Neutron Calibrations: Dosimetry and Personnel Protection*

Dan Jardin, NIST

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4/13/26

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

* with detours into neutron source calibration and high activity irradiation (indicated by gray slide background)

Disclaimer

Certain commercial equipment, manufacturers, instruments, or materials are identified in this presentation in order to specify the experimental procedure adequately. Such identification is for informational purposes only and is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the manufacturer, materials, or equipment are necessarily the best available for the purpose.

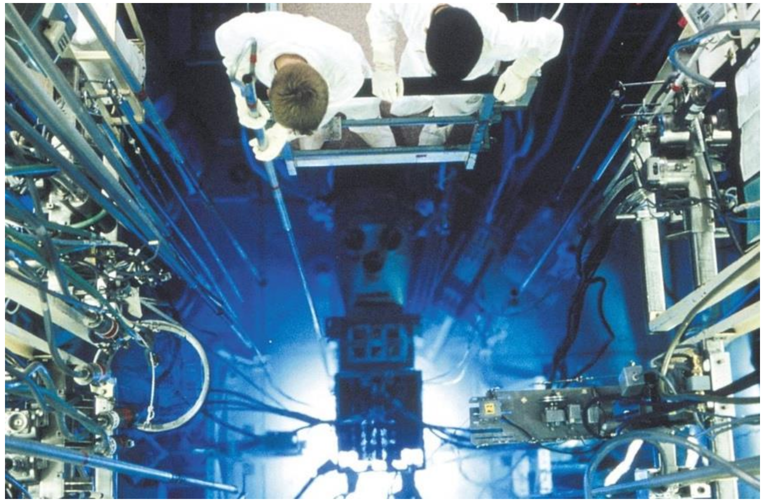
Introduction

- Lab & meter calibrations managed by Alan Thompson for decades
- Alan promoted to Division Chief in 2023 (Acting since 2022)
- I was hired as his successor mid-2023
  - PhD in 2019: searched for direct detection of Dark Matter
  - Postdoc: launched a rocket into space w/ advanced spectral imaging dets
- I jumped from astrophysics to nuclear physics
  - Still learning subtleties of neutron behavior
- I've been doing calibrations ~2 yrs
  - 6 months to get trained
  - Facility was down for 6 months last year

Referring to neutron meters like this: ^{3}He proportional counter inside HDPE with readout for handheld use.

Applications

- Anywhere you want to know if neutron radiation is present
- Supports billion-dollar industries
- Other common customers:
  - Instrument manufacturers
  - Other calibration laboratories



Nuclear energy – personnel protection

Homeland security – cargo screening

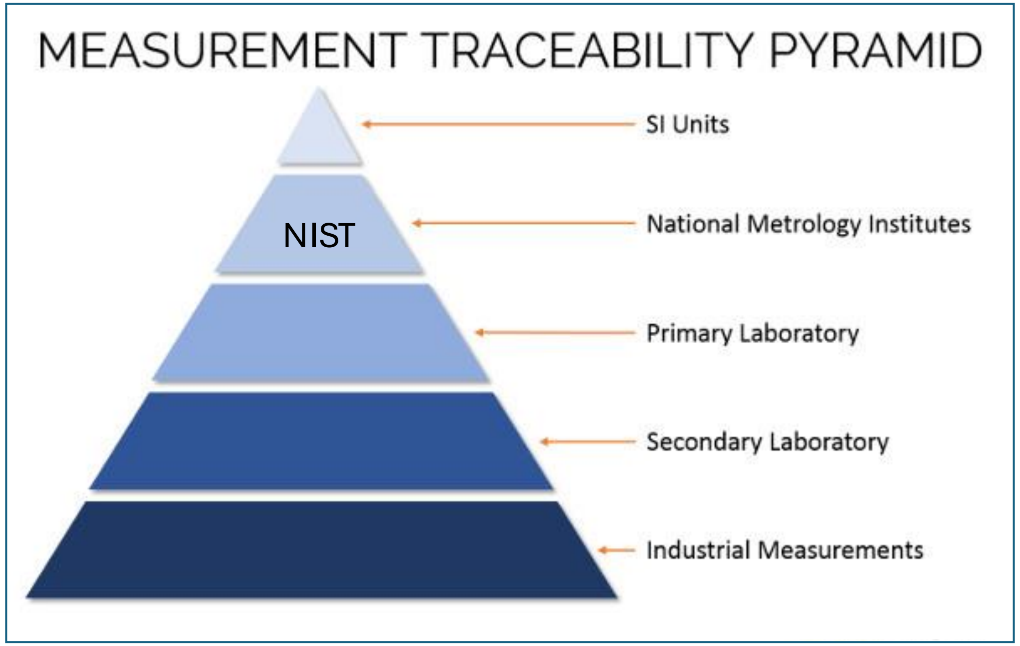
Defense – field detection

Medicine – radiation exposure

Traceability

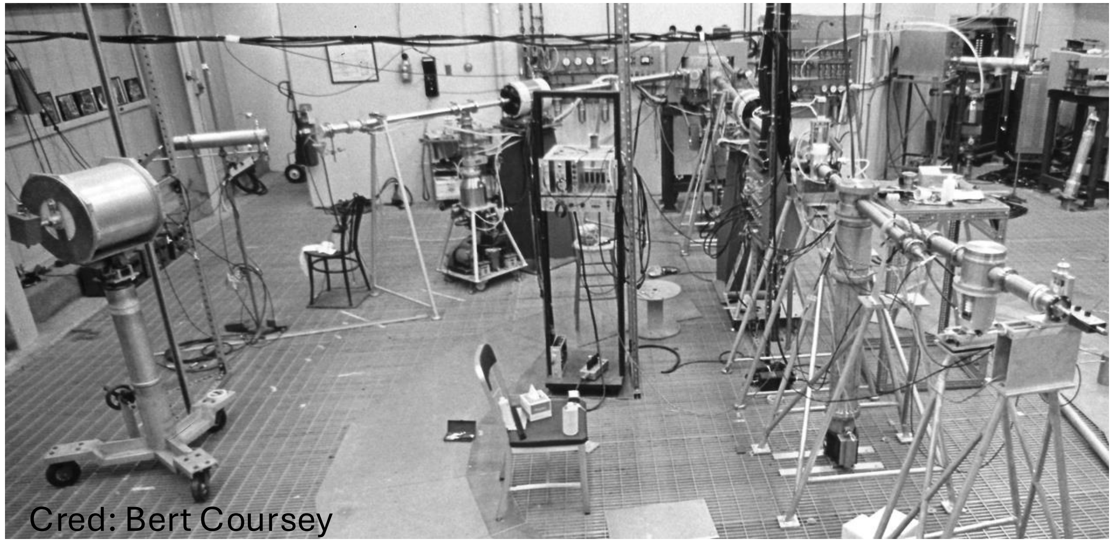
The <u>property of a measurement result</u> whereby the result can be <u>related to a reference</u> through a documented unbroken <u>chain of calibrations</u>, each contributing to the measurement uncertainty. (VIM, 2012)

