Novel, Low-Cost, Neutron-Alpha Spectroscopy, Safety and Dosimetry Using Tensioned Metastable Fluid Detector (TMFD) Sensor Technology

EFCOG Nuclear Facility Safety Conference, Albuquerque,NM
February 26, 2020

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In Collaboration with
Savannah River National Laboratory (C. Lewis/T.Lorier/D.DiPrete)

Sponsor: DOE-AU-NSRD (Program Manager: A. Levin (Retd.), Project Manager: P. Frias)

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PURDUE
UNIVERSITY

[redacted]

Greetings from Purdue University – The Boilermakers

Inventors of the “Barn” Unit

Purdue University – *Fact Sheet*

Established(1874)	– 39
Enrollment (2013-14)	~74,341
Degrees Awarded (1874-Present)	- ~602,778
Alumni (*Living*)	- 375,000+
Budget (2014)	~ $2.3B
Ranking(academic –engr)	- Top 10 (US)
Faculty/Staff	~ 19,248
Physical Plant	- 19,172 acres
President	- M.Daniels

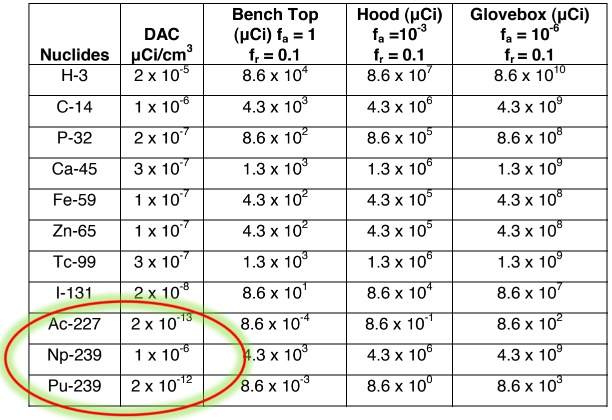
2019-2020 AU-NSRD Project Ongoing (Purdue-SRNL)

Monitoring Air-borne **Alpha-Fission** Actinides (Pu/Am/Cm/U..) &/vs Background Rn-Po Contamination

Why?

- Inhaling Pu/Am/Cm is x1,000 more toxic than from Rn/Po Progeny **(Rn is EVERYWHERE)**
- → Stringent safety limits: e.g., for Pu-239 (~10^{-3} pCi/L; DAC~0.2 Bq/m^3); Rn (~4-40+ pCi/L)
- CAMs often cannot tell if detected alphas are from Rn-222 (5.5MeV) or Am-241 (5.5MeV)
- Requires stand-down (Rn Progeny Decay; Mass-Spec/Chem./LS Spectrometry Assessments)
- Well known DOE-wide safety/operation challenge (Past 50+y)
- Can lead to mission disruptions, outages, potentially over-expose workers to Pu/Cm/Am/U

Table 5.18-1 Example of maximum activity (q) allowed for normal operations (for specified assumptions)

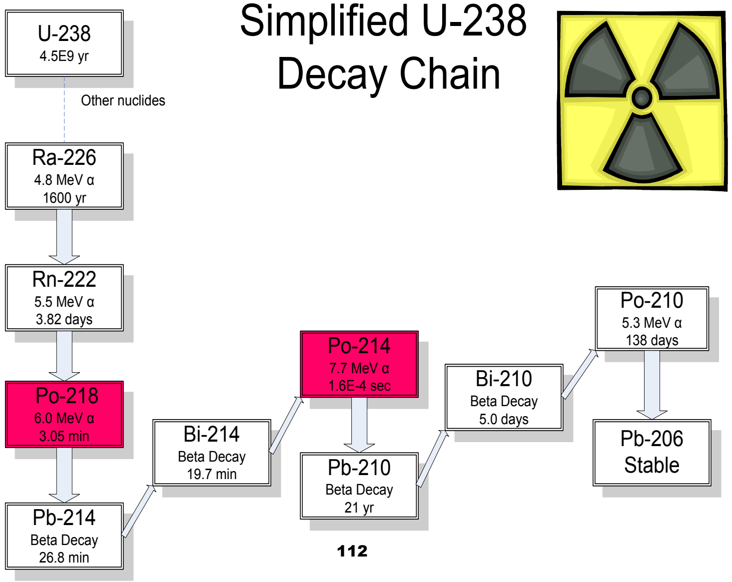


Nuclides	DAC µCi/cm^3	Bench Top (µCi) $f_a = 1$ $f_r = 0.1$	Hood (µCi) $f_a = 10^{-3}$ $f_r = 0.1$	Glovebox (µCi) $f_a = 10^{-6}$ $f_r = 0.1$
H-3	2×10^{-5}	8.6×10^{4}	8.6×10^{7}	8.6×10^{10}
C-14	1×10^{-6}	4.3×10^{3}	4.3×10^{6}	4.3×10^{9}
P-32	2×10^{-7}	8.6×10^{2}	8.6×10^{5}	8.6×10^{8}
Ca-45	3×10^{-7}	1.3×10^{3}	1.3×10^{6}	1.3×10^{9}
Fe-59	1×10^{-7}	4.3×10^{2}	4.3×10^{5}	4.3×10^{8}
Zn-65	1×10^{-7}	4.3×10^{2}	4.3×10^{5}	4.3×10^{8}
Tc-99	3×10^{-7}	1.3×10^{3}	1.3×10^{6}	1.3×10^{9}
I-131	2×10^{-8}	8.6×10^{1}	8.6×10^{4}	8.6×10^{7}
Ac-227	2×10^{-13}	8.6×10^{-4}	8.6×10^{-1}	8.6×10^{2}
Np-239	1×10^{-6}	4.3×10^{3}	4.3×10^{6}	4.3×10^{9}
Pu-239	2×10^{-12}	8.6×10^{-3}	8.6×10^{0}	8.6×10^{3}

Proposed Solution/Challenge:

- TMFDs already capable of separately detecting Pu & Rn isotopes at ultra-trace levels.
- Adapt TMFD (Rn) sensing technology to also include Pu (x10^3 lower activity)
- Alternately, field R-TMFD (Rn) sensor in tandem with existing CAMS

Radon (Alpha Emitter) is Present Worldwide – In Air We Breathe (~21,000/y Lung Cancer Fatalities in USA – EPA)



Simplified U-238 Decay Chain

U-238
4.5E9 yr

Other nuclides

Ra-226
4.8 MeV α
1600 yr

Rn-222
5.5 MeV α
3.82 days

Po-218
6.0 MeV α
3.05 min

Pb-214
Beta Decay
26.8 min

Bi-214
Beta Decay
19.7 min

Po-214
7.7 MeV α
1.6E-4 sec

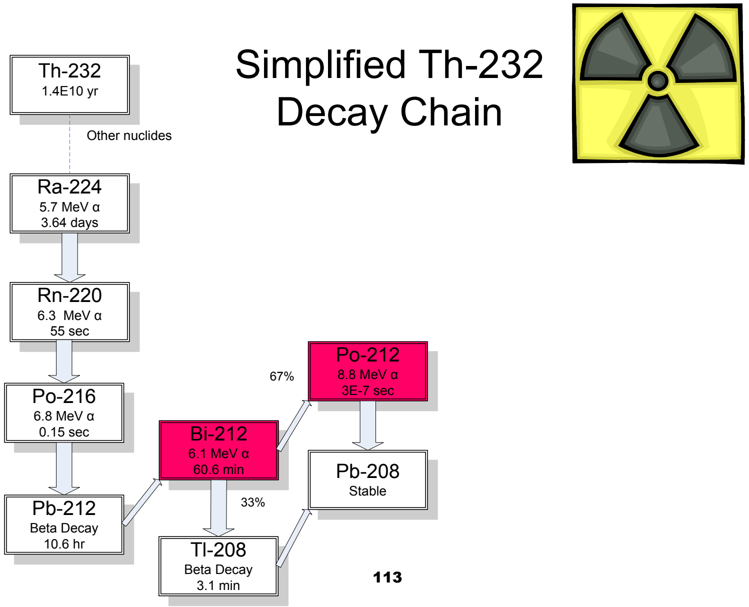
Pb-210
Beta Decay
21 yr

Bi-210
Beta Decay
5.0 days

Po-210
5.3 MeV α
138 days

Pb-206
Stable

112



Simplified Th-232 Decay Chain

Th-232
1.4E10 yr

Other nuclides

Ra-224
5.7 MeV α
3.64 days

Rn-220
6.3 MeV α
55 sec

Po-216
6.8 MeV α
0.15 sec

Pb-212
Beta Decay
10.6 hr

Bi-212
6.1 MeV α
60.6 min

67%

Po-212
8.8 MeV α
3E-7 sec

33%

Tl-208
Beta Decay
3.1 min

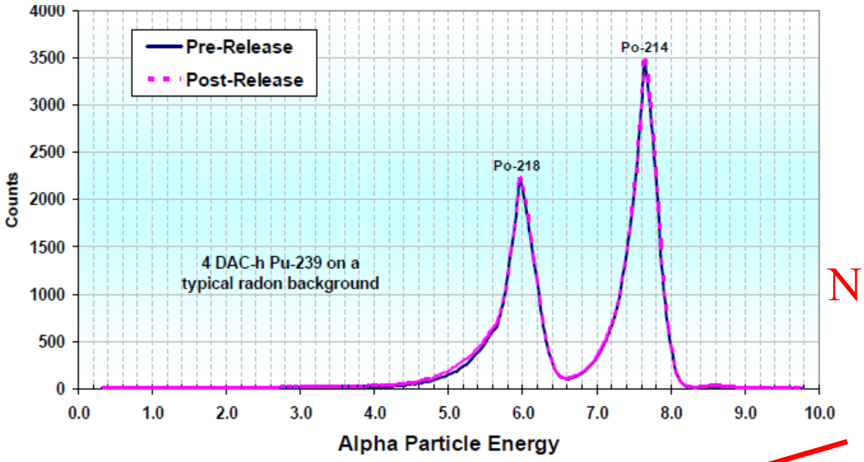
Pb-208
Stable

113

Source: T. Voss

Challenges in Monitoring ^{239}Pu (or ^{235}U) from Rn Contamination PIPS-based CAMS

1,000x More Rn in Air than Pu/Am/U/Cm



Needs for PSF; Self-shielding, etc.

