Micro-Pocket Fission Detectors (MPFDs)

SBIR Commercialization Project (Phase I)
June 2022 – June 2023

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Subcontractors:
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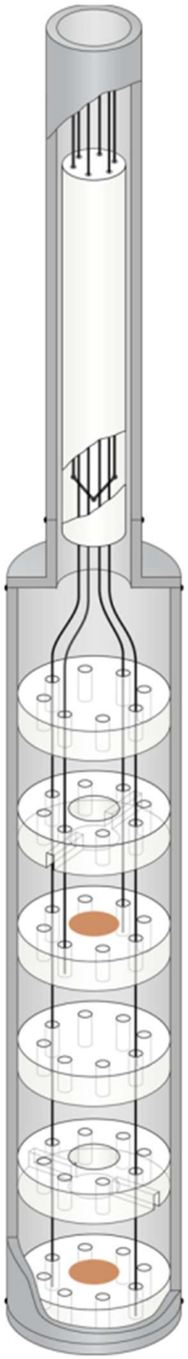
Kansas State University – Douglas McGregor

MICRO-POCKET FISSION DETECTOR (MPFD)



Motivation

There is a need for real-time, distributed, in-core neutron flux sensors to support advanced test reactor experiments and development of next-gen reactors

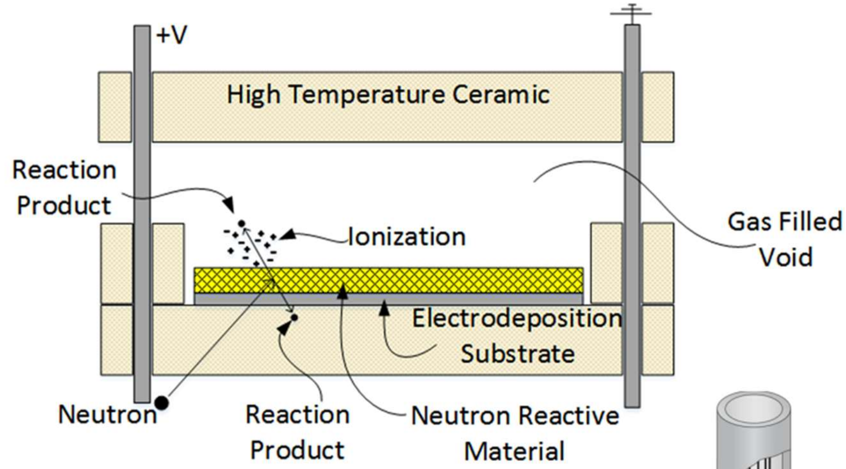
MPFDs can

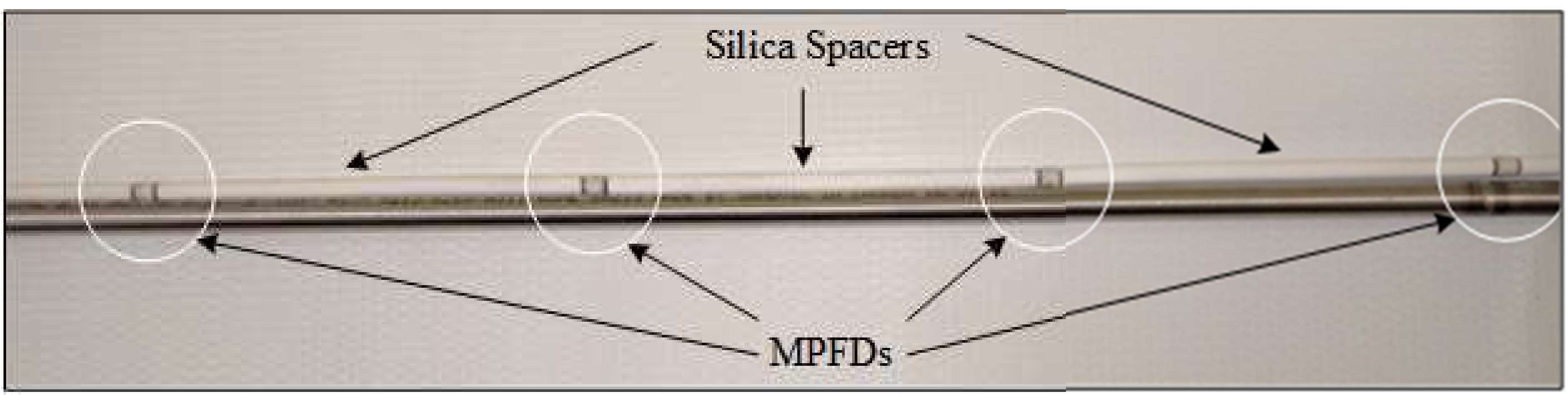
- be deployed in-core with minimal flux perturbation
- reduce need for iron-wire/foil activation fluence measurements
- improve accuracy of neutron radiation monitoring
- deliver multi-nodal and multi-energy group response

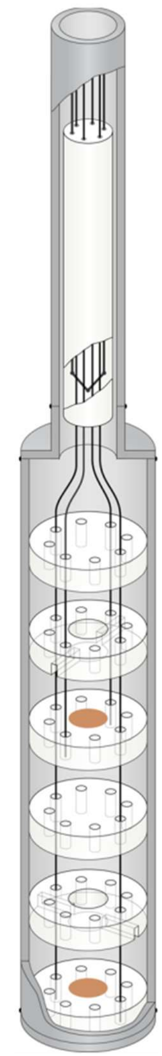
MPFDs have garnered interest from government, university, and commercial reactor-related groups

MPFD OVERVIEW

- Real-time, multi-nodal, in-core neutron sensor
- 0.5-3 mm^3 fission chamber
- Pulse and/or current mode operation
- Successful deployments at KSU TRIGA, UWNR, and INL-TREAT
- Potential Uses: Startup/performance verification, flux mapping, experiment fluence monitoring, power monitoring







MPFD OPERATION AND PERFORMANCE

- Reactor power/flux level and pulse transient tracking feasibility previously proven by Nichols and Reichenberger

