Nuclear explosion monitoring:
What can neutrinos add to the global system?

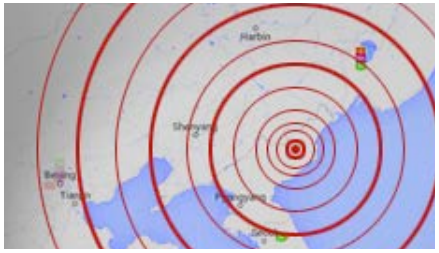
$\bar{\nu}_e$ + = ?

Rachel Carr, MIT

Applied Antineutrino Physics

October 11, 2018 – Livermore, California

Hypothetical roles for neutrinos in nuclear explosion monitoring:

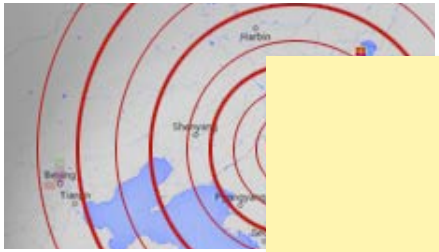


Detect explosions otherwise missed by global network.

Confirm nuclear nature of detected explosion.

Estimate fission yield and indicate fusion yield or seismic decoupling.

Hypothetical roles for neutrinos in nuclear explosion monitoring:



For each case, consider:

1. Signal physics
2. Detection strategy
3. Costs & benefits within existing explosion monitoring network

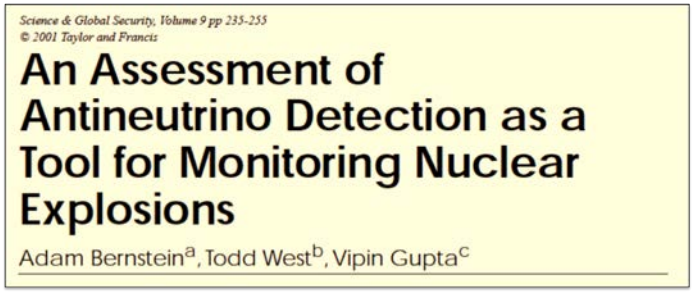
Use neutrinos to detect missed explosions?

Neutrino signal from a nuclear fission explosion:

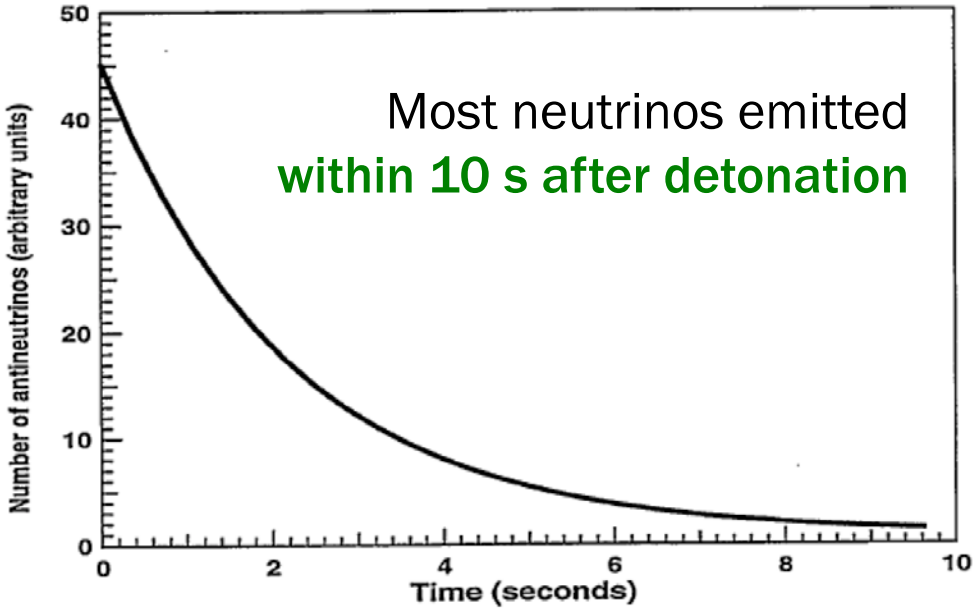
10^{24} neutrinos per kiloton fission yield

Compare to reactor:
1 kton ≈ 1 GWh

Unlike reactor, signal comes ~all at once


Science & Global Security, Volume 9 pp 235-255
© 2001 Taylor and Francis
An Assessment of Antineutrino Detection as a Tool for Monitoring Nuclear Explosions
Adam Bernstein[a], Todd West[b], Vipin Gupta[c]

A. Bernstein et al.
Science & Global Security (2001)



Use neutrinos to detect missed explosions?

