NEUTRON DETECTION FOR ZERO-KNOWLEDGE PROTOCOL

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OUTLINE

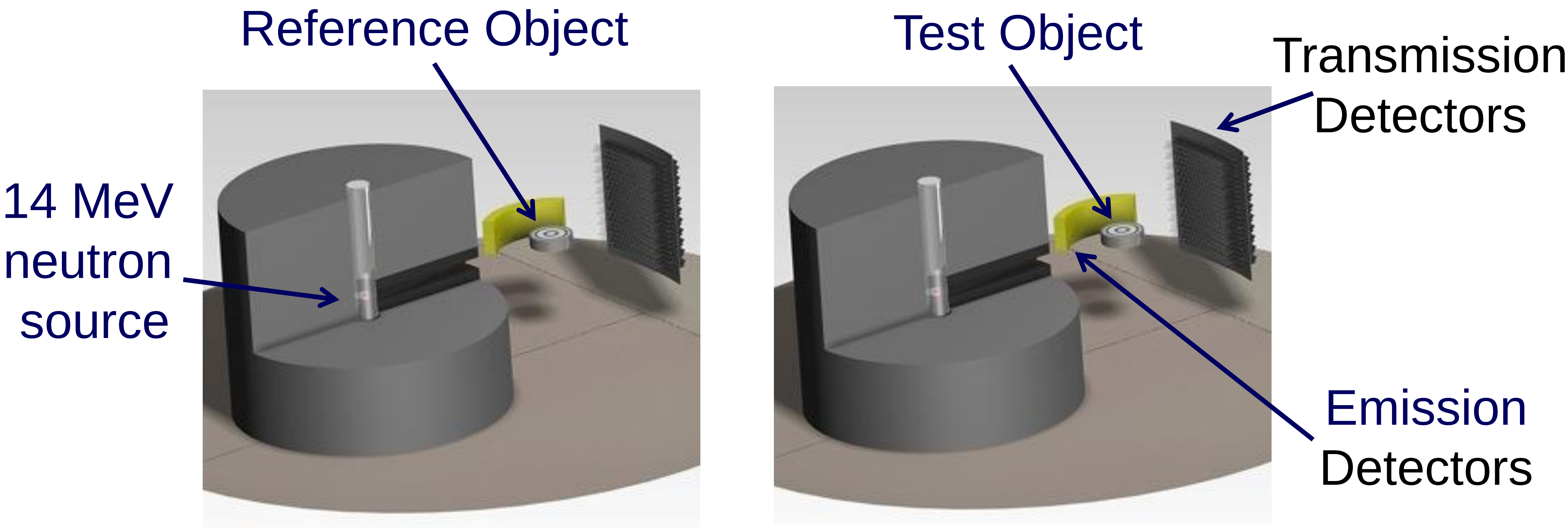
- Zero-knowledge protocol for warhead verification
- Superheated emulsions (superheated drop “bubble” detectors)
- Neutron activation imaging