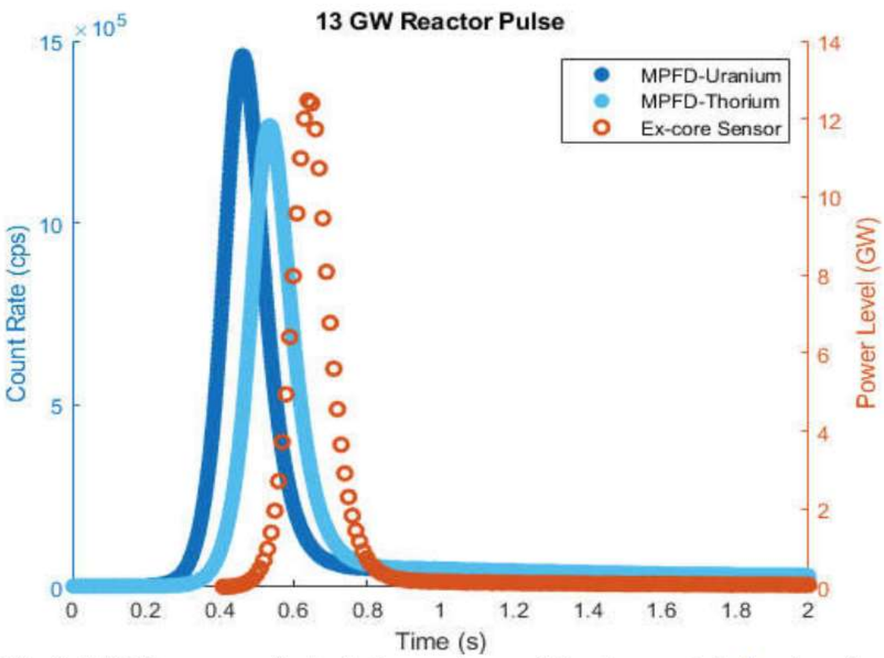


Fig. 9. MPFD response for both the uranium and thorium coated chambers for the 13 GWth reactor pulse.

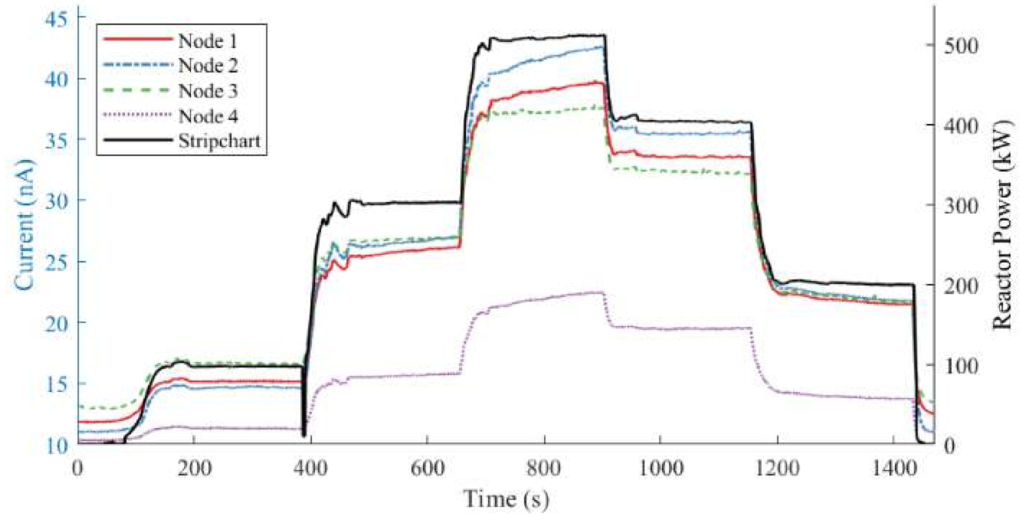


Fig. 5-5. Plot of DRT for MPFD array 3 performed in current mode. Note that raw count rate is presented for MPFD response.

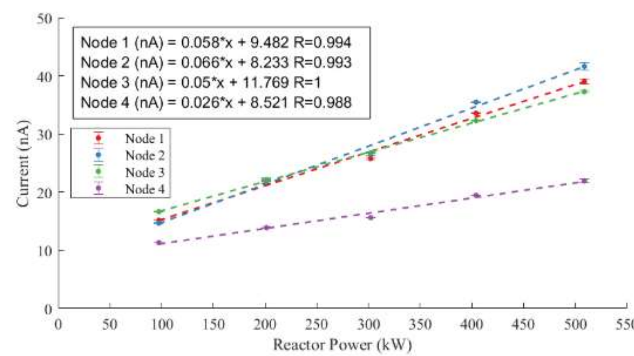


Fig. 5-7. Current mode linearity response of MPFD array 3 based on data presented in Fig. 5-5. Linear least-square equations are shown for each node.

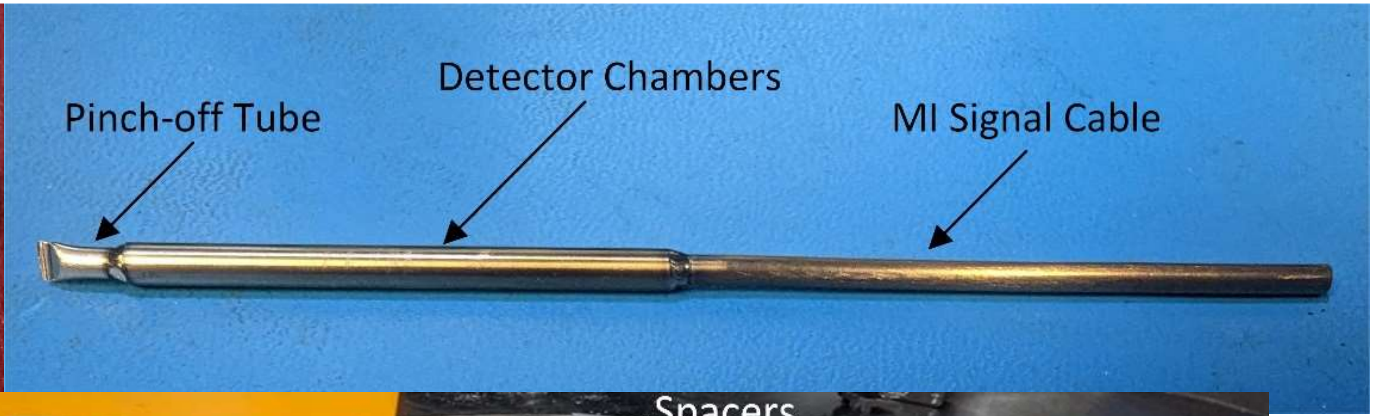
M. A. Reichenberger, "Micro-pocket fission detectors: development of advanced, real-time, in-core, neutron-flux sensors," Department of Mechanical and Nuclear Engineering, Kansas State University, 2017.