- All measurements can be traced back to a reference (e.g., artifact, fundamental constant, etc.)
- Establishes end-user confidence
- Often required by regulation
- NMI responsibilities include:
  - Establish the reference standard
  - Participate in CCRI comparisons



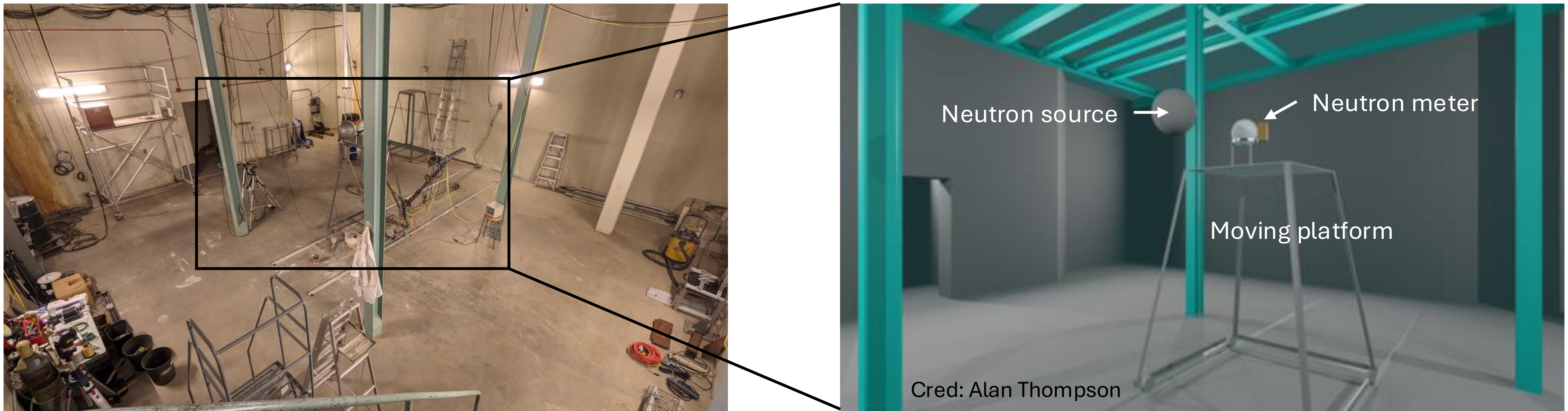
Low Scatter Facility

- Control room and magnet room
- 12.3 m x 12.2 m x 6.7 m main room
  - Open space, Al false floor, and Al walls reduce neutron scattering
  - Primarily used for storage
- Designed for beam experiments using Van de Graaff generator



Calibration Range

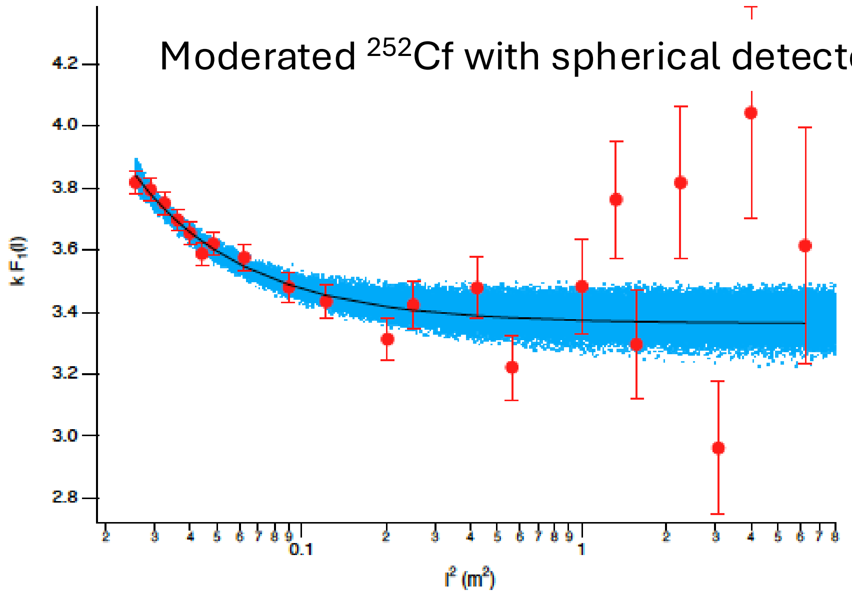
- Objective: record response of instruments in a standardized field
- Established early 1980s, mostly unchanged since (for now)
- Calibrations performed in 11.7 m x 11.1 m x 4.6 m room
  - Beneath the Low Scatter room with concrete walls and floor
- Instruments put on 2.1 m moving platform to control distance from source and reduce neutron scattering from the floor

