Multi-modal, multi-energy approach for neutron interrogation of spent fuel
RSLN-022-19, Year 3 of 3

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Acknowledgments: Gladys Arias-Tapar, Keith Chase, Irene Garza, Larry Franks

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Reviewed for Classification
Paul P. Guss, MSTS, 1302
September 6, 2021

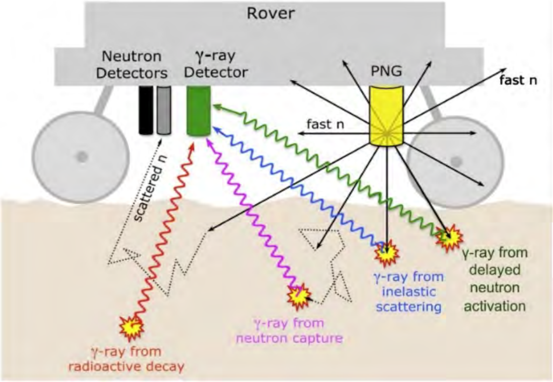
Challenge

- Geo-repositories are currently being built for the long-term storage of spent fuel casks. Safeguards methods are needed for effectively verifying the contents of spent fuel in casks as they are transferred into the repository and to provide assurance that the stored casks remain intact over time within the repository. Methods to determine U and Pu concentrations in spent fuel when transferred to a storage cask will be required.

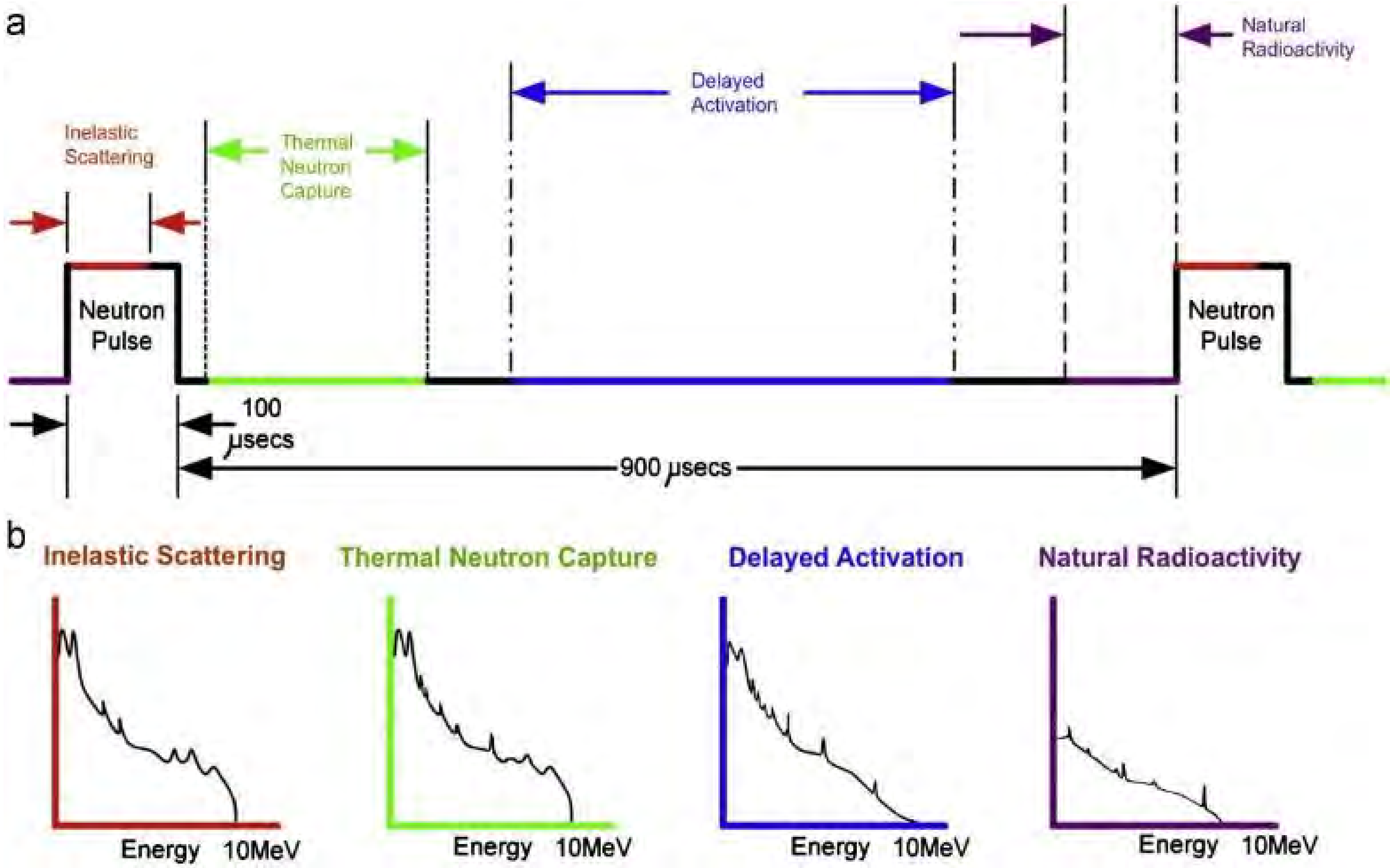
Innovation

- What is new in our formulation is the application of the Bodnarik[1] method of acquiring gamma spectra in fixed time windows to more effectively determine the constituency of the materials, the mass of the materials, and the determination of the presence of SNM and HE.

[1] Bodnarik J., D.M. Burger, A. Burger. G. Evans, A.M. Parsons, J.S. Schweitzer, R.D. Starr, K.G. Stassun. "Time-Resolved Neutron/Gamma-Ray Data Acquisition for In Situ Subsurface Geochemistry," Nucl. Inst. and Methods in Phys. Research A, v. 707, (2013), p. 135-142; http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140005993.pdf.