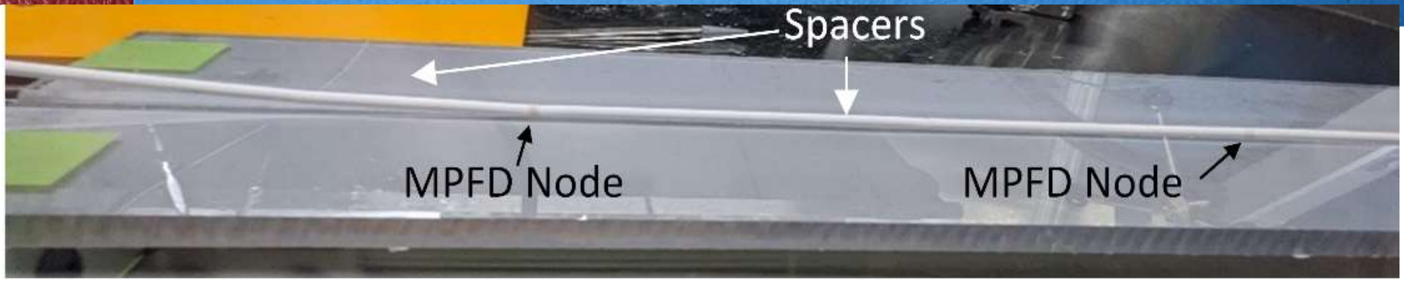
D. M. Nichols, "Development and optimization of the micro-pocket fission detector," Mechanical and Nuclear Engineering, Kansas State University, 2022.

Nichols, D. M., et al. (2019). Reactor Pulse Tracking using Micro-Pocket Fission Detectors in Research Reactors. 2019 IEEE Nucl. Sci. Symp.

MPFD SBIR COMMERCIALIZATION

- SBIR Phase I focused on subcomponent redesign for manufacturability and reliability
  - Redesigned chamber, disks, and fissile material configuration
    - More customizable design (e.g., chamber height, location)
  - Developed batch-production fissile material electroplating
  - Integrated gas pinch-off tube for precise and repeatable detection gas backfill

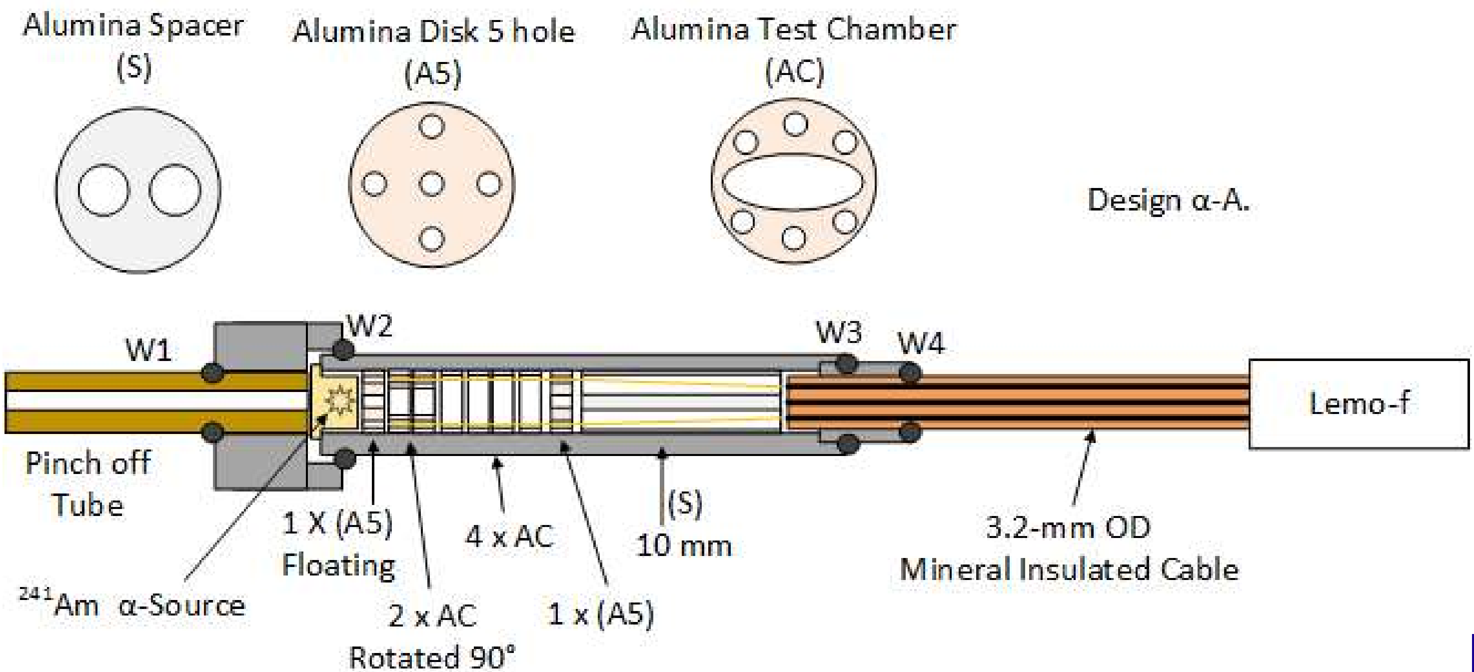




DESIGN PROOF OF CONCEPT

Phase I Prototype

- MPFD mockup fabricated with pinch-off tube, welded chamber, and mineral insulated cable
- Loaded with internal ^{241}Am source
- Used to test electronics, chamber/weld integrity, and longevity
  - Will be repeatedly temperature cycled to ensure weld and pinch-off integrity
  - Tested every month to ensure no change in signal, (e.g., gas leak, moisture diffusion from MIC)
  - Possibly irradiated and retested