Table 1. Summary data on key alpha-emitting isotopes of concern in DOE Nuclear Facilities [3,4]

Isotope	Alpha Energy (MeV)	Half-Life	#Atoms/Bq (calculated)
^{238}Pu	5.5	~85y	~10^{9}
^{241}Am	5.48	~400y	~10^{10}
^{239}Pu	5.16	~25,000y	~10^{12}
^{222}Rn (U-Decay Chain)	5.5	3.8d	~10^{5}
^{218}Po (U-Decay Chain)	6	3min.	~10^{2}
^{214}Po (U-Decay Chain)	7.7	140×10^{-6}s	~10^{4}
^{220}Rn (Th-Decay Chain)	6.3	55s	~10^{2}
^{212}Bi (Th-Decay Chain)	6.1	1h	~10^{3}
^{212}Po (Th-Decay Chain)	8.8	0.3×10^{-6}s	~10^{-7}

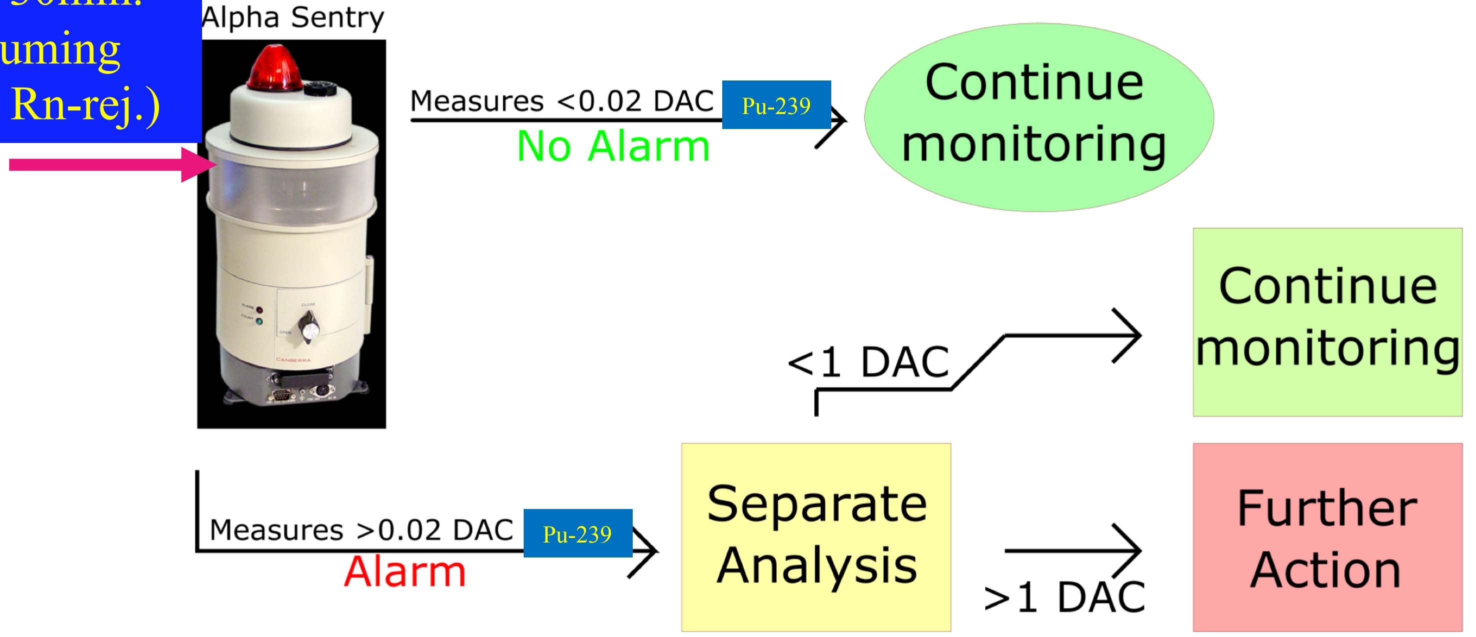
Desirable Characteristics- (n,α,f) Radiation Monitors*

- Real-Time Functionality (Reduced dose to responders/public)
- High Detection Efficiency → Major ALARA/Economy Impacts
- Spectroscopic (“Nuke” or Not?)
- Blind to Common Background Radiation (gamma-beta)
- SNM Tracking Capability – Real Time
- Ultra-Trace Level Monitoring (esp. alpha sources)
- One Unit for Key Radiation Types/Uses (α,n,FF)
- Lower Cost (x10+)
- Operable under low to high temperatures/humidity; mech. shocks
- Light-weight (Portability); Robust; Field Worthy
- Intuitive, Readily Deployable-Understandable
- “Smell-Sip” the air/water for SNM/FP/Actinide “odors” ???

(*) – Present day systems: Costly ($50K-$500K); Relatively Inefficient; Bulky; Off-Site Forensics

Common DOE CAM (e.g., Alpha-Sentry $10-20K) Based Approach (1 DAC for 2,000h → 5 Rem Annual Max. Limit) 0.02DAC →100 mRem (40DACh; Common Alert Set Point)

100L/min. for 35h+30min. (Assuming 95% Rn-rej.)



1*DAC (Pu-239) = 2.59e-5 Bq/L

PURDUE NUCLEAR ENGINEERING
METASTABLE FLUIDS AND ADVANCED RESEARCH LABORATORY

Why TMFD Technology?
– For Neutron, Alpha, Fission Detection/Spectroscopy

- 100% gamma-beta-muon blindness (to 700+ R/h fields)
- Thermal (eV) and Fast (1-100 MeV) Neutron Detection
- ~60-80% intrinsic detection efficiency (neutrons)
- ~95%+ intrinsic efficiency (alpha/fission); x100 below LS
- ~1.4 keV energy resolution
- Spectroscopy; Distinguish between (α,n);fission; cosmics
- Temperatures (0-50C); To 95%RH; Shock Tolerant
- On-Off within seconds to microseconds
- 10^{-9}s to 10^{-12}s event timing and multiplicity possibilities
- Directionality/Source positioning with 1/2 TMFD units
- Low-cost sensing material (<< 0.1$/g)
- SNMs/actinides/neutrons from air/fluid borne (Am/Pu vs Rn)
- Active and Passive Interrogation
- Tech. Transfer to Fielding - by Purdue via SALabs,LLC

1st Prize Paper Award – Nov.2016 IEEE SENSORS Intl.Conf. (*) – Demo Units For Viewing at Tech. Cafe

Paper No. 1287

Live Demonstration:

Femto- to-Macro Scale Interdisciplinary Sensing with Tensioned Metastable Fluid Detectors

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***Abstract*—*Live interaction, interdisciplinary multi-physics demonstrations using the tensioned metastable fluid detector (TMFD) sensor systems are proposed. TMFDs utilize centrifugal-acoustic forcing to place ordinary liquids like water into sub-zero (i.e., below vacuum) pressure states of metastability such that interacting subatomic scale particles, or even eV photons can be detected via visible-audible transient bubbles that nucleate from nm scales growing to visible mm scales. Interactive experiments will cover diverse areas such as: nuclear physics (detecting neutrons – tell-tale signal from U/Pu fission using a unique NRC-licensed public use neutron source, study of cosmic rays); health-nuclear medicine (measuring of lung-cancer causing Radon in air at ultra-trace 1 part in 10^{17}); Optics (monitoring and tracking a nanosecond pulsed laser beam); Acoustics-Piezoelectrics-Fluidics-Heat Transfer-.Mechanics.*

Keywords—TMFD, Fluidics, Acoustics, Radiation, Optics

I. INTRODUCTION & BACKGROUND

Ordinary fluids like water at room temperature can indeed be placed under tension, even negative (Pneg) pressures (yes – even below perfect vacuum) as scientifically confirmed only a few decades ago leading to the novel TMFD sensor class [1]. Briefly, tensioned fluids are in state of metastability; their intermolecular bonds weakened such that, select stimuli types can "poke" holes into them to create transient bubbles that can rapidly (within µs) grow to states that are visible-audible to humans. Amazingly, conventionally hard to detect sub-atomic neutral particles like neutrons or ions (tell-tale signatures from U/Pu nuclear fission) can be now detected with unparalleled intrinsic efficiency [1-2]. Stimuli types may also include ordinary UV-IR photons. The scientific principles and potential transformational uses have been published elsewhere [e.g., 1-2]. Unlike complex/expensive conventional sensors for radiation-photon detection which rely on extensive electronc trains, PMTs, scintillators, etc., TMFDs are based on intuitive, centrifugal force as from common rotary tools, and/or resonant mode acoustic vibrations from piezo-electric elements. Two distinct forms of hand portable, table-top systems: C(Centrifugal)-TMFDs and Acoustic(A)-TMFD systems will be used for demonstrations and hands-on experiences.