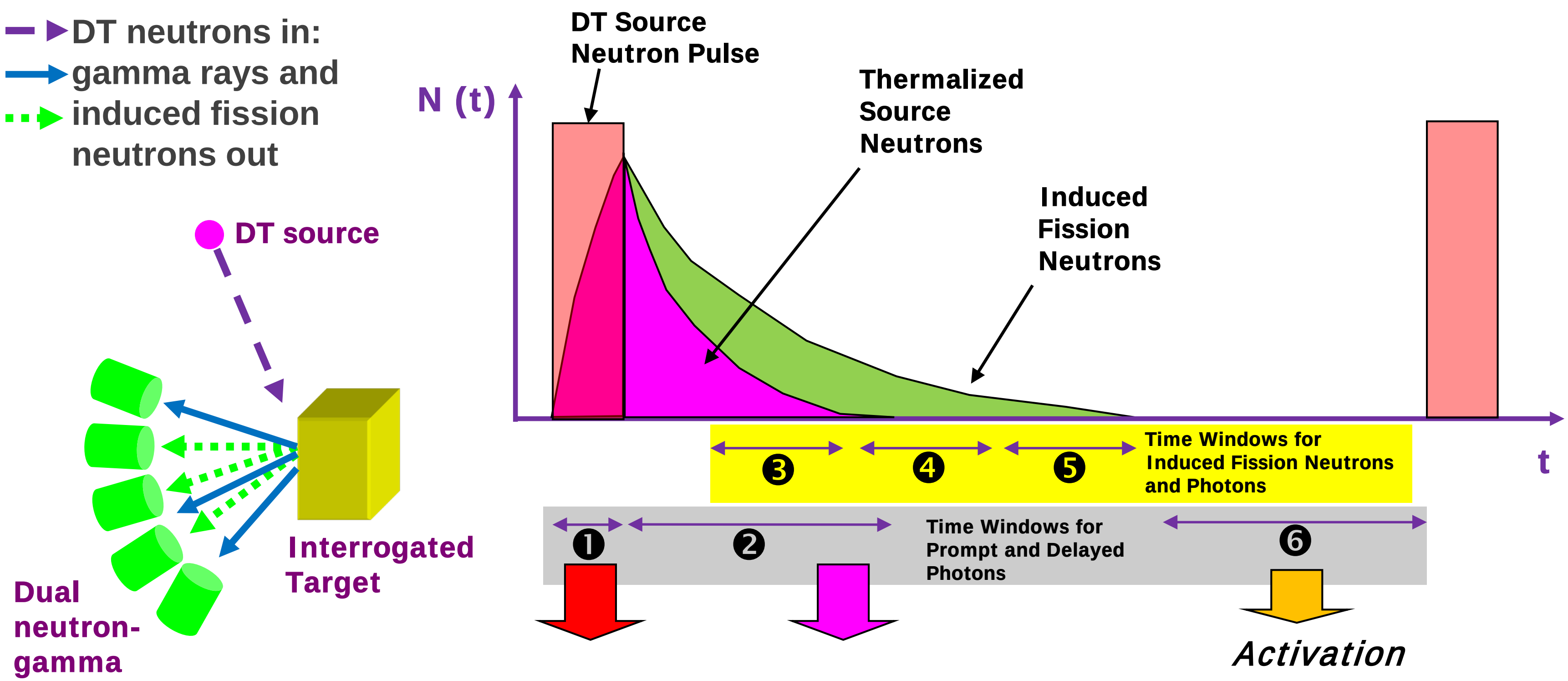


Technical Approach



a) Placement of timing windows relative to each neutron pulse.
b) Examples of different spectral shapes seen in different timing windows.

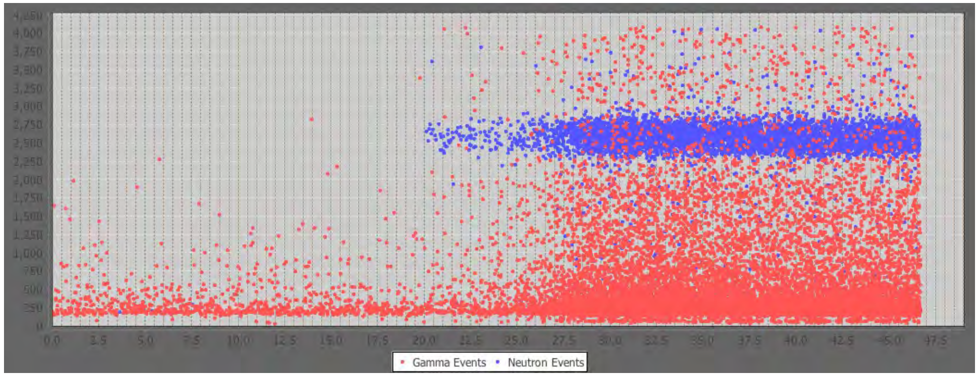
Innovation

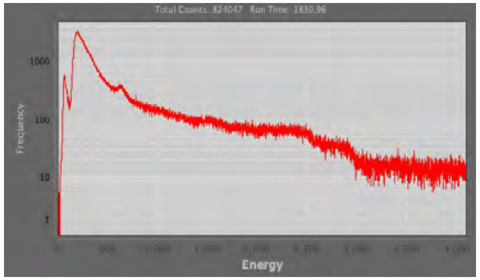


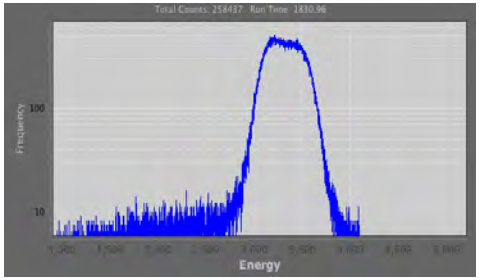
Reactions	(n,n’γ), (n,pγ)	(n,γ)	(n,α), (n,p)
Gamma Rays	Prompt	Prompt	Delayed
Isotopes	C, O, N, …	H, S, CL, Fe, N …	O, AL, Si, …

Technical Approach

Experimental setup with Aluminum target facing STNG tube, and CLYC detector.