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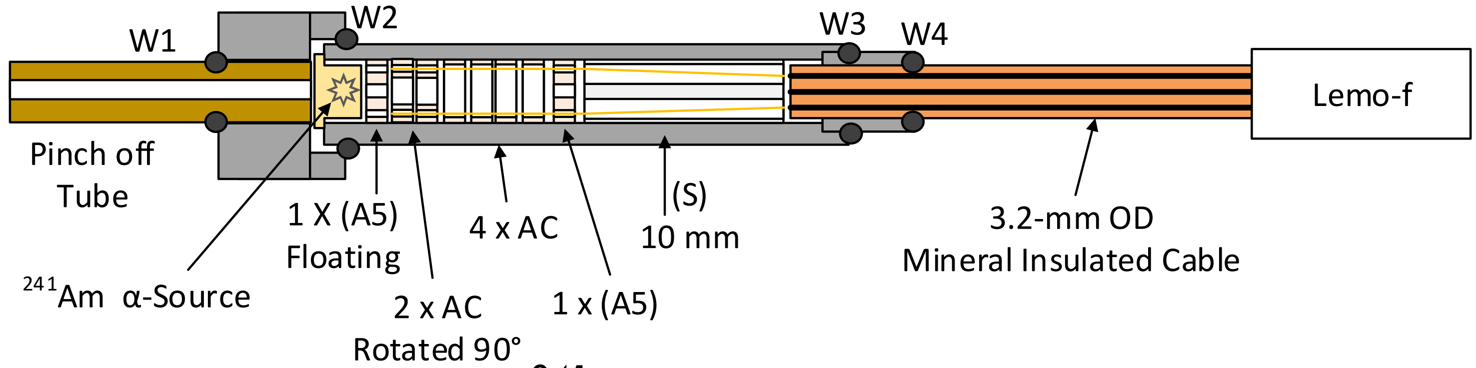
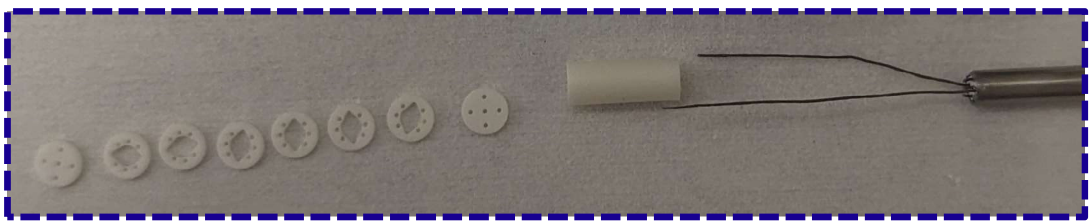
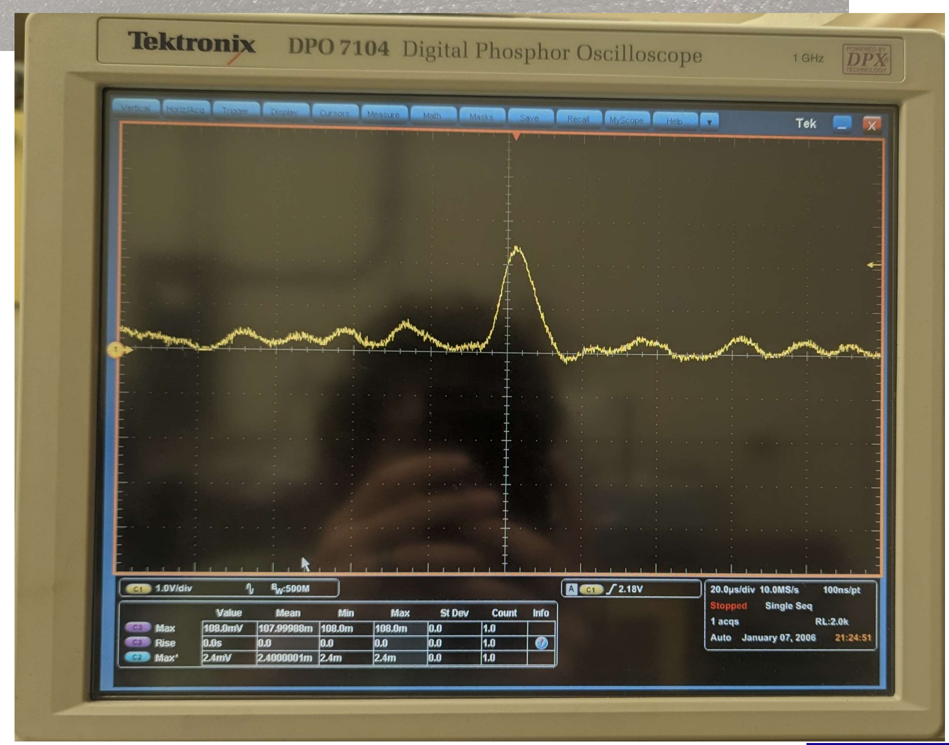


Phase I Prototype

- 2-mm chamber
- 3 atm argon backfill
- ~600 keV energy deposited in chamber from ^{241}Am. (Expect 5-MeV from Fission)