ZERO-KNOWLEDGE PROTOCOL (ZKP): ALICE CONVINCES BOB OF A CLAIM, WHILE REVEALING NOTHING BEYOND THE TRUTH OF HER CLAIM

Key Elements: Interaction and Randomness

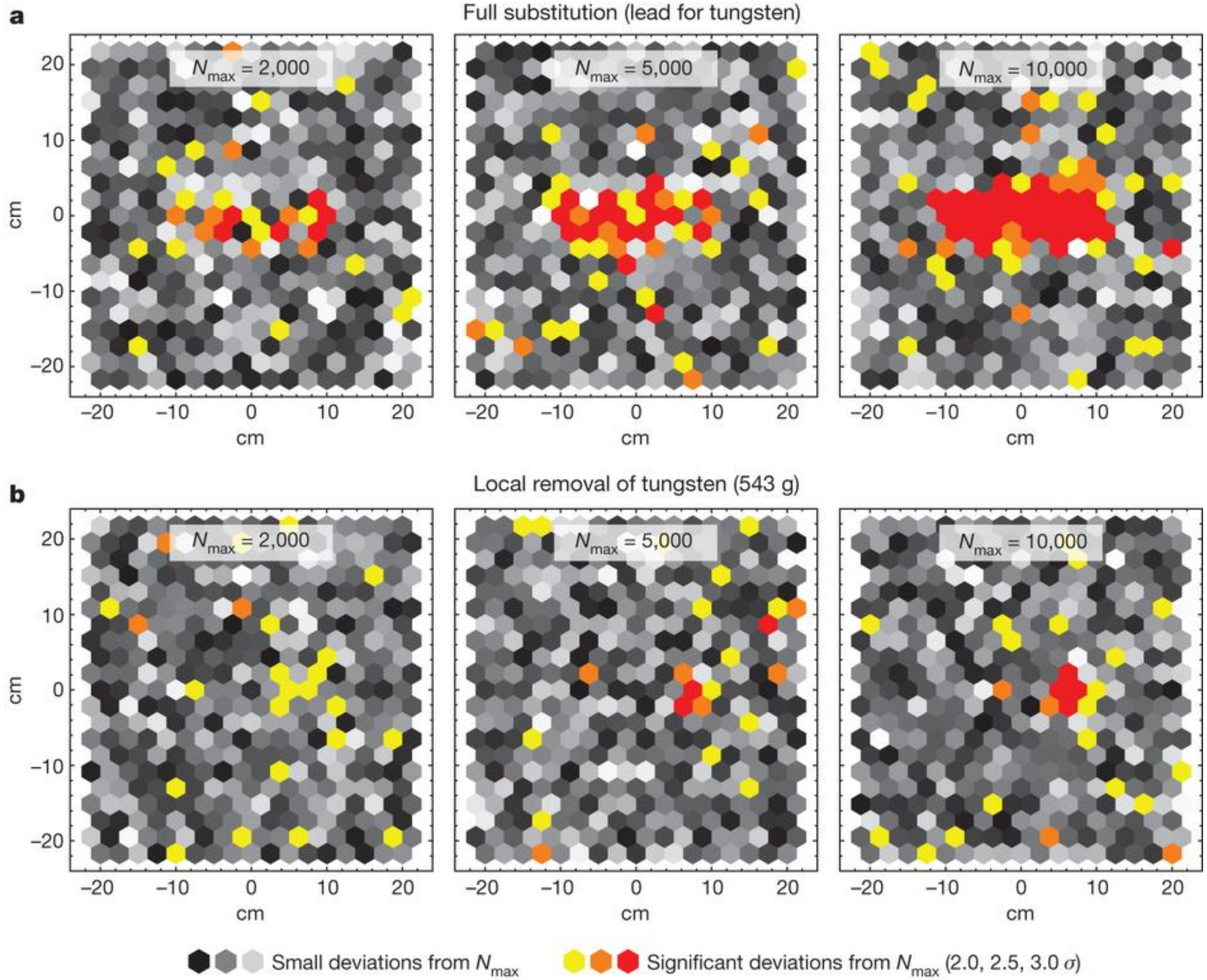
Glaser, Barak, Goldston, *Nature,* **510** (2014): 497–502

ZKP WARHEAD VERIFICATION



Detector arrays to be preloaded by host with counts that sum with neutron radiographic image to N_{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_{max}.
- For a match – even the Poisson noise carries no info.