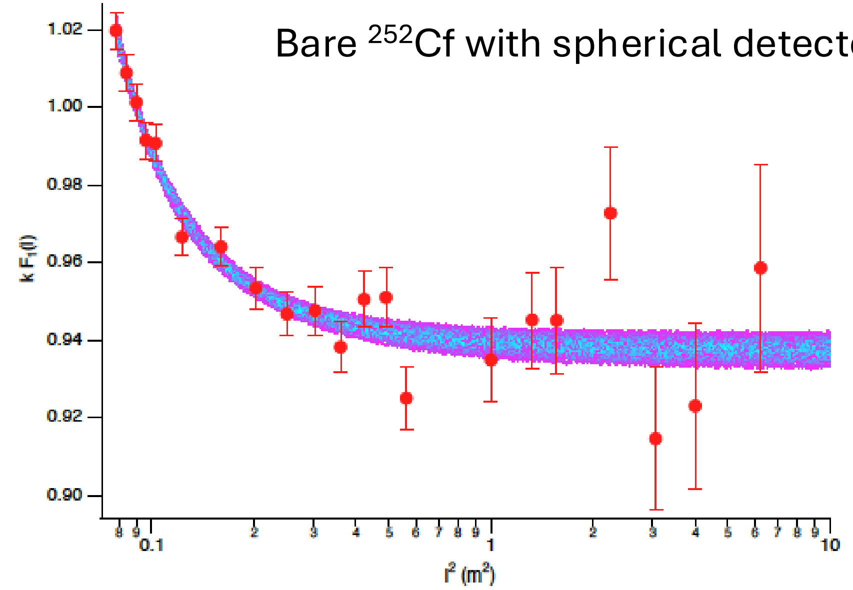


Neutron Corrections

- Corrections are calculated as a function of distance, per ISO 8529-2
  - Geometry of source and meter
  - Air scatter (outscatter)
  - Room return (inscatter)
- Components simulated in MCNP (red)
- Best fit sampled using MCMC (dots)
  - Random point plotted from each curve
- Repeat for every combination of source type and detector type

<u>Geometry Correction</u>





Cred: Alan Thompson

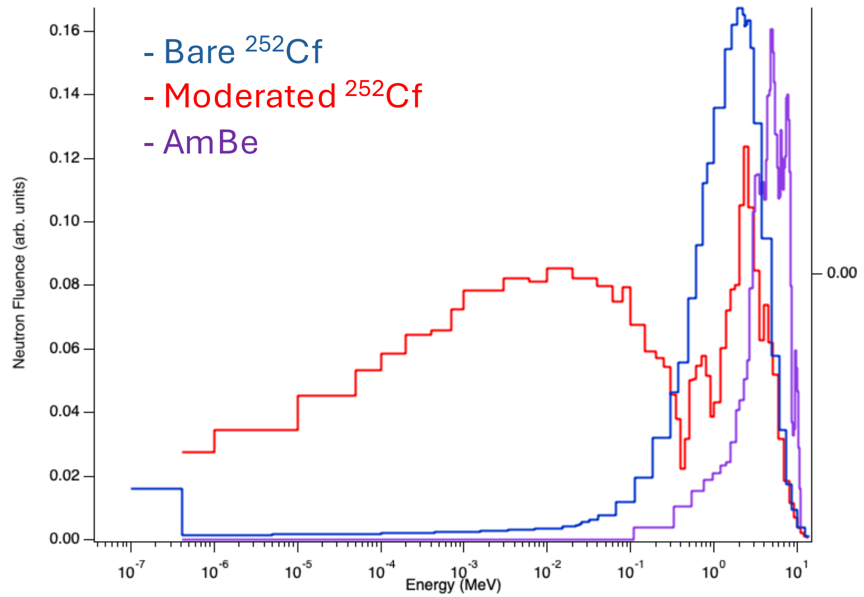
Sources Available

1 mrem = 10 μSv

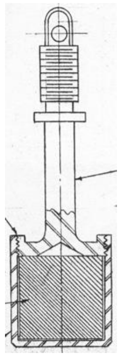
Source Type	Neutron Process	Emission Rates* [n/s]	Dose Rates§ [mrem/hr]
Bare ^{252}Cf	Fission	5×10^5 to 6×10^6	1 to 500
Moderated ^{252}Cf	Fission, D_2O, Cd	5×10^5 to 1×10^8	1 to 600
^{241}Am + ^{9}Be "AmBe"	Alpha-neutron	2×10^6 to 1×10^7	10 to 800

* Calculated activity on 4/13/26
§ Cut off when room return >10%
New moderated ^{252}Cf source in service as of March 2026!

Neutron Source Spectra



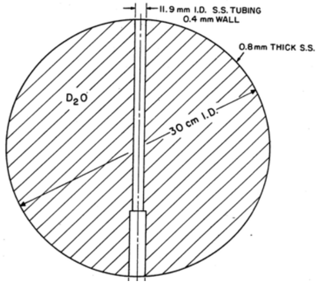
Bare



Cred: Alan Thompson

Right cylinder with thin (20 mil) encapsulation

Moderated



Cred: Schwartz & Eisenhauer

30 cm SS sphere with D_2O

Tube pulls into center bore

Cd shell painted for protection

AmBe

Featureless cylinder, size of D battery

Custom basket for deployment

Source Storage

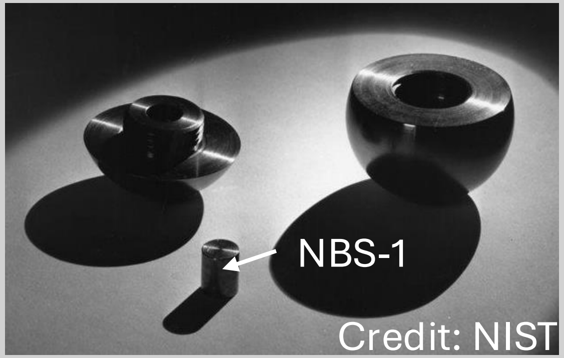
Sources hang from ends of poly rods by ball chains

- Sources stored in revolving carousel
  - ~2 m into concrete floor
- AmBe source doesn't fit in carousel
  - Stored in water barrel → upgrading to shielded 55 gallon drum
  - Requires temporary "igloo" → upgraded to rolling, shielded water bucket