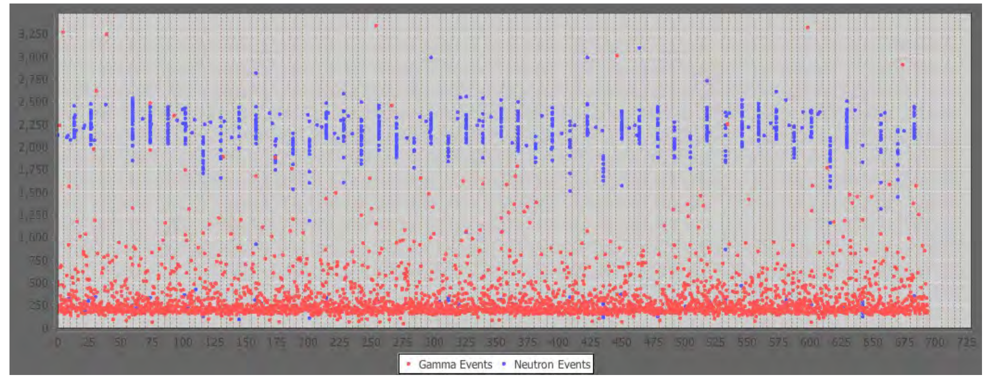


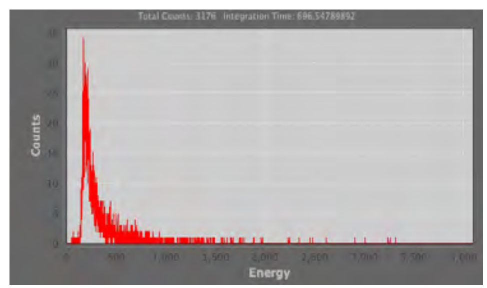


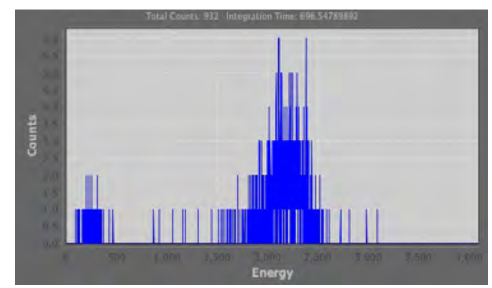
Waterfall display showing energy on the y-axis, time on the x-axis. Neutron events are blue, and gamma event are red.

Technical Approach

Experimental setup with CLYC detector facing DU target for DPF.