Glaser, Barak, Goldston, *Nature,* **510** (2014): 497–502

DETECTOR REQUIREMENTS
NON-ELECTRONIC DETECTION & STORAGE

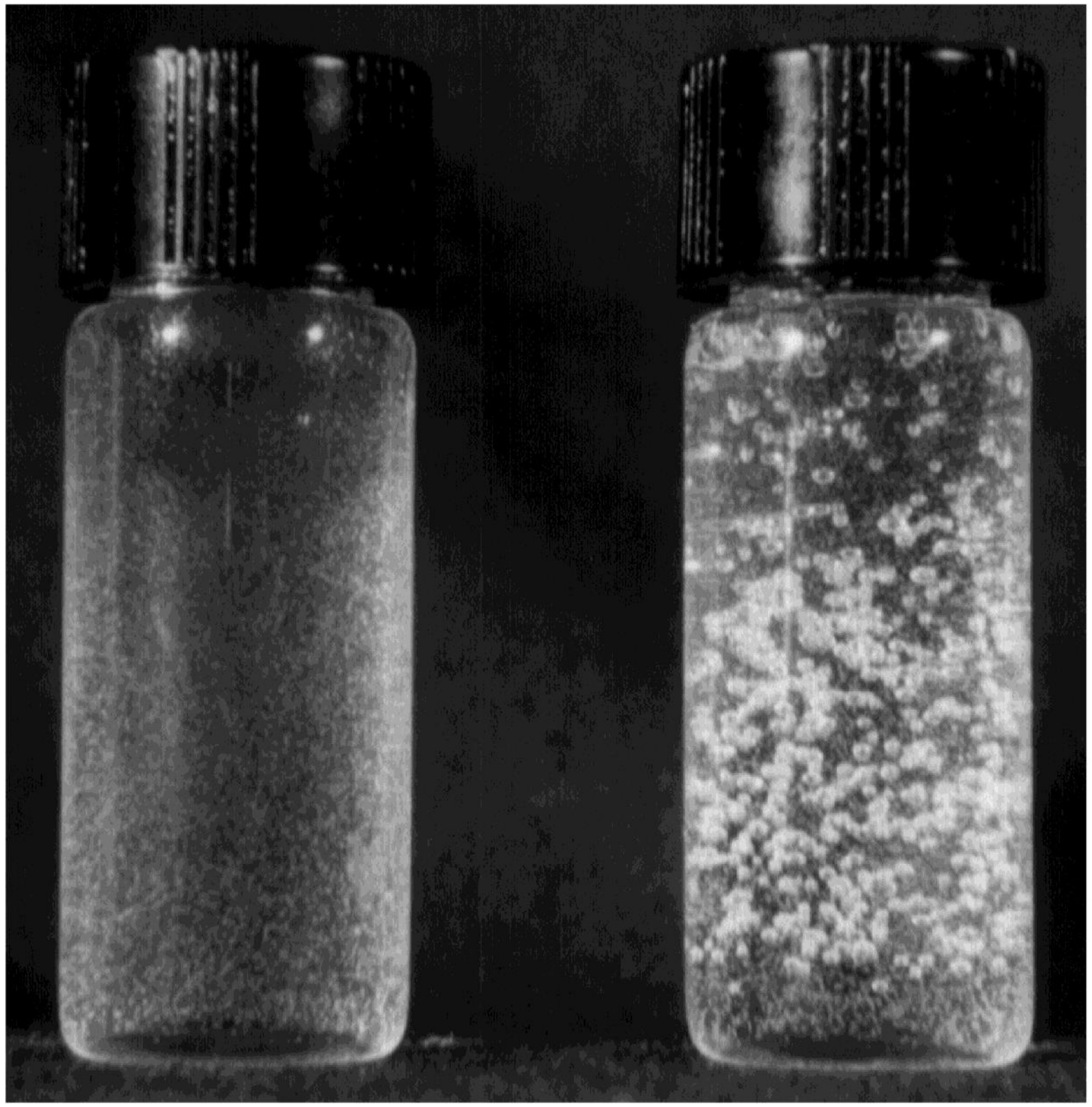
TRANSMISSION

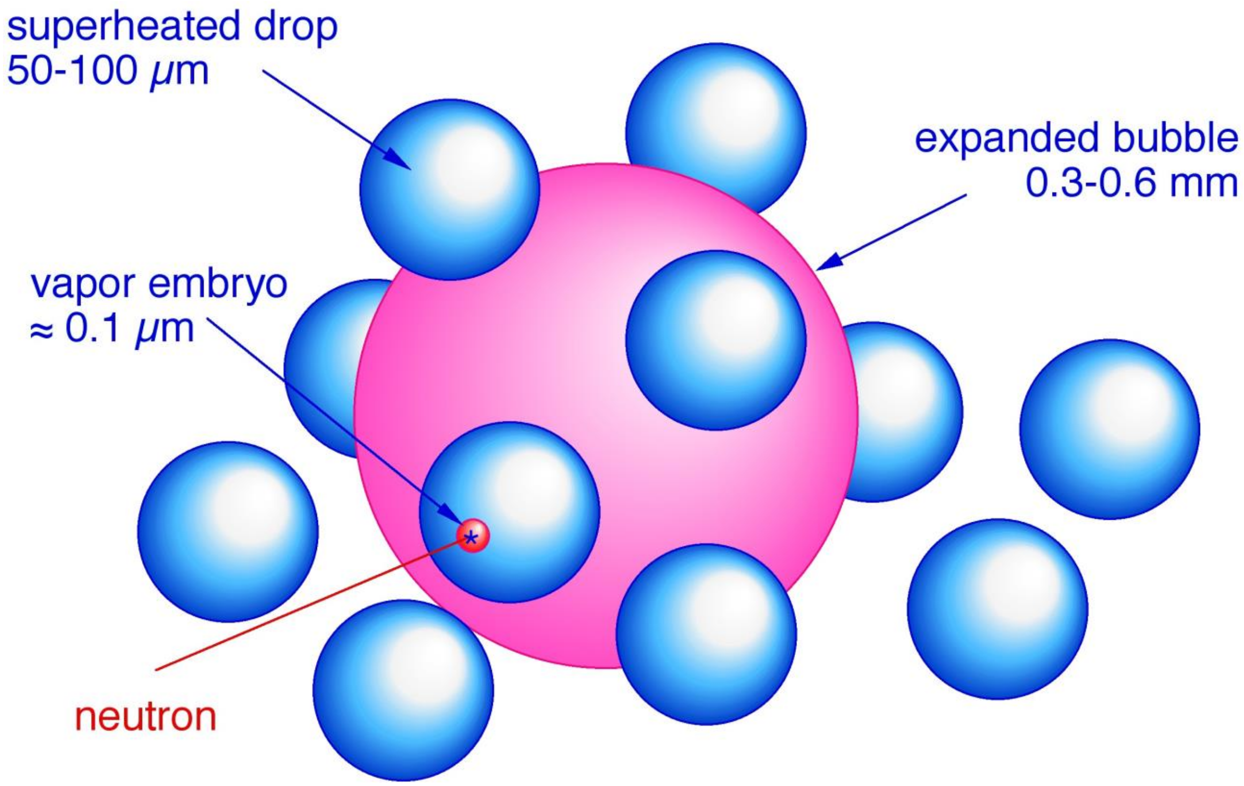
- Capable of storing 5,000 – 10’s of thousands of counts
  - Preloads indistinguishable from measurement counts
- Sensitive only to 14 MeV neutrons
  - Energy threshold ~10 MeV, insensitive to γ’s
- 0.24% absolute detection efficiency gives 20,000 cts/hr

