Antineutrino Detection Use Case Overview

Patrick Huber

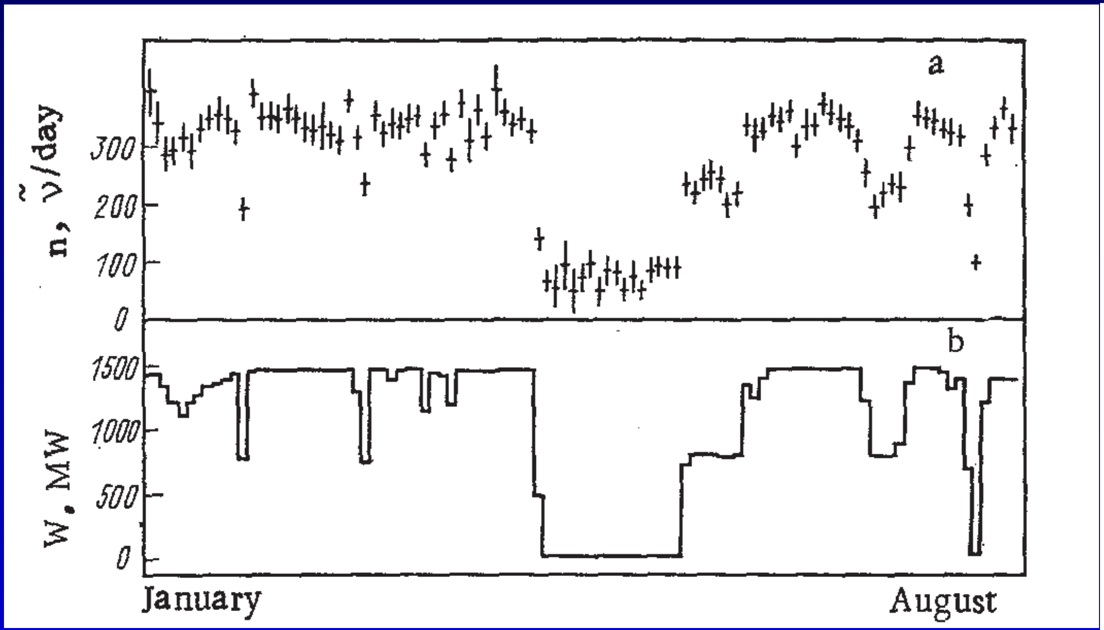
Center for Neutrino Physics – Virginia Tech

Applied Antineutrino Physics 2018
Lawrence Livermore National Laboratory
October 10–11, 2018

Reactor monitoring

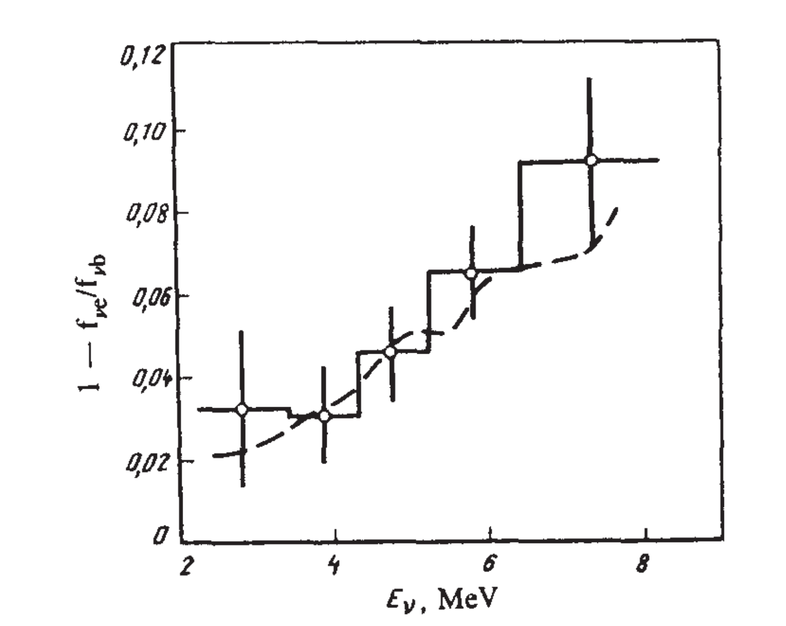
All done before. . . , also I gave a very similar talk at AAP2014.