Table-top CTMFD and ATMFD sensor setups are shown in Figs. 1a, 1b, respectively – AC/DC powered.

Figure 1a. Centrifugal Tensioned Metastable Fluid Detector Setup/Operation **movie clip** **http://web.ics.purdue.edu/~ahagen/link_1.mp4**	Figure 1b. Acoustically Tensioned Metastable Fluid Detector Setup/Operation **movie clip** **http://web.ics.purdue.edu/~ahagen/link_2.mp4**

II. INTERACTIVE DEMONSTRATIONS

A. Special Nuclear Material (SNM) Identification

Imagine a sub-atomic 10^{-27} kg (almost mass-less) particle with only ~10^{-12} J making a liquid boil on demand in space-time, without any superheat at ~20C!!! Merely, by changing the Pneg tensioned fluid state. Such sensing capability is unparalleled. Using USNRC's first of kind license to Purdue, now for the first time enables our small (~10cc) on-ff source of neutrons for public demonstrations- we will show that state-of-art sensors are ineffective. Then, we demonstrate how the simple macro-scale TMFD apparatus allows a lay-person to spectroscopically detect, in-effect visibly see/hear neutrons via recordable bubble pops. (**http://web.ics.purdue.edu/~ahagen/link_1.mp4**) - **movie clip.**

B. Tracking a laser beam with directionality and intensity

Imagine studying optical phenomena via fluidics and heat transfer to also sense and map transient pressure profiles [1,3] in non-contact mode!!! Ref. 1 (Fig. 9) shows a track of bubbles delineating the directional characterization of a common ns UV pulse(~0.3 mJ) at only 1bar below vacuum (-10^5 Pa). (**http://web.ics.purdue.edu/~ahagen/link_3.mp4**) - **movie clip.**.

C. Real-time Radon in air detection with TMFDs

Radon is a gas that enters homes/dwellings at ultra trace quantities (1:10^{17}) but which, according to the EPA, causes 25,000 lung cancer deaths in the USA alone. Conventional (~$10K+) Rn sensors are complex, unaffordable, and require days/weeks to provide reliable estimates. Live demonstration will be given using CTMFDs (**http://web.ics.purdue.edu/~ahagen/link_1.mp4**-- **movie clip**) on how Rn in air may also be detected in near real time.

III. VISITOR EXPERIENCE

Visitors will handle TMFDs hands-on, learn novel sensing for wide-ranging arenas: terrorism; portal screening; medicine; energy; interdisciplinary engineering sensing applications.

REFERENCES

[1] R. P. Taleyarkhan, J. Lapinskas, Y. Xu, "Tensioned metastable fluids and nanoscale interactions with external stimuli.." Nucl. Engr. Des., 238 (2008) 1820-1827.

[2] B. Archambault et al., "Transformational Nuclear Sensors – Real-time monitoring of WMDs, Risk Assessment and Response," IEEE HST-2010 978-1-4244-6046/10 (2010) 421-427.

[3] A. Hagen et al.,, "Characterization and optimization of a tensioned metastable fluid nuclear particle sensor using laser based profilometry," ASME Journal of Nuclear Engineering and Radiation Sci 1 (4), 041004-1-10 (2015).

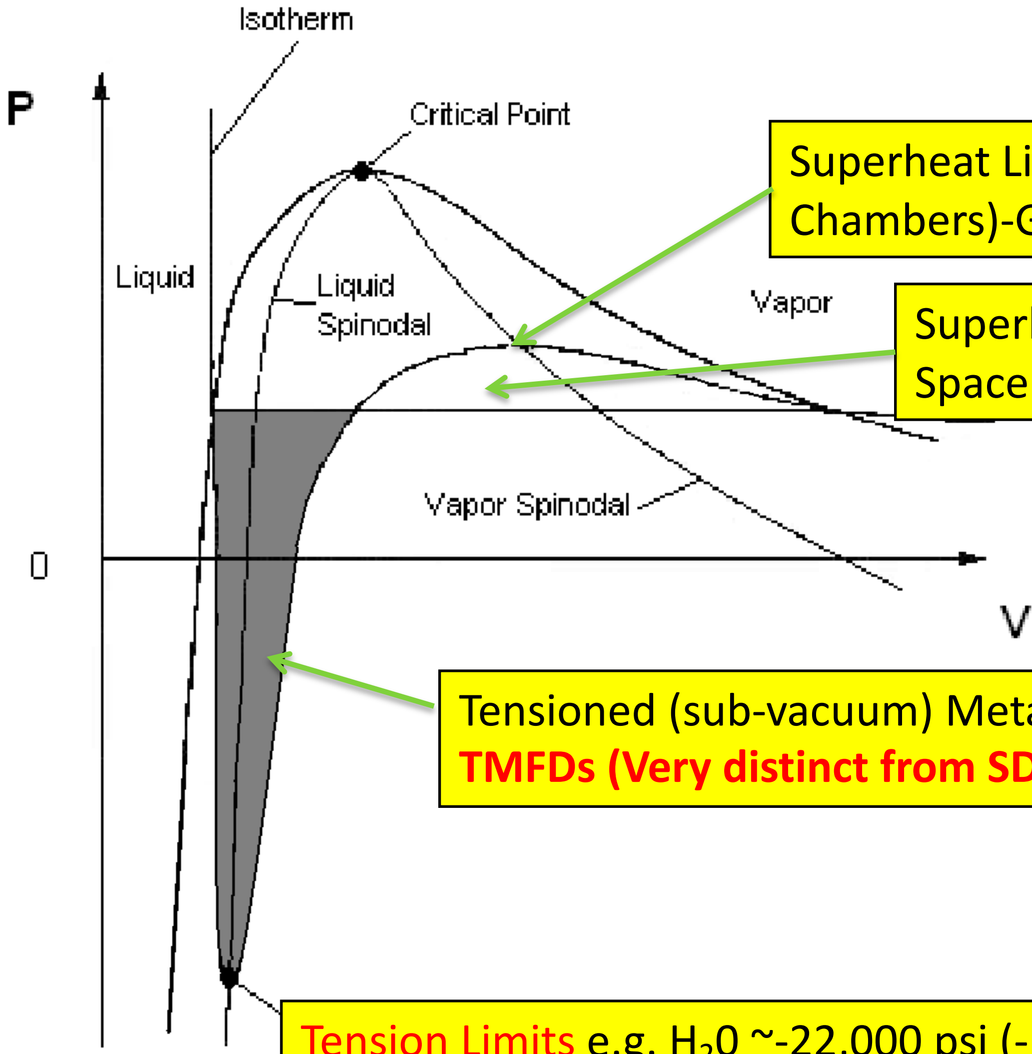
Sponsors: U.S. (DoE, DoD,DHS, NSF); SALabs.,LLC,, Purdue Univ.

Brief Introduction to TMFD Science & Technology

Metastability – Brief Primer

Liquids Can be Stretched and Superheated?

Sub-Ze e – Trees)



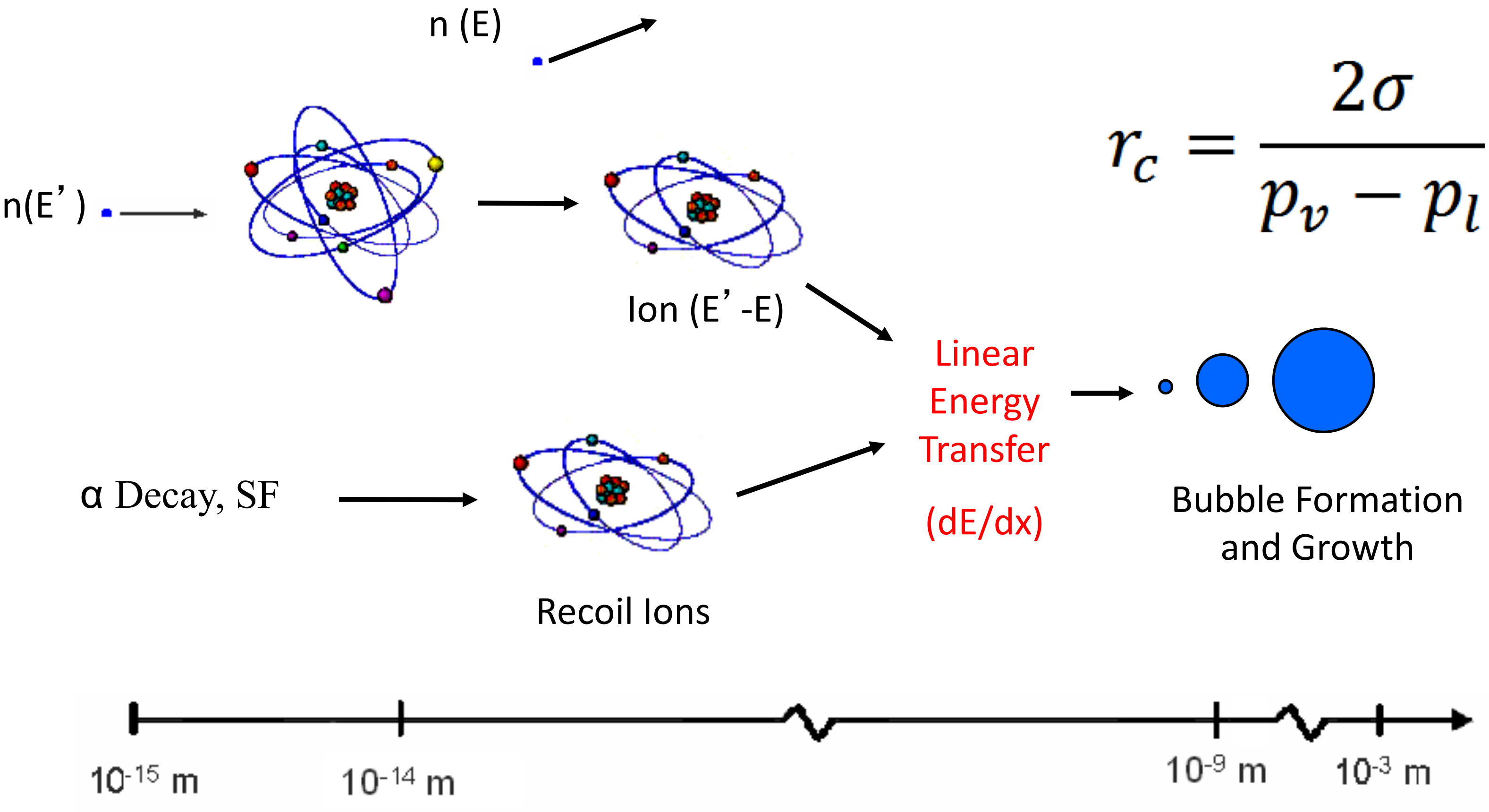
Superheat Limit (Bubble Chambers)-Glasser, 1960 → SDDs

