Nondestructive Assay of ^{237}Np using Organic Scintillators

MTV Workshop, 2020

11 March

M.Y. Hua, T.A. Plummer, S.D. Clarke, and S.A. Pozzi
University of Michigan

^{237}Np is a potentially weapons-usable isotope.

- The goal of nondestructive assay is to precisely measure/verify the mass of an unknown sample in a reasonable amount of time.

- ^{237}Np is a potentially weapons-usable isotope.
  - US DOE: “other nuclear material”
  - Reportable in gram quantities

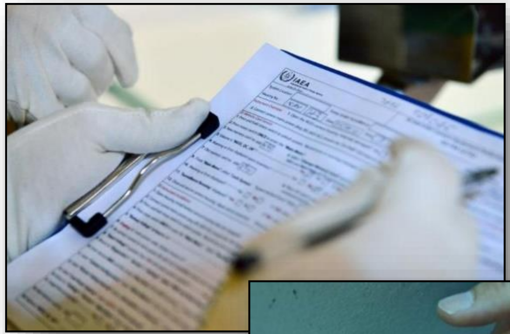
  - Bare sphere critical mass of 40-60 kg
  - International community recognizes the possibility of ^{237}Np-based weapons
  - 3000 kg annually produced in US
  - Applications in space for ^{238}Pu production

- The capability to efficiently assay ^{237}Np is a missing piece of the verification and safeguards toolbox.

National Nuclear Security Administration

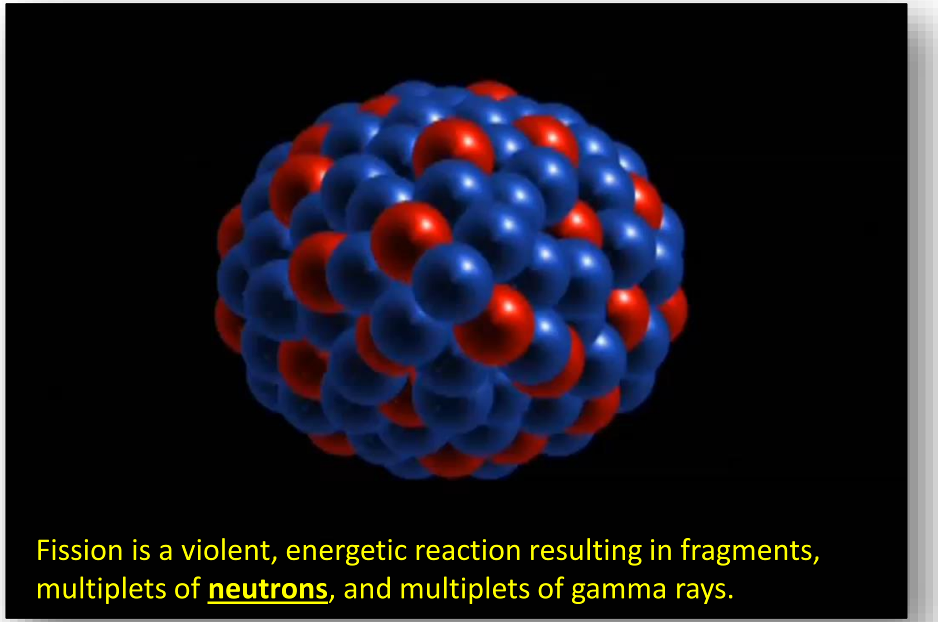
Developing a ^{237}Np-assay system is critical to NNSA's mission.