With Gd-doped water…

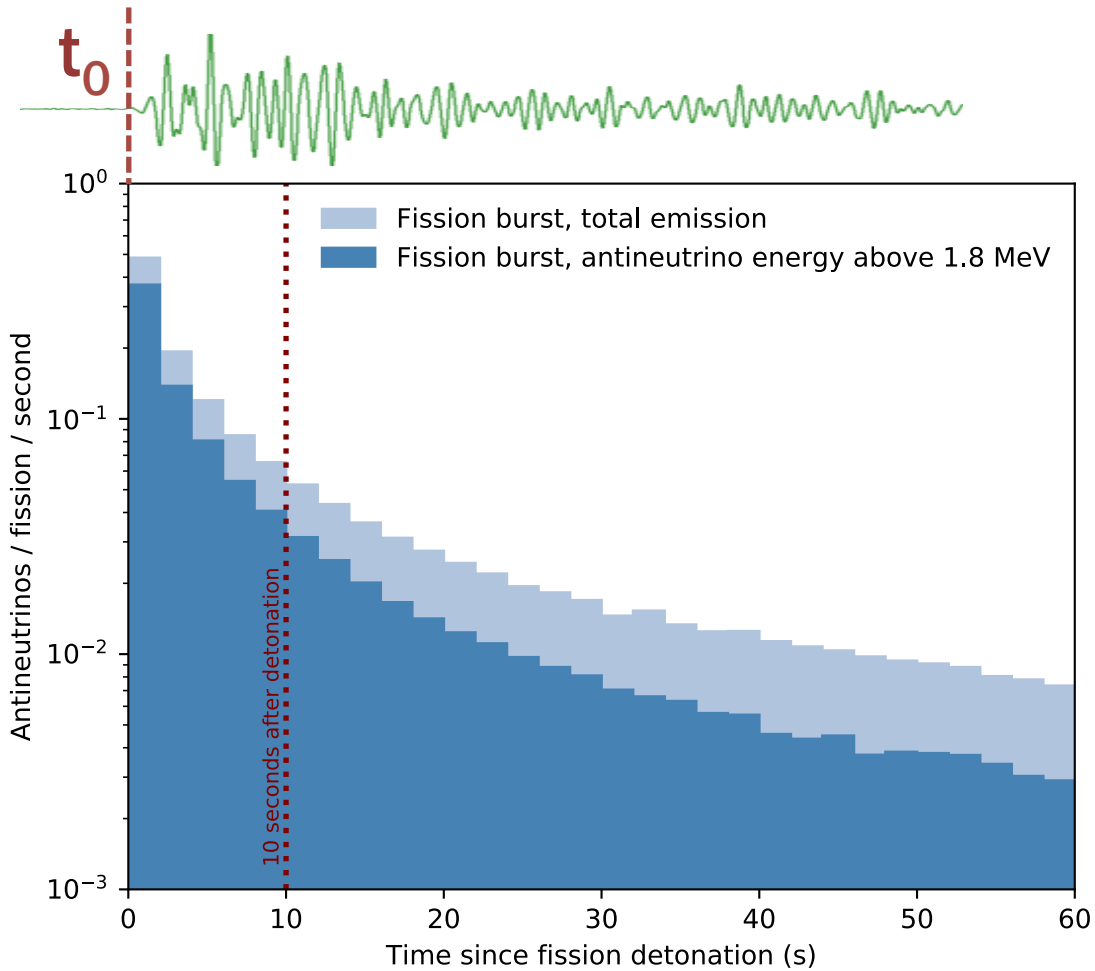
Need 60 × Super-K to see 10 ν from 1 kton @ 100 km

> *"In short, while antineutrino detectors are in theory very attractive for [Comprehensive Test Ban Treaty] verification, engineering difficulties and* ***ultimately physics limitations severely proscribe actual applications."***
>
> —***A. Bernstein*** *et al. (2001)*

Cost of capable detectors ≫ **Benefit to CTBT regime**

Confirm nuclear nature of explosion?

