National Aeronautics and Space Administration

Low Level Neutron Spectroscopy

ICCF-24 Solid State Energy Summit Workshop

July 25-28, 2022

L. P. Forsley,[1,2,3] B. Baramsai,[2,4] T. Benyo,[2] B. Steinetz,[2] and P. Ugorowski[2,4]

1. lawrence.p.forsley@nasa.gov
2. NASA Glenn Research Center, Cleveland, OH
3. GEC LLC, Annandale, VA
4. HX5, Cleveland, OH

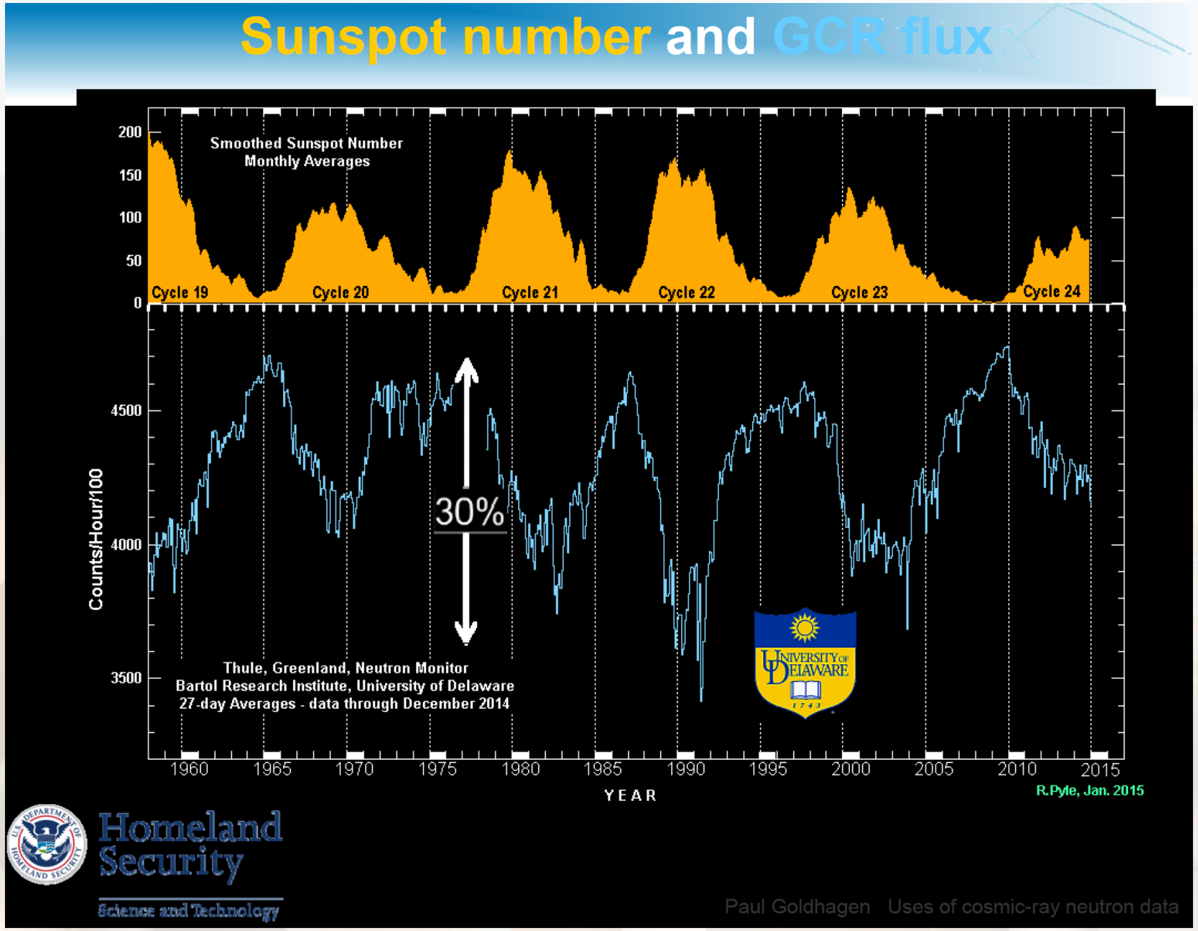
V1.5

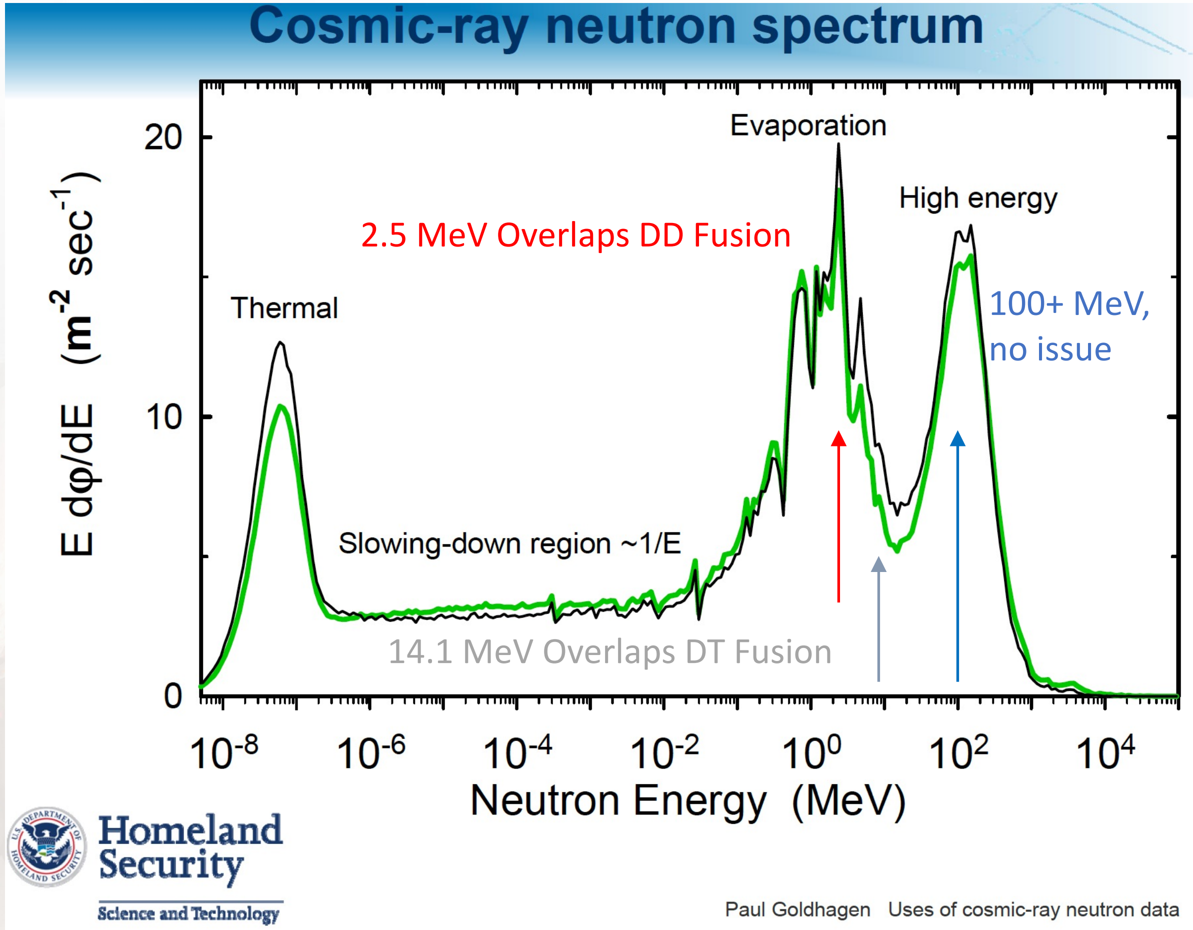
Problem and the Promise

1. *Neutrons have no charge*
   1. Matter looks like empty space!
2. *Neutrons can only be detected indirectly by scattering or capture*
   1. Depending upon method efficiency may run from a few percent to < .1 %
   2. Scattering produces light pulses (scintillators)
   3. Background $\boldsymbol{\gamma}$ sources influences scintillators
   4. Captured by witness materials (producing $\boldsymbol{\gamma}$ or β), or