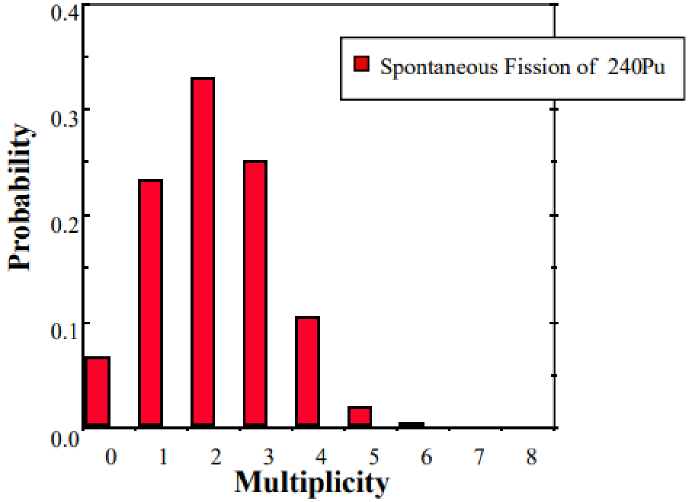
- **Material Management and Minimization**
  - "The most difficult step in the development of an improvised nuclear device is acquiring weapons-usable nuclear material."
- **Global Material Security**
  - "The mission of the Office of Global Material Security (GMS) is to prevent terrorists from acquiring nuclear or radiological material that could be used in an attack on the United States, its interests, or allies."
- **Nonproliferation and Arms Control**
  - "NNSA's Office of Nonproliferation and Arms Control (NPAC) strengthens nonproliferation and arms control regimes to prevent proliferation, ensure peaceful nuclear uses, and enable verifiable nuclear…"
- **Research and Development**
  - "NNSA advances its nuclear threat reduction mission by developing ways to detect and monitor foreign nuclear fuel cycle and weapons development activities, special nuclear material movement or diversion, and nuclear explosions."



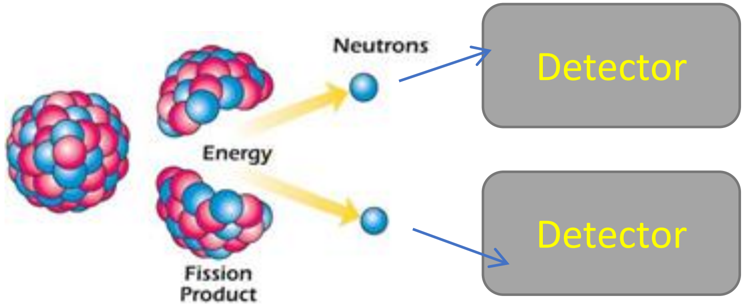
Technical Approach

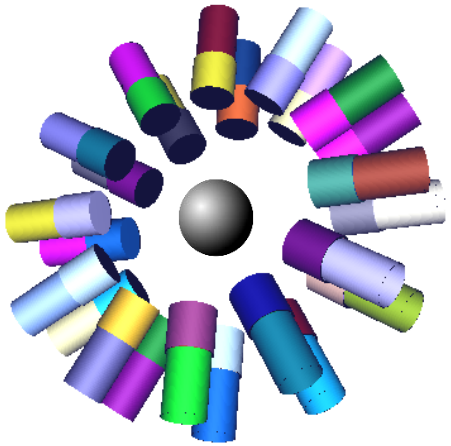
- We cannot just weigh samples… (Pb or Np?)
- We use something unique to the nuclear material: fission.
  - Multiplets of neutrons
    - Correlated
    - Follow a distribution
- We can use calibration curves to estimate sample mass from the doubles and triples multiplicity rates.
- Typically measure neutrons with ^{3}He detectors.