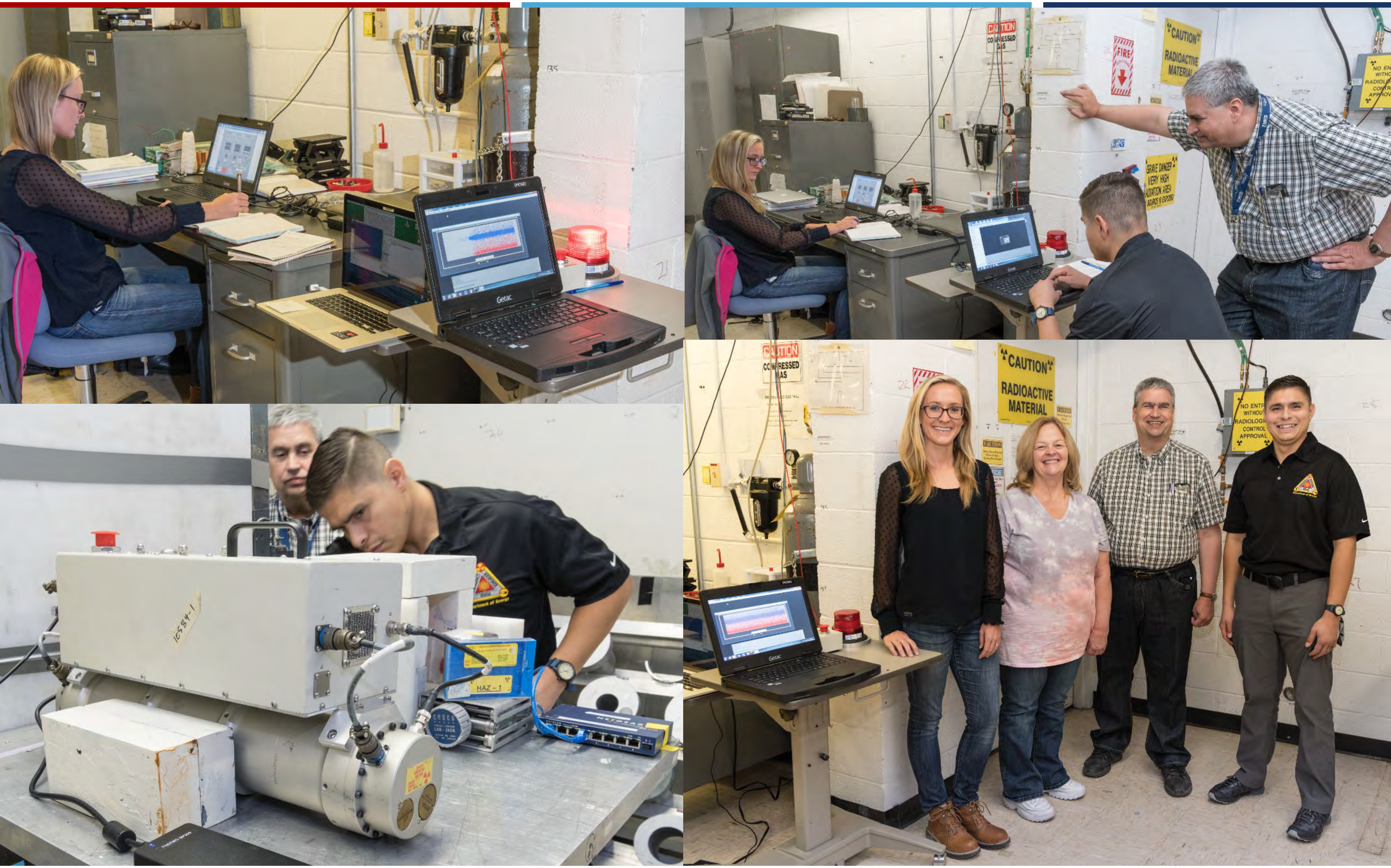






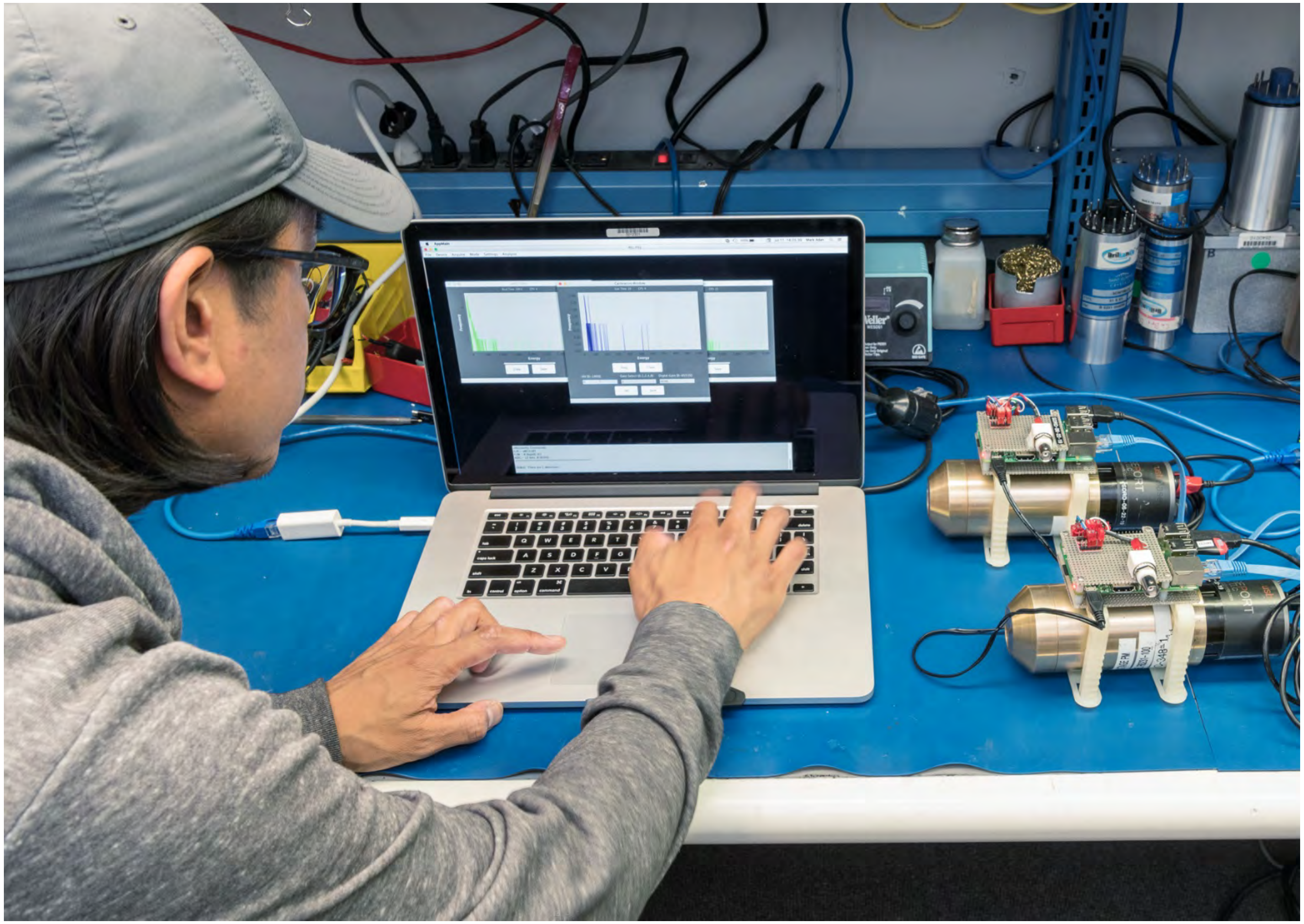
Waterfall display showing energy on the y-axis, time on the x-axis. Neutron events are blue, and gamma event are red.

Technical Approach - MP320 Campaign



October 2019 Campaign

Technical Approach



Setting up the 2-detector electronics.

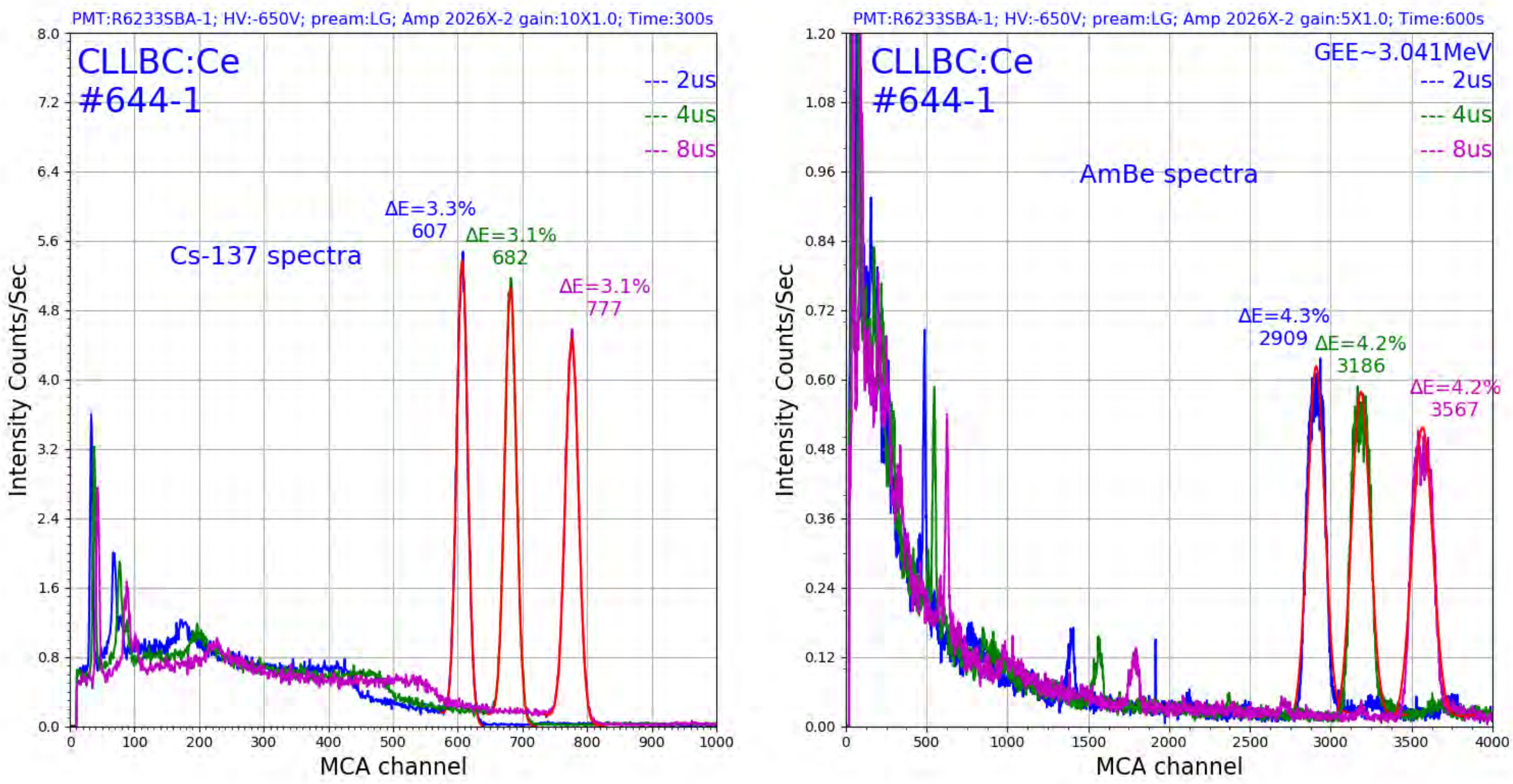
Technical Approach – MP320 Campaign

April 2021 Campaign

Research team setting up experiment at the A1 Source Range. Shown are NRD Engineer Ron Guise and UNLV Professor Alex Barzilov.