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)

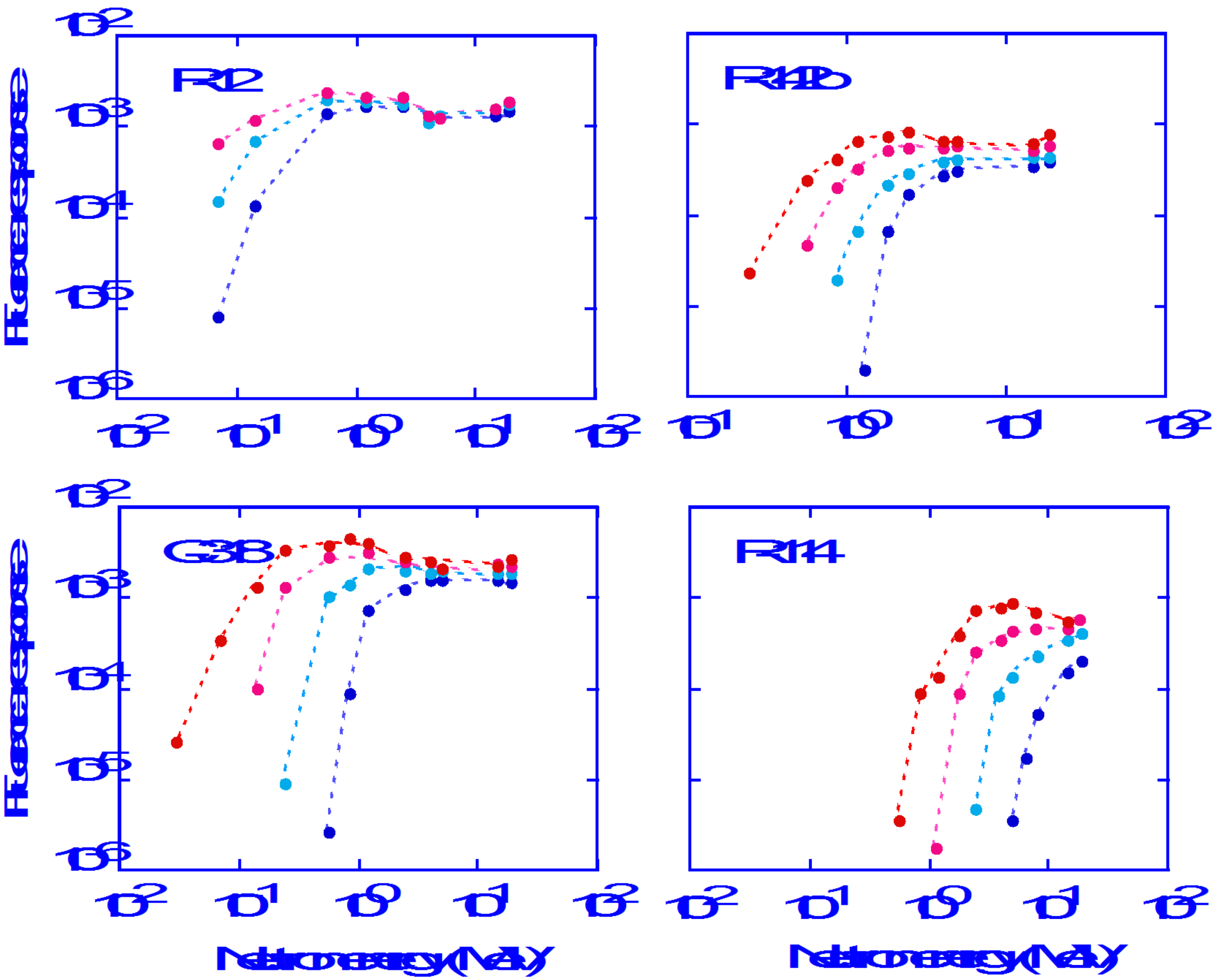
SUPERHEATED EMULSIONS





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