   5. Moderated and captured by ^{3}He, ^{6}Li, or ^{10}B detectors (producing α, ^{3}H or ^{7}Li)
3. *Real-time, temporally-resolved, neutron spectroscopy*
   1. Nearly simultaneous detection with the nuclear reaction, *unlike calorimetry*
   2. Allows nuclear exit channels to be identified by Kinetic Energy
   3. Possibly differentiated from background by timing
   4. Time-of-Flight is the spectroscopy "Gold Standard"
4. *However, LENR is nearly aneutronic and the D(D,p)T reaction is favored 10^{6} times over the D(D,n)^{3}He reaction.*

Complications[1]

National Aeronautics and Space Administration





Cosmogenic generated neutrons from secondary reactions complicate measuring low level experimental neutron fluxes.

Anti-correlated with high sunspot activity!

1. P. Goldhagen, “Use of Cosmic-Ray Neutron Data in Nuclear Threat Detection and Other Applications”, *Neutron Monitor Community Workshop*—Honolulu, Hawaii (October, 2015).

Methods

National Aeronautics and Space Administration

1. Counting

1. Efficiency is a few percent at best.
2. BF_3 and ^3He Detectors: Need Moderation, most sensitive to thermal
3. Witness materials: activated and measured by gamma or beta
    1. Have thresholds, e.g. thermal, or activation in 100’s of keV or a few MeV

2. Spectroscopy

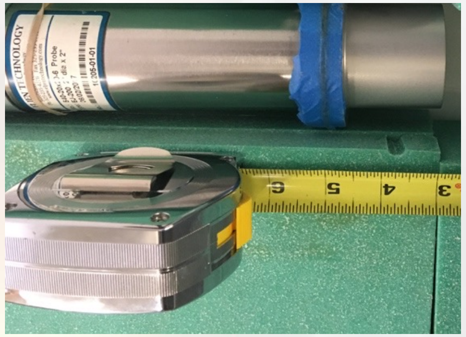
1. Multiple Moderated Detectors, (^3He Remballs) unfolded spectra
2. U2D moderated multiple ^6Li detectors
3. Liquid and solid scintillators (*temporal information 200 nsec*)
    1. 10% efficiency < 10 MeV KE, 5% efficiency > 10 MeV KE
4. Pulse Shape Discrimination
    1. Differentiate between gammas and neutrons
5. Neutron Spectra Unfolding
    1. Use the moderated response of the Remballs, or scintillator light output, geometry, to approximate (n,p) (n,C) neutron recoil response in keVee (equivalent electron units)
    2. Calibrate keVee to keV/MeV neutron KE