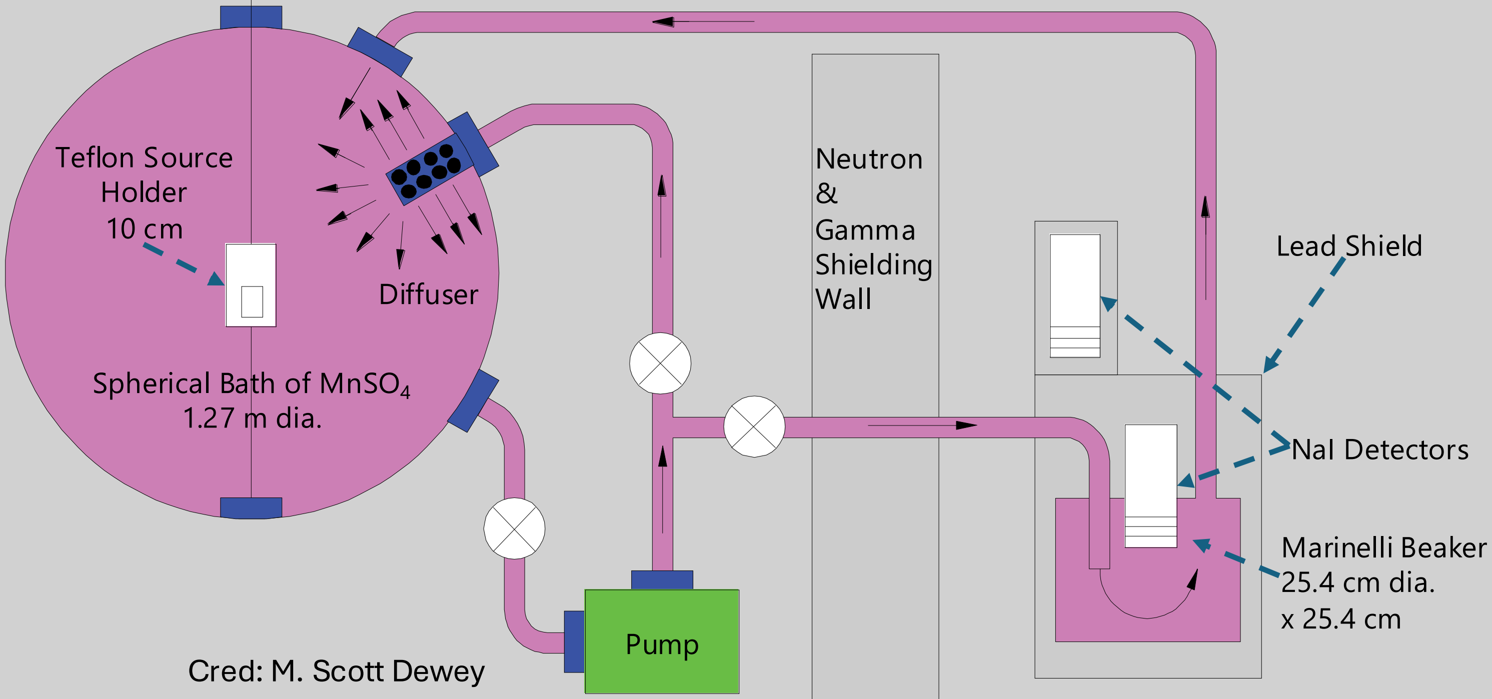
AmBe storage update

"Igloo" update

Source Emission Calibration

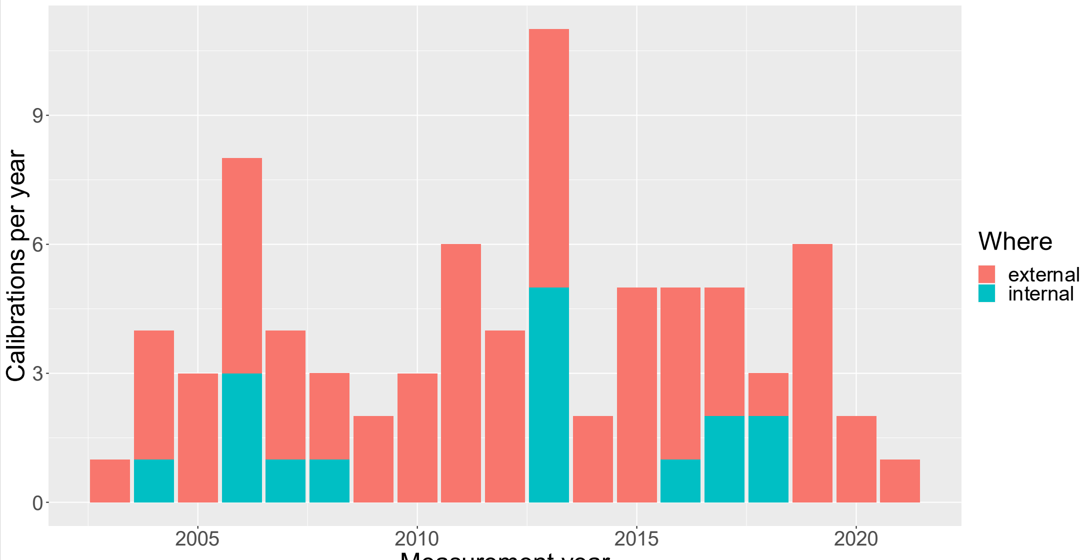


- All neutron sources calibrated using [Mn Bath at NIST]
- Traceable to NBS-1, the national standard source (RaBe, γ-n)
- Activated Mn emits light: $^{55}Mn + n \rightarrow {}^{56}Mn \rightarrow {}^{56}Fe + \gamma$
- Activated solution plumbed to NaI detectors

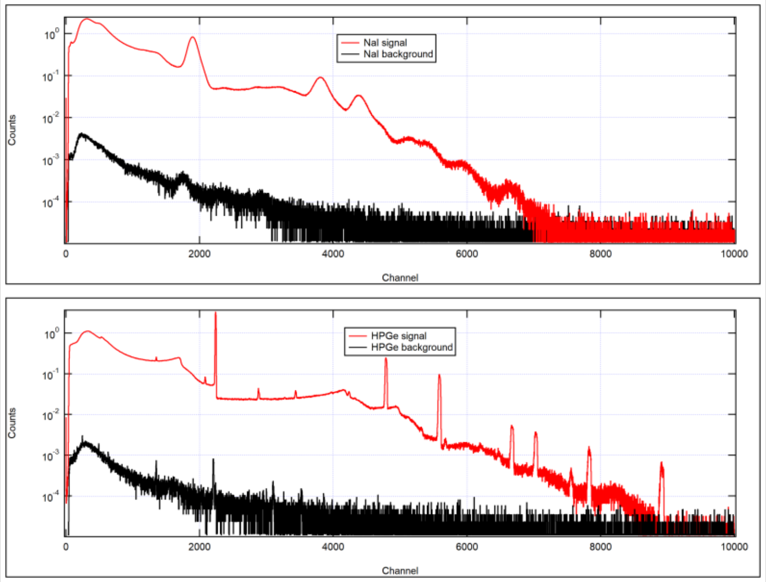


Source Emission Calibration

- Mostly ^{252}Cf; some AmBe; rarely RaBe, AmLi, or ^{244}Cm
- SKU 44010C: Neutron source emission rates 10^5-10^8 n/s
- SKU 44020C: Neutron source emission rates 10^8-10^{10} n/s
- Upgrading to HPGe → 20x S/N → sensitive to lower activities