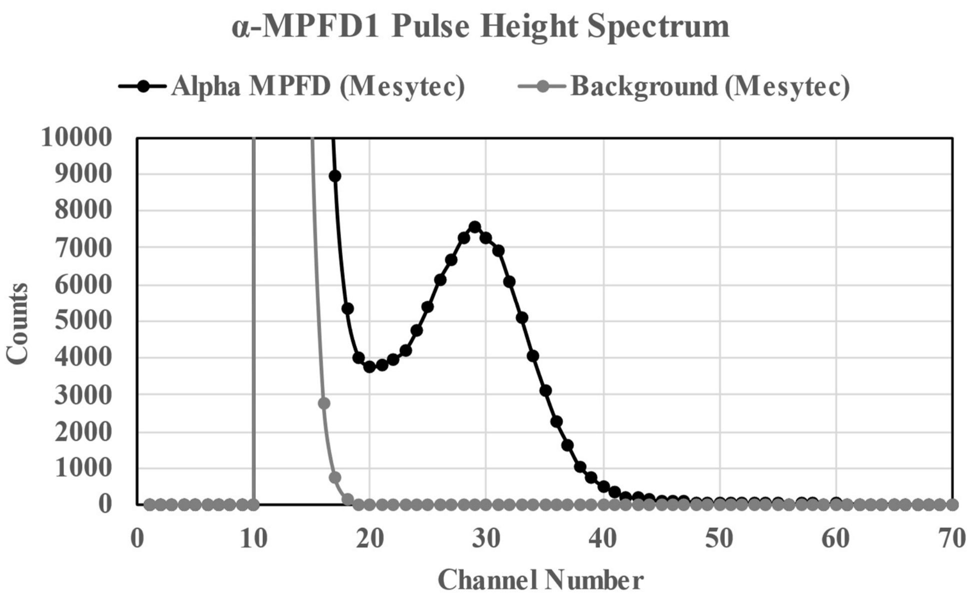


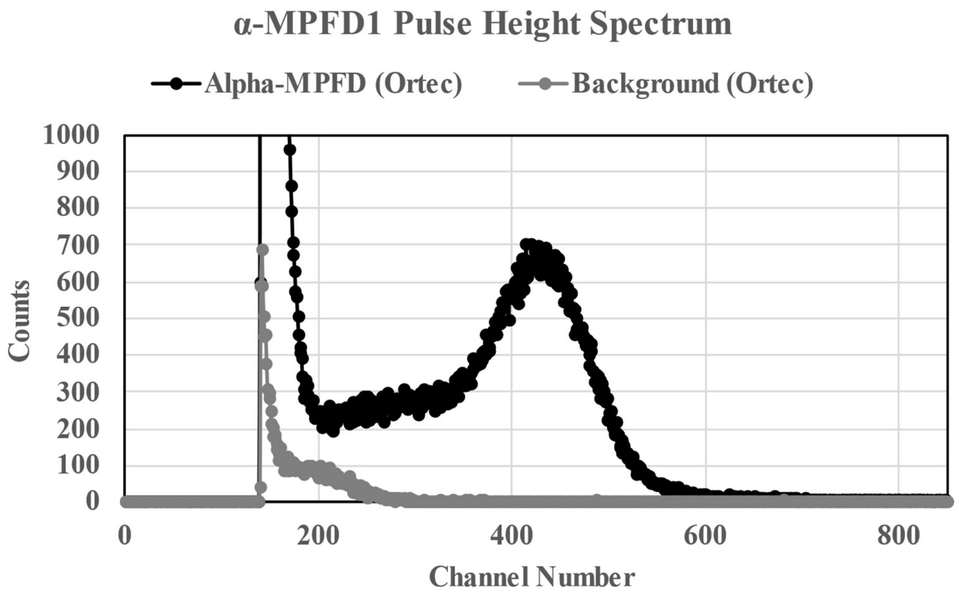


DESIGN PROOF OF CONCEPT

Phase I Prototype

- Pulse mode operation confirmed!
  - Pulse height spectra measured with Ortec 142 PC/2022 Amp, and Mesytec MPFD-1 Electronics
- Proved MIC-welded chamber-pinch off tube design is functional
- Next step repeat measurements at elevated temperatures and after temp cycling
- Results inform final design iterations in Phase II.

