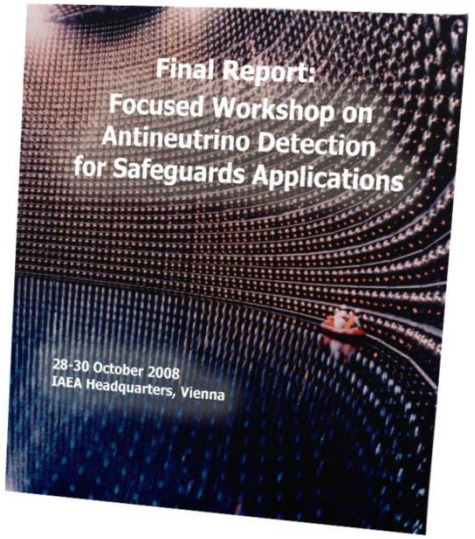
IAEA Recommendations



Next Generation Designs focus:

- Shipper-receiver differences,
- Bulk Process/ Online Refuel Reactor Verification
- Research reactor power
- Safeguards by Design, Integrated Safeguards
- Aboveground Detection
- Cheaper
- Manufactured from Safeguards friendly material

Cf 10 MW produces 3kg of P_{239} / Year 8 kg is useful

Recommendation from A. Bernstein @ LLNL:

$1/r^2$ + Power Output are crucial i.e. Get as close as you can to the highest power reactor

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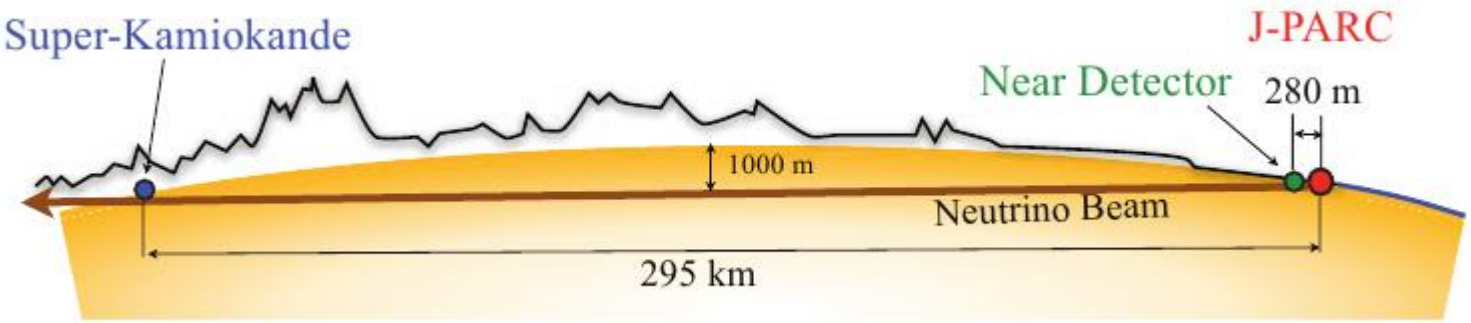
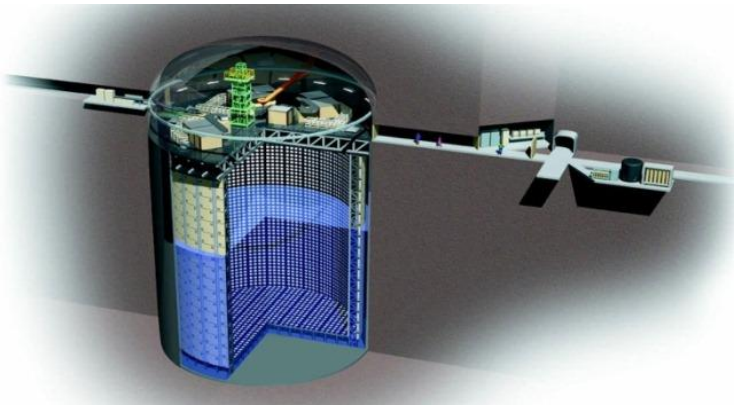
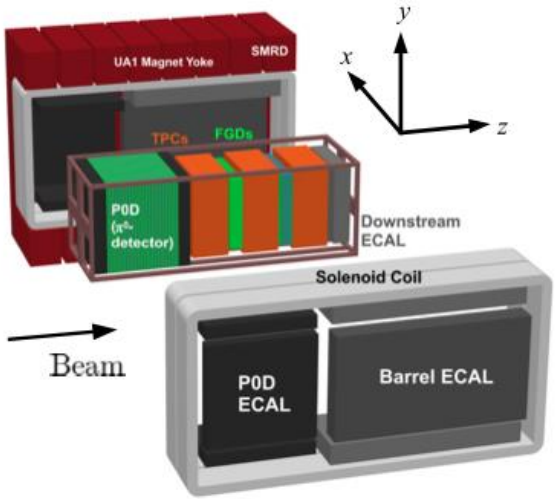
"Final Report: Focused Workshop on Antineutrino Detection for Safeguards Applications", IAEA Headquarters, Vienna Austria, 2008.