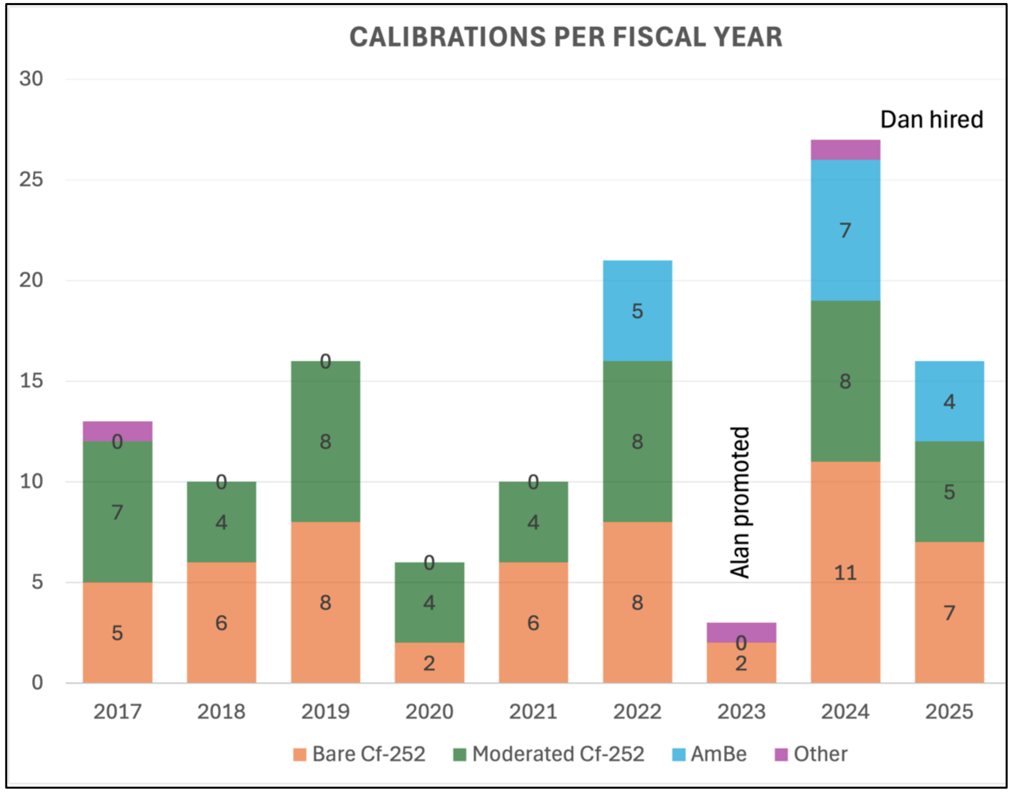
Cred: M. Scott Dewey



NaI vs. HPGe

Cred: M. Scott Dewey

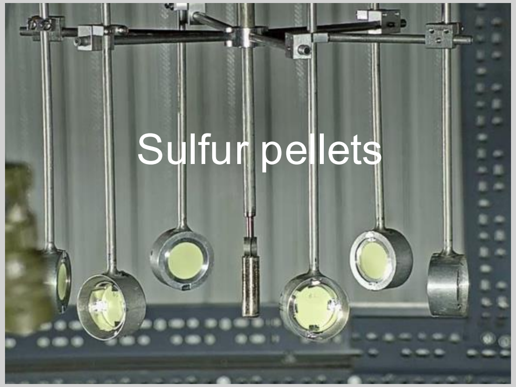
Services Provided

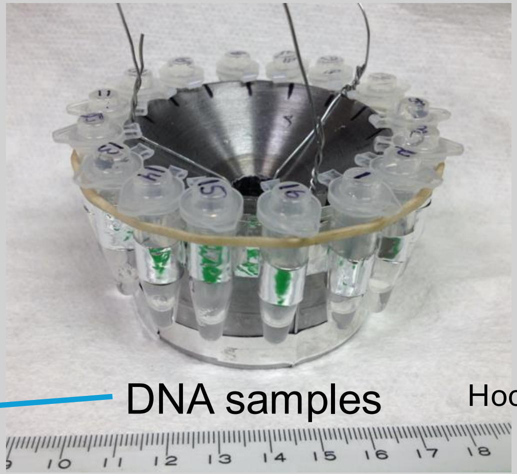


- SKU 44060C: Neutron Personnel Protection Instrumentation/Dosimeters using ^{252}Cf Fission Neutrons
  - Typical calibration without special requests
  - Performed with bare or moderated ^{252}Cf
- SKU 44100S: Special Tests of Neutron Instrumentation, Dosimeters, or Other Devices
  - Catch-all for other calibrations, including AmBe
  - CNIF irradations under this SKU as well
- Collaboration
  - Research projects with more involvement
  - Testing at other locations
  - Culminates in publication(s)
- Interlaboratory comparisons
  - Ensures consistency of services offered

Special Irradiations

- Californium Neutron Irradation Facility for high-dose, fast, & monoenergetic neutron irradiations
  - Anhydrous borax walls shield room return
  - ^{252}Cf (new 5 mg source, ~10^{10} n/s)
  - D-D generator (2.5 MeV, ~10^{6} n/s)
  - D-T generator (14 MeV, ~10^{8} n/s)
- Measurement program examples:
  - Detector calibration: sulfur & dark matter
  - Radiation hardness: electronics
  - Dosimeter development: alanine pellets
  - Activation assessment: concrete degradation
  - Biological samples: DNA
  - Nuclear energy: fission and fusion industries





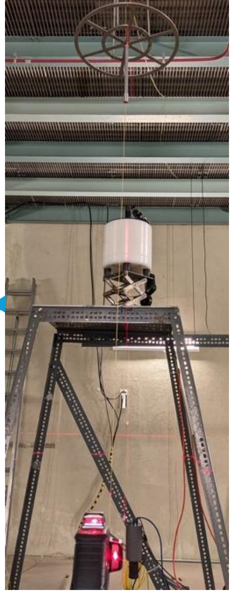
Joel Beazley presenting on alanine pellet dosimeters 4/14 @ 16:20
Joey Robertson presenting on DNA dosimetry 4/15 @ 11:10 (maybe plenaries 5 & 6 too)