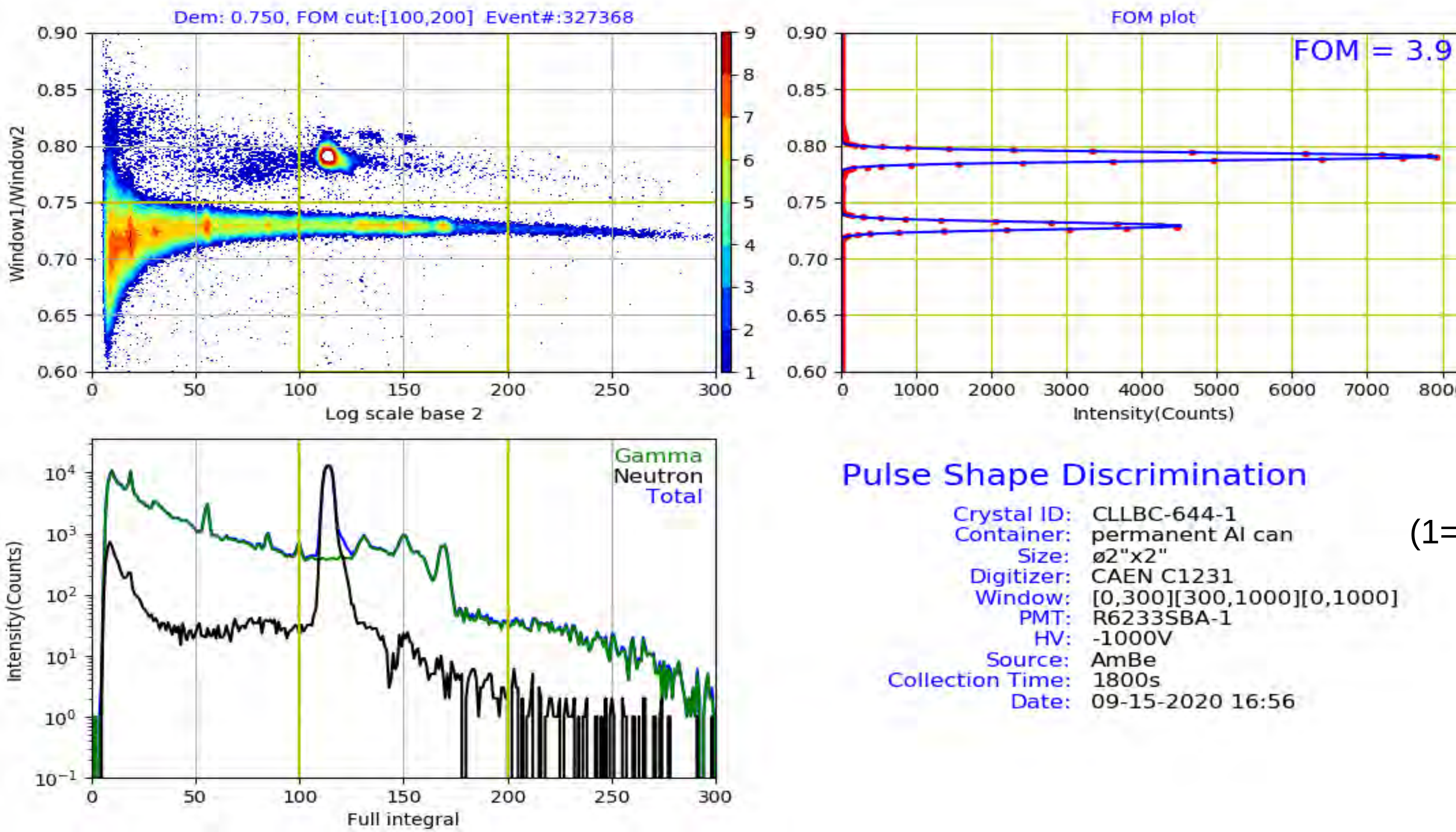
Two-detector setup with new larger elpasolites detectors on the left and on the right of the neutron source in the far background.

Technical Approach



CLLBC-644-1, ø2"×2"

Technical Approach

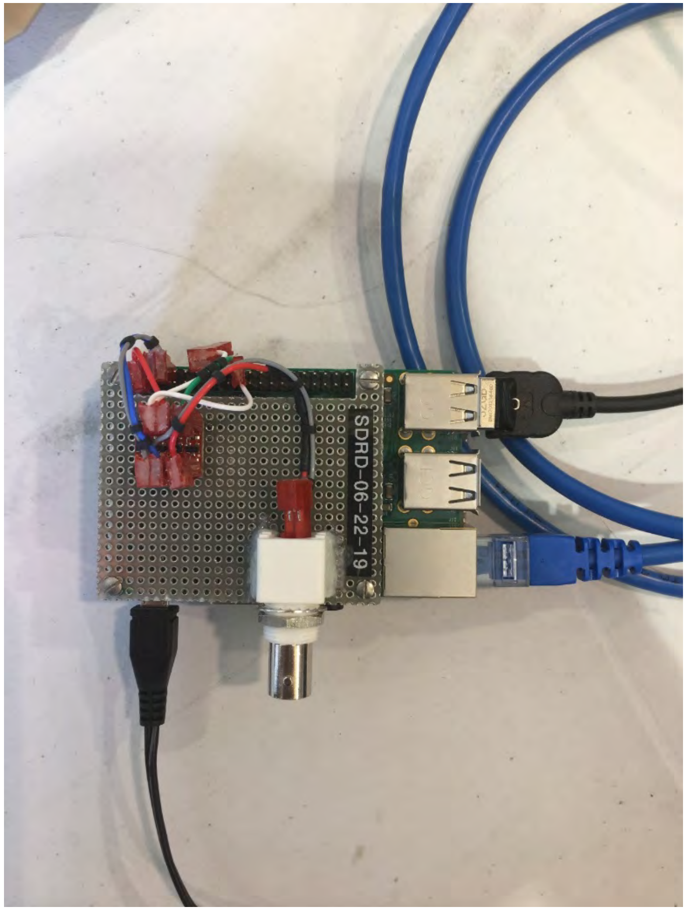


(1=4ns)

09-15-2020

Technical Approach

Setting up the detector table.

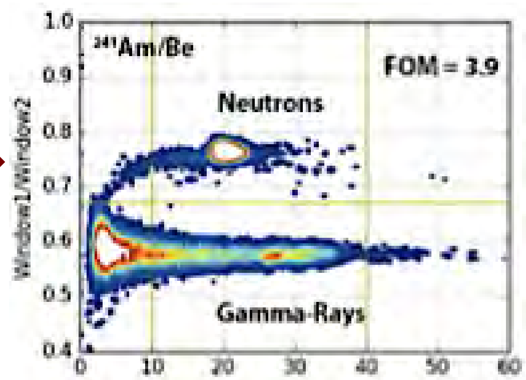


Embedded processor for data acquisition.