The T2K Experiment







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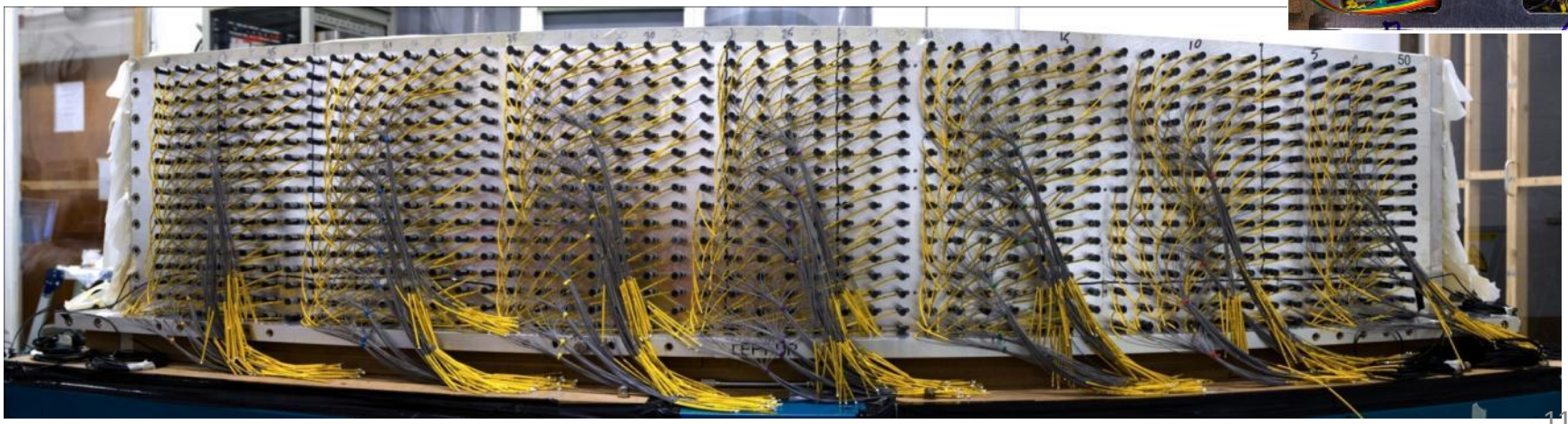
The T2K Near Detector Barrel ECal

•Designed and built at Liverpool University and Daresbury Laboratory – Shipped whole to Japan!