Easier than detection *per se*. Can use seismic signal as analysis trigger.

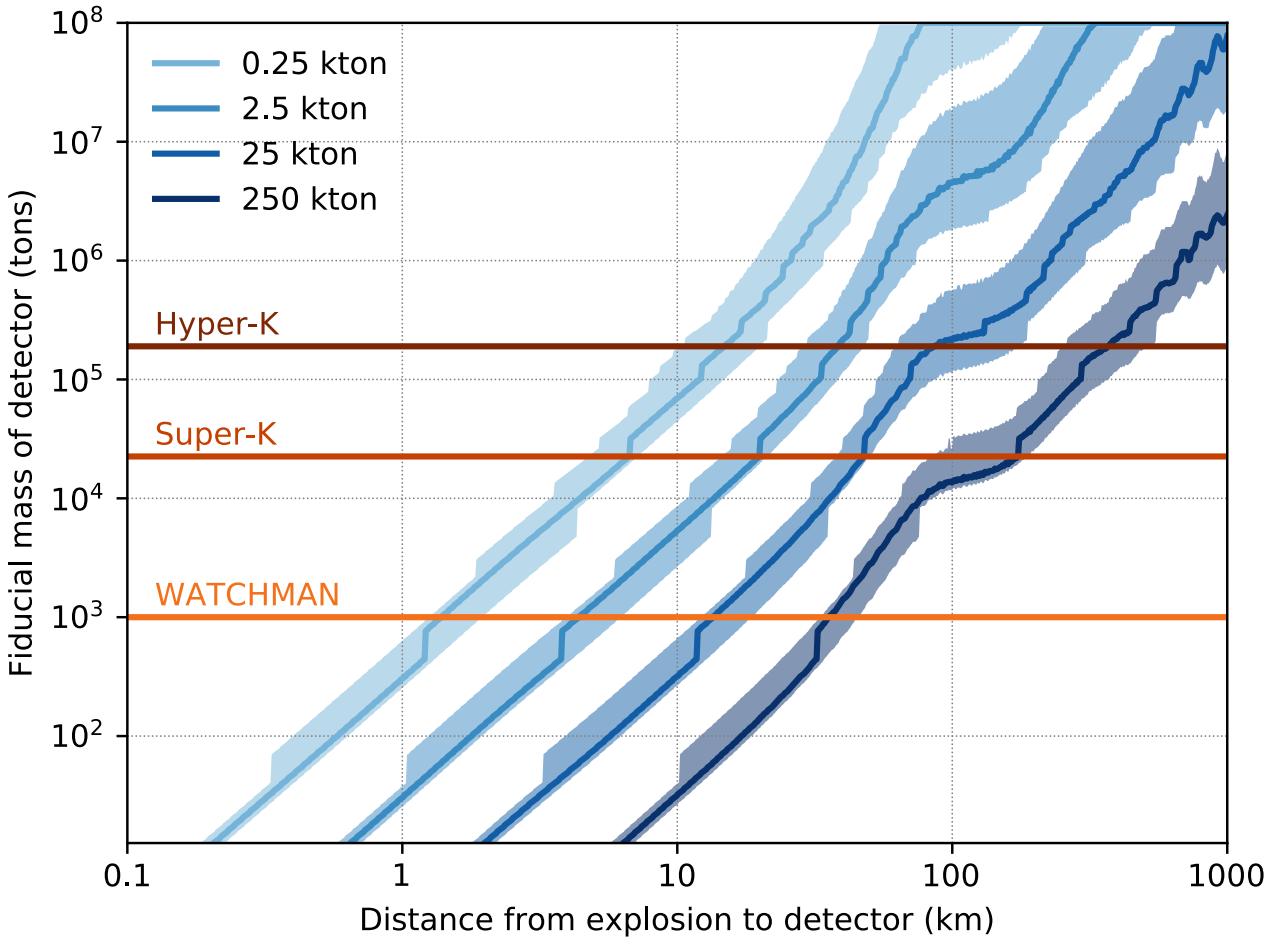


Simple summation model of neutrino emission from ^{235}U explosion

R. Carr, F. Dalnoki-Veress, A. Bernstein (2018)

Confirm nuclear nature of explosion?