Power monitoring



Korovkin *et al.*, 1988

Fuel burn-up



Klimov *et al.*, 1994

Recent results on fuel evolution Daya Bay, 2017; RENO, 2018; DANSS, 2018 confirm our general understanding!

The standard detector

4.3E29 target protons

No overburden

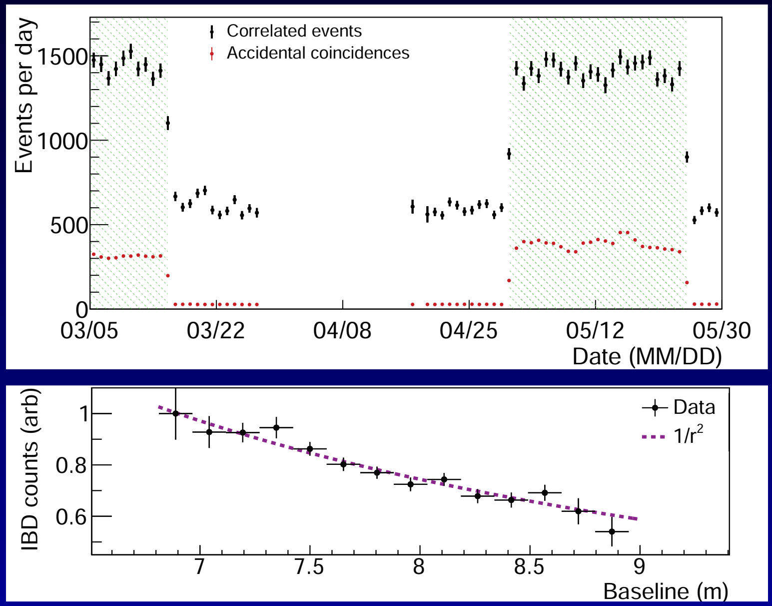
Irreducible cosmogenic background

How far have we come with respect to the blue box detector (BBD)?

reactor	fuel	moderator	power [MWth]	$t_{\rm SQ}$ [d]	standoff [m]
5MWe	NU	graphite	20	450	20
IR40	NU	D_20	40	300	20
ELWR	LEU	H_20	100	330	20

Recent advances

PROSPECT is a 2D segmented surface detector using Li-doped liquid scintillator. PSD to reject cosmogenic backgrounds, significant shielding.



PROSPECT, 2018

$$S = 711\left(\frac{m}{2\,[\mathrm{ton}]}\right)\left(\frac{P}{85\,[\mathrm{MWth}]}\right)\left(\frac{10\,[\mathrm{m}]}{L}\right)^2 \mathrm{d}^{-1}$$

$$B = \frac{711}{1.32}\left(\frac{m}{2\,[\mathrm{ton}]}\right) \mathrm{d}^{-1}$$

Reactor status – near-field

Simplest thing to ask: Is the reactor on or off?

I use time to 95% C.L. detection based on a PROSPECT-sized detector with PROSPECT background, purely rate-based.

5MWe	IR40	ELWR
1.2d	8 h	1.5 h

Time to detection at 95% C.L.

⇒Can be done with a xerox copy of PROSPECT.

NB – scaling from the CONUS presentation at Neutrino 2018 indicates 7.5 ton years of exposure.