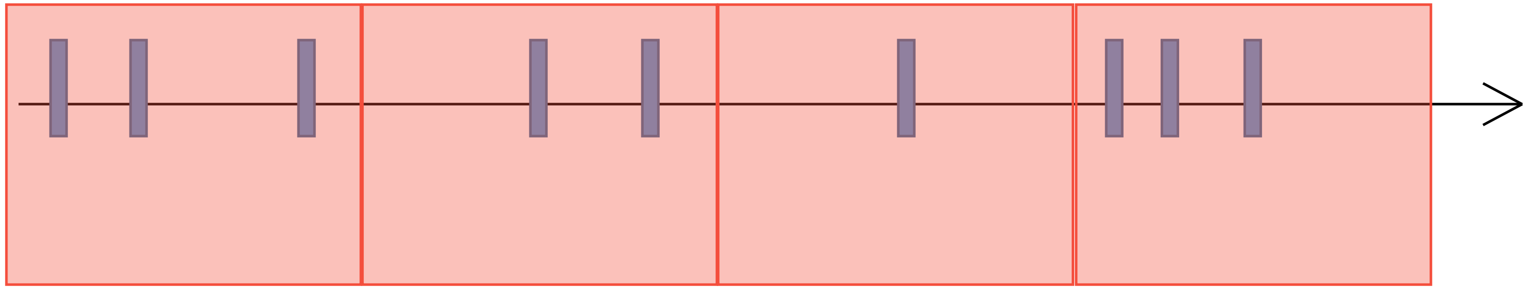


Technical Approach: Neutron Multiplicity Counting





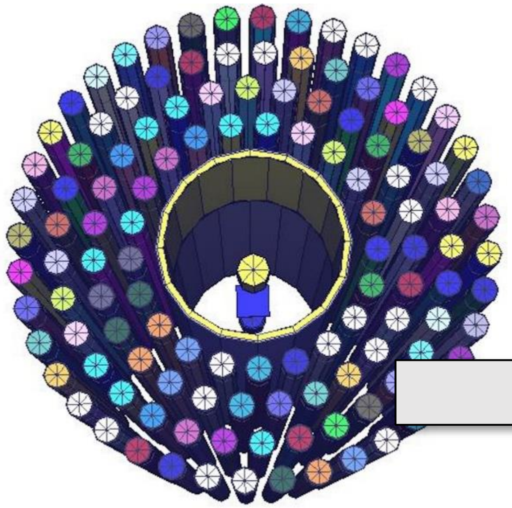
The important signature is:
times of neutron detections



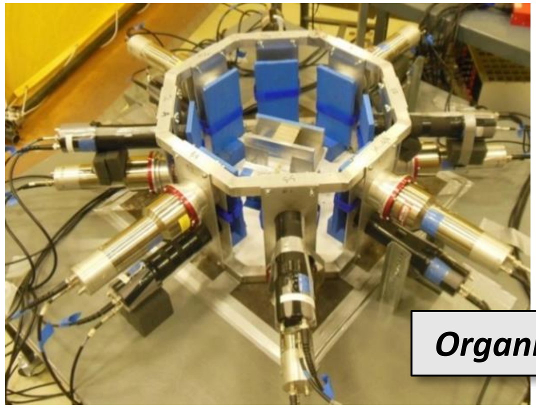
- Count neutrons in small time windows
- Use factorial moment counting to obtain neutron doubles and triples rates

We will compare current ^{3}He-based detectors with newer organic scintillation detectors.

- Collect neutron detection times; turn them into multiplicity rates.
  - ^{3}He uses moderation ⇒ slower.
  - Organic scintillators don't ⇒ faster.
- Simulate a 20-minute measurement and calculate doubles and triples multiplicity rates.
- Simulate 20 masses logarithmically distributed between 10 and 1000 g.
- Need 12% relative uncertainty to differentiate two sequential masses.



^{3}He multiplicity counter.