Size of Gd-doped water detector required for
90% probability of confirming nuclear fission at 99% CL



Central values scaled from WATCHMAN efficiency and backgrounds

R. Carr, F. Dalnoki-Veress, A. Bernstein (2018)

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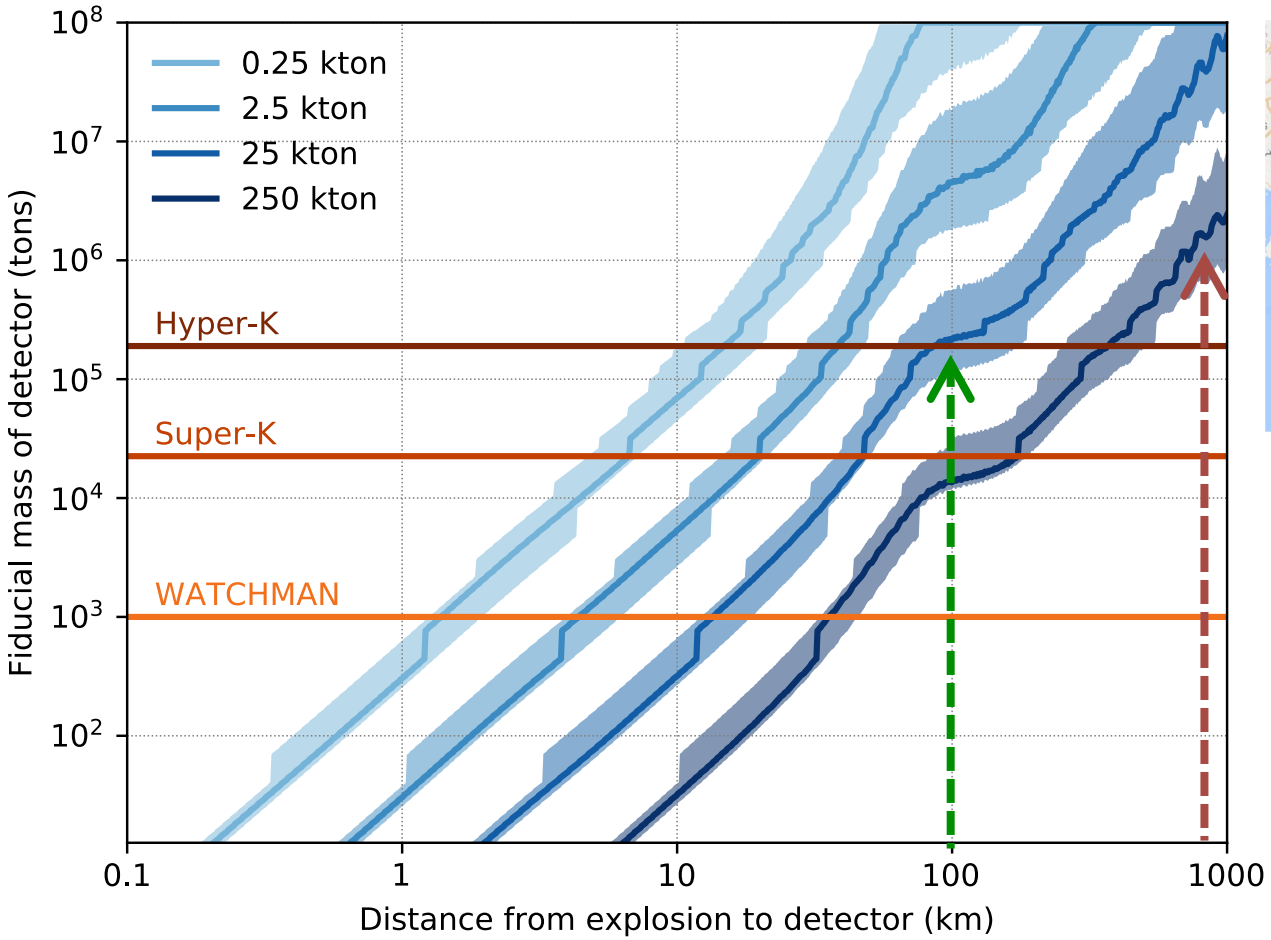

Example: Hyper-K for
~25 kton @ 100 km

... but ~10× Hyper-K for
250 kton @ 900 km *(above)*

Confirm nuclear nature of explosion?