Cred: Shannon Hoogerheide

Calibration Procedure (1/3)

1. Customer requests quote using NIST Store
2. Customer places order if satisfied with quote
3. Instrument gets shipped to NIST
4. Unpack, inspect, and document the instrument
5. Place instrument on the moving platform
6. Set up desired source (bare, moderated, or AmBe)
7. Adjust instrument height to middle of the source

Calibration Procedure (2/3)



8. Align instrument to source using triple-axis laser
9. Measure source-to-detector distance
   - If moderated, “kiss” detector to the D_2O sphere to define zero

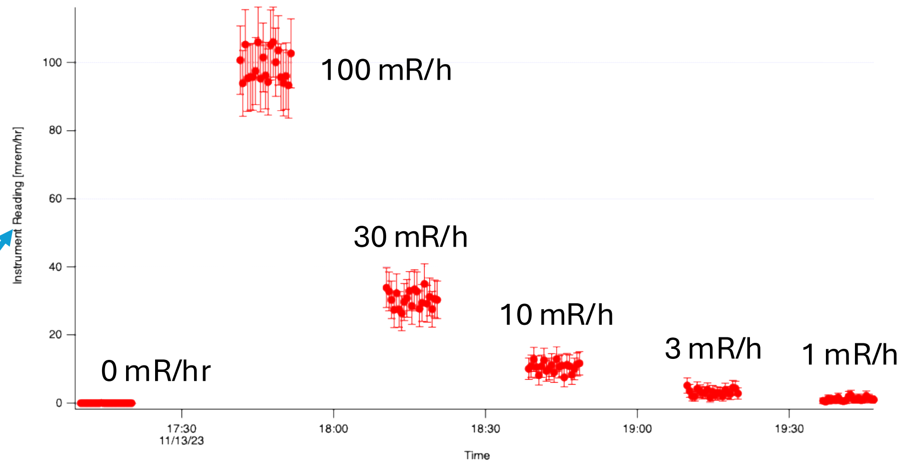
10. Align video camera to instrument output display
11. Calculate Plan Table for dose rates and corresponding distances
12. Attach source to bead chain on Kevlar string
13. Remotely move platform to first position on Plan Table

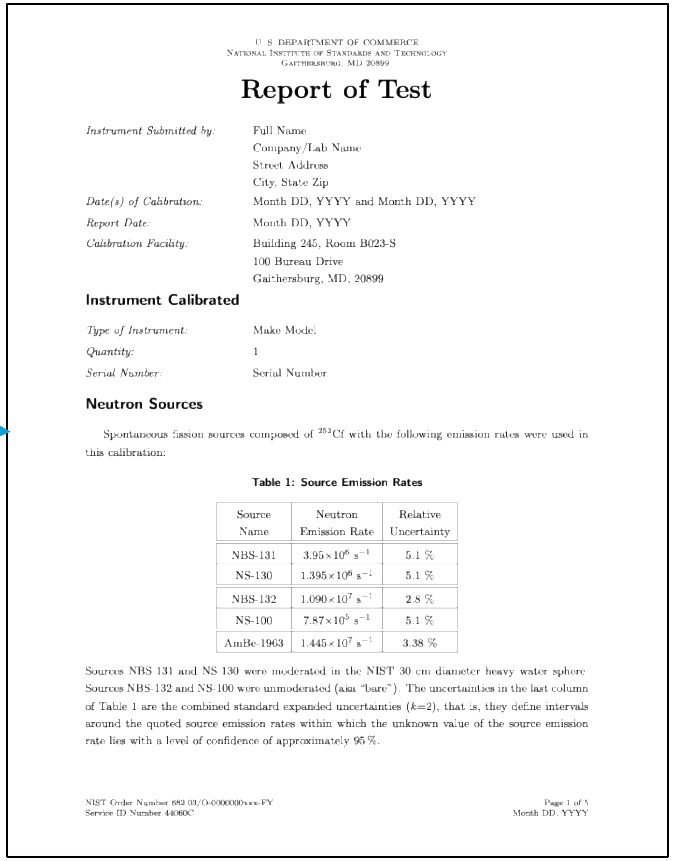
Example Plan Table

sourceName	month	day	year	SourceFluence	D_SS	D_CC	FFDE	CorrPct	RealDose	D_scale
NBS-132	11	13	2023	1.09E+07	23.59	35.02	97.786	2.265	100	22.59
NBS-132	11	13	2023	1.09E+07	52.81	64.24	29.065	3.217	30	51.81
NBS-132	11	13	2023	1.09E+07	102.5	113.9	9.239	8.236	10	101.51
NS-100	11	13	2023	786585	42.98	54.41	2.9229	2.636	3	41.98
NS-100	11	13	2023	786585	84.36	95.79	0.94292	6.054	1	83.36

Calibration Procedure (3/3)

14. Remotely raise source into position
15. DAQ computer takes periodic screenshots from camera
16. Repeat for other measurements in Plan Table
17. Remotely lower source back into storage well
18. Download data and analyze
19. Generate the calibration report
20. Obtain signatures and upload report
21. Ship instrument back to customer





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GAITHERSBURG, MD 20899

Report of Test

Instrument Submitted by: Full Name
Company/Lab Name
Street Address
City, State Zip

Date(s) of Calibration: Month DD, YYYY and Month DD, YYYY

Report Date: Month DD, YYYY

Calibration Facility: Building 245, Room B023-S
100 Bureau Drive
Gaithersburg, MD, 20899

Instrument Calibrated

Type of Instrument: Make Model

Quantity: 1

Serial Number: Serial Number

Neutron Sources

Spontaneous fission sources composed of ^{252}Cf with the following emission rates were used in this calibration:

Table 1: Source Emission Rates

Source Name	Neutron Emission Rate	Relative Uncertainty
NBS-131	3.95×10^6 s^{-1}	5.1 %
NS-130	1.395×10^6 s^{-1}	5.1 %
NBS-132	1.090×10^7 s^{-1}	2.8 %
NS-100	7.87×10^5 s^{-1}	5.1 %
AmBe-1963	1.445×10^7 s^{-1}	3.38 %

Sources NBS-131 and NS-130 were moderated in the NIST 30 cm diameter heavy water sphere. Sources NBS-132 and NS-100 were unmoderated (aka "bare"). The uncertainties in the last column of Table 1 are the combined standard expanded uncertainties (k=2), that is, they define intervals around the quoted source emission rates within which the unknown value of the source emission rate lies with a level of confidence of approximately 95 %.