Superheat Metastability Space →**SDDs**

Tensioned (sub-vacuum) Metastability Space → **TMFDs (Very distinct from SDDs)**

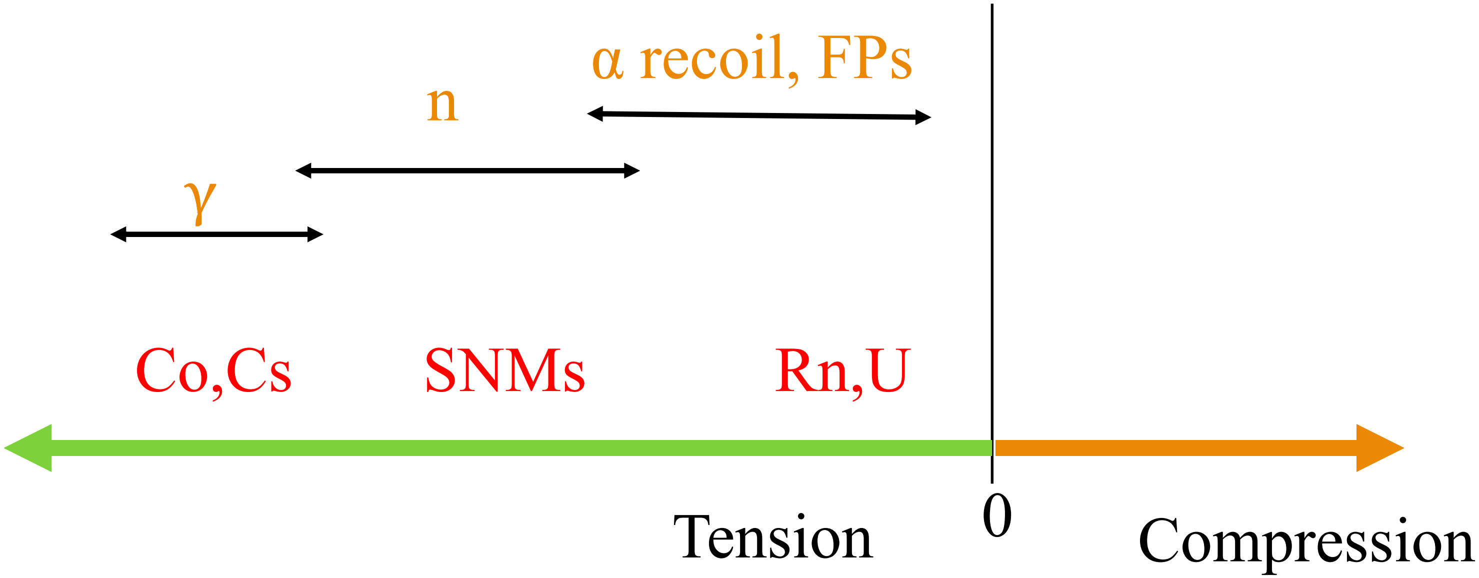
Tension Limits e.g. H_20 ~-22,000 psi (-1,700 bar)

Detection Control via Triggering Stored Energy Release
dE/dx = ~1(for ϒ,β); ~ 10^3 to 10^4 (for n, α, FPs)



$$r_c = \frac{2\sigma}{p_v - p_l}$$

Metastable Fluid Detector
- Same System for Multiple Uses



α recoil, FPs

n

γ

Co,Cs

SNMs

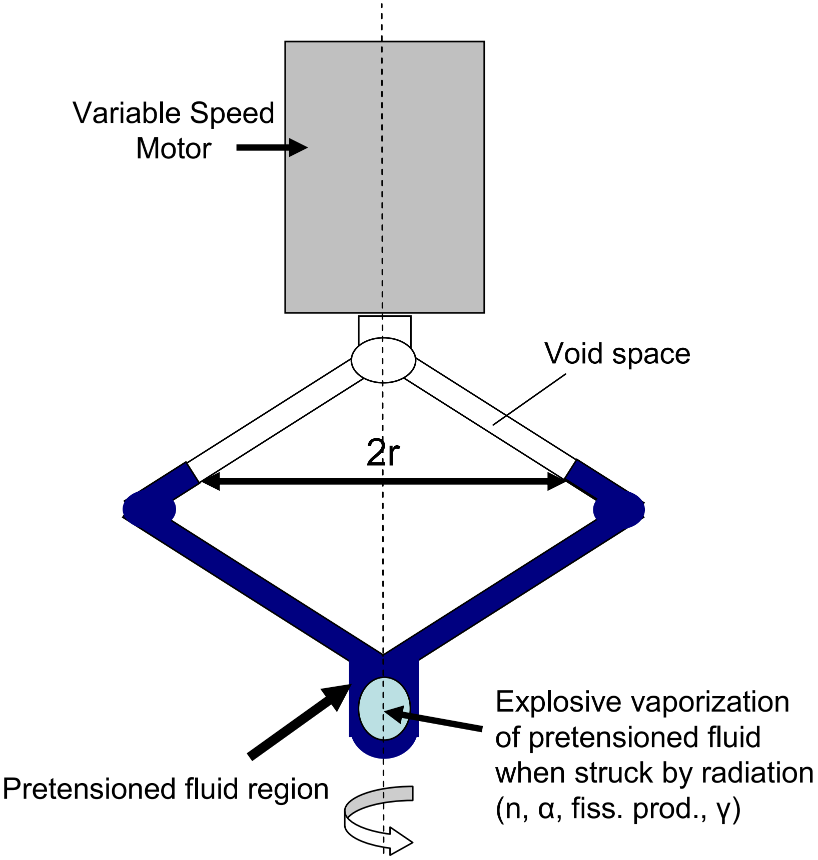
Rn,U

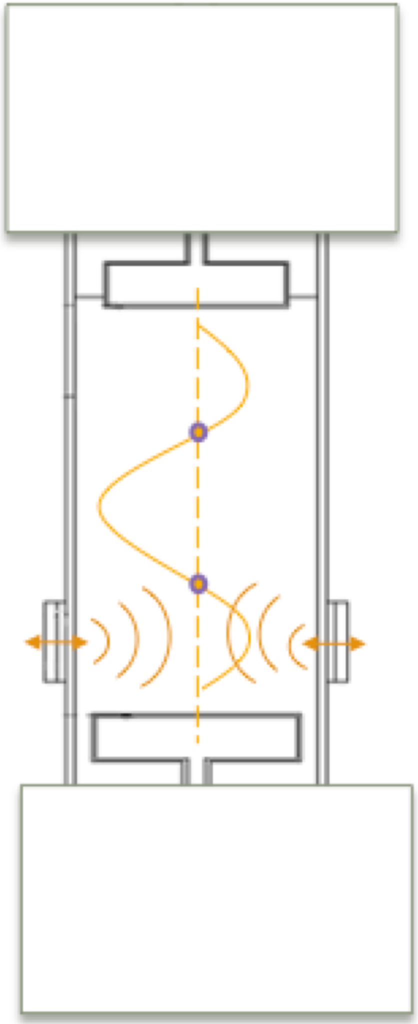
Tension

0

Compression

CTMF & ATMF Detectors



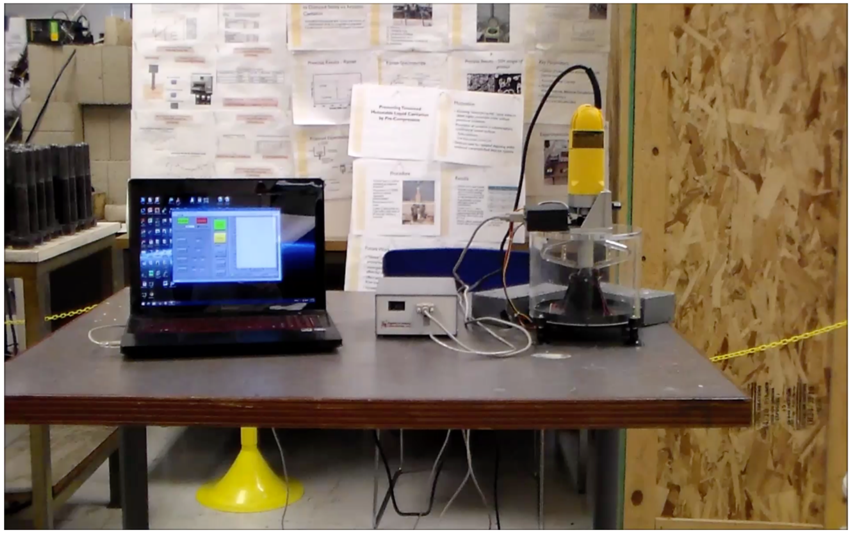


Hand Portable (~2-3 kg; 0.25m x 0.25m x 0.3m)