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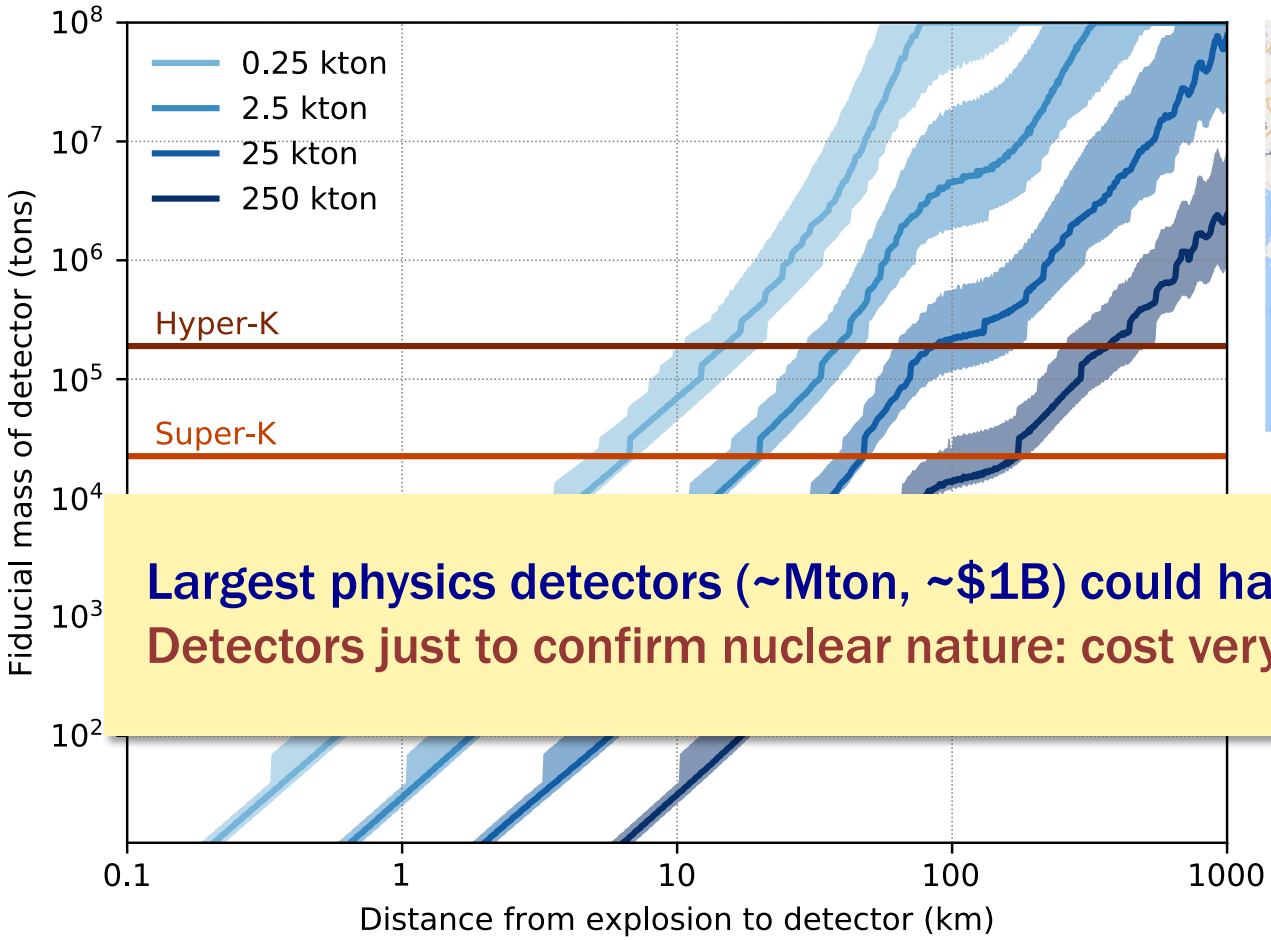


Largest physics detectors (~Mton, ~$1B) could have some value here.
Detectors just to confirm nuclear nature: cost very high, benefit limited.

Estimate fission yield of explosion?