3. Integrating Solid State Nuclear Track Detectors (SSNTD)

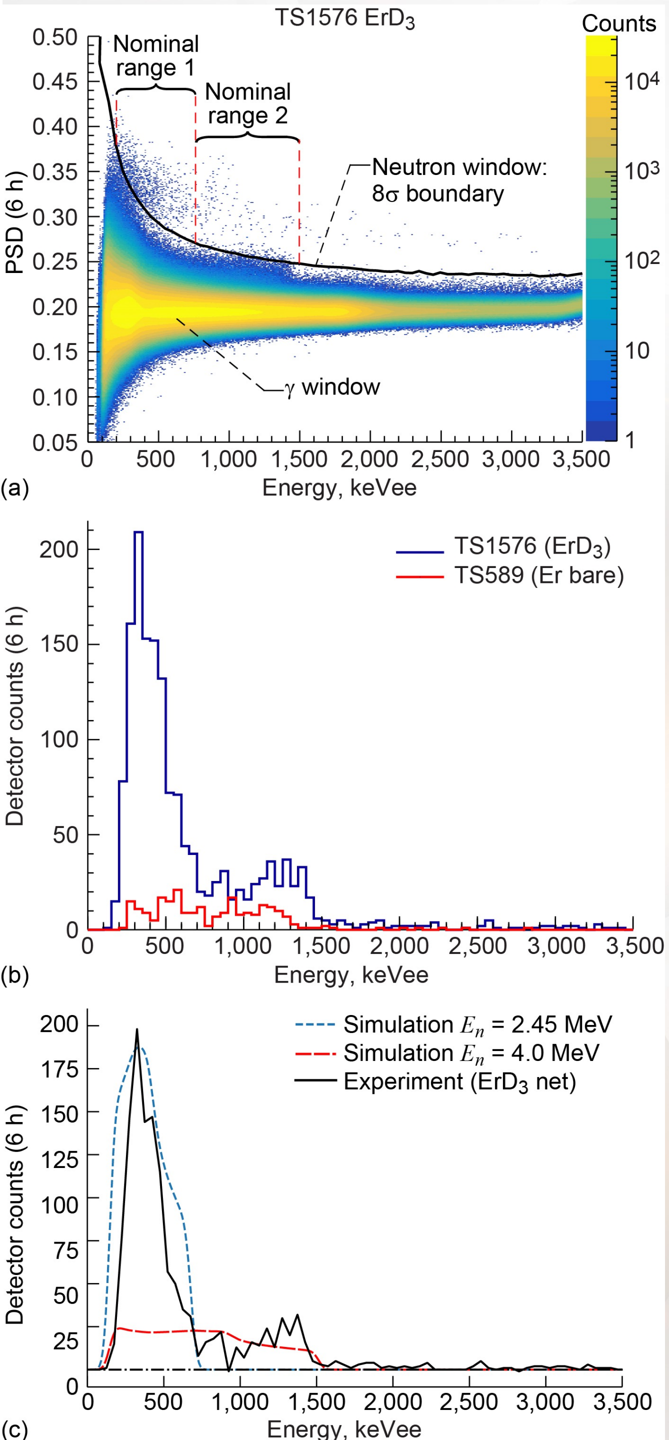
1. Poor neutron detection efficiency, on the order of $10^{-3} – 10^{-5}$, > 100 keV KE
2. Spectral resolution is poor, charged particles and neutron recoils > 100 keV/nucleon
3. Permanent record

Components of NUSTL’s new neutron spectrometer

PMT and Scintillator



SSNTD



Neutron Scintillator Spectroscopy[1]

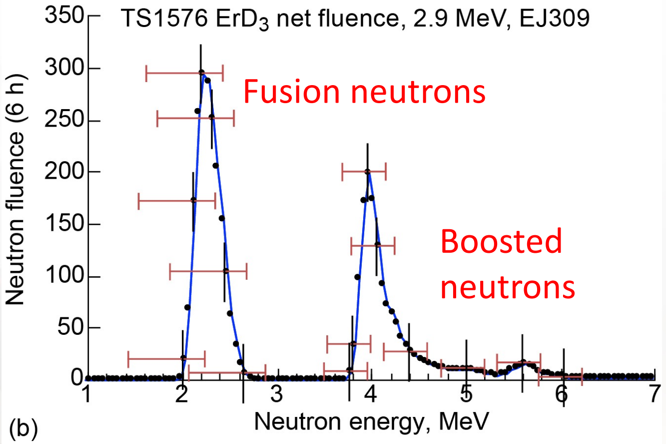
National Aeronautics and Space Administration

Raw counts showing 8 σ pulse shape discrimination between 10^{14} γ/sec and neutrons. *Most of the neutrons thrown away!*