Embedded Processor

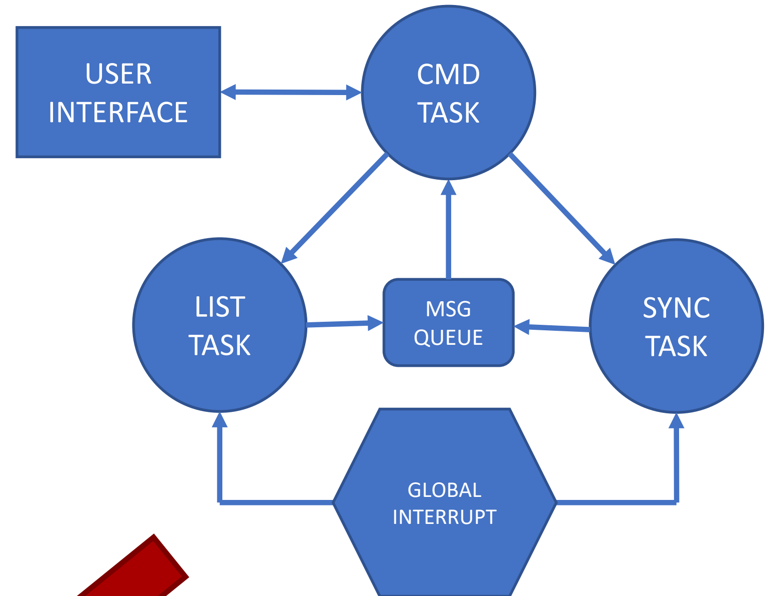
Technical Approach

usbBase: eMorpho MCA + HV with USB & GPIO



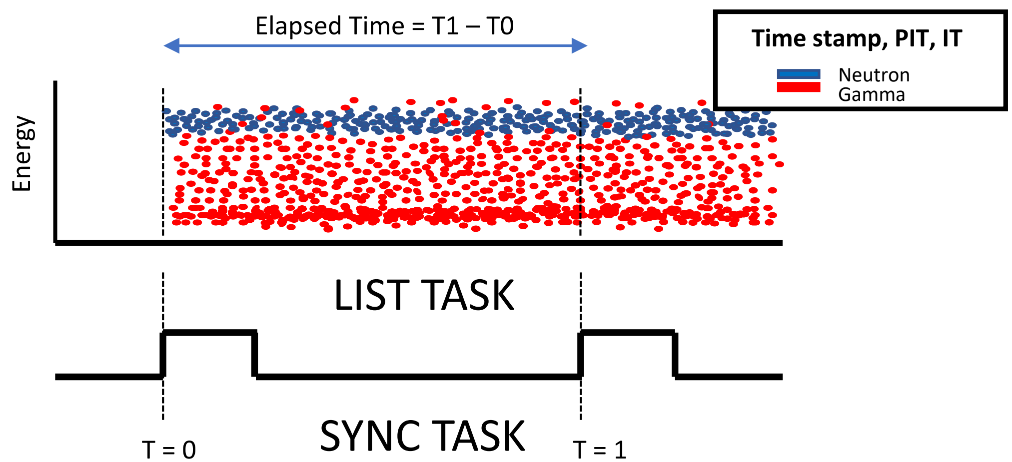
PSD Factor Plot

$$FoM = \frac{\Delta S}{FWHM_{\gamma} + FWHM_{n}}$$



System Architecture.