For known ^{235}U explosion, viewed in 1 Mton detector:

L	True yield	Most probable 68% CL interval on yield, based on $\bar{\nu}$
600 km	250 kton	170–330 kton (i.e., $\sim$ 30% uncertainty)
200 km	50 kton	40–60 kton (i.e., $\sim$ 20% uncertainty)

Possible in largest proposed physics detectors, with limited coverage.
Purpose-built detectors: benefit significant, but cost very high.

Indicate seismic decoupling, or fusion yield?

In principle, compare signals:

Neutrino > seismic → possible seismic decoupling

Neutrino < seismic → some yield from fusion

In practice:

Need Mton or larger detector
Need very high precision on seismic & neutrino signals
Need to know isotope mix that fueled explosion
Effects could combine and complicate interpretation …

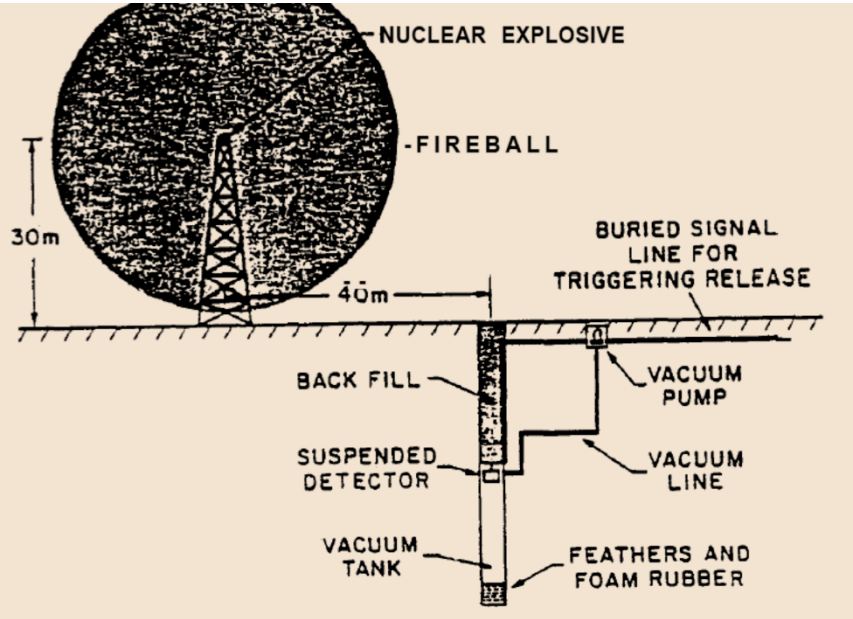
A stretch even for largest proposed physics detectors.
Purpose-built detectors: benefit significant, but cost extremely high.

What can neutrinos add to the global monitoring system for nuclear explosions?

In theory, some valuable information.
In practice, explosion monitoring is probably
not a strong niche for neutrinos, beyond incidental
capabilities in large physics detectors.

We can see this as a good thing.
It is a testament to the power of existing explosion
monitoring technology. Neutrinos may have better niches.