”See-Hear Radiation”

(Tensioned Metastable Fluid Detectors)

CTMFD



ATMFD

ACCOMPLISHMENTS – NEUTRON BASED SNM DETECTION/SPECTROMETRY/DOSIMETRY
→ Towards Successful Fielding & Marketing in Multiple Arenas (Safety-Security-Safeguards)

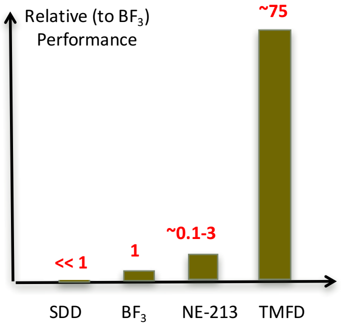


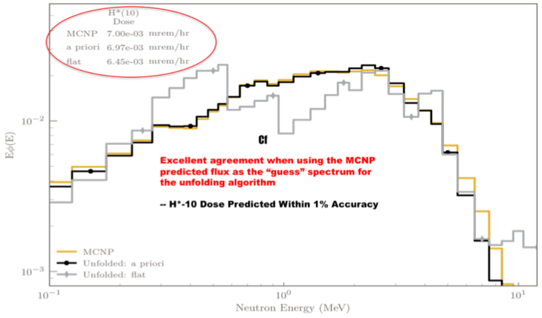
Fig. 3. Relative neutron detection efficiencies of state-of-art sensors vs TMFD [Taleyarkhan et al., 2016] Ref. 14. 1st Prize IEEE Award.

TASK 4

ULTRA-LOW H*-10 DOSE & SPECTRUM UNFOLDING RESULTS (300CM; 16CC H*TMFD):

- FISSION SPECTRUM SOURCE (CF-252)

– Fuji NSN3/SNOOPY/BONNER SPHERES UNABLE TO FUNCTION in ~ 7 mic.Rem/h



Excellent agreement when using the MCNP predicted flux as the "guess" spectrum for the unfolding algorithm

-- H*-10 Dose Predicted Within 1% Accuracy

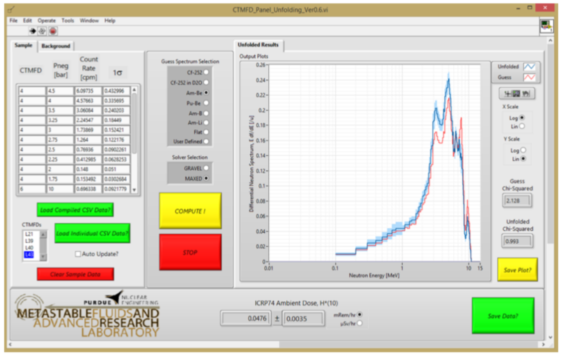
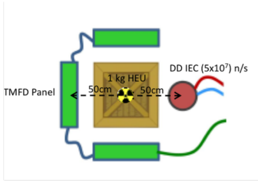


Figure 4. PC data unfolding and remote logging software available for ease of use in H*(10) mode. Remote or local operation (USB or Ethernet) of CTMFDs – Single and Arrays are possible.

Figure 1. CTMFD (Model HP-MCTMFD, customizable)

Figure 1. H*TMFD (Model H*TMFD, customizable)



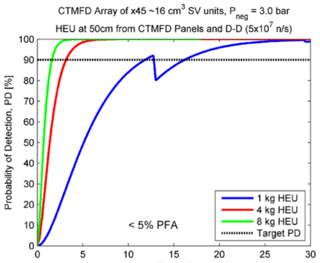
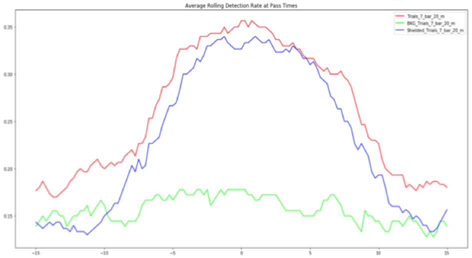


Figure 5: Probability of detection for varying amounts of HEU.

70ft Standoff; ~30mph



PAST ACCOMPLISHMENTS (DOE / Industry Supported)
– TRACE LEVELS ALPHA NUCLIDE DETECTION SPECTROSCOPY
-- Actinides (U, Pu, Am, Cm,..)
-- Radon & Progeny (pCi/L levels; 2 min. sampling; EPA-Ref.Lab Vetted)

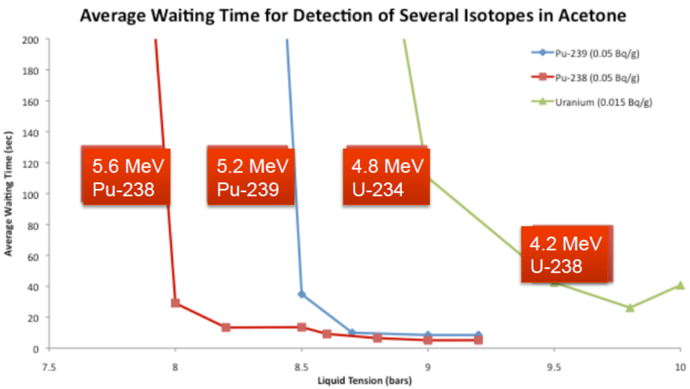
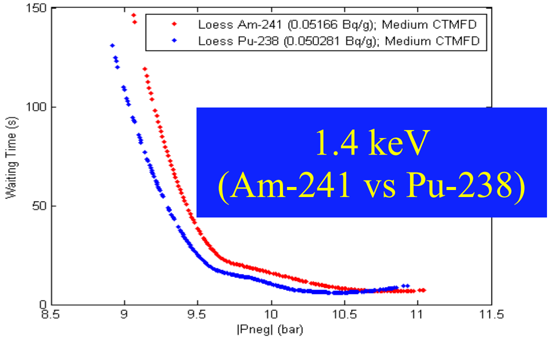


Figure 2. Real-Time, ~100% detection efficiency, alpha spectroscopy with CTMFD system.



1.4 keV
(Am-241 vs Pu-238)

Fig. 1b. High Resolution (1 keV) Actinide (Pu/Am) Alpha Spectrometry with TMFD sensors – Ref. 12.

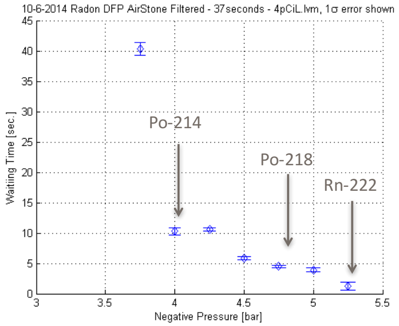
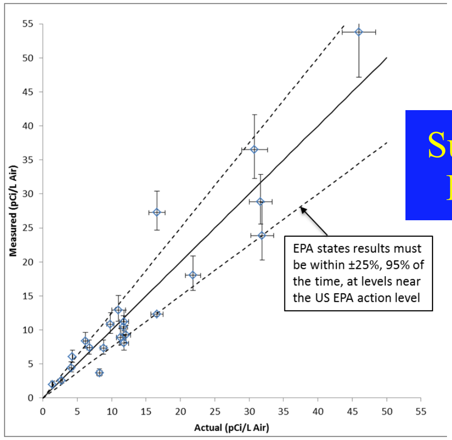


Fig. 2. Rn and Progeny Alpha Spectrometry with TMFDs – meeting/exceeding EPA Rn-certification standards [Boyle et al.13] 2017- Best Paper Award.



EPA states results must be within ±25%, 95% of the time, at levels near the US EPA action level

Successful AARST-Std
EPS Ref.Lab. Tested

Present Project – Two Part Solutions

Part 1: Assess Potential for Novel Alpha Detector Architecture – Radical Departure (Solely TMFD Based Extension of TMFD for Actinide ID +/- Rn); No Need for CAMS.