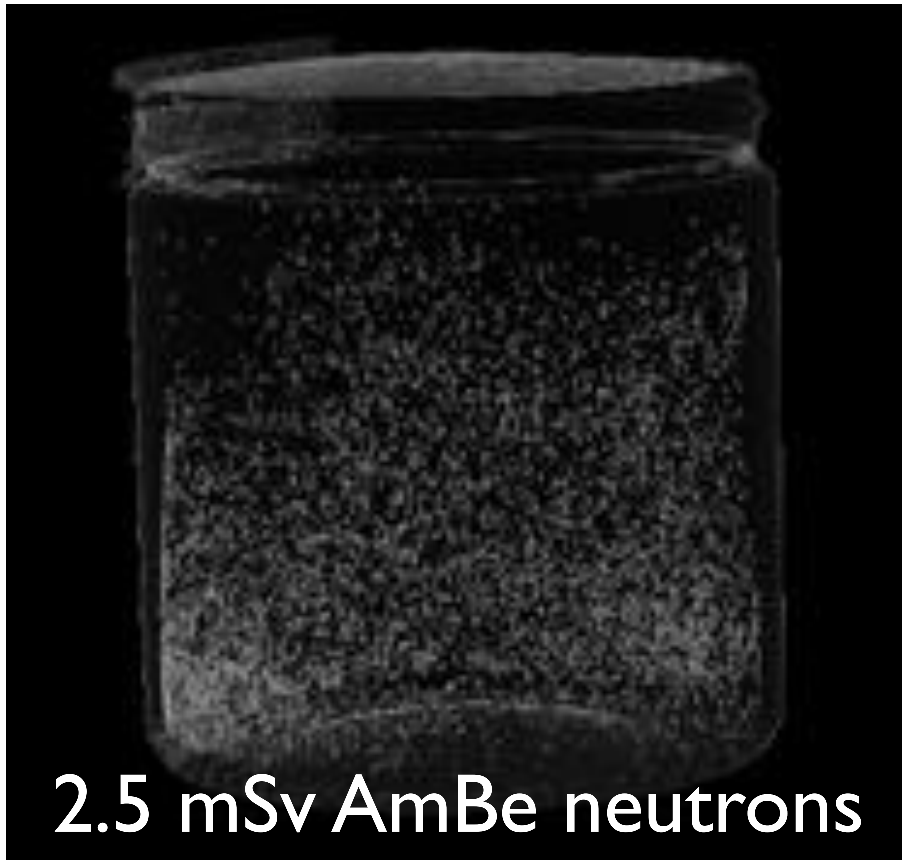
SUPERHEATED EMULSIONS



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

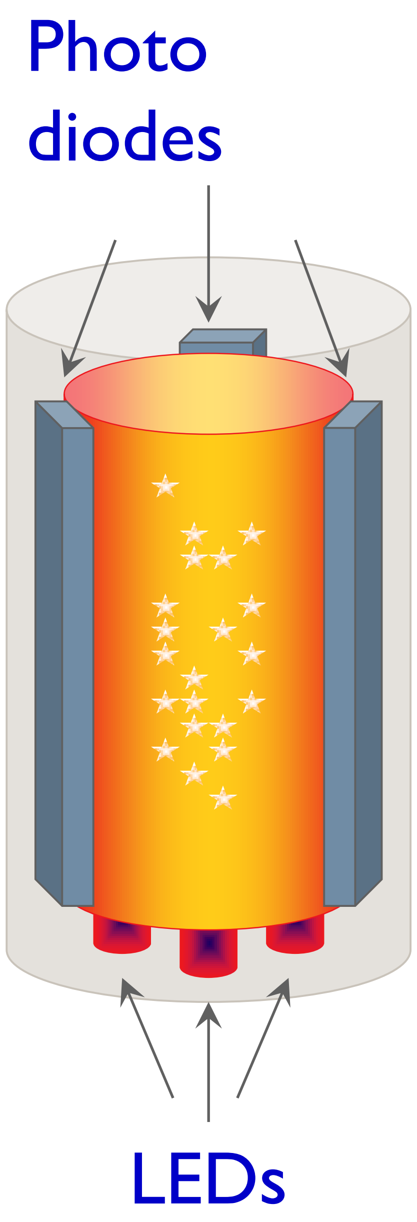
d'Errico, *NIM B*, **184** (2001) 229-254

