Detector System Component Feasibility for Fresh Nuclear Fuel Signature Analysis

2023 MTV Workshop

March 22

Cat Barker
PhD Student, UF
Andreas Enqvist
University of Florida

Introduction and Motivation

- Fresh nuclear fuel has similar safeguard concerns as spent nuclear fuel with a lower number of NDA developed tools for composition verification
  - Developing discernable signatures for multiple fresh nuclear fuel compositions
  - Optimizing a system of low-cost, commercial off the shelf complementary detectors to verify fresh nuclear fuel shipments and long-term storage
- There is a current safeguard opportunity for fresh nuclear fuel that has the potential to be mitigated with a low-cost, low-effort radiation detection system
  - This will provide reassurance and minimize concerns from delivery and storage from manufacturing all the way to nuclear facilities and power plants

Mission Relevance

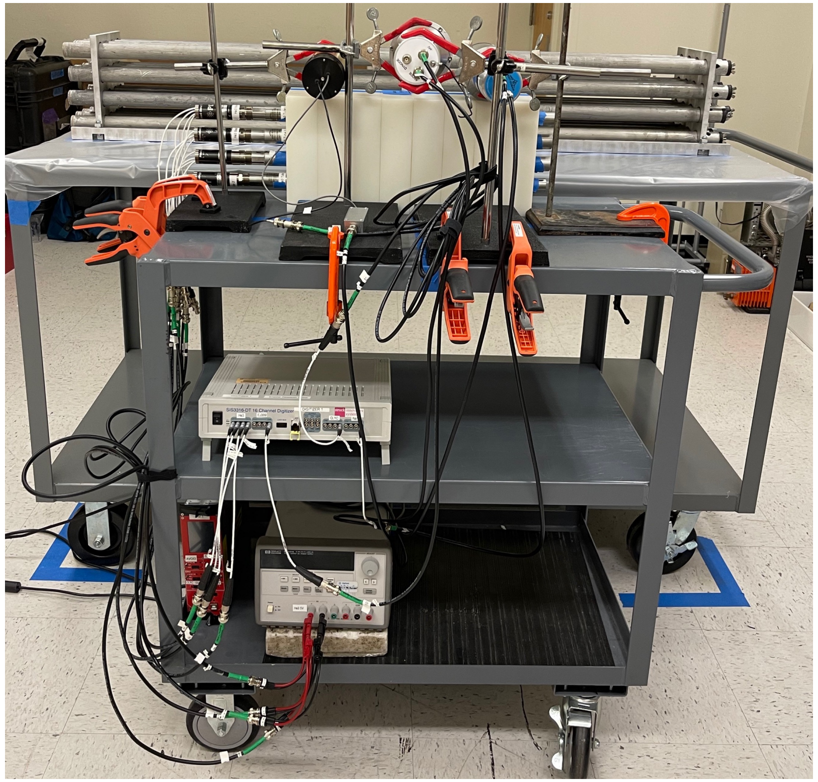
- Fresh nuclear fuel has a lower radiological signature and is not as useful for nuclear weapons development
  - Thus, a lower number of resources are set aside for NDA of fresh nuclear fuel
  - Creates a safety and security gap
- *This research will design, test, and validate a discernable, measurement signature for fresh nuclear fuel that can be NDA verified by nuclear personnel at each step in the nuclear fuel cycle*

Technical Approach

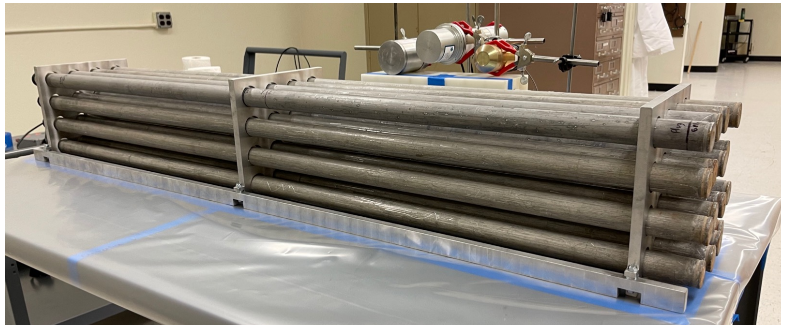
- Phase 1 (now-May ‘23) – Feasibility measurements using a cost-vs-value approach to determine optimal multi-detector configuration
- Phase 2 (Summer-Winter ‘23) – Proof of concept signature validation against fresh nuclear fuel
- Phase 3 (Spring ‘24) – Application of derived data sets to ML algorithms