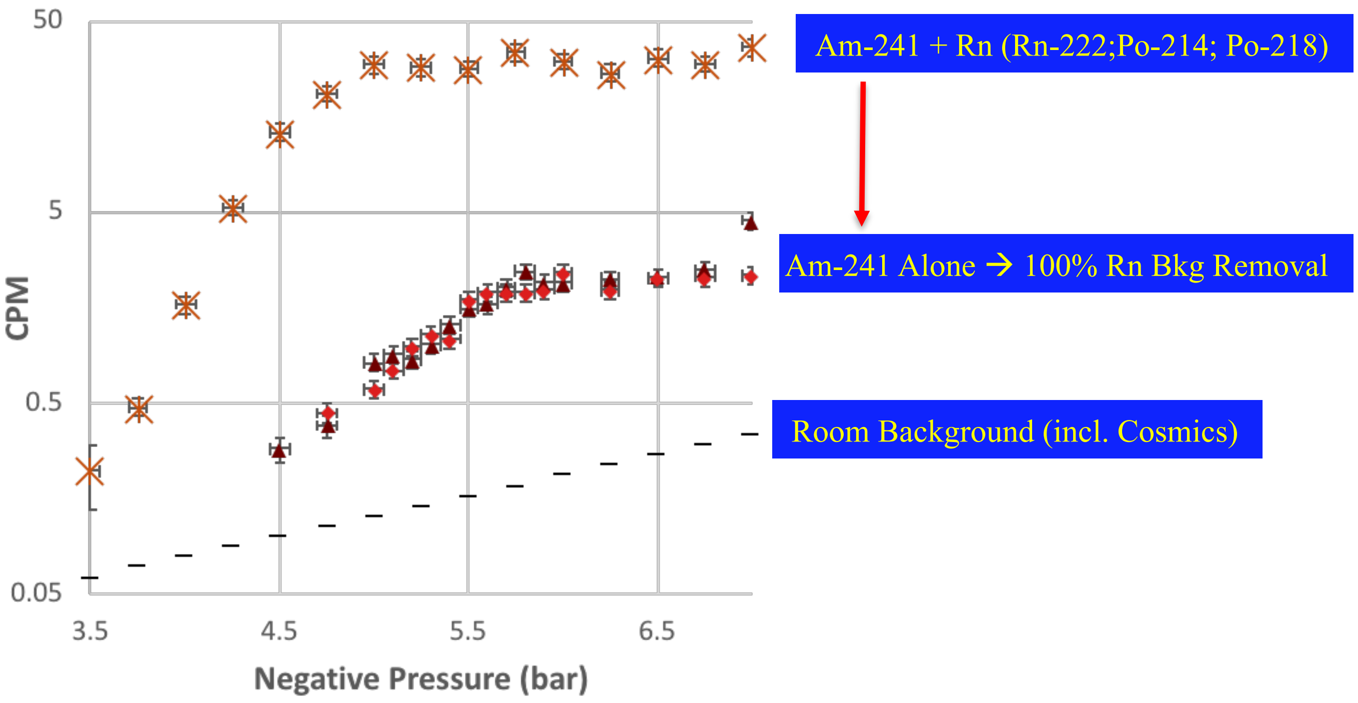
Part 2: Develop /Demonstrate Technology (SRNL Wish) for Alleviating Key Current Needs of Existing DOE Site CAM Systems

→ 10+x Faster if CAM Alarmed Filters are Due to Pu/Am/Cm/U with 100% Rn-Progeny Rejection w/o Long Waits/Bio-Assays

Alpha Spectrometry via TMFDs at x100 Lower Levels than LS-Beckman6500

~100% Rejection of Dissolved Rn

~100% Retention & Spectrometric Detection of Actinides (Pu/Am/..)



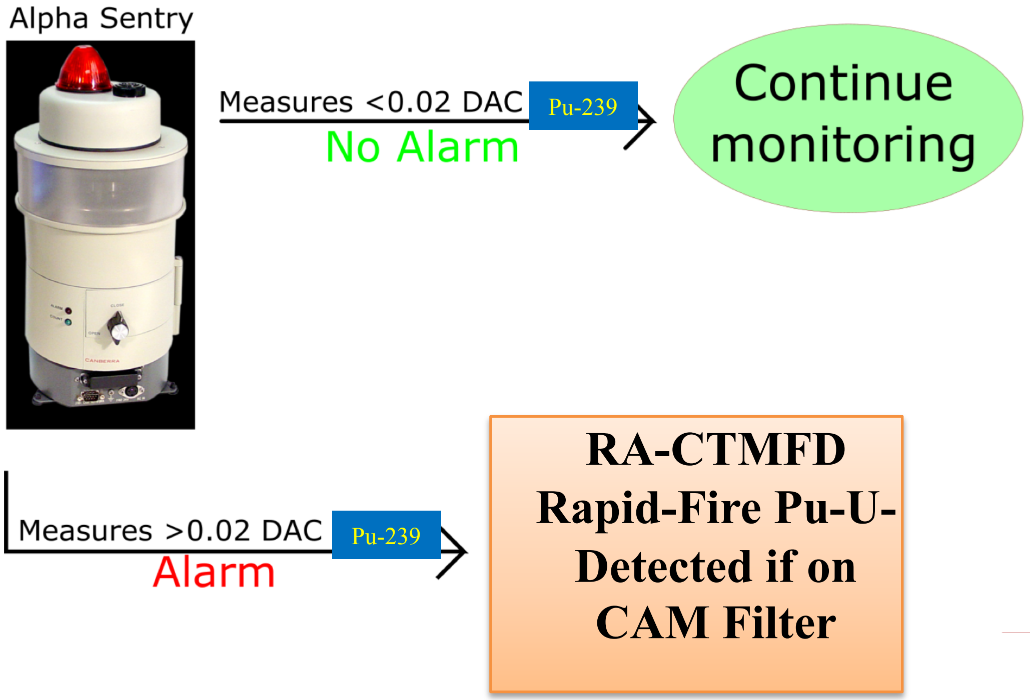
Am-241 + Rn (Rn-222;Po-214; Po-218)

Am-241 Alone → 100% Rn Bkg Removal

Room Background (incl. Cosmics)

Successfully Detected Dissolved Actinide in Isolation via Complete Removal of Rn Background

PART 2: CTMFD Coupled to CAMs for Rapid Verification (per 2019 SRNL Wish-List / Feedback)



Alpha Sentry

Measures <0.02 DAC **Pu-239**

No Alarm

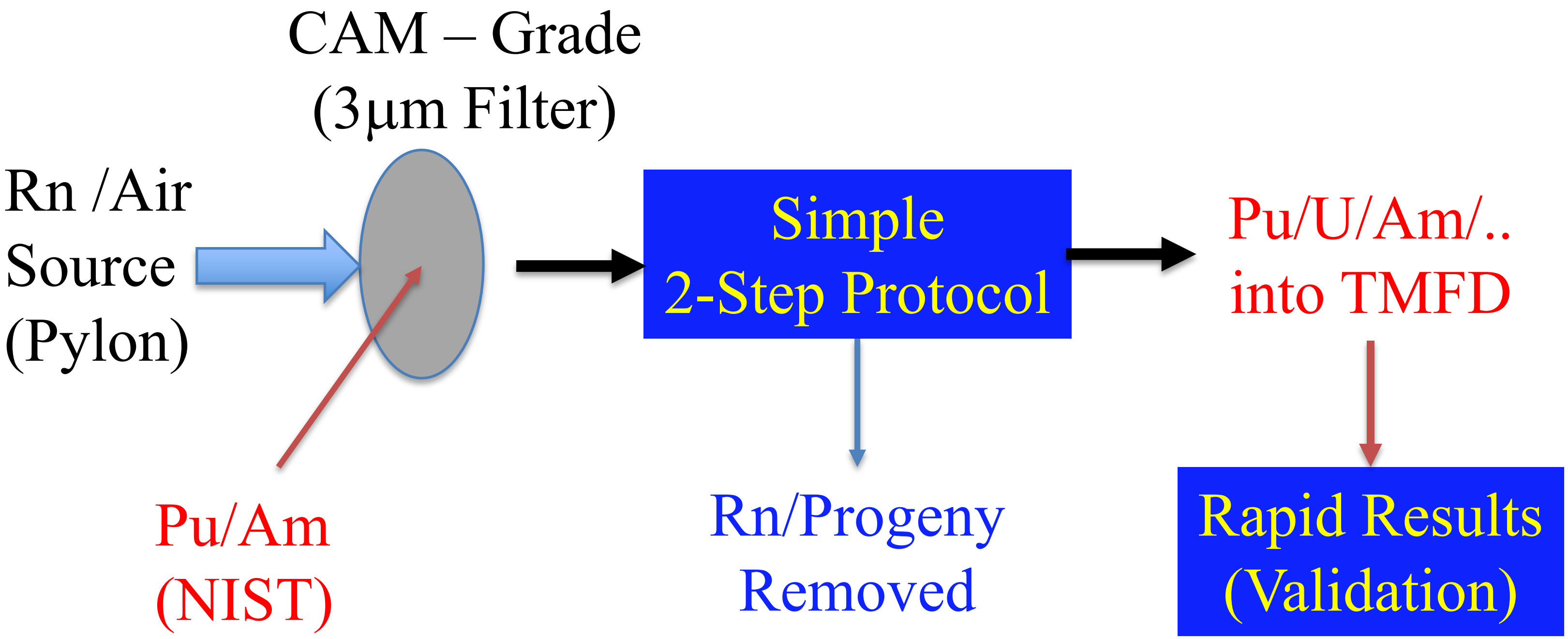
Continue monitoring

Measures >0.02 DAC **Pu-239**

Alarm

RA-CTMFD Rapid-Fire Pu-U-Detected if on CAM Filter

Successful CAM Filter Based Pu/U/Cm/Am.. Spectroscopic CTMFD Monitoring Protocol & Apparatus - ~100% Rn-Progeny Rejection



CAM – Grade (3μm Filter)

Rn /Air Source (Pylon)

Pu/Am (NIST)

Simple 2-Step Protocol

Rn/Progeny Removed

Pu/U/Am/.. into TMFD

Rapid Results (Validation)