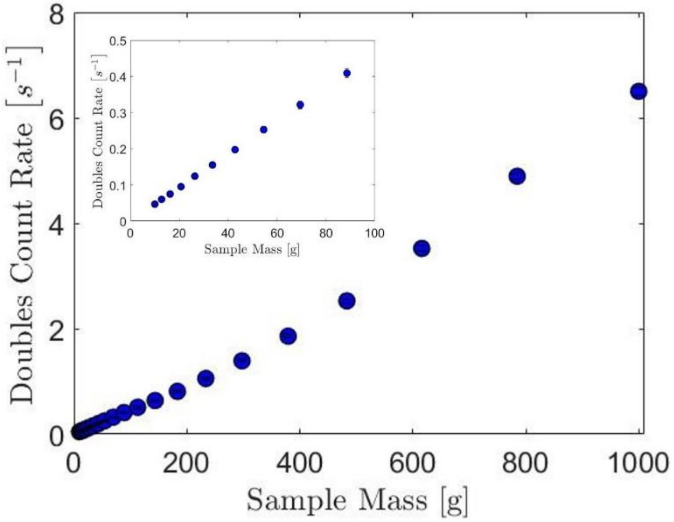


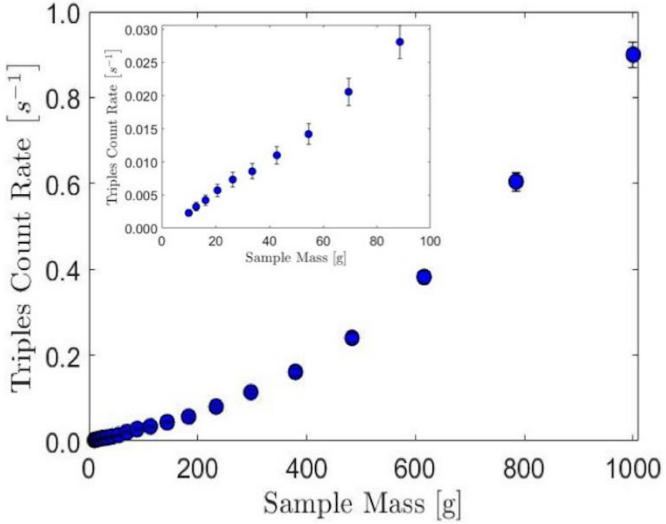
Organic scintillator multiplicity counter.

Simulated Results

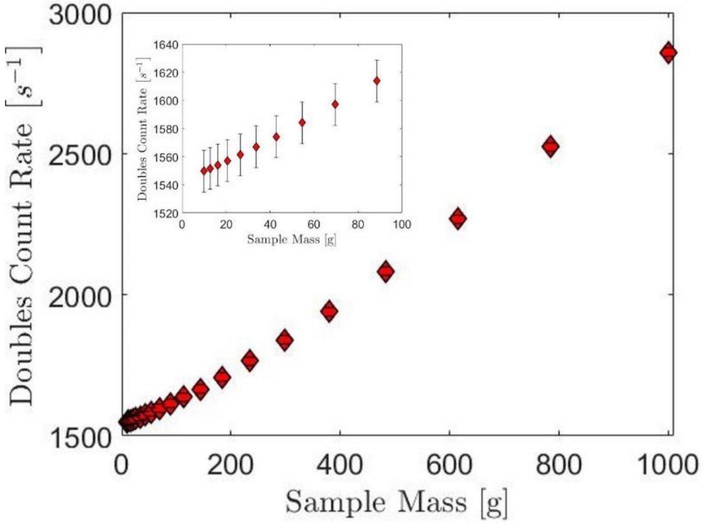
- The organic scintillators discriminate the doubles rates at least <u>4.5 times faster</u> than the ^{3}He system.
- Organic scintillators can discriminate the triples rates in 20 minutes.
- The ^{3}He system would require 6 days.
- In simulations, organic scintillators are better!
- What about in the real world?