NIST Order Number 682.03/O-0000000xxx-FY
Service ID Number 44060C

Page 1 of 5
Month DD, YYYY

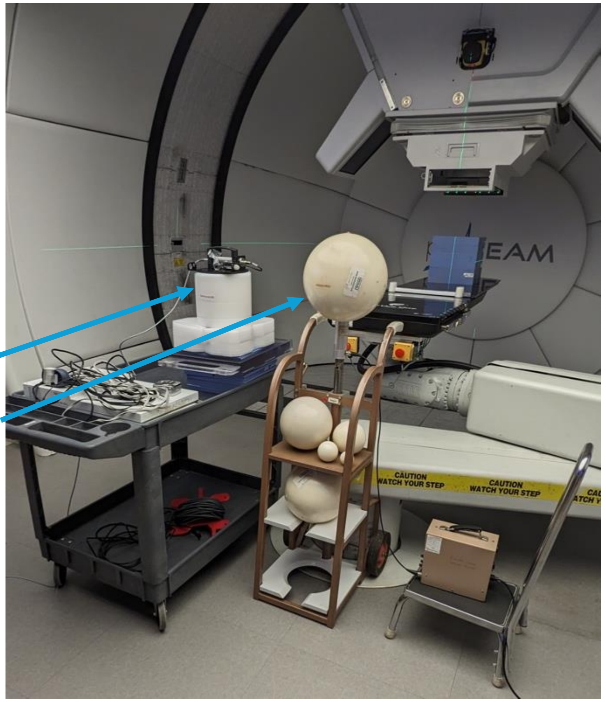
NCI Collaboration

- Neutrons generated by proton beam can lead to secondary radiation for patient and health care workers
- Went to Maryland Proton Treatment Center to make measurements around the room with the proton beam on
  - Measured neutron dose rates with WENDI meter
  - Measured neutron spectra with Bonner Sphere Spectrometer
- Used to validate simulation tools

BSS paper in *Frontiers in Oncology* soon
WENDI paper already in progress

Detectors were calibrated at NIST prior to field use

WENDI ratemeter and Bonner Sphere Spectrometer each measured various positions around the room

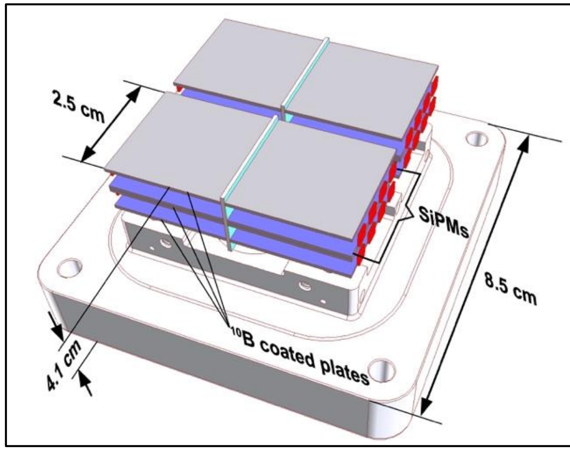


UMD Collaboration

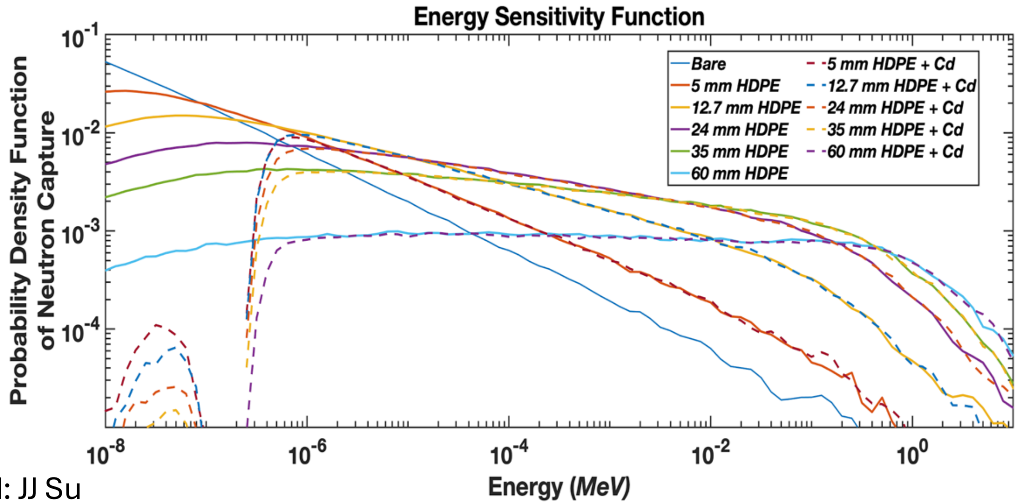
$$^{10}B + n \rightarrow [^{11}B]^* \rightarrow \alpha + {}^{7}Li + 2.8\ \mathrm{MeV}$$
$$2Xe \rightarrow Xe_2^* \rightarrow 2Xe + h\nu\ (170\ \mathrm{nm})$$

- Developing a novel spectrometer (alternative to ^{3}He)
- Robust & easily scalable to array of cells
- Different HDPE attachments modify energy response
- Energy spectrum reconstructed using ML
- Previously funded by NASA for lunar deployment development