•State of the art neutrino detection technology

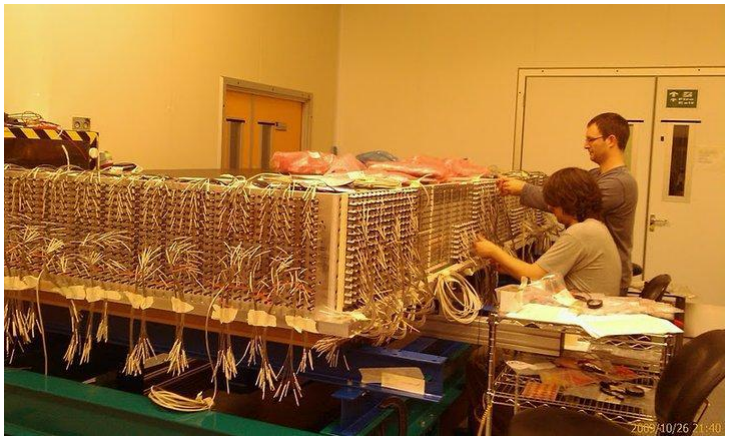
•Plastic Scintillator
•WLS Fibre
•MPPC Si-PMs – First Large Scale Use

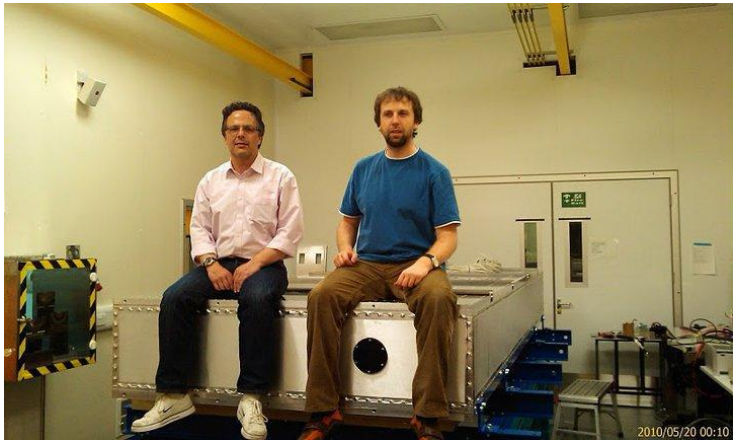
•Earthquake proof!

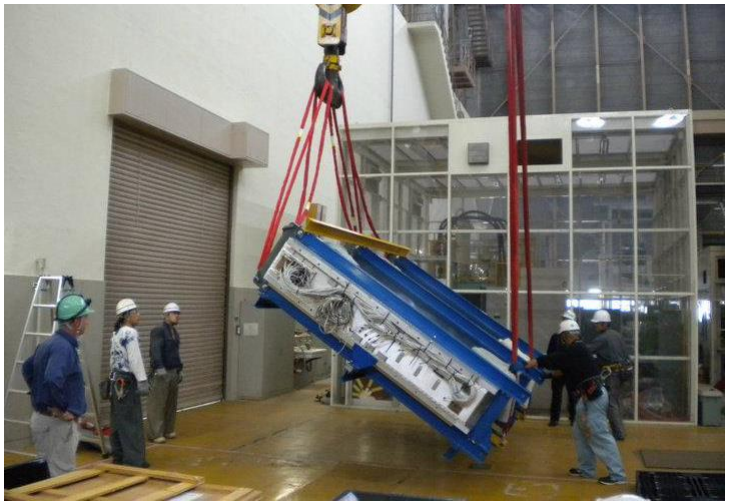


An assembled ECal Module

Barrel ECal Build at Liverpool







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A Safeguards Friendly Detector

Non-volatile/toxic/corrosive	Plastic Scintillator	✓
Non-liquid	Plastic Scintillator	✓
Easy operation	Low voltage MPPCs, simple interface	✓
Cheap	Extruded Plastic, MPPCs	✓
Transportable	Liverpool -> Wylfa in ISO container	✓
Robust	T2K ECal design, MPPCs	✓
Above ground operation	In-built cosmic ray veto	✓
Deployable in ISO container	Deployed in container for field-test	✓

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Applying ND280-ECal Technology

- Spin off from T2K
  - Exploit man years of development
  - Robust transportable design
  - Earthquake resistant technology

- System constructed and tested in laboratory at Liverpool
  - Modified ECal design
  - T2K electronics
  - Cosmic ray veto system
  - Structural and cooling improvements

- Detector Vital Statistics
  - 3000 channels
  - 1 ton active mass

- The necessary introductions for site access were facilitated by DECC and ONR in response to an approach from the UK Support Programme to the IAEA*.