Neutrinos from nuclear explosions:
a clever idea… **still undetected.**



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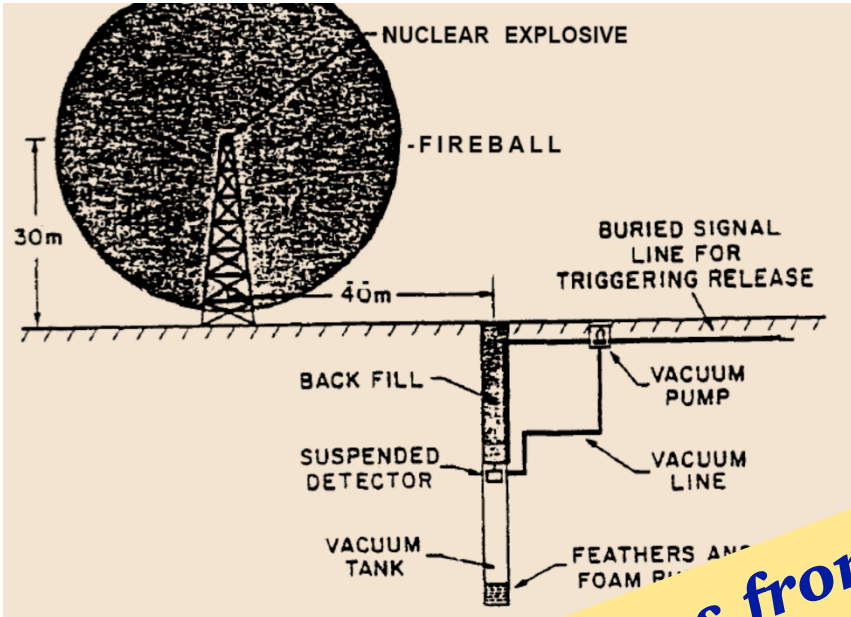
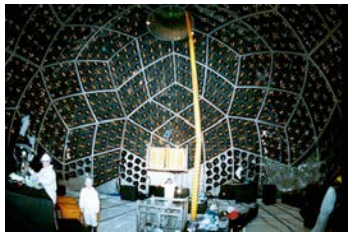
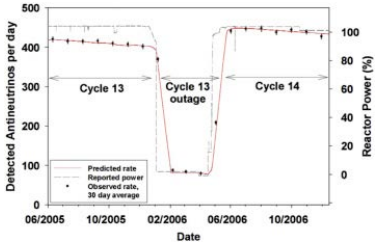
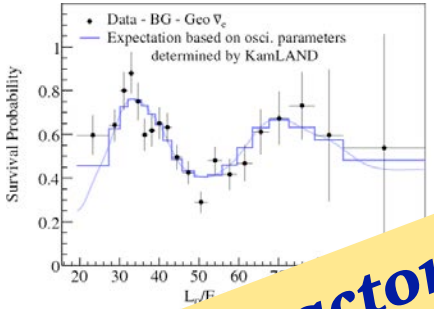
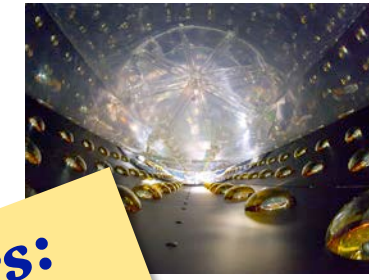


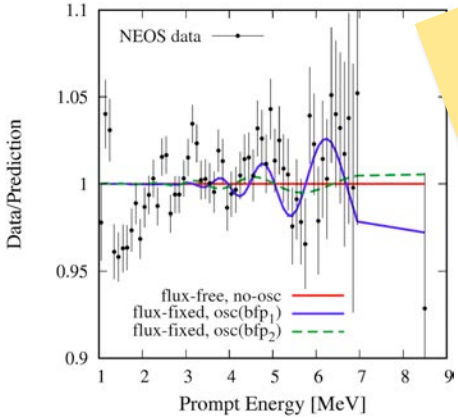


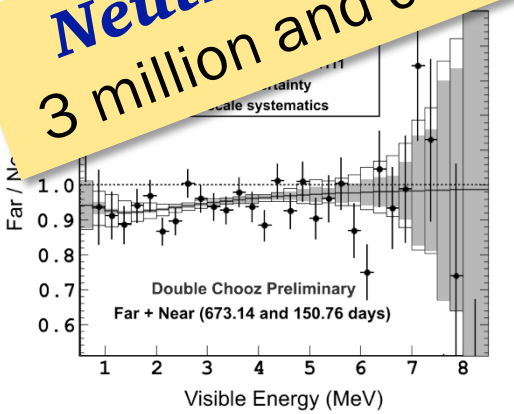






Neutrinos from nuclear reactors:
3 million and counting = a proven resource.





Thank you

R.C., **Ferenc Dalnoki-Veress, Adam Bernstein.** "Sensitivity of Seismically Cued Antineutrino Detectors to Nuclear Explosions." Phys. Rev. Applied 10, 024014 (2018).

MIT Laboratory for
Nuclear Security and Policy

Latest North Korean test visible in Super-K?

< 5% chance of neutrino from latest North Korean test in Super-K

An estimate of Sep. 2017 test:

$Y = 250$ kilotons*

*"The nuclear explosion in North Korea on 3 September 2017: A revised magnitude assessment." NORSAR. 12 Sep 2017.