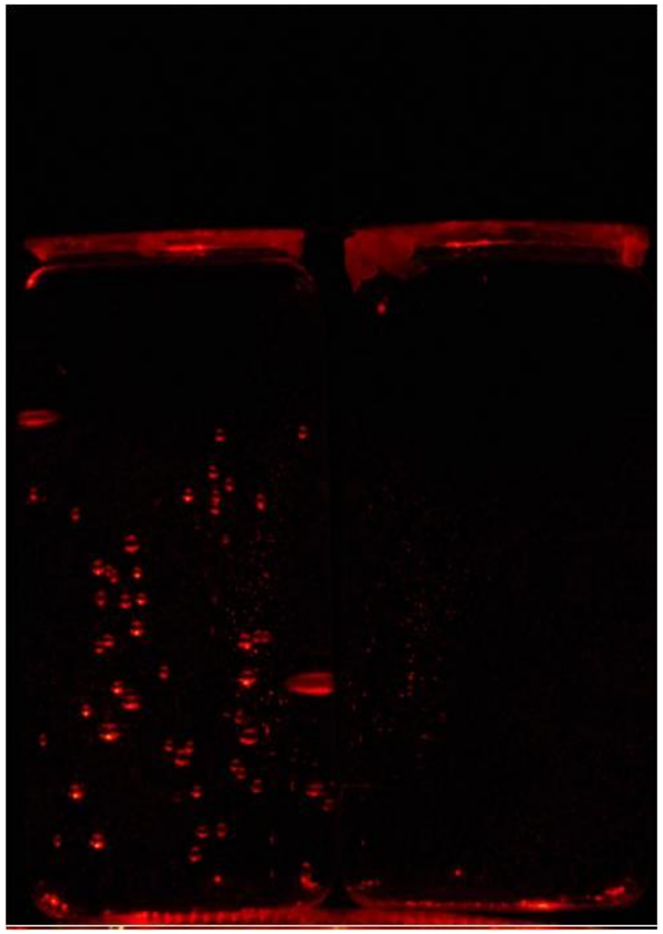
SUPERHEATED EMULSIONS



- 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



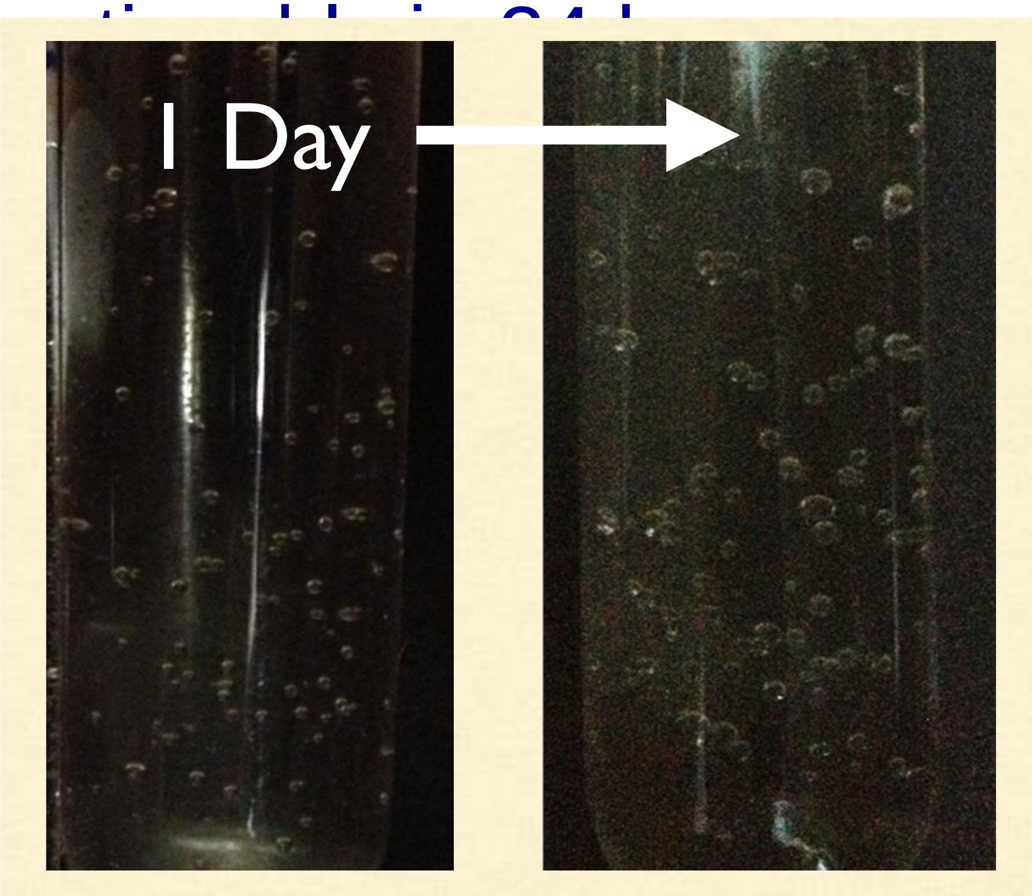


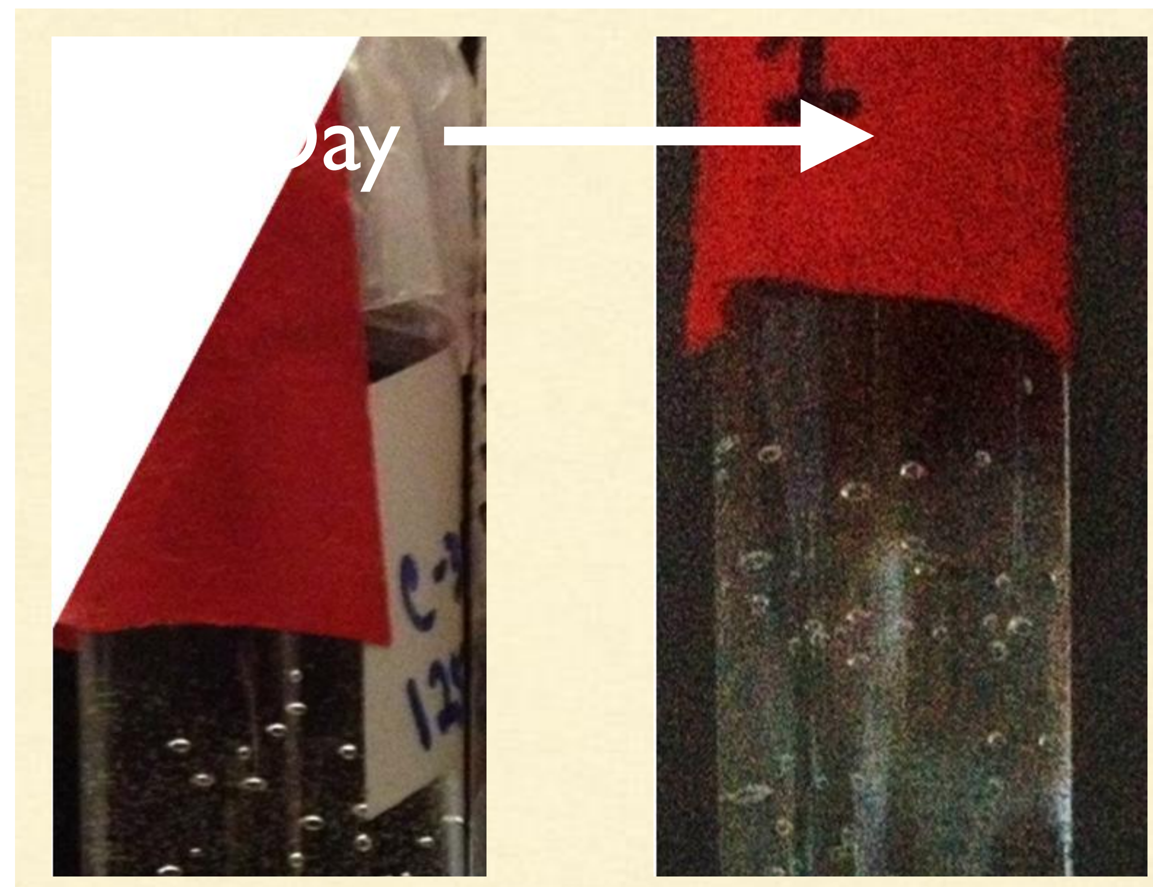
Scattered light

