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

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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 $\approx$ 1 GWh

Unlike reactor, signal comes $\sim$ all at once

Most neutrinos emitted within 10 s after detonation

A. Bernstein et al.
Science & Global Security (2001)
Use neutrinos to detect missed explosions?

With Gd-doped water...
Need $60 \times \text{Super-K}$ to see $10 \, \nu$ 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 $\gg$ 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

![Graph showing the required size of detectors for different distances from the explosion site.](image)

Central values scaled from WATCHMAN efficiency and backgrounds

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

Example: Hyper-K for ~25 kton @ 100 km
... but ~10× Hyper-K for 250 kton @ 900 km (above)
Confirm nuclear nature of explosion?

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

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

Rachel Carr (MIT) — AAP 2018
**Estimate fission yield of explosion?**

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

<table>
<thead>
<tr>
<th>$L$</th>
<th>True yield</th>
<th>Most probable 68% CL interval on yield, based on $\bar{v}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>600 km</td>
<td>250 kton</td>
<td>170–330 kton (i.e., $\sim 30%$ uncertainty)</td>
</tr>
<tr>
<td>200 km</td>
<td>50 kton</td>
<td>40–60 kton (i.e., $\sim 20%$ uncertainty)</td>
</tr>
</tbody>
</table>

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

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


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:

\[ Y = 250 \text{ kilotons}^* \]

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

Distance to Super-K site:

\[ L = 900 \text{ km} \]

Fiducial volume of Super-K:

\[ V = 22,500 \text{ m}^3 \ (N_p = 1.5 \times 10^{33}) \]

Detection efficiency (without Gd):

\[ \eta < 0.20 \]

\[
N_{\text{obs}} \approx \frac{\eta Y}{4\pi L^2} \frac{1.45 \times 10^{23}}{\text{kton}} \text{ fiss.} \int_{t_0}^{\infty} dt \int_{E_{\text{min}}}^{\infty} dE \Phi_{\nu}(E, t) P_{\text{surv}}(E, L) \sigma(E) \lesssim 0.05
\]
Neutrino energy spectrum: explosion vs. reactor

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

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