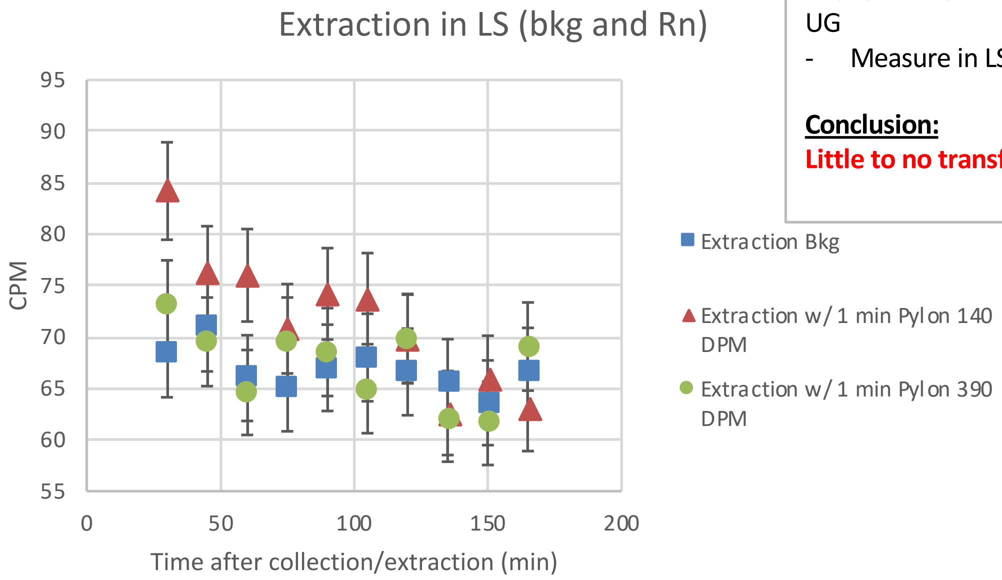
Radon Rejection Protocol Verification – PC/LS 6500 Beckman Results

Only Radon-Air Collection on Filter

→ LS 6500 Testing

→ If Rn-Progeny present (~400 cpm)

→ Results → Same as Background →~100% rejection

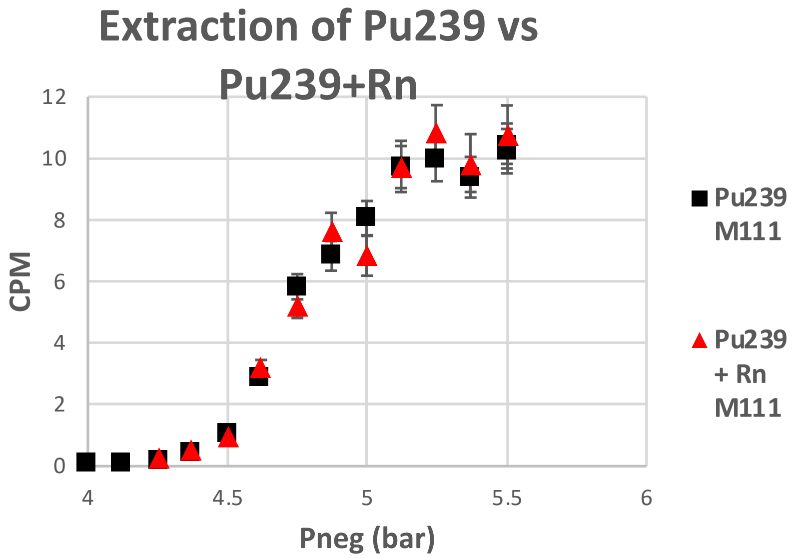


<u>Process:</u>
- Measure CPM on filter using PC counter
- Do extraction process
- Dilute extraction (6mL) by a factor of 3x (so 18mL total: 16 DFP 2 TBP)
- Take 1 mL of Dilution and add to 15mL of UG
- Measure in LS for 10, 15-min counts

<u>Conclusion:</u>
Little to no transfer of radon daughters

RA-CTMFD RESULTS
- Successful Radon Rejected Actinide Alpha Spectroscopy

Combined Radon/Progeny + Pu239 Extraction in CTMFD
(Utilized NIST Certified Pu-239 + 800 CPM Pylon Rn Source)



Process:

1) Make 12 mL of NIST-plutonium stock in nitric acid
2) Use half for an extraction without radon, and half for an extraction with radon
3) Measure extraction of each half

Proportional counter: 178 cts in 40 seconds -> 266 CPM
-> ~33% efficiency so -> ~800 DPM (13 Bq)

If all gets transferred, **~125 CPM in CTMFD**

Conclusion:

- Accurate (NIST) Pu-239 Alpha Activity Detected
- Confirmed ~100% Rn-Progeny Rejected

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RA-CTMFD vs Alpha Sentry (Mirion)

Parameter	Alpha Sentry/PIPS	RA-CTMFD
Efficiency	26-33% (400 keV Res.)	~99% (NIST) (1.4 keV Res.)
Radon Rejection?	~0 to ~90 % (depends on dust; PSF needed)	~99+% (No PSF)
LLD	6 CPM	~0.4 CPM (15cc) ~0.04 CPM (1.5cc)
Time to measure at LLD	35 hrs (1+ week with Rn??)	~1-5 hrs
Spectroscopy	~2 weeks (Limited) (~400 keV res.)	1-2 days (~1.4+ keV resplution; ~1cc CTMFD)

SUMMARY OF ACHIEVEMENTS

- Developed and tested for Rn-Progeny Removal while retaining actinides →Novel
- Successful Protocol for CAM filter based Rn Rejection & Pu-Am-U-.. Detection
  - → Tested for Am/Pu-239/Pu-238/DU actinides trapped on CAM filter
- Novel approach for CAM filter based collection
  and 100% Rn-Progeny Rejected Actinide Monitoring
  - → Avoid Background Uncertainties & need for PSF algorithms
- 5-10x improved 0.02DAC level detection/Identifications vs Alpha-Sentry
  (Awaits Direct Field Validation/Testing at DOE sites)
- Novel CTMFD-Alpha Spectroscopy Algorithms and Framework (Promising)
  - → via Unfolding of RM and Pneg vs Count Rate Data
  (Awaits R&D for mixed actinides & resolution improvements)

- Significant Spinoff Benefits / Alternate Field Applications
- Broadscope Benefits

BROADSCOPE IMPACTS

- Graduate, Undergraduate Student Research → PhD/MS/Projects
- Inner-City High School Student/Teacher Participations → Science Fairs
- Student Staff → Transitions to DOE National Lab Scientific Staff
- International / National Conference (Invited/Contributed) Talks & Papers
- Journal / Conference / Report Publicatios & Trade Journal Visibility
- Benefits to Various Other Federal Agency Missions
- Enhancing Nuclear Safety in General → Furthering DOE-AU Core Missions

CURRENT STATUS

PURDUE IN COLLABORATION WITH SRNL

- ASSESSMENTS vs CAMS/SS/MS (by 7/15/2020)
- OPTIMAL ARCHITECTURES

- NOVEL, LOW-COST, HIGH EFF., Air-Borne ACTINIDE MONITOR

- DOCUMENTATION, IP PROTECTIONS

- SBIR, etc. TOWARDS TRL 9 & COMMERCIALIZATION

H*10 & ALPHA – SPECTROMETRIC NEUTRON DOSIMETRY SYSTEM PRODUCT BROCHURES

- → Tech.Vetted (+/-10%) by ORNL vs State-of-Art Bonner Sphere Spectrometry
- → Up to x10 Lower Weight-Cost-Time; Rugged; 100% Gamma-Beta Blind
- → Ultra-Low (~5 µRem/h) towards 20+ Rem/h (Spectrometry + Survey Modes)

TECHNOLOGY*PROFILE*

HP-H*TMFD *–H*10 Enabled Tensioned Metastable Fluid Detector*

Novel, Low Cost (**γ/β** -Blind), Spectroscopic Hand Portable Neutron Monitor

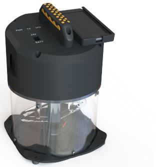


Figure 1. CTMFD (Model HP-H*CTMFD, customizable)

Low Cost, High Efficiency Real-Time Neutron Detection/Dosimetry: The Hand Portable Light Weight-CTMFD (HP-H*TMFD, Fig.1) offers significant advantages over the current state of the art in neutron detection. Advantages include rapid, high intrinsic efficiency (>27%) neutron detection, 100% γ/β blind – ^{137}Cs /^{140}La gammas (> 3-700 R/hr) and ^{32}P betas (>10^{7} pCi/L) sources, and spectroscopic capabilities including ready discrimination between (α,n) and spontaneous fission neutron sources. The HP-CTMFD system may also be configurable for detection of neutrons spanning energies from eV-MeV energies in the same system via the use of borated detector fluids. Additionally, the HP-CTMFD system utilizes non-flammable and non-export regulated detection fluids and technologies.

Real-Time Low-Cost, High Efficiency (27%+) (thermal & fast) Neutron Spectroscopy: An inherent capability of TMFD systems concerns on demand tailoring of fluid tension (negative Pressure – Pneg) levels allowing for on-demand neutron energy discrimination and spectroscopy (see Fig. 2).

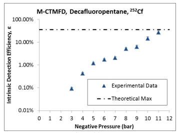


Figure2. User configurable intrinsic neutron detection efficiency from 0.01% up to 27% for bare ^{252}Cf

This offers an unprecedented opportunity for real-time dosimetry and spectroscopy as well – thereby, permitting separation of fission from random (α,n) neutrons from Pu-Be or cosmic type sources. By simple scanning of P_{neg} states, neutron source type and intensity may be directly evaluated while exposed to gamma-beta fields of ~700+ R/hr. Spectroscopy is done by recording detection rate at few P_{neg} states (4 ~ 10 recommended) and unfolding into 152 energy groups, from 0.1 MeV to 15 MeV (thermal energy group is also possible with an optional borated configuration). This is accomplished by providing an initial guess spectrum to the unfolding routine. Several common guess "a priori" spectrums are included, as well as the ability to provide a user defined spectrum which greatly simplifies the unfolding process. Calculation and display of dosimetric quantities based on ICRP74 conversion coefficients are included.