- Instant read out
- Count rate insensitive

SUPERHEATED EMULSIONS

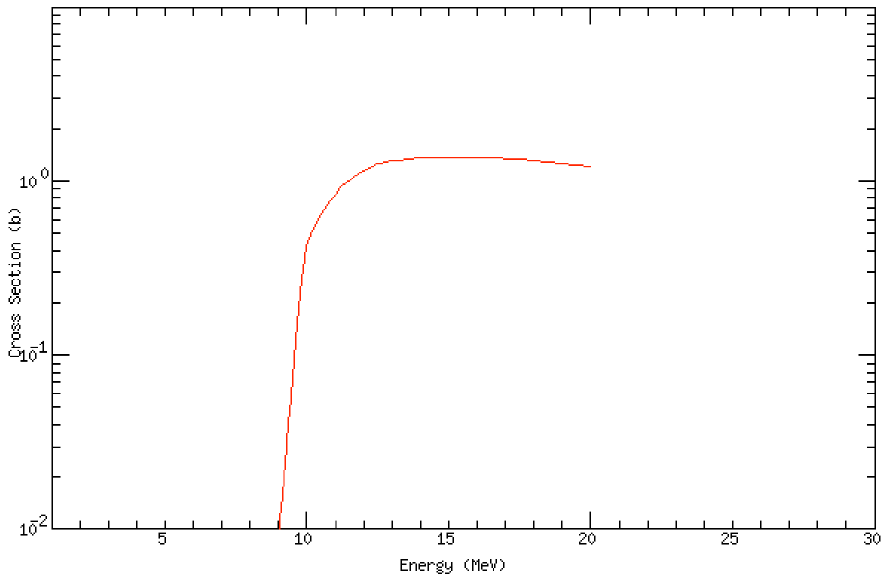
Bubbles in commercial polymer-based detectors expand

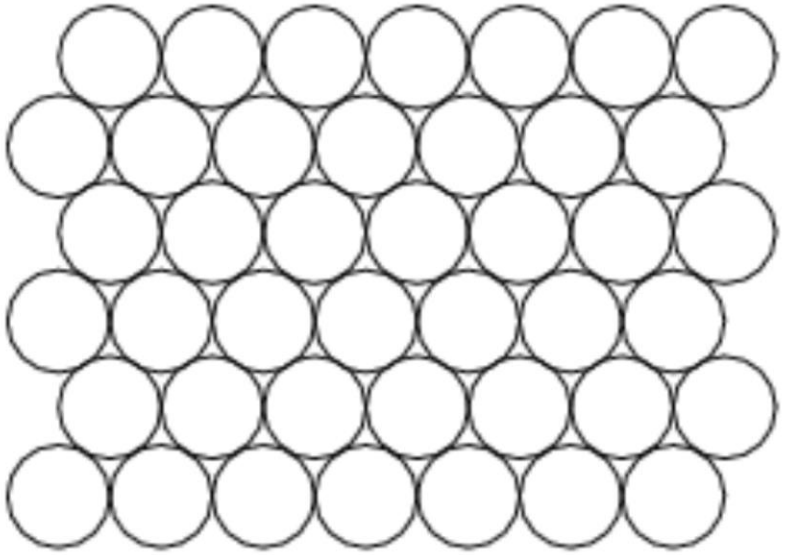




Bubbles in aqueous gel do not.