*The UK Support Programme is funded by the Department of Energy and Climate Change, to provide technical support to the IAEA Department of Safeguards. The Programme is administered by NNL under contract to DECC.

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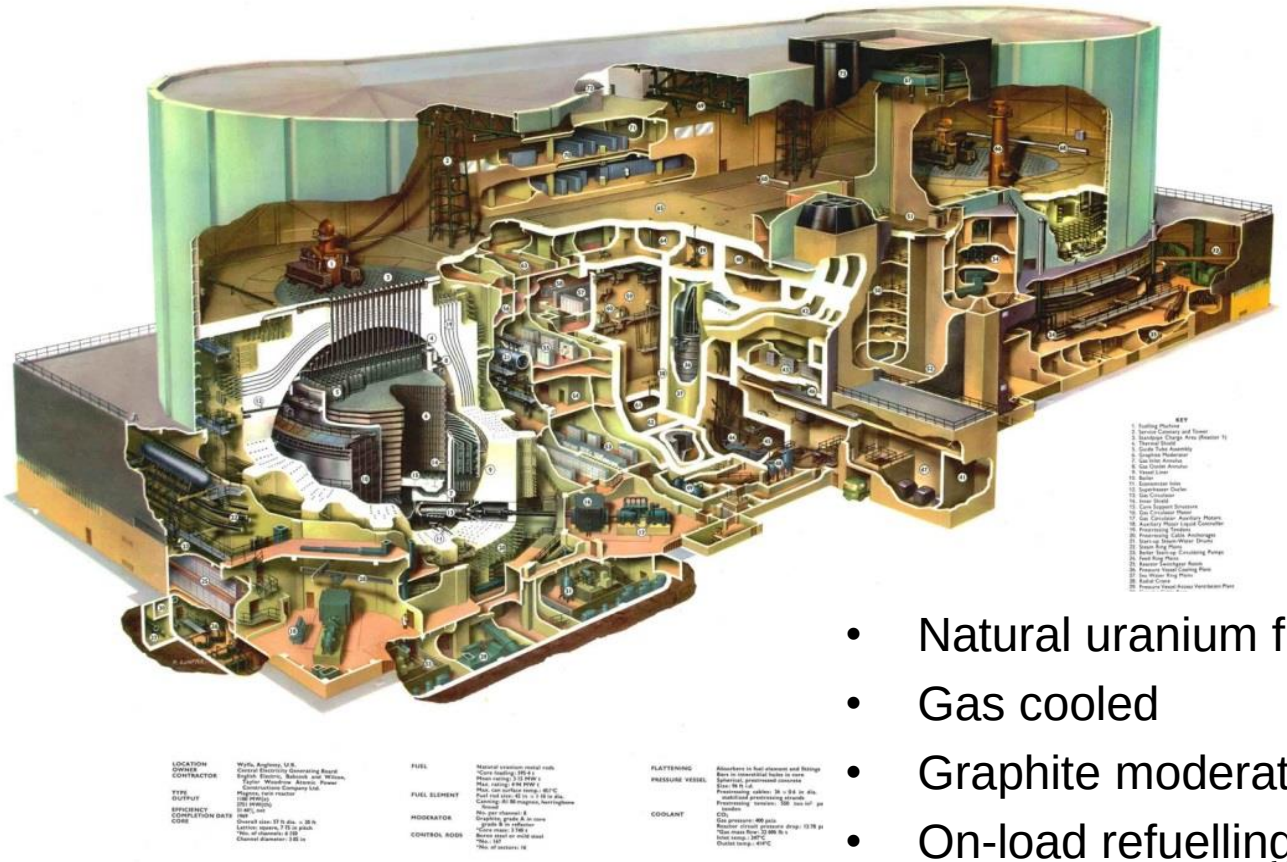
Wylfa Power Station – Last of the Magnox

Reactor 2 – Shutdown 2012

Reactor 1 – Operating until 12/2015



- Natural uranium fuel
- Gas cooled
- Graphite moderation
- On-load refuelling!

