NEUTRON DETECTION
FOR ZERO-KNOWLEDGE PROTOCOL

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OUTLINE

• Zero-knowledge protocol for warhead verification

• Superheated emulsions (superheated drop “bubble” detectors)

• Neutron activation imaging
ZERO-KNOWLEDGE PROTOCOL (ZKP): ALICE CONvinces BOB OF A CLAIM, WHILE REVEALING NOTHING BEYOND THE TRUTH OF HER CLAIM

Key Elements: Interaction and Randomness

ZKP WARHEAD VERIFICATION

Detector arrays to be preloaded by host with counts that sum with neutron radiographic image to $N_{\text{max}}$ everywhere. ZKP: Inspector selects which preload goes with which object!
ZKP WARHEAD VERIFICATION

• If the object and the preload don’t match – you see it.

• More visible with greater $N_{\text{max}}$.

• For a match – even the Poisson noise carries no info.

DETECTOR REQUIREMENTS
NON-ELECTRONIC DETECTION & STORAGE

TRANSMISSION
• Capable of storing 5,000 – 10’s of thousands of counts
  - Preloads indistinguishable from measurement counts
• Sensitive only to 14 MeV neutrons
  - Energy threshold ~10 MeV, insensitive to γ’s
• 0.24% absolute detection efficiency gives 20,000 cts/hr

EMISSION (spontaneous and driven)
• Capable of storing thousands of counts
  - No imaging, so detectors may be ganged together
• Sensitive dominantly to fission neutrons
  - Energy threshold ~500 keV, insensitive to γ’s
    (a 250 keV neutron source would eliminate all driven non-fission sources of neutrons above 500 keV)
SUPERHEATED EMULSIONS

- Fluorocarbon droplets in a steady superheated state.
- Vaporizations triggered by neutrons above selectable threshold energies.
- Can be totally insensitive to γ-rays.
SUPERHEATED EMULSIONS

- Energy thresholds depend on composition & temp.
- Accurate temperature control required
- ~3% absolute efficiency achievable

SUPERHEATED EMULSIONS

- Emulsified fluids can be chosen to respond only to high-LET radiation.
- Bubbles remain trapped after formation and can be counted with a variety of techniques (e.g. MRI, optical tomography, light scattering)
SUPERHEATED EMULSIONS

Scattered light

• Instant read out

• Count rate insensitive
SUPERHEATED EMULSIONS

Bubbles in commercial polymer-based detectors expand noticeably in 24 hours.

Bubbles in aqueous gel do not.
Detector is an array of activation slugs
~ 3 cm long, 1.6 cm diameter

- Nb is an attractive mono-nuclidic option for transmission
  \(^{93}\text{Nb}(n,2n)^{92m}\text{Nb}\), \(E_{\text{th}} = 9\) MeV, 10 d half-life
- In for emission detectors
- Count γ’s in bank of well detectors
NUCLEAR ACTIVATION IMAGING

Clean spectra and low background may allow use of NaI detectors.
CONCLUSIONS

- Zero-knowledge protocol is a new approach based on differential radiography + differential emission
  - ZKP has unusual detector requirements
  - Key among them is reproducibility
- Superheated emulsions hold promise, R&D must tackle
  - Temperature sensitivity
  - Read out optimization
- Neutron activation imaging has different challenges
  - Potentially complex preloading
  - Maintenance of bank of γ detectors
- We are open to innovations. Come talk with us.