Technical Specifications:

Detection Range: *Thermal to 15 MeV neutrons*
Intrinsic Efficiency: *To ~27% at 11 bar (see Fig. 2); Configurable for 90%+; Multiple ranges available.*
Energy Response: *User configurable (variable Pneg) to desired neutron energy threshold*
Gamma Rejection: *100% rejection tested up to >3 R/hr (^{137}Cs); and, >700 R/hr (^{140}La, E_{γ} = 1.6 MeV)*
Background: *variable, <0.001-0.02 CPS (cosmic neutrons)*
Operating Temperature: *-40 to +40 °C (depending on configuration)*
Operating Humidity: *0 – 90% (non-condensing)*
Size: *21 x 21 x 30 cm (D x W x H)*
Weight*: ~3 kg*
Power*: ~150W Universal AC Adapter, or 24VDC*
Battery*: Lithium Ion, >4~5 hours battery life, depending on sensitivity setting (~1hr recharge time)*

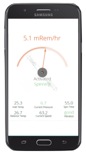
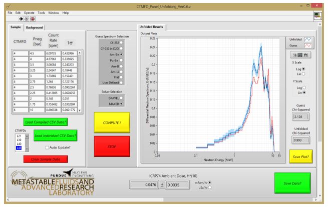


Figure3. Mobile Android based software available for operation in survey instrument mode.

Dual Operational Modes: An inherent capability of TMFD systems concerns on demand tailoring of fluid tension (P_{neg}) levels allowing for on-demand neutron energy discrimination and spectroscopy (see Fig. 4). ICRP74 ambient neuron dose accuracy (H*(10)) independently verified at DoE's ORNL to ~±20% for all sources tested, i.e, ^{241}Am-Be, ^{252}Cf, ^{252}Cf in 5cm HDPE/steel & ^{252}Cf in 2.5cm of lead. Multiple configurations available to allow operation from 5 µRem/hr to 0.5 mRem/hr in spectroscopic mode, and up to 20 Rem/hr in survey mode.



CTMFD	Pneg [bar]	Count Rate [cpm]	1σ
4	4.5	6.09735	0.432996
4	4	4.57663	0.335695
4	3.5	3.06084	0.240203
4	3.25	2.24547	0.18449
4	3	1.73869	0.152421
4	2.75	1.264	0.122176
4	2.5	0.76936	0.0902261
4	2.25	0.412985	0.0628253
4	2	0.148	0.051
4	1.75	0.153492	0.0302684
6	10	0.696338	0.0921779

Guess Chi-Squared: 2.128
Unfolded Chi-Squared: 0.993
ICRP74 Ambient Dose, H*(10): 0.0476 ± 0.0035 ● mRem/hr ○ µSv/hr

Figure 4. PU-VI-H*TMFD GUI -data unfolding and remote logging software available for ease of use in H*(10) mode. Remote or local operation (USB or Ethernet) of CTMFDs – Single and Array Form Architectures.

Customized Product Overview: Low Cost, Portable, Light (x5) Weight, High (27%+) Efficiency & High Sensitivity Neutron Spectrometry & Dosimetry solutions.

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TECHNOLOGY*PROFILE*

H*-TMFD – Novel, low cost (**γ/β** -Blind) lightweight, high efficiency neutron spectrometer & H*(10) dosimeter


Figure 1. H*TMFD (Model H*TMFD, customizable)

Low Cost, High Efficiency Real-Time Neutron Spectrometry & Dosimetry: The H*(10) capable Tensioned Metastable Fluid Detector (H*TMFD, Fig.1) offers significant advantages over the current state of the art in neutron detection. Advantages include light-weight, rapid, high intrinsic efficiency (>27%) fast neutron detection, 100% γ/β blind – ^{137}Cs /^{140}La gammas (> 3-100 R/hr) and ^{32}P betas (>10^{7} pCi/L) sources, and spectroscopic capabilities. The H*TMFD system may also be configurable for detection of neutrons spanning energies from eV-MeV energies in the same system via the use of borated detector fluids. Additionally, the H*TMFD system utilizes non-flammable and non-export regulated detection fluids and technologies.

Neutron Spectroscopy: Neutron Spectroscopy is accomplished by recording detection rates at few P_{neg} states (4 ~ 10 recommended) and unfolding into 152 energy groups, from 0.1 MeV to 15 MeV (thermal energy group is also possible with borated configurations). This is accomplished by providing an initial guess spectrum to the unfolding routine. Several key guess "a priori" spectrums are included, as well as the ability to provide a user defined spectrum which greatly simplifies the unfolding process. Calculation and display of dosimetric quantities based on ICRP74 conversion coefficients are provided.

Table 1. Measured ambient neutron dose comparison against a Ludlum 42-5 BSS.

Test Location	Source Configuration	H*TMFD (~6hr) Ambient Neutron H*(10) Dose Rate (mRem/hr, 1σ)	Ludlum 42-5, BSS (ORNL~26hr) Ambient Neutron H*(10) Dose Rate (mRem/hr, 1σ)
ORNL	Cf (2.33×10^{5} n/s) at 123cm	0.271 ± 0.030	0.228 ± 0.015
ORNL	Cf (2.33×10^{5} n/s) behind 1" Pb at 123cm	0.245 ± 0.025	0.239 ± 0.015
ORNL	Cf (1.20×10^{5} n/s) behind 1" Pb at 123cm	0.146 ± 0.021	0.137 ± 0.011
ORNL	Cf (2.33×10^{5} n/s) behind 2" HDPE at 123cm	0.139 ± 0.014	0.138 ± 0.012
ORNL	Cf (1.20×10^{5} n/s) behind 2" HDPE at 123cm	0.082 ± 0.008	0.082 ± 0.009
ORNL	Cf (2.33×10^{5} n/s) behind 2" SS304 at 123cm	0.182 ± 0.018	0.194 ± 0.014
ORNL	Cf (1.20×10^{5} n/s) behind 2" SS304 at 123cm	0.114 ± 0.011	0.124 ± 0.009
PU	Cf (3.0×10^{4} n/s) at 100cm	0.036 ± 0.005	0.032 ± 0.005
PU	AmBe (2.8×10^{4} n/s) at 100cm	0.046 ± 0.006	0.042 ± 0.004
PU	PuBe (2.3×10^{6} n/s) at 200cm in 11cm Thick Paraffin Shell	0.404 ± 0.037	0.385 ± 0.025
PU	Cf (3.0×10^{4} n/s) & AmBe (2.8×10^{4} n/s) at 100cm	0.081 ± 0.011	0.079 ± 0.007

Technical Specifications:

Detection Range: *Thermal to 15 MeV neutrons*
Spectroscopic Range: *0.1 MeV to 15 MeV neutrons*
Detection Efficiency: *Up to ~27% at 10 bar (see Fig. 2); Configurable for 90%+; Multiple ranges available.*
Dose Rate Range: *5 µRem/hr to 1 Rem/hr in spectroscopic mode, up to 20 R/hr in survey mode*
Energy Response: *User configurable (variable Pneg) to desired neutron energy threshold*
Gamma Rejection: *100% rejection tested up to >3 R/hr (^{137}Cs); and, >100 R/h (^{140}La, E_{γ} = 1.6 MeV)*
Background: *variable, <0.001-0.02 CPS (cosmic neutrons)*
Operating Temperature: *-40 to +40 °C (depending on configuration)*
Operating Humidity: *0 – 90% (non-condensing)*
Size: *50 x 50 x 125 cm (D x W x H)*
Weight*: ~15 kg*
Power*: ~600W Universal AC Adapter, or 24VDC*

Dual Operational Modes: An inherent capability of TMFD systems concerns on demand tailoring of fluid tension (P_{neg}) levels allowing for on-demand neutron energy discrimination and spectroscopy (see Fig. 4). ICRP74 ambient neuron dose accuracy (H*(10)) independently verified by DoE's ORNL to ±25% for all sources tested, i.e, ^{241}Am-Be, ^{252}Cf, ^{252}Cf in 5cm HDPE, ^{252}Cf in 5cm steel & ^{252}Cf in 2.5cm of lead. Multiple configurations available to allow operation from 5 µRem/hr to 1 mRem/hr operation in spectroscopic mode and up to 20 R/hr in survey mode.

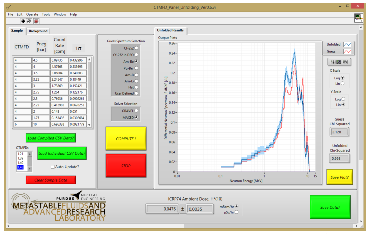

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Figure 4. PC data unfolding and remote logging software available for ease of use in H*(10) mode. Remote or local operation (USB or Ethernet) of CTMFDs – Single and Arrays are possible.

Customized Product Overview: Low Cost (x10 less than ROSPEC), Portable, Lightweight (x4 less than BSS), High Sensitivity and Accuracy Neutron Spectrometry & Dosimetry solutions.

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SPONSORSHIP BY DOE AU-NSRD GRATEFULLY ACKNOWLEDGED

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