Reactor status – mid-field

1950 U.S. Army topographic map

Yongbyon

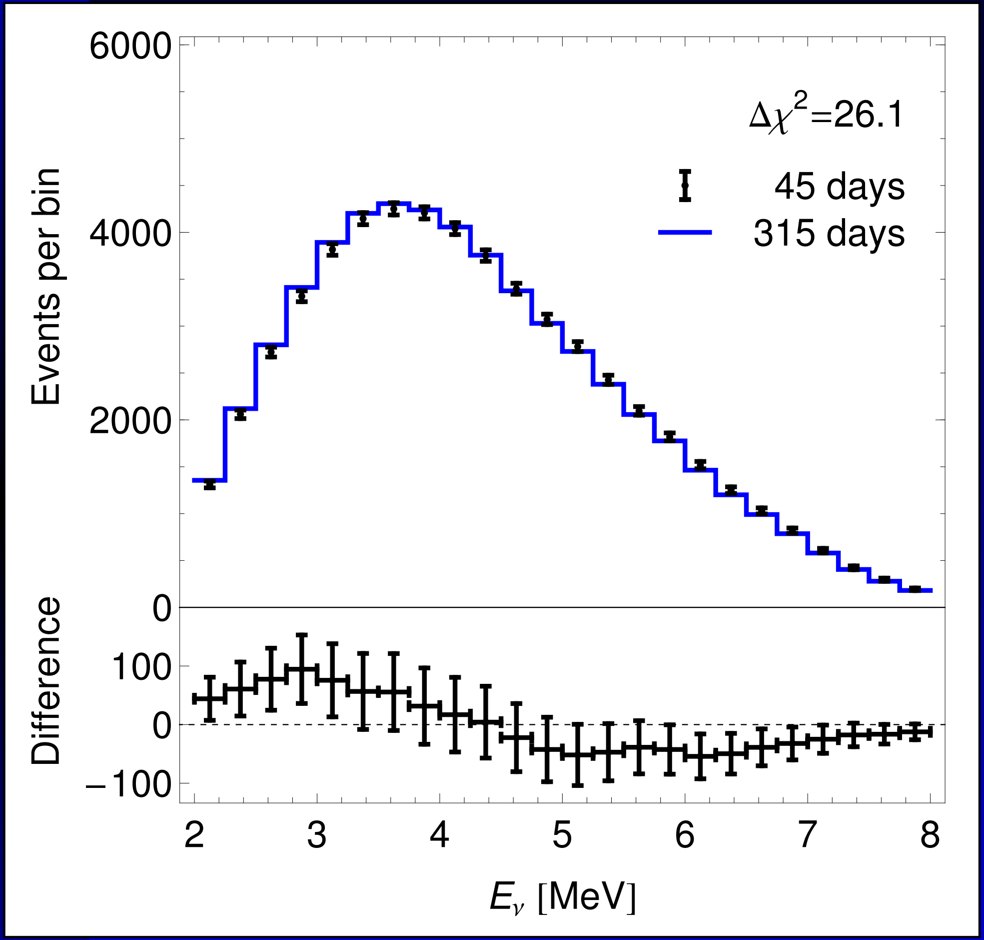
450 m mountain (Yak-san) at about 2 km from the reactors.

$\sim$ 300 m.w.e. overburden possible at around 1 km distance, similar to Daya Bay near detectors, scale from Daya Bay, 2012.

5MWe	ELWR
100 d	1 week

Time to detection at 95% C.L. for a 50 ton detector of Daya Bay-like detector performance.

Exploiting the energy spectrum



Comparing a reactor core at 45 days in the cycle to the same core at 315 days in the cycle

This is based on the blue box detector with zero background.