Phase 1 Ongoing Work

- Feasibility Measurement Criteria
  - Quantity of detectors required
  - Speed and accuracy of detector verification
  - Overall efficiency of neutron and gamma detections
  - Suitability of observables to advanced ML/data algorithms



(a)



(b)

Fig. 1. Multi-detector system configuration (a). Four different detectors, seven detectors in total able to simultaneously measure radiation from fresh nuclear fuel mock-up (b).

Phase 1 Detectors

- Detectors being evaluated:
  - Saint-Gobain He-3 proportional counter
  - Eljen EJ-309 liquid scintillator
  - Hilger Crystals NaI(Tl) detector with Bicron PMT-base
  - $Cs_2LiYCl_6:Ce^{3+}$(CLYC) scintillation detector

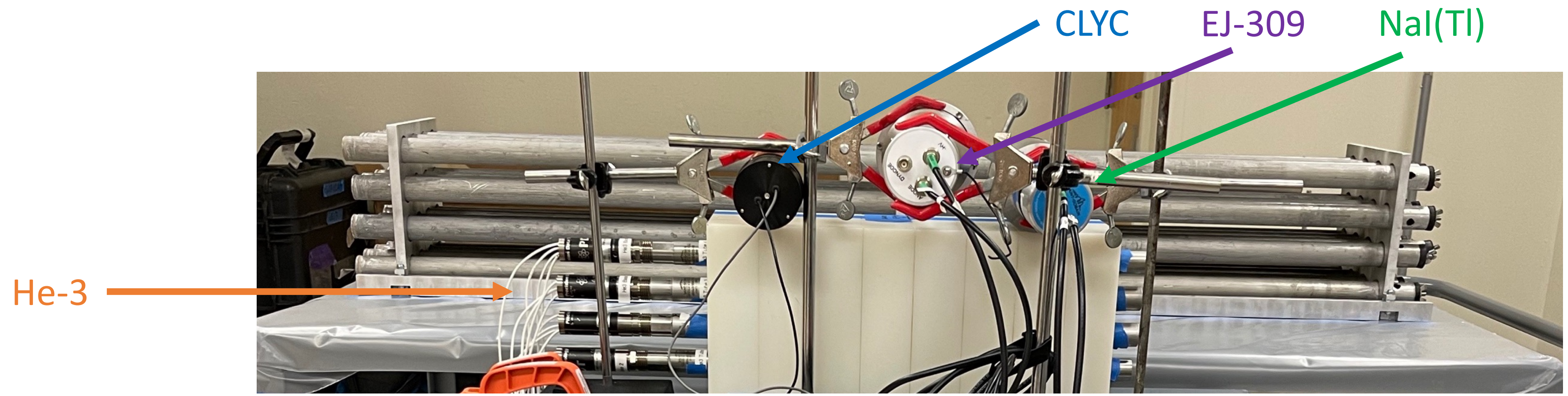
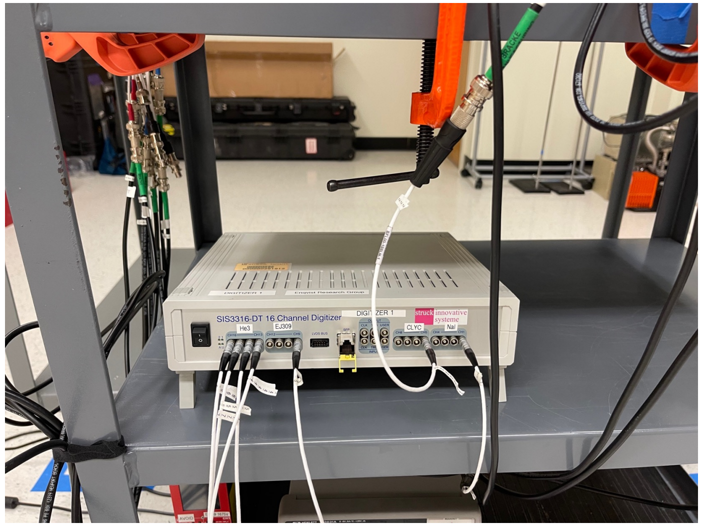


Fig. 2. Close up of the four different detectors.