Image from :http://econtent.unm.edu/cdm/singleitem/collection/nuceng/id/41/rec/48

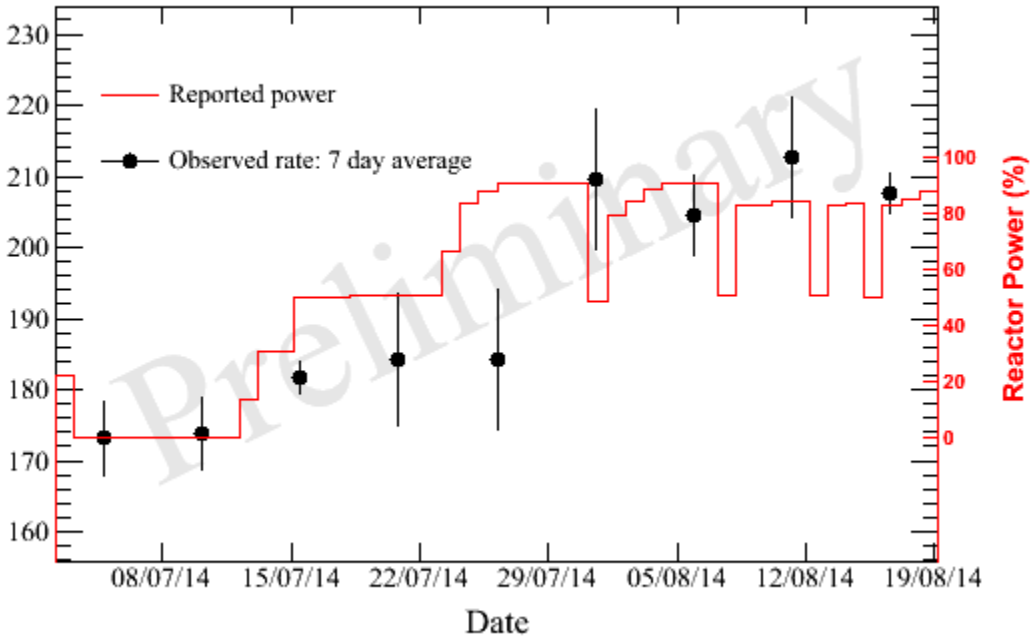
Field Test Deployment – Wylfa Power Station

Deployment Negotiated via UK support program to the IAEA

Reactor Start-up July 2014

~210 evts/day after cuts

- Deployed ~60 m from the core aboveground
- 1.6 GW_{th} power
- Even better if closer
  - c.f. $1/r^2$ dependence on flux
- Only just started!



Summary

- A safeguards friendly anti-neutrino detector has been constructed at University of Liverpool
  - Direct Technology from fundamental research!
- Shipped in a ISO shipping container to Wylfa power station, UK for field test
  - Drop and plug in design – highly transportable
  - Only requires power connection
- Support from UK support program for deployment and grant submission to research council and Innovate-UK
- Currently taking data
- Observation of Reactor on/off

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Containerisation

- Convert ISO 20ft shipping container into mobile lab
  - Power supply
  - Lighting
  - Power conditioning
  - Humidity/Temperature control
- Load detector, electronics & shielding
- Assembled & configured before dispatch
- Drive and Drop
  - Plug it in at power station
  - Ready for operations
- Whole transportable, ready to operate package!