MCA Acquisition

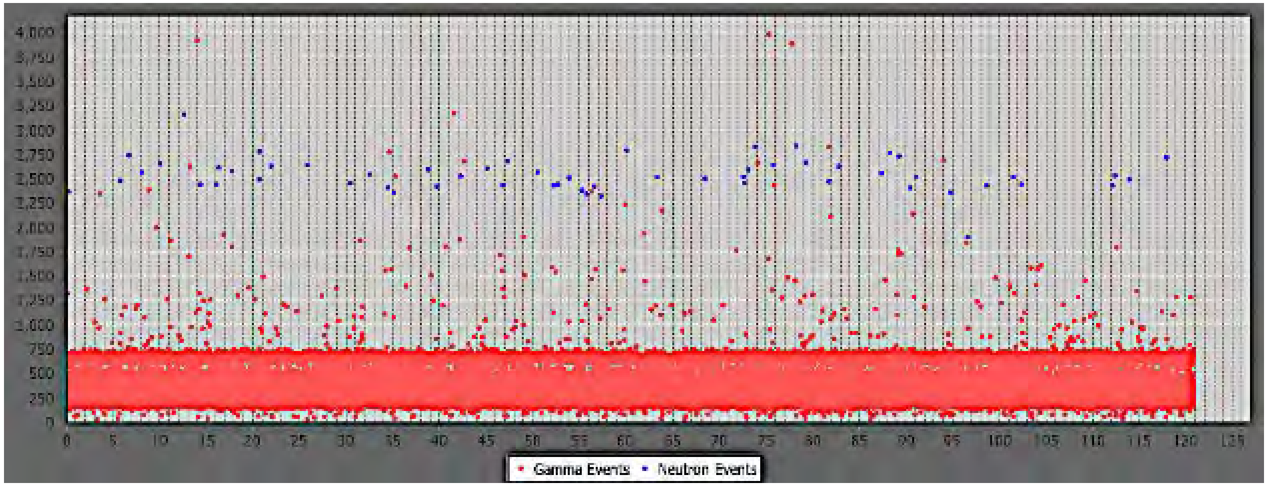


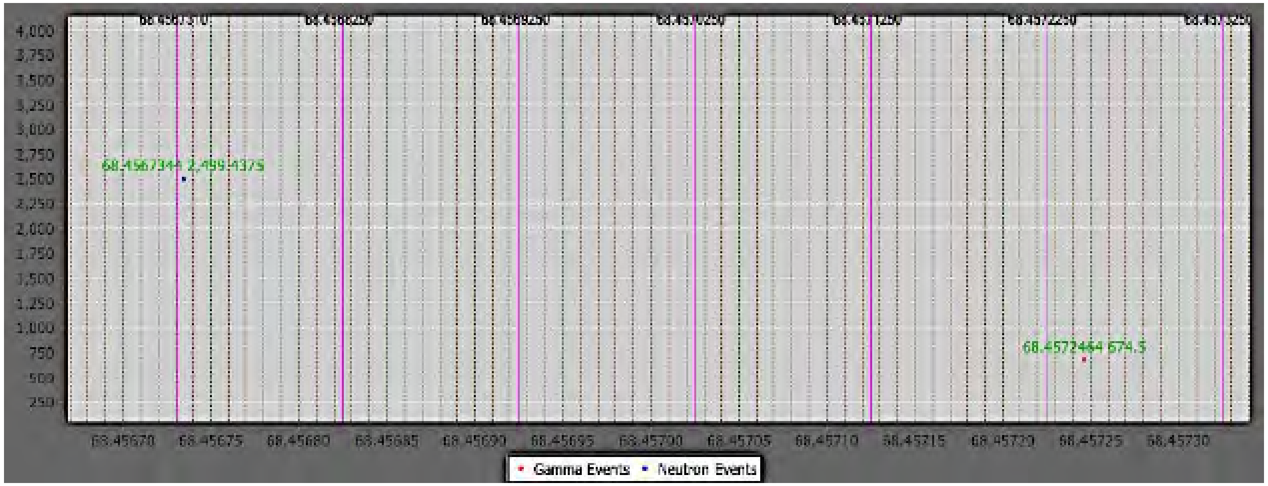
List Mode Acquisition and Pulse Synchronization Diagram

NEVADA NATIONAL NNSS SECURITY SITE
Managed and operated by Mission Support and Test Services

SDRD SITE-DIRECTED RESEARCH & DEVELOPMENT

Technical Approach

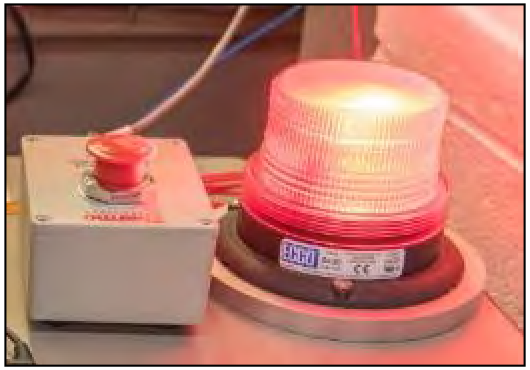


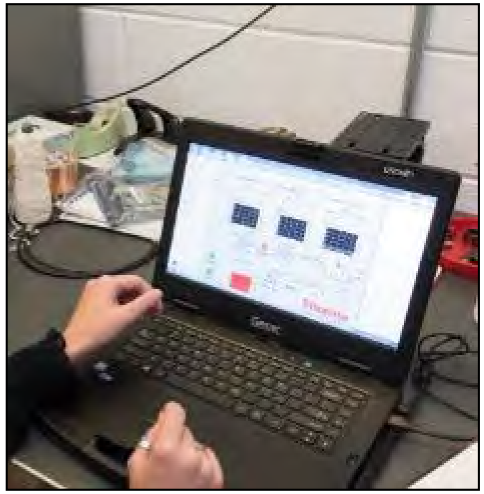


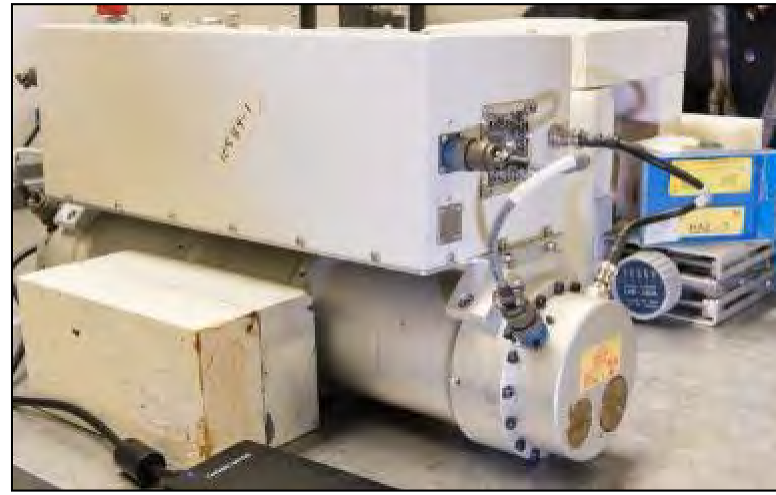
List Mode Energy-Time plots with External 10 kHz Triggers

MCA Acquisition

Technical Approach







MP320 Neutron Generator – System Specifications

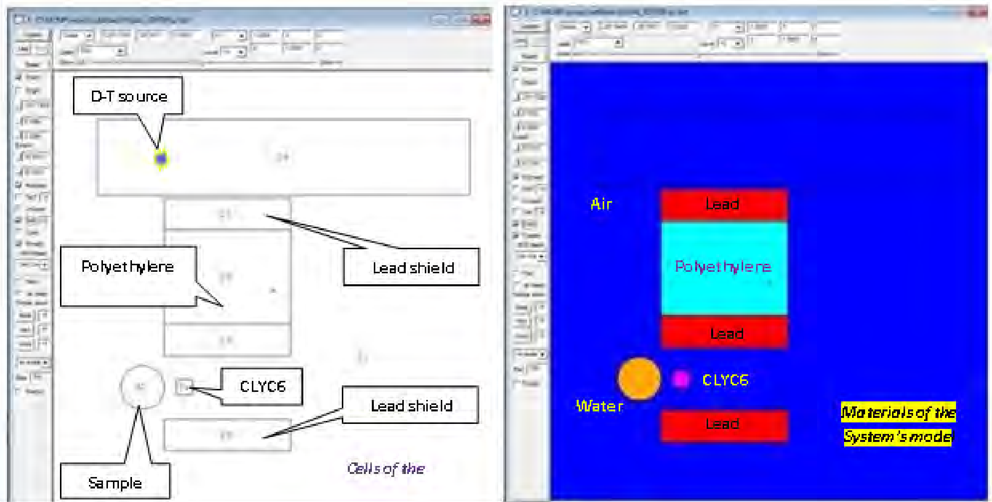
- 14.1 MeV neutrons from D-T fusion reaction
- Neutron yield: 1.08 × 108 neutrons/s
- Pulse rate: 250 Hz to 20 kHz continuous
- Duty factor: 5% to 100%
- Low power: less than 50 W
- Pulse rise and pulse fall time: Less than 1.5 μsec
- Minimum pulse width: 5 μsec
- Safety Features: key lock, remote and local emergency on/off buttons, pressure switch
- Software: open source text or GUI