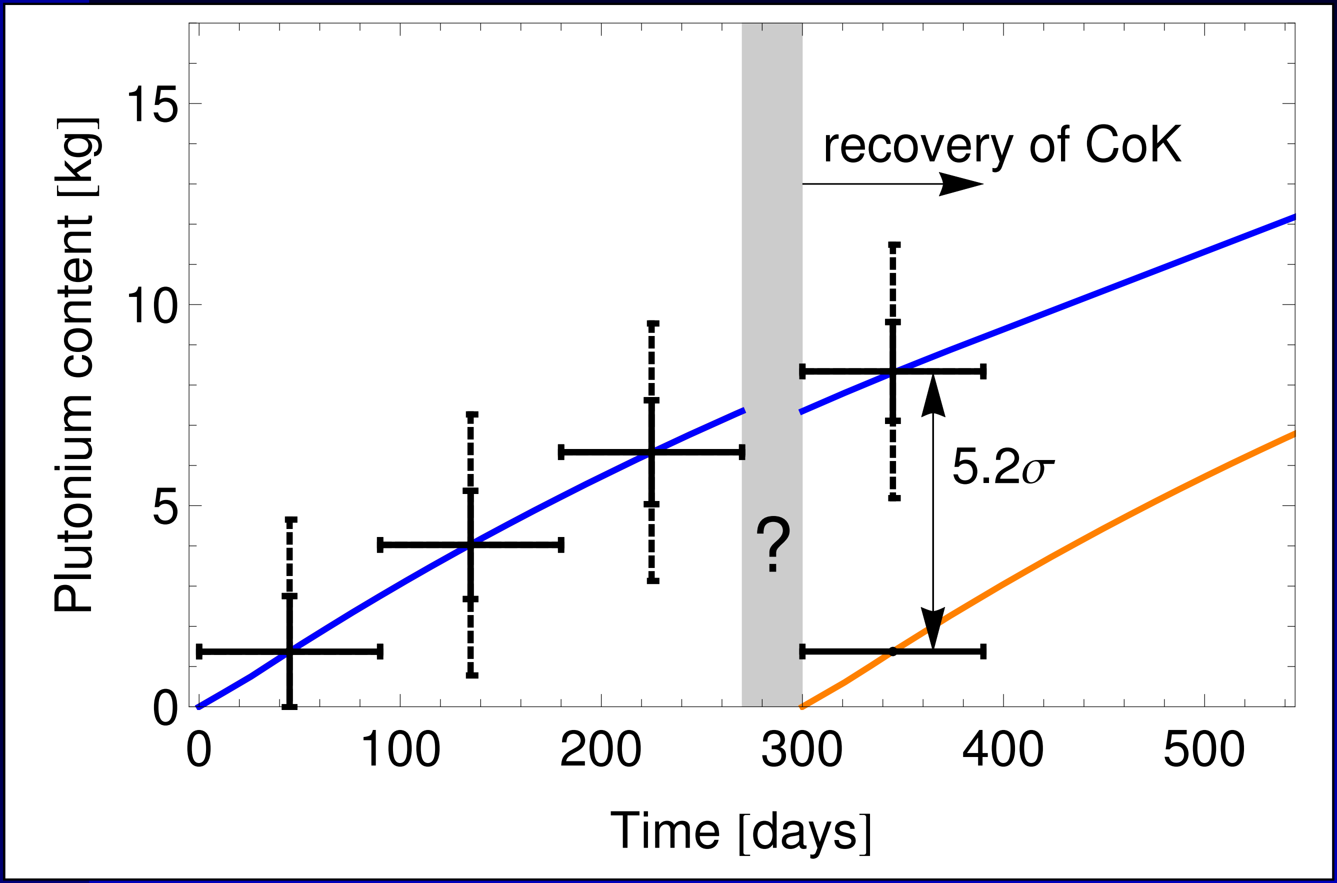
Key to the capability to restore the continuity of knowledge, unique to antineutrinos...

The N^{th} month scenario

- Full inspector access for N-1 month
- Reactor shutdown in the N^{th} month
- Loss of the continuity of knowledge in the N^{th} month

Reasons could range from technical glitch, over a diplomatic tensions (Twitter!) to full scale diversion – finding out which one is the true one can make the difference between peace and war.

IR40



270 days corresponds to 93% plutonium-239

An undeclared refueling can be detected at 90% C.L. within 7 days.

blue box detector, zero background

Reactor core swap detection

6 times PROSPECT $\simeq$ BBD, all times scale as m^{-1}.
BG level 1 corresponds to PROSPECT.
$t_{\rm SQ}$=300–450 days, time to make 8 kg plutonium.
Core swap at $t_{\rm SQ}$, gets easier for $t > t_{\rm SQ}$.