Phase 1 Equipment

- Measurement Equipment:
  - Struck SIS3316-DT 16 Channel Digitizer
  - Hewlett-Packard E3631A DC Power Supply (for He-3 detectors)
  - CAEN High Voltage Power Supply



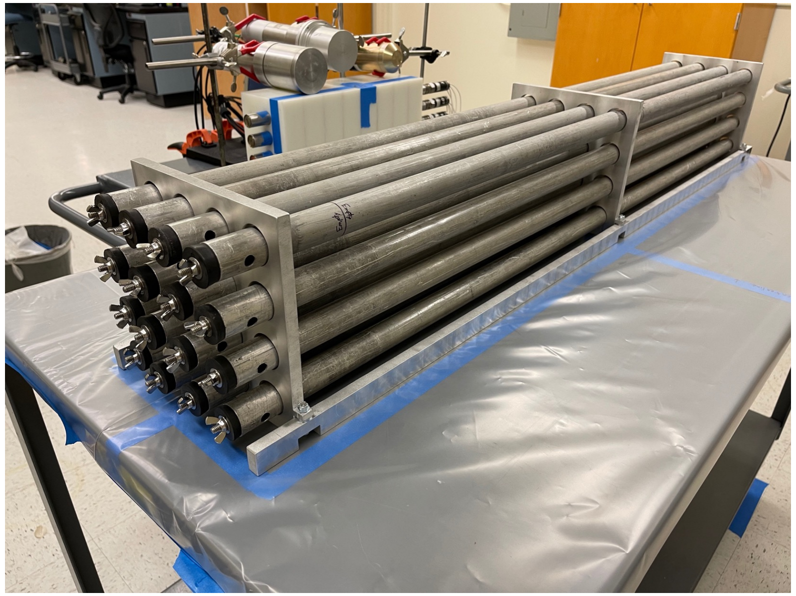
(a)

(b)

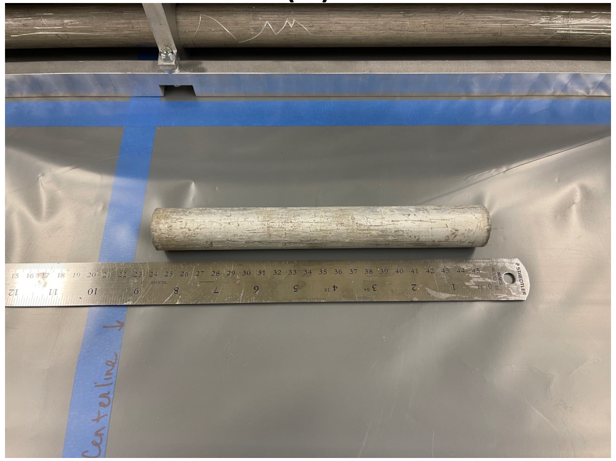
Fig. 3. Each detector is connected on individual channels on the digitizer (a). The two separate power supplies are shown in (b).

Phase 1 Experimental Design

- PWR and BWR fresh fuel configurations are modeled using natural uranium array
  - Up to 16 aluminum casings holding 6 natural uranium slugs with option to use Cf-252 as an active measurement neutron source
  - Adjustable configuration – 3x3, 4x4, Cf-252 location placement, fewer fuel slugs – each used to simulate different fresh fuel configurations



(a)



(b)

Fig. 4. The fresh fuel mock-up assembly is shown in (a) to include the aluminum stand. The black end caps can be removed to insert the uranium slugs (b). When completely filled, the 4x4 assembly weighs nearly 500 lbs.