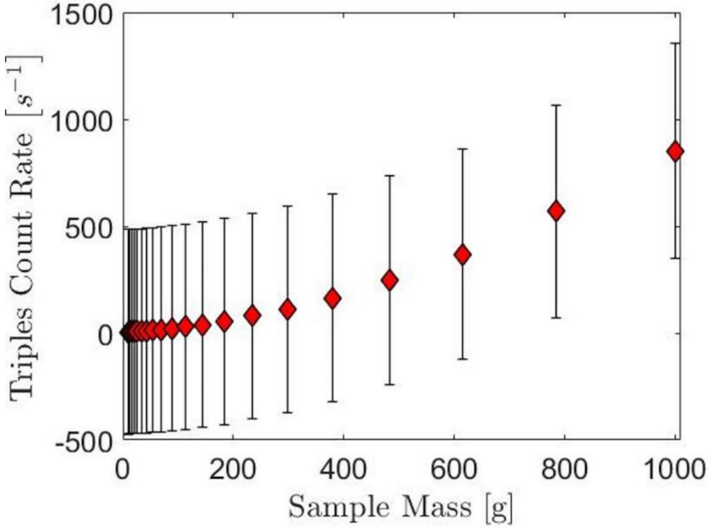
Organic Scintillator-Based System





^{3}He-Based System





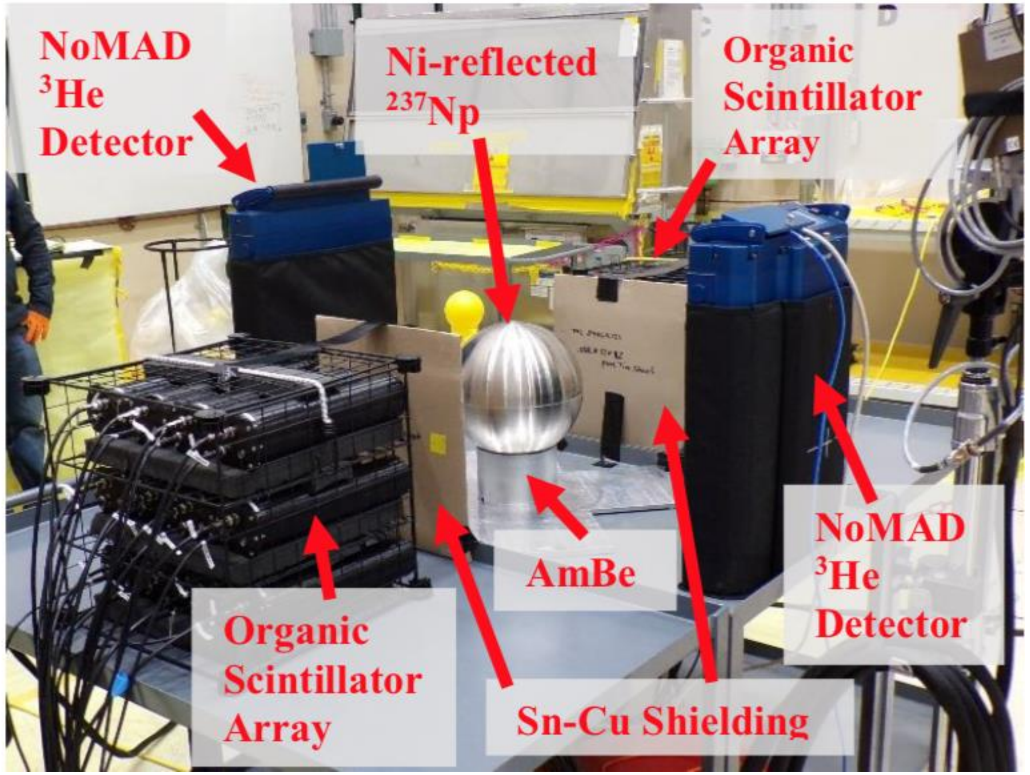
A 6-kg sphere of ^{237}Np was measured at the Device Assembly Facility.