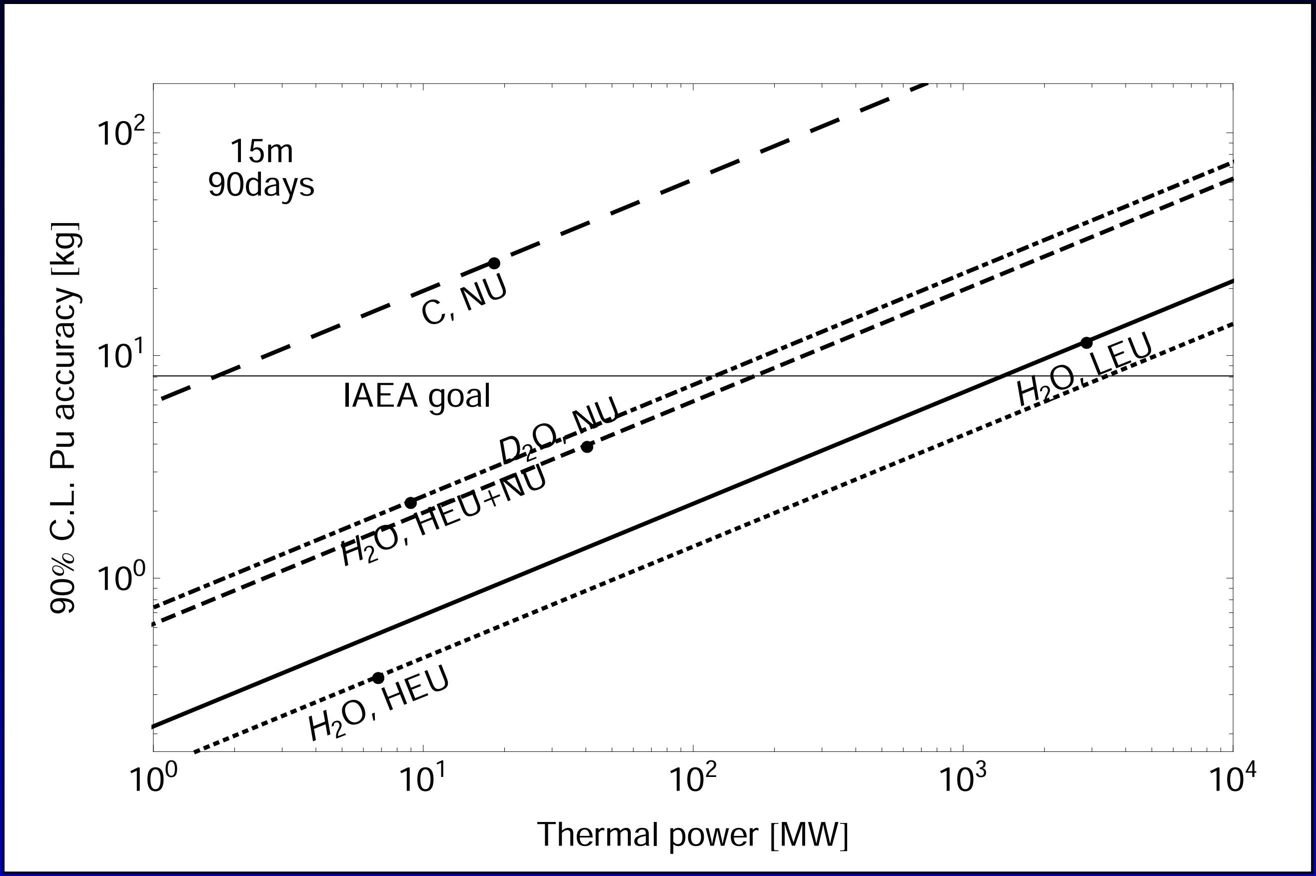
BG level	ELWR	IR40	5MWe
1	134	109	1154
0.5	83	59	830
0.2	56	30	637
0	45	16	527

Days to detection at 95% C.L.