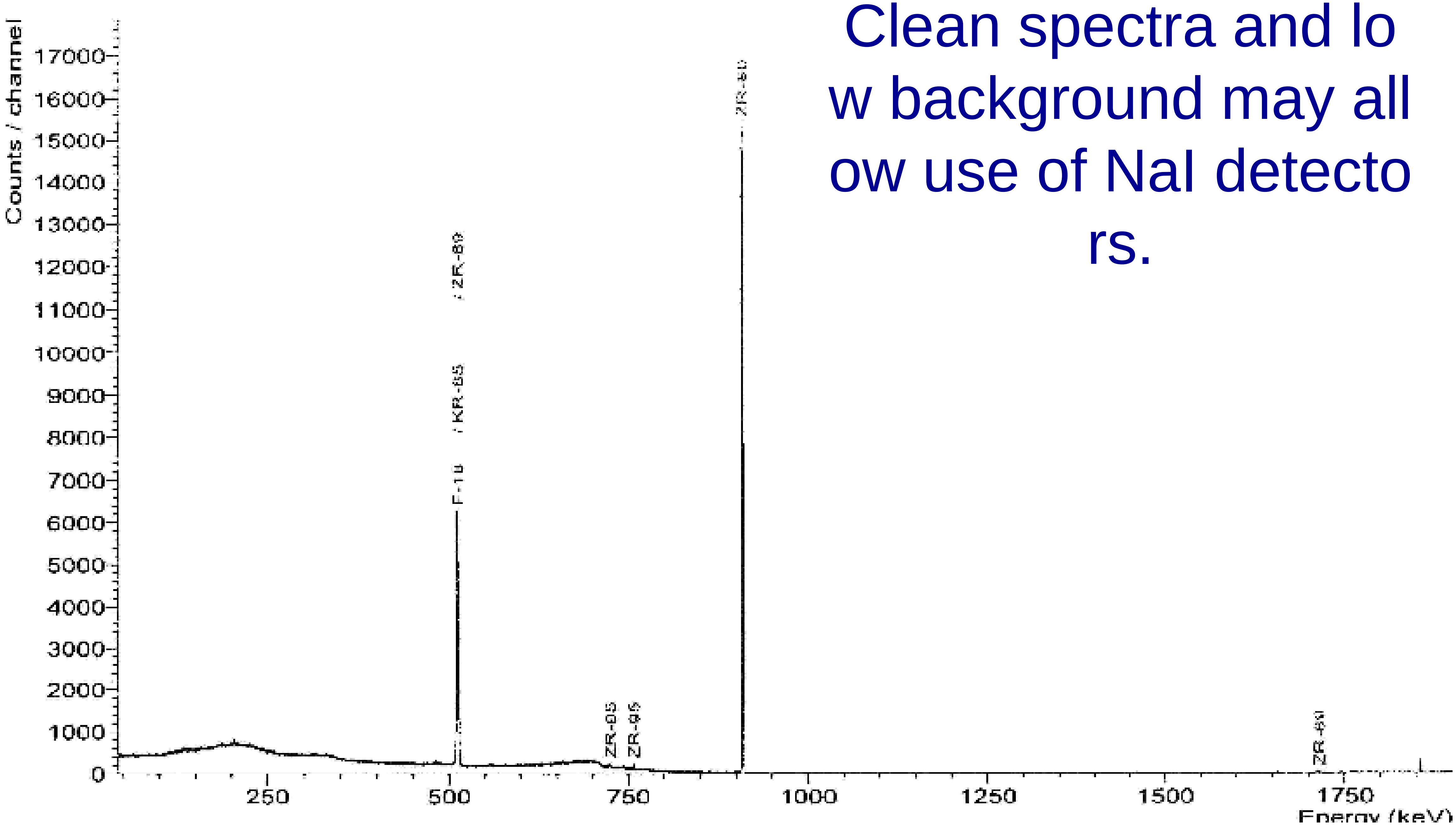
NUCLEAR ACTIVATION IMAGING





- Detector is an array of activation slugs
  - ~ 3 cm long, 1.6 cm diameter
- Nb is an attractive mono-nuclidic option for transmission
  - ^{93}Nb(n,2n)^{92m}Nb, E_{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.