NoMAD ^{3}He-based detector:
15 ^{3}He tubes in polyethylene

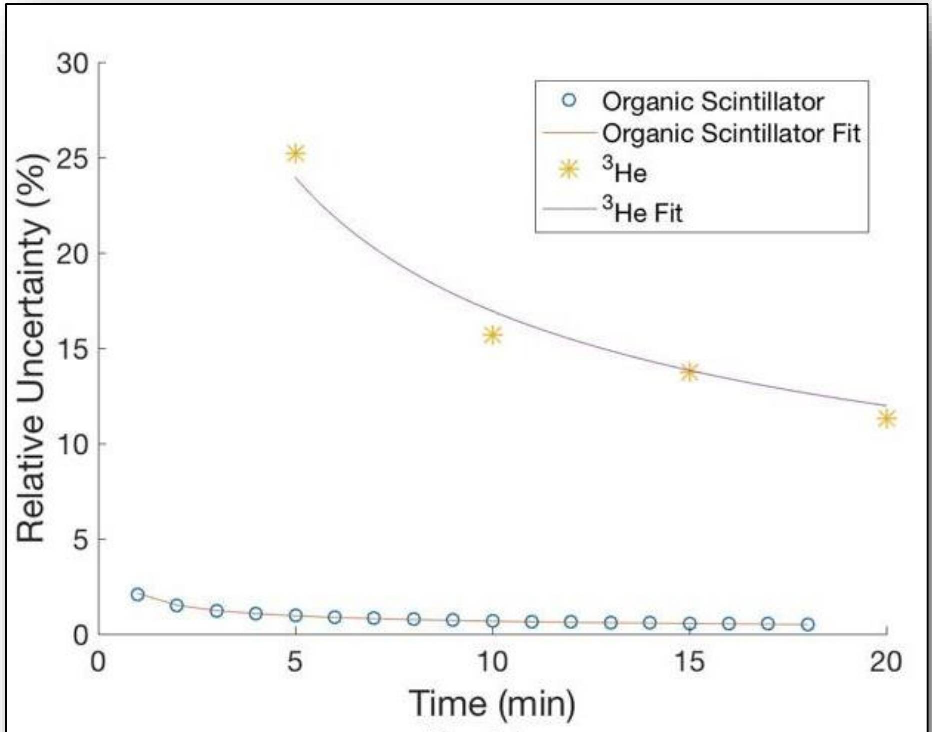
20-minute measurement

12 *trans*-stilbene organic scintillator system

18-minute measurement



Measured Doubles Rate Results



Doubles

- Time to achieve 1% relative uncertainty:
  - Organic scintillators: 4.54 minutes
  - ^{3}He systems: 2871 min = 2 days
- Time to achieve 10% relative uncertainty:
  - Organic scintillators: < 3 seconds
  - ^{3}He systems: 30 minutes
- Relative uncertainty falls off as a function of $1/\sqrt{measurement\ time}$
  - There could be a systematic asymptote we have not reached.

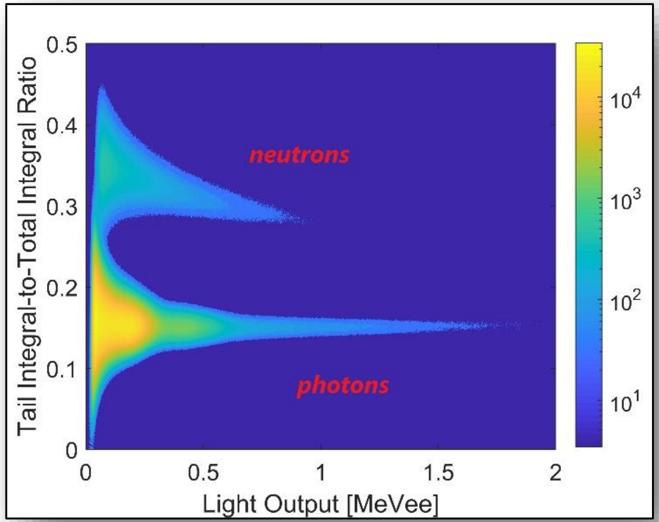
Conclusion for Technical Work

- Organic scintillator systems should replace ^{3}He and be deployed for the assay of ^{237}Np.

- The additional capabilities of organic scintillators may increase the scope of application.
    - 3 seconds ⇒ measure material flowing in pipes
        - Uranium
        - Plutonium
        - Neptunium

Future Work

- Preliminarily investigate assaying plutonium flowing in a pipe.
  - What is the max flow speed?
  - What corrections need to made?
- Investigate bulk samples.
  - Multiplicity counting assumes point sources…
- Use the information contained in the emitted photons.

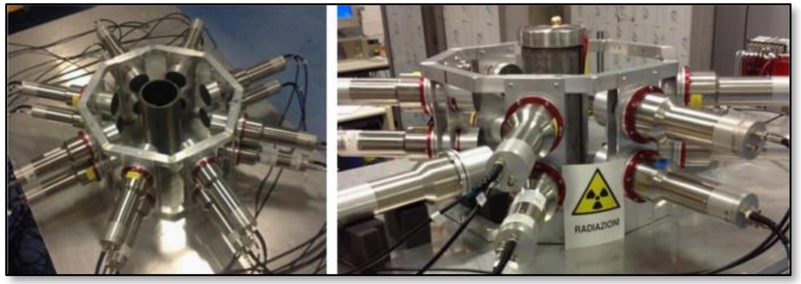


Expected Impact

UofM Work

- Direct detection of fission neutrons
- Compton edge calibration
- Neutron cross-talk corrections