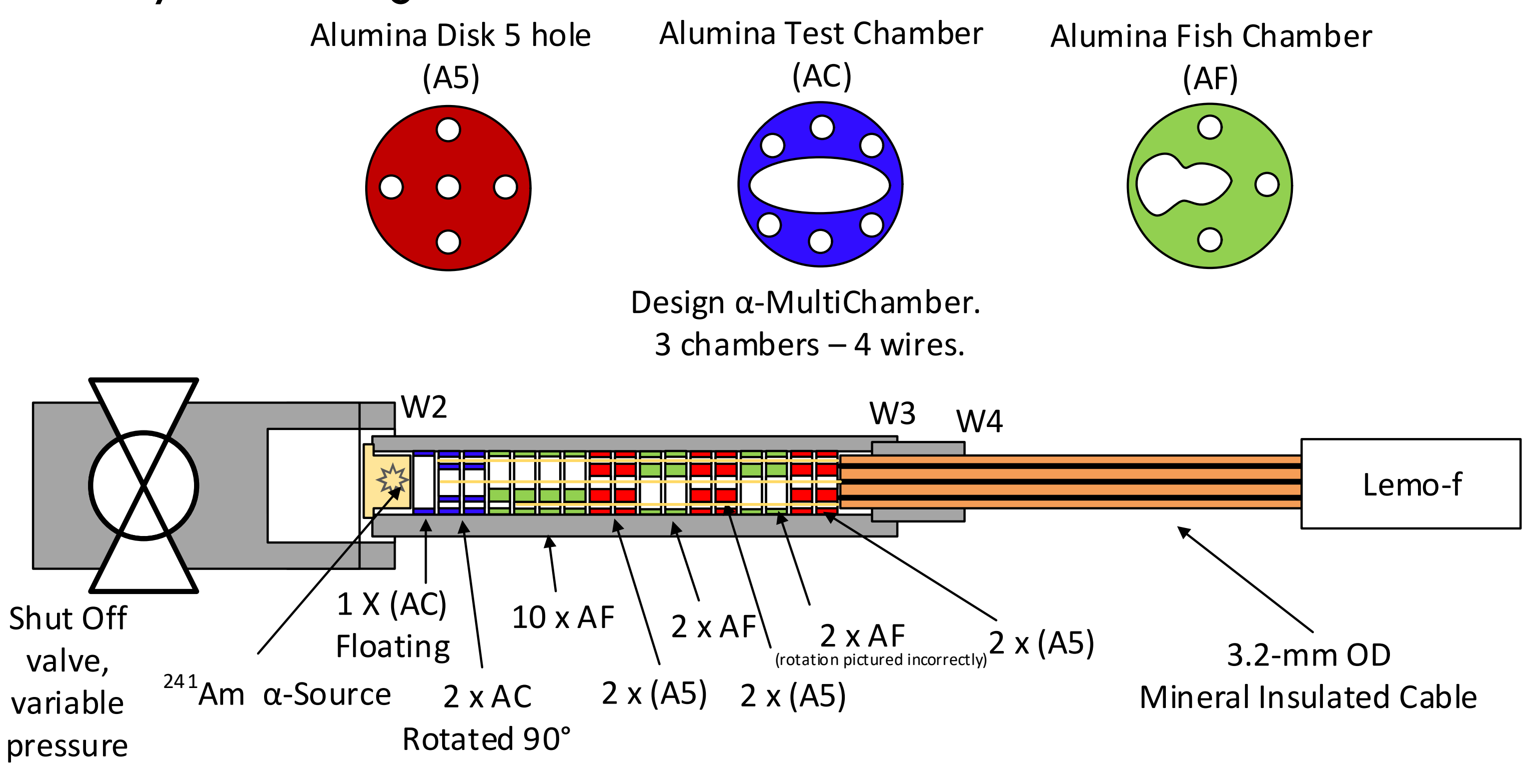




DESIGN PROOF OF CONCEPT – 2

Phase I Multi-Chamber Prototype

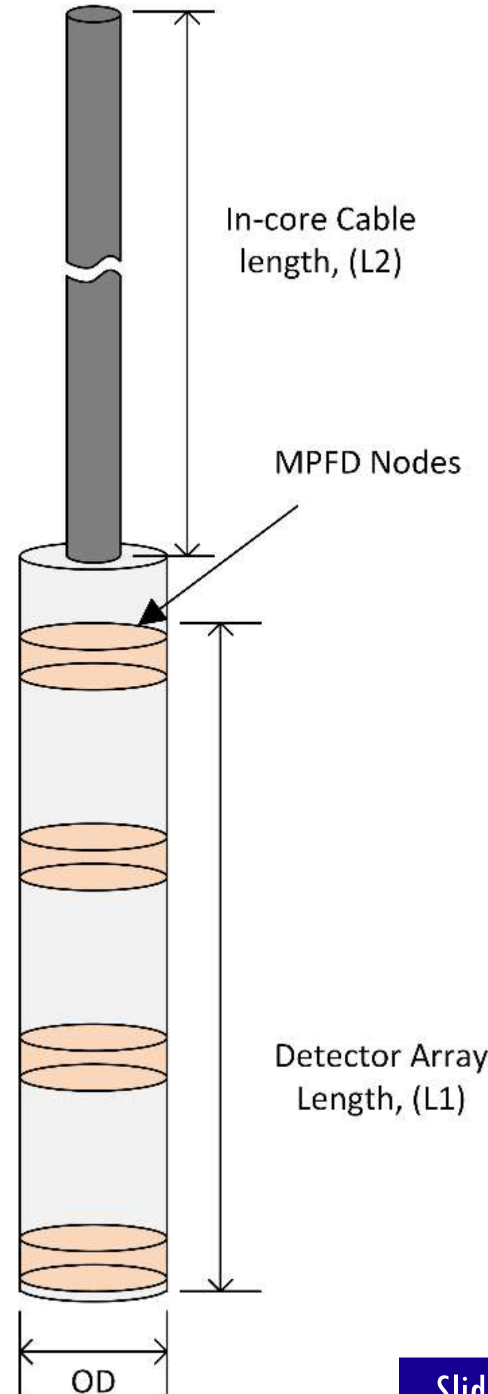
- 3 chamber design with only bottom chamber open to ^{241}Am alpha particles
- Design will test for chamber cross-talk via capacitive coupling through the common cathode
- Chamber will not be permanently sealed, allowing for test, characterization, and optimization of gas fill pressure
- Ready for testing



COMMERCIAL MPFD SPECIFICATIONS

End of Phase II Targets

- Number of nodes – 1-4
- Chamber size: 0.5-3 mm^3
- Chamber Tube OD: 3-4.7 mm
- Detector Array Length (L1): up to ~3 m
- Mineral Insulated Cable (MIC) OD: 3.18 mm
- MIC Length: ~10-15 m (researching upper limit)
- Fissile Coatings: U (up to 19% ^{235}U), Th
- Temperature: Target up to 1000°C
- Flux Monitoring: Proven 10^8, target 10^{16}
- Total Fluence with <5% response change: Target 10^{22}
- Pulse, Campbelling, and Current mode operation
- Signal Processing Electronics –
  - COTS, e.g. Instrumentation Technologies, Mesytec, Ortec, etc
  - New/Joint Development

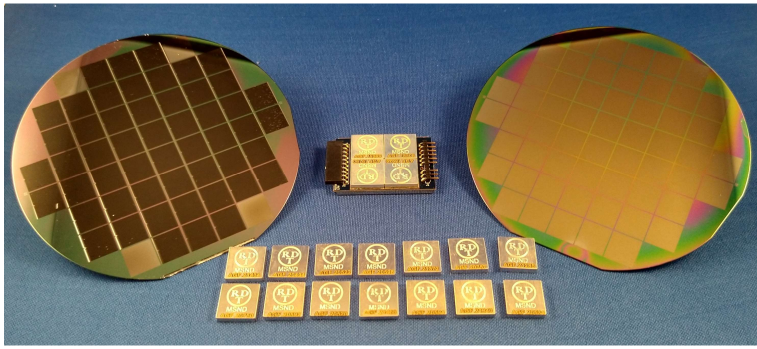


CURRENT STATUS/WHAT'S NEXT

- SBIR Phase II focus on full system builds
  - Prototype testing and evaluation at KSU TRIGA, then INL ATR-C, TREAT, or OSURR for concurrent high-temp, high-flux testing and evaluation
  - "Sufficiently Meritorious" but not selected for funding

- Currently seeking R&D/Commercialization funds (Phase II – like)
  - Remaining problems to be solved
    - Purchase manufacturing equipment
    - Electrodeposition vendor/supplier and licensing
    - Calibration methods
    - Signal integrity testing (temperature, vibration, RF-noise)
    - NQA-1 certification (down the road)
    - Joint/Concurrent signal processing electronics development effort

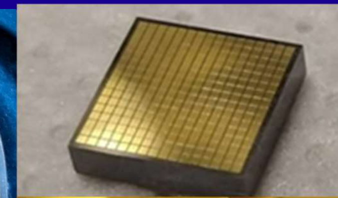
OTHER RDT DETECTORS



- MSNDs & Domino – TRL9
  - Silicon-based, compact, low-power, solid-state neutron detectors
  - 30-45% int. th. n. det. eff.
  - Distributed network, hand-held, beam lines

- Li-Foil Neutron Detectors – TRL9
  - Large-Area, gas-filled proportional counters
  - 40% int. th. n. det. eff.
  - Area monitors, portal monitors, backpacks, soil-moisture
- NRID – TRL7
  - Neutron source detect, locate, and ID
  - Looking for R&D for dosimetry and spectrum unfolding
- DSC-Domino ~ TRL5
  - MSND-based, simultaneous fast-n, thermal-n, and witness detectors
  - SNF-loaded DSC radiation profile measurements/monitoring
  - Ex-core neutron leakage distributed monitoring, space neutrons,
  - Ongoing SBIR Phase II (2023-2025)








QUESTIONS?