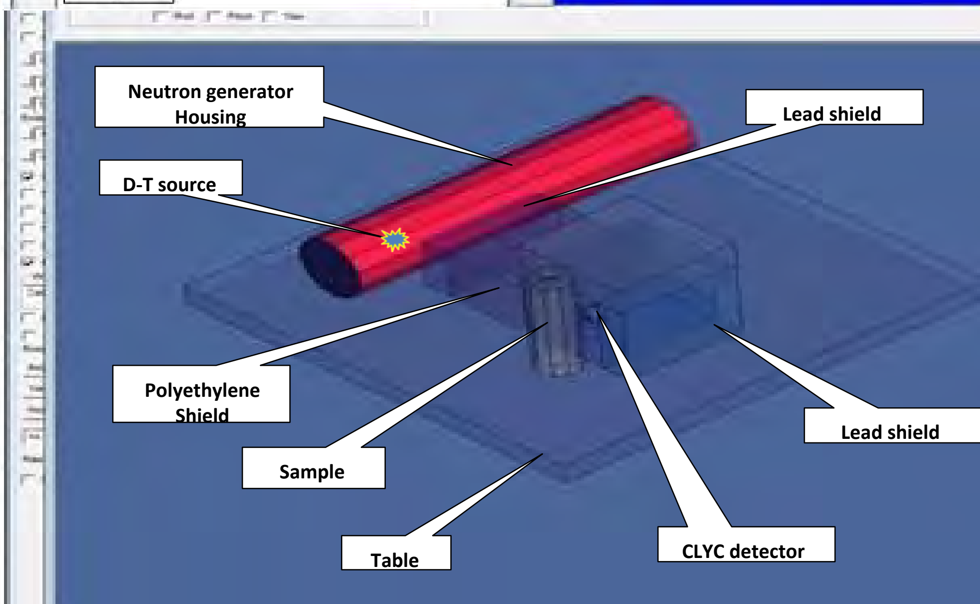
Technical Approach

MP320 Campaign

Targets

Technical Approach

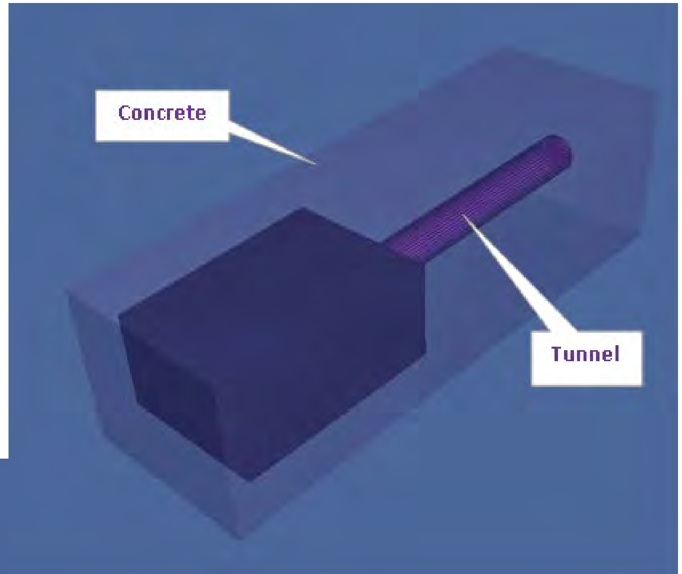


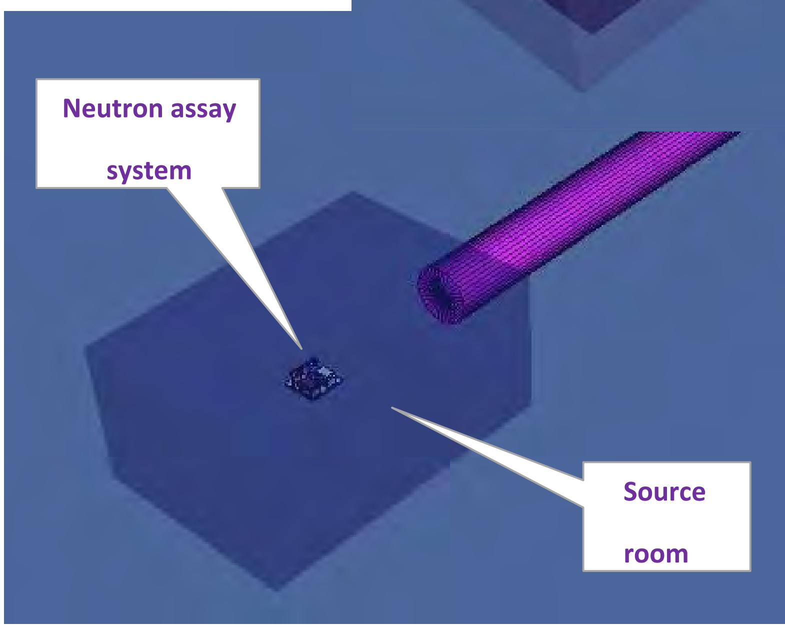


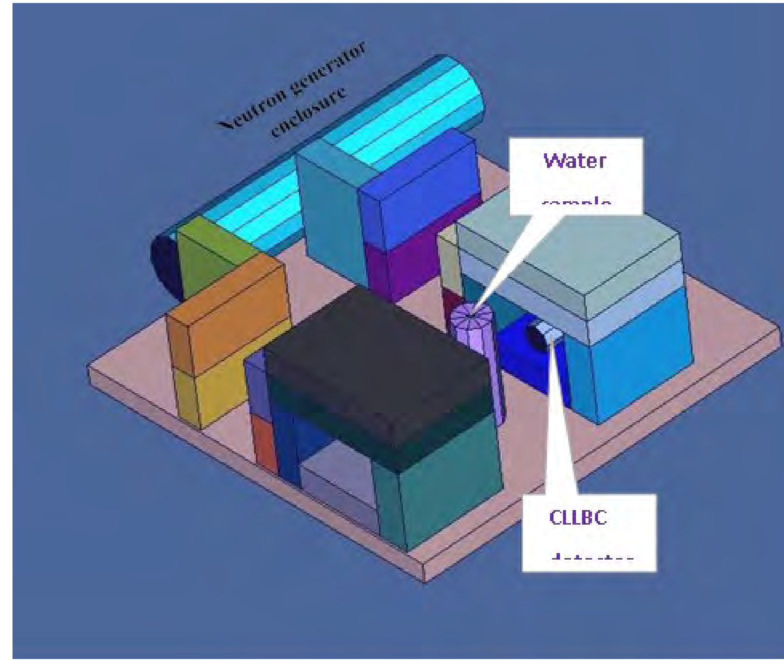
Built MCNP Model