- EJ-309 liquid scintillator characterization
- Use of additional signatures to reduce burnable poison-induced bias

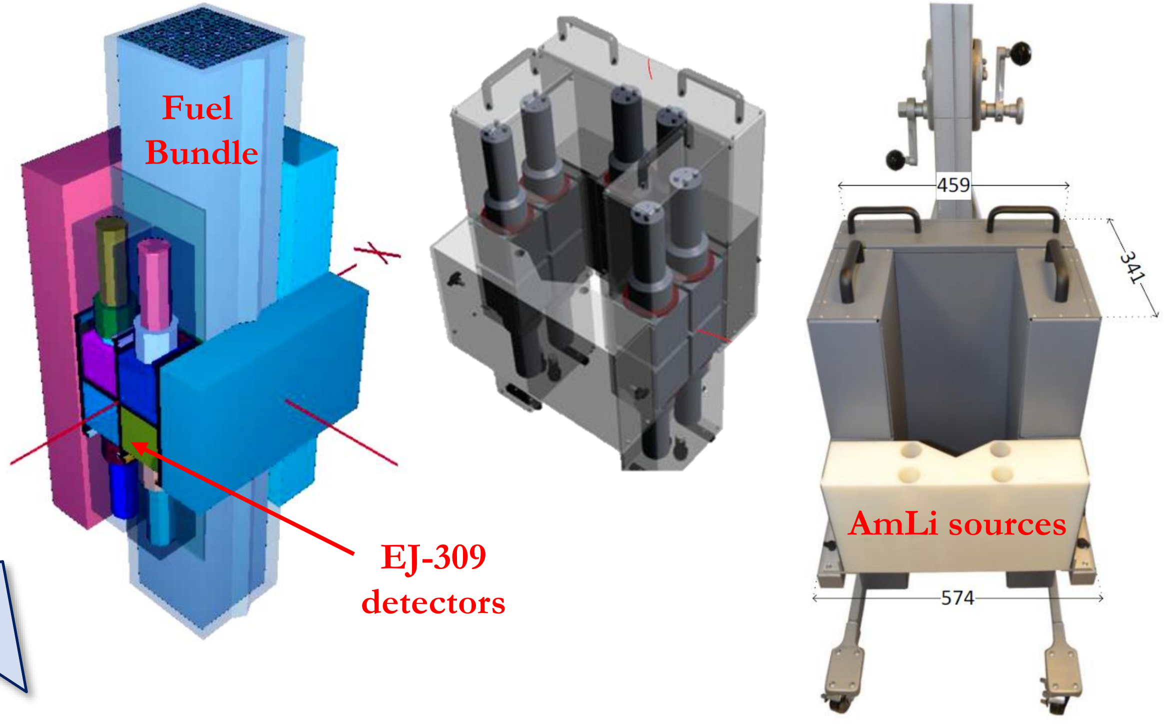


The First FNWC at the JRC Facility in Ispra (2013)

- Pu Measurements with the FNWC
- Differential Die-away Self-Interrogation

FNCL detector in 3-panel configuration

The IAEA has developed and deployed a fast-neutron collar for the assay of fuel bundles.



Measurements with a New FNCL
FNCL Tests at Nuclear Fuel Fabrication Plant in Brazil
IAEA Uses FNCL to measure fuel containing burnable poisons

MTV Impact

- Measurements of special nuclear material and other material at the Device Assembly Facility.
- Existing collaboration with Los Alamos National Laboratory.
  - Jesson Hutchinson
  - George McKenzie
- Potential collaboration with other universities (e.g. Prof. Enqvist at Florida)
- Potential collaboration with Y-12 on assaying material in pipes.
- Technology transition to the International Atomic Energy Agency
- Space travel

Acknowledgements

The Consortium for Monitoring, Technology, and Verification would like to thank the NNSA and DOE 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

Nondestructive Assay of ^{237}Np using Organic Scintillators

MTV Workshop, 2020

11 March

M.Y. Hua, T.A. Plummer, S.D. Clarke, and S.A. Pozzi
University of Michigan