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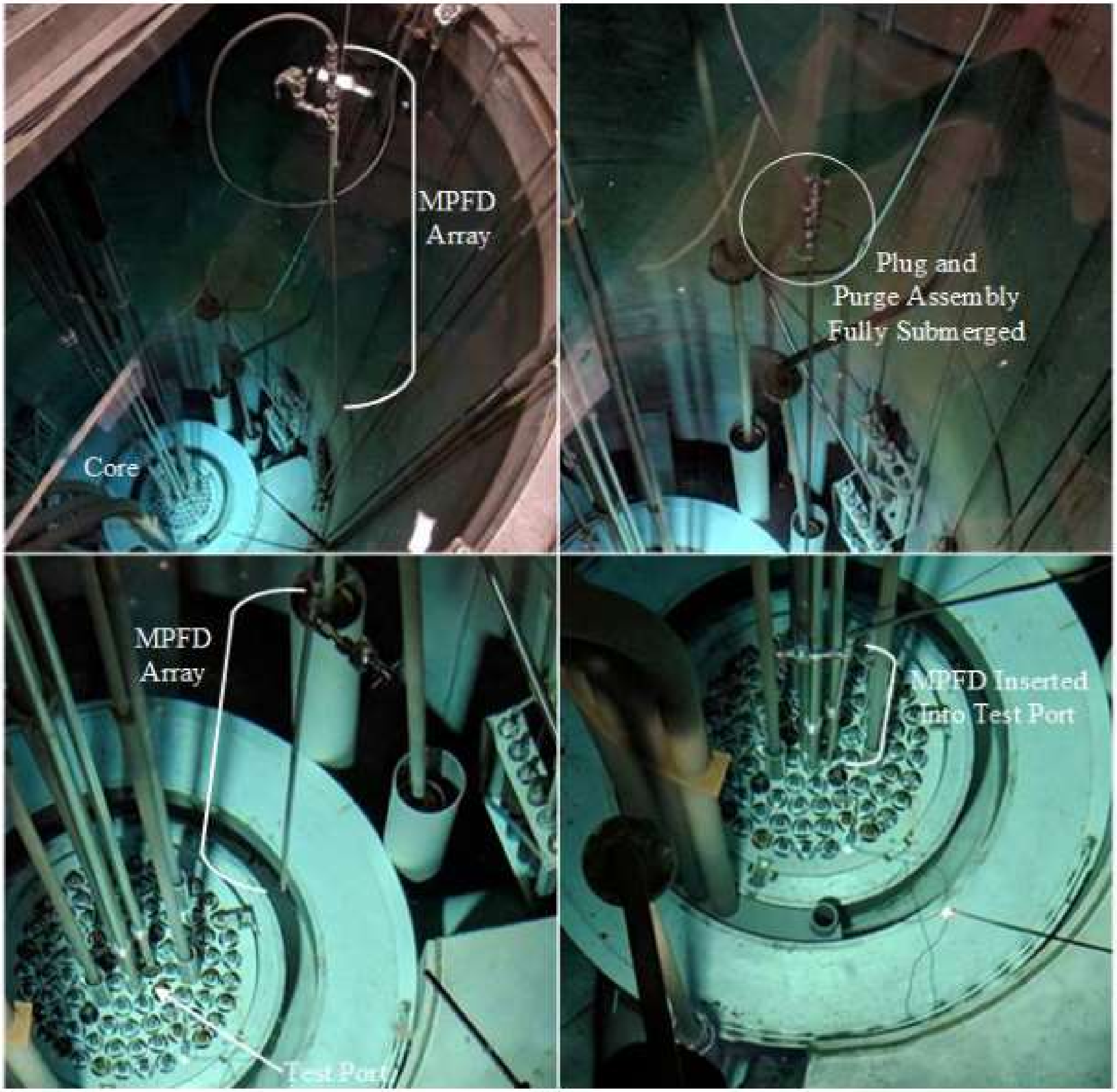
PREVIOUS MEASUREMENTS – KSU TRIGA & UWNR



PREVIOUS MEASUREMENTS – POWER RAMPING

- Observed linear response with reactor power

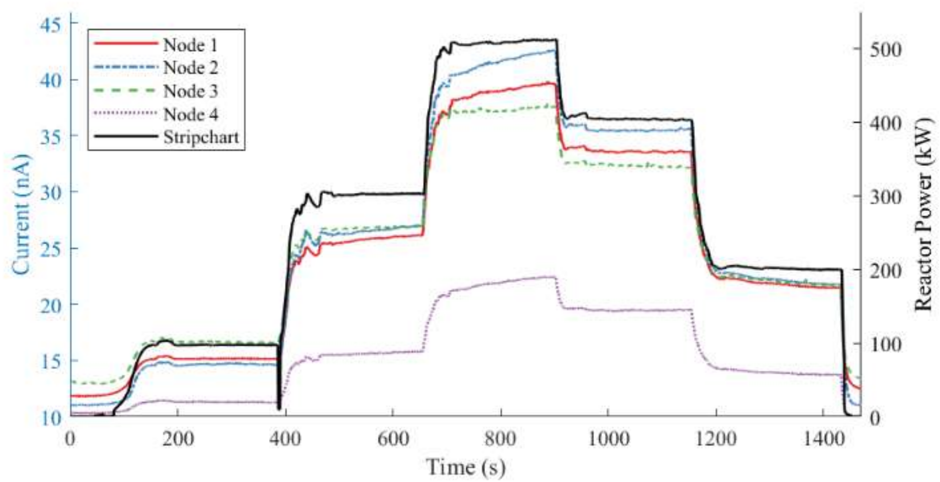


Fig. 5-5. Plot of DRT for MPFD array 3 performed in current mode. Note that raw count rate is presented for MPFD response.

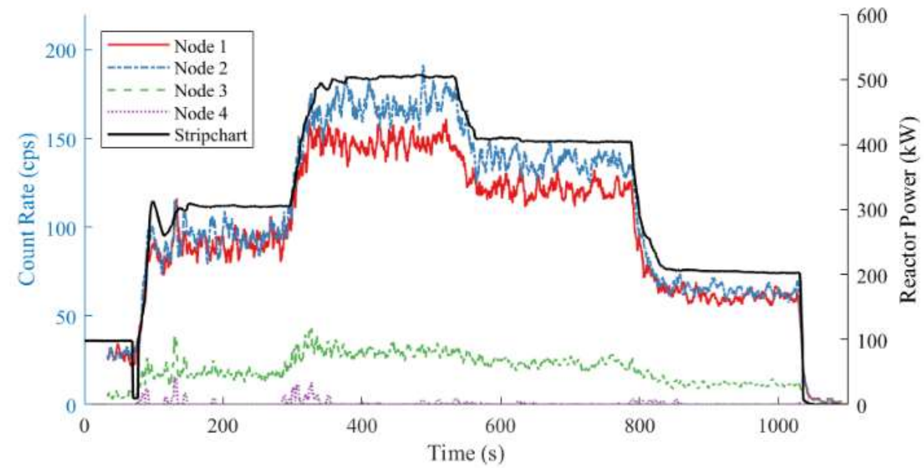


Fig. 5-6. Plot of DRT for MPFD array 3 performed in pulse mode. Note that MPFD data presented is smoothed with a moving average window of 200 data points.

Current Mode

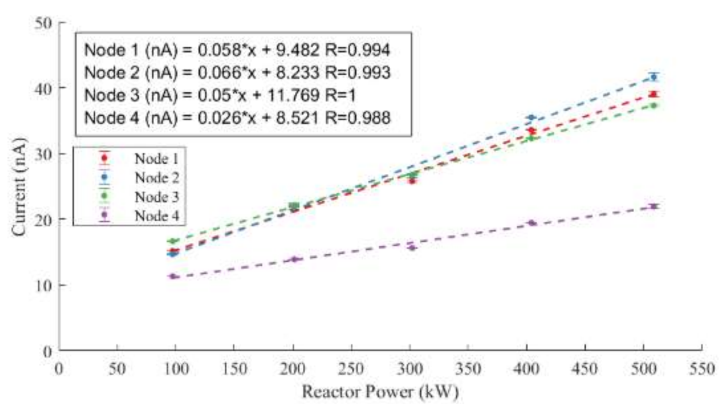


Fig. 5-7. Current mode linearity response of MPFD array 3 based on data presented in Fig. 5-5. Linear least-square equations are shown for each node.