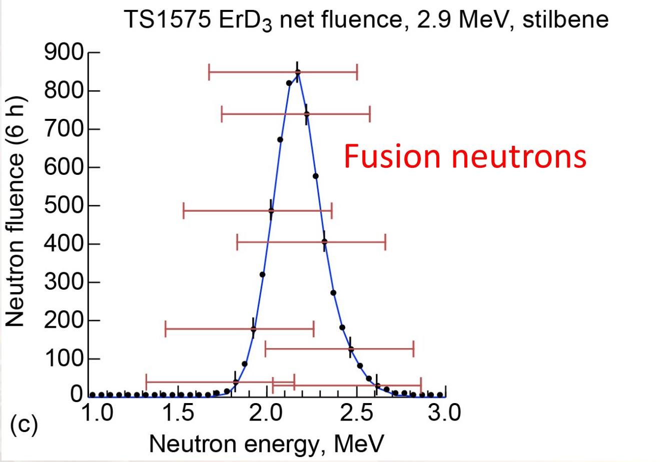
Compare deuterated sample With bare metal control Similar neutron backgrounds

Subtract control from deuterated sample for net flux

Net neutron flux with modeled response of different energy neutrons (2.45 MeV & 4.0 MeV)



Resulting neutron spectra



Similar results with different scintillator on different run.

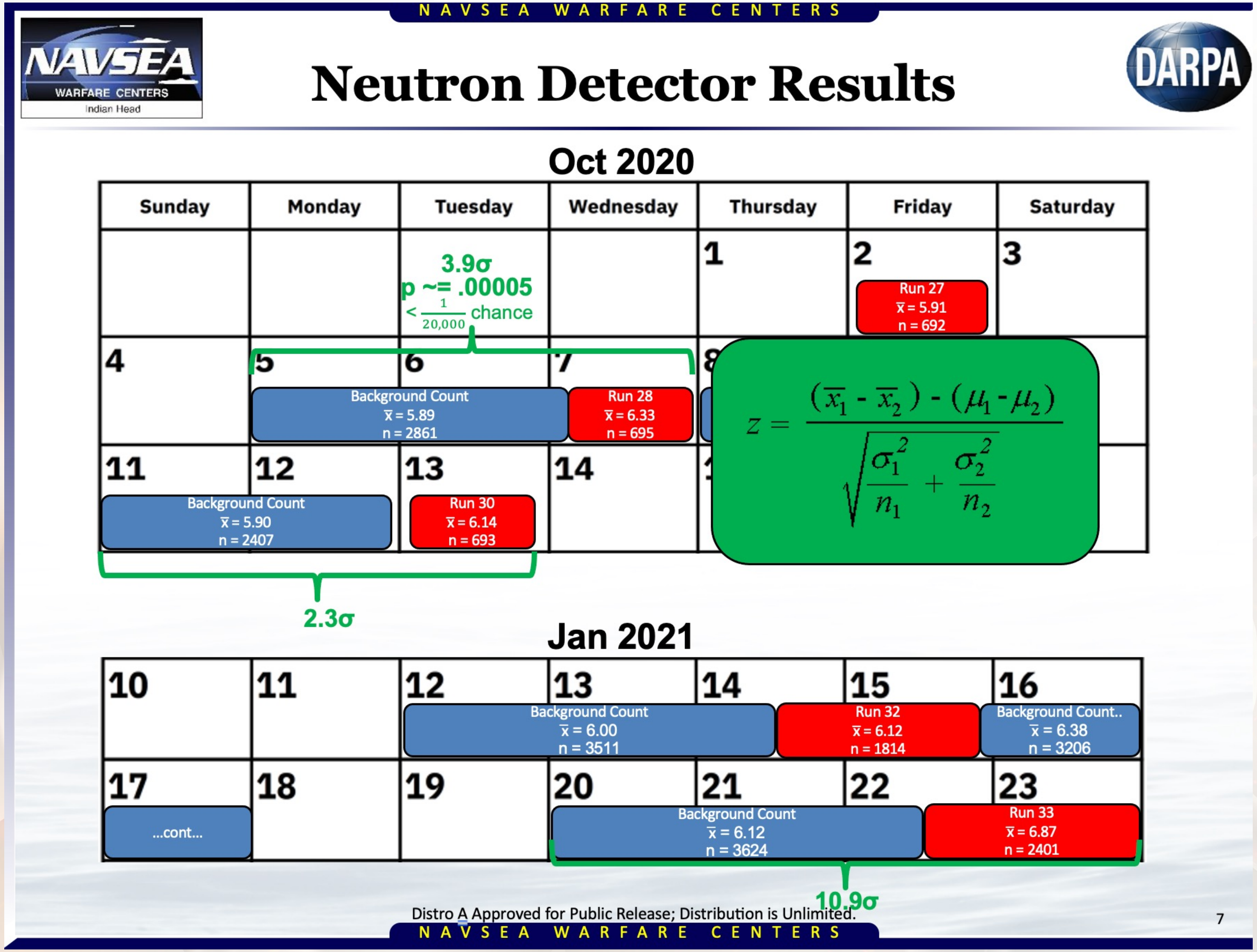
Experiments using bremsstrahlung photoneutrons to drive fusion reactions in deuterated metals.