Phase 1 Initial Results

- Successful, simultaneous measurements with four different detector types using the same digitizer

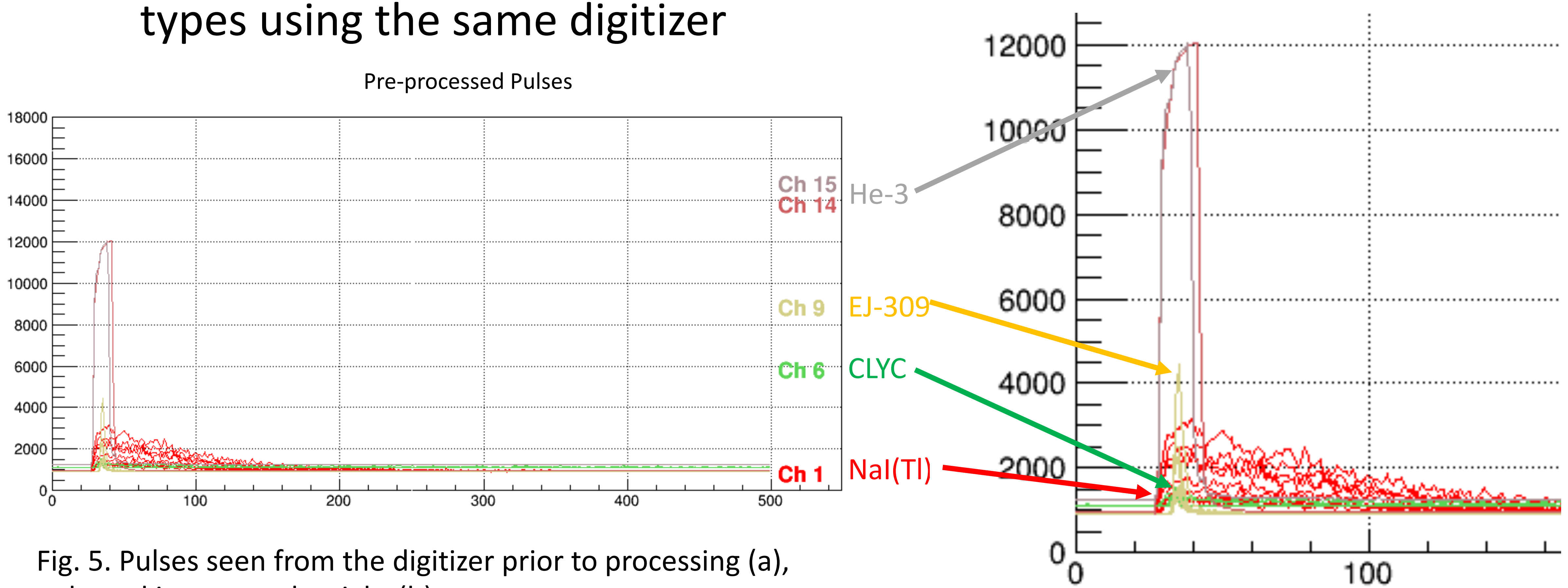


Fig. 5. Pulses seen from the digitizer prior to processing (a), enlarged image on the right (b).

Expected Impact

- Phase 1 will provide framework for versatile, multi-detector system
- Completion of research will aid in understanding the obstacles and opportunities for swift nuclear materials inventory verification

MTV Impact

- MTV provides critical networking, lab, and industry connections and support
- Developing relationship and collaborations with nearby fresh fuel manufacturers and nuclear power plants
- Aim to conduct site visit (and possible measurements) at Hatch Nuclear Power Plant and Florida Power and Light nuclear facilities by summer/fall 2023
- Scheduled to conduct measurements with the National Criticality Experiments Research Center (NCERC)

Conclusion

- A multi-detector system has potential to rapidly verify and differentiate between fresh nuclear fuels – this methodology could be adapted to other nuclear fuel cycle stages
- The work demonstrates there are ways to balance both safeguard and efficiency concerns in the nuclear materials realm

Next Steps

- Complete feasibility measurements for dissemination at SORMA 2023
- MCNP simulations by summer 2023
- NCERC experiments July - August 2023
- Power Plant & Fuel Fabrication measurements and site visits fall 2023

Acknowledgements

The Consortium for Monitoring, Technology, and Verification would like to thank the DOE-NNSA for the continued support of these research activities.

This work was funded by the Consortium for Monitoring, Technology, and Verification under Department of Energy National Nuclear Security Administration award number DE-NA0003920