Pulse Mode

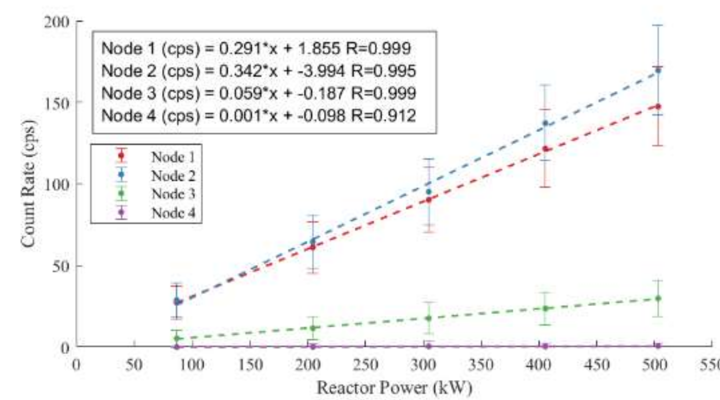
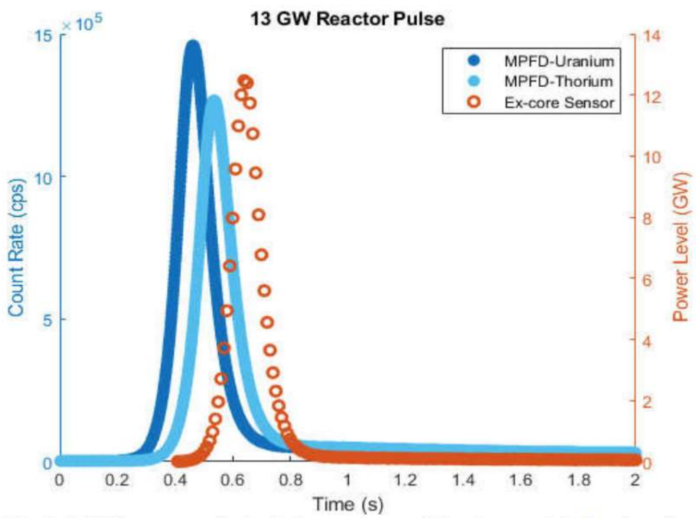


Fig. 5-8. Pulse mode linearity response of MPFD array 3 based on data presented in Fig. 5-6. Linear least-square equations are shown for each node.

PREVIOUS MEASUREMENTS – TRANSIENT TRACKING

- Ability to track pulsed transients



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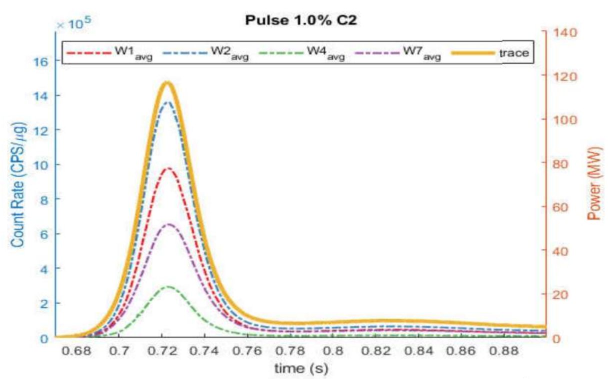

Fig. 7. Averaged response of MPFD wands distributed throughout the UWNR core. These wand locations are indicated in Fig. 2.

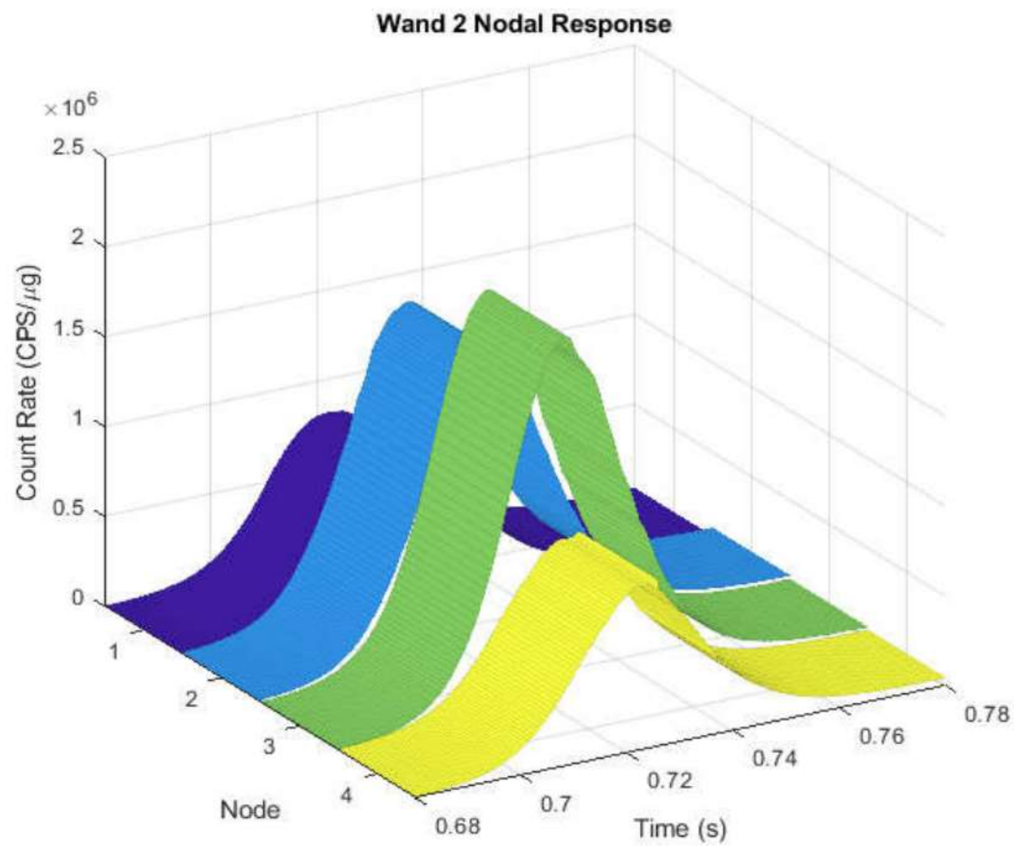

Fig. 8. Axially distributed detector response for Wand 2. Nodes 1, 2, 3, and 4 are located at +4.5, +1.5, -1.5, and -4.5 inches displaced from the center plane of the fuel region respectively.

Data from:
Nichols, D. M., et al. (2019). Reactor Pulse Tracking using Micro-Pocket Fission Detectors in Research Reactors. 2019 IEEE Nucl. Sci. Symp.