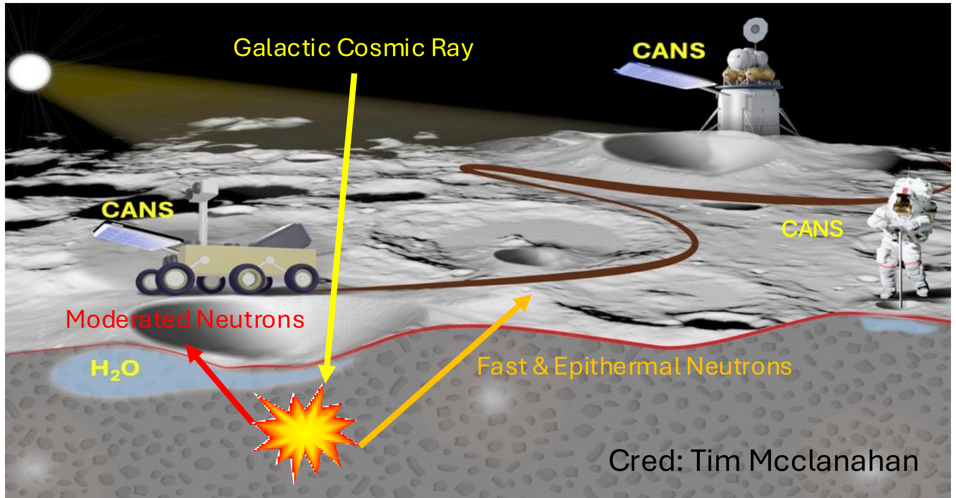
Drawing of one unit cell



Cred: Les Putnam



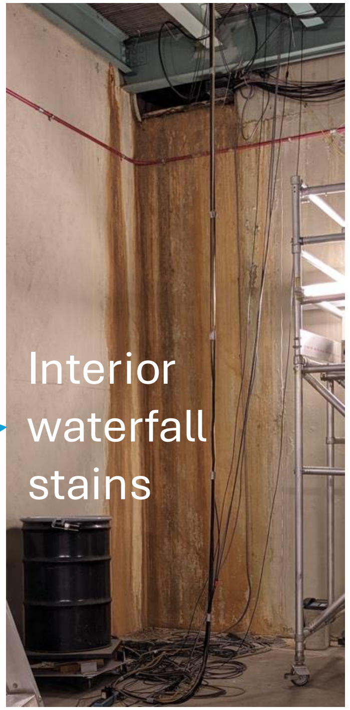
Cred: JJ Su

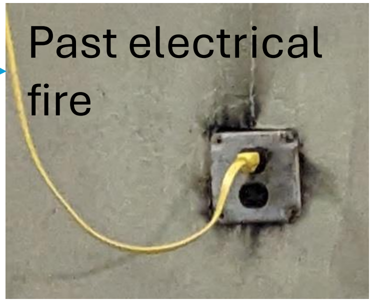


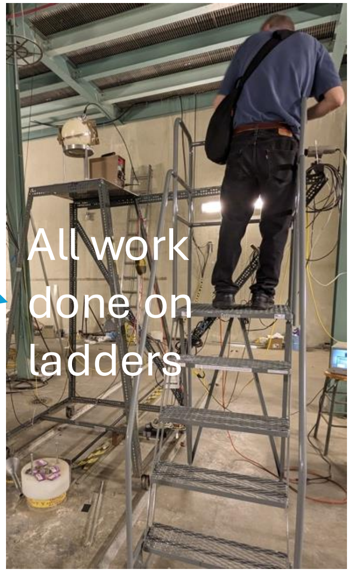
Lunar deployment methods to locate subsurface hydrogen

Planned Facility Upgrades*

- Resume building modernization§
  - Ineffective HVAC controls
  - Water intrusion affects neutron measurements
  - No Wi-Fi or cell service is inconvenient and unsafe
  - Faulty & noisy electrical is dangerous
- Move calibrations upstairs to Low Scatter room
  - Concrete floor and walls scatter neutrons
- Budget for regular acquisition of new sources
  - ^{252}Cf is expensive ($1M/mg) with short half-life (2.65 y)
  - Incorporate AmBe better to meet increasing need
- Budget to upgrade equipment



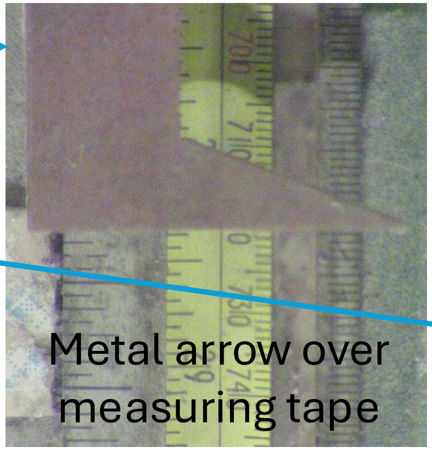


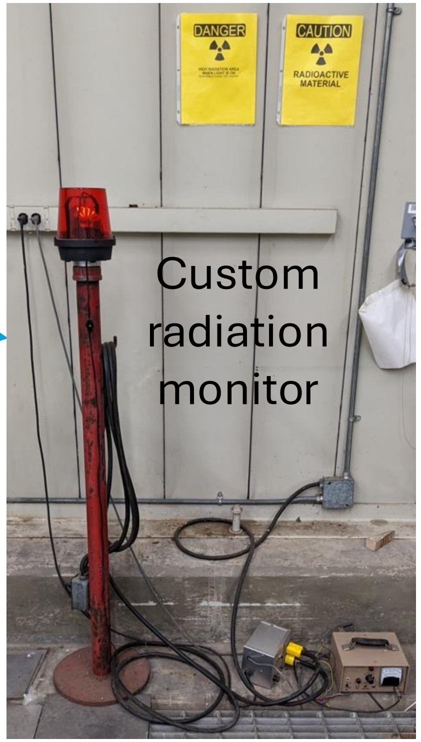


* If/when funding permits
§ This includes Mn Bath and CNIF too

Equipment Upgrades

- Remote monitoring cameras and displays
  - → Low res, grainy, shading, some B/W
  - → Buy HDMI monitors and new cameras – high res, PTZ , PoE
- Moving cart and location tracking
  - → Manual control, tracking via ruler glued to floor
  - → Build or buy 80-20 cart, laser distance, computer controlled
- Radiation area monitor
  - → Custom setup difficult to debug, old wiring exposed
  - → Buy plug-and-play commercial monitor
- Source deployment via Kevlar string & reel
  - → Source sticks (can't push), string wears
  - → Replace with pneumatic system, can be automated
- DAQ computer not allowed on NIST network
  - → Not able to remotely access data or download programs
  - → Buy new computer that meets security requirements





NIST Neutron Calibration Facilities

Thank You

Questions?