Fusion neutrons and boosted neutrons observed repeatedly. Different detectors. Both TiD_2 and ErD_3

[1]. B. Steinetz, et al., "Novel Nuclear Reactions Observed in Bremsstrahlung-Irradiated Deuterated Metals", NASA/TP-20205001616 (2020), published first in *Phys. Rev. C* **101**, 044610 (20 April 2020),

Neutron Bursts: Co-deposition or Cosmogenic?

National Aeronautics and Space Administration



HIVER Project

Neutron Detection with ^{3}He REMBALL[1]

Two of three significant neutron counts from experiments at Indian Head were correlated with a cosmogenic background neutron increase at University of Delaware, Newark, DE (100 miles distant):

3.9σ October 5-7, 2020

2.3σ October 11-13, 2020

The third count was not correlated and may be indicative of signal from experiment:

10.9σ January 20-23, 2021

[1] C. Gotzmer, et al. "Solid State Verification of Nuclear Particles in Electrochemical Cells", *ICCF-24: Solid State Energy Summit*, Mountain View, CA, (July, 2022)

So What?

1. **Spectroscopic Neutron Detection**
   - Identify the nuclear exit channel by neutron energy
   - Temporally resolve with real-time spectroscopy
   - Neutrons travel at up to .2% speed of light : *what was the environment that just produced them?*
   - Scattered neutron energy broadening used in laser fusion as core density monitor
2. **Nearby Neutron Detection Control Detector**
   - Unambiguously know the cosmogenic neutron contribution
3. **Compare Temporal Neutron Detection**
   - Use time-resolved multiplicity to further resolve background neutrons
   - Correlate experimental conditions, e.g. pressure, I/V, etc.
   - Slow diagnostics can be viewed as post-triggers for fast (100s of ns) scintillators
4. **PE and BPE passive neutron shielding**
   - Reduce Cosmogenic neutron scattering
   - Reflect, and moderate, experimental neutrons back, but with energy losses
5. **Anti-coincidence active shielding**
   - Further reduce the background by vetoing cosmogenic neutrons

Going Forward

National Aeronautics and Space Administration

- Apply real-time neutron spectroscopy to a variety of LENR/LANR/LCF Systems.
- Are all forms of LENR/LANR/LCF aneutronic?
- What are the conditions that produce neutrons?
- Are the neutrons correlated or anti-correlated with other factors?
- Since neutron spectroscopy, and especially time-of-flight, is recognized by physicists it is less difficult to demonstrate new science using accepted diagnostics.

Like Goldilocks and the three bears:
neutrons are our friends if just enough to detect but not too many![1]

[1] Neutrons are also useful