Distance to Super-K site:

$L = 900$ km

Fiducial volume of Super-K:

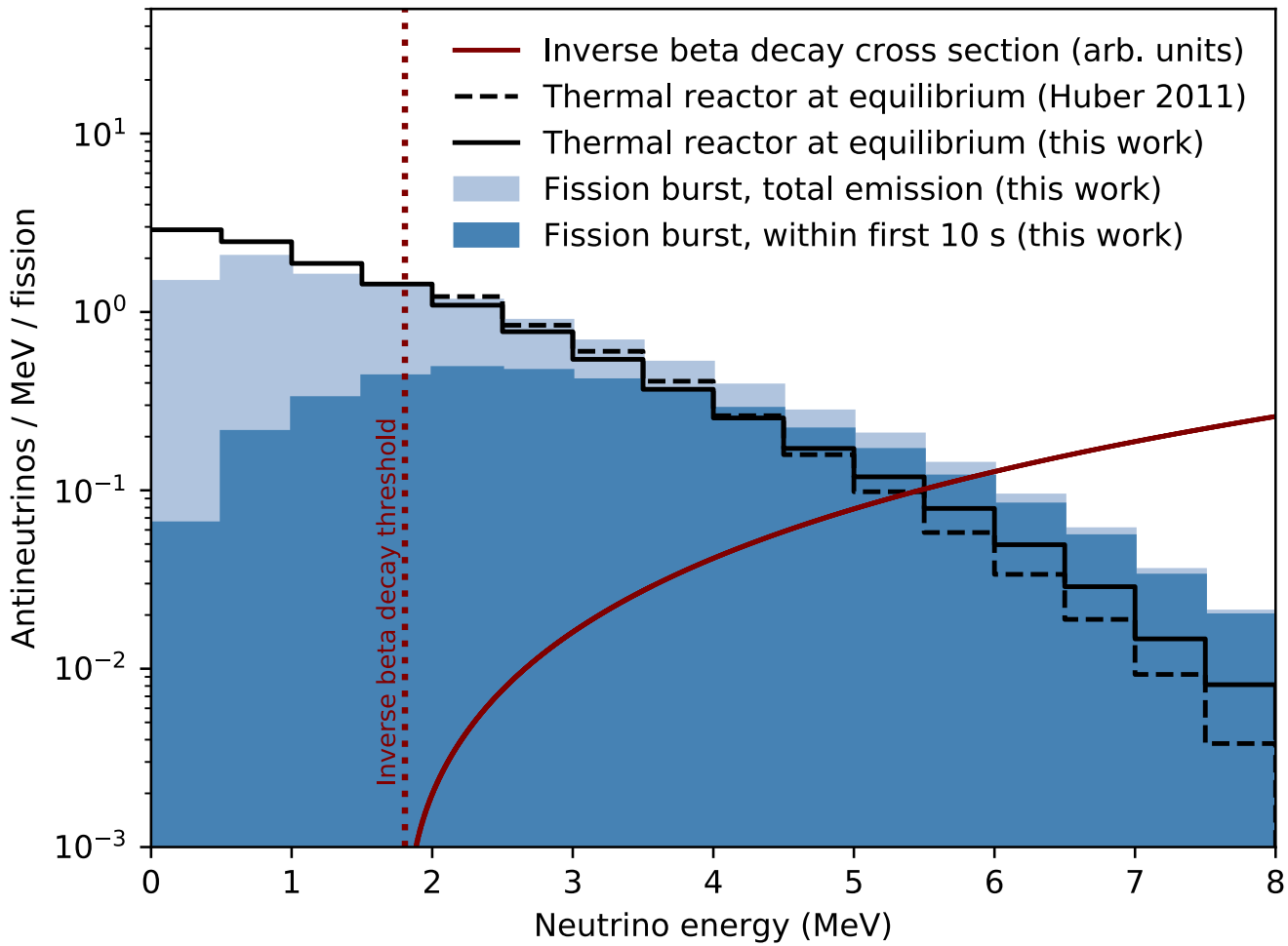
$V = 22{,}500\ \mathrm{m}^3\ (N_p = 1.5 \times 10^{33})$

Detection efficiency (without Gd):

$\eta < 0.20$

$$\mathbf{N_{obs}} \approx \frac{\eta Y}{4\pi L^2}\ \frac{1.45 \times 10^{23}\ \mathit{fiss.}}{\mathit{kton}}\ N_p \int_{t_0}^{\infty} dt \int_{E_{min}}^{\infty} dE\ \Phi_\nu(E,t) P_{surv}(E,L)\sigma(E) \lesssim \mathbf{0.05}$$

Neutrino energy spectrum: explosion vs. reactor



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