This is based on a full spectral fit and uses the same analysis techniques as used in our prior DPRK and Iran papers.

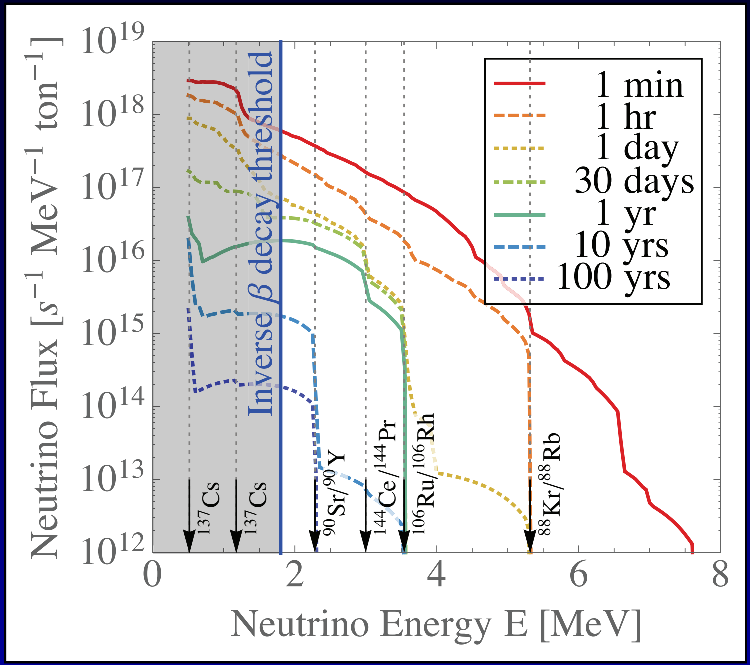
Modest background reduction yields $t < 90\,$d,
but not for the 5MWe.

Measuring in-core Pu mass



The amount of neutrinos from plutonium per unit mass of Pu depends on neutron flux density: graphite moderated, NU-fueled reactors have a very low neutron flux density.

Spent fuel detection



There is flux from spent fuel above IBD threshold.

Even decades after discharge.

Nearly all in strontium-90.

This would be very useful to find reprocessing wastes
→ nuclear archeology, endgame of denuclearization.

Challenges:

rates are low and all signatures are below 3 MeV.

DPRK example

8 kg of plutonium (1 SQ) leaves about 2 mol of strontium-90 in the waste stream.

55 IBD events in BBD at 10 m in one year.

BG	1 SQ	10 SQ	100 SQ
0.01	1.7	0.024	0.00089
0.1	17	0.18	0.0024
1	170	1.7	0.018

Years to detection at 95% C.L.

Technical summary

Antineutrino monitoring provides good security-relevant sensitivities for a a wide range of small to medium sized reactors.

For near-field, detector capability is existing, see PROSPECT talk**.**

3D segmented detectors combined with PSD could yield another factor 5–10 improvement in S/B see CHANDLER talk**.**

Can we ever do this with solid scintillator? see NuLAT talk.

Calibration of antineutrino yields crucial next step, **still**.

Safeguards summary

Antineutrino monitoring can **detect a core swap within a few months, even with demonstrated background levels.**

Antineutrino monitoring is non-intrusive and can be performed *in situ* at a running reactor.

IAEA safeguards (INFCIRC/153 and 540) probably not the right context.

Regional nuclear deals offer a better case.

References

V. Brdar, P. Huber, J. Kopp,
Phys. Rev. Appl. **8** (2017) 054050.

E. Christensen, P. Huber, P. Jaffke, T. Shea,
Phys. Rev. Lett. **113** (2014) 042503.

E. Christensen, P. Huber, P. Jaffke,
Science & Global Security **23** (2015) 40.

P. Huber, Phys. Rev. **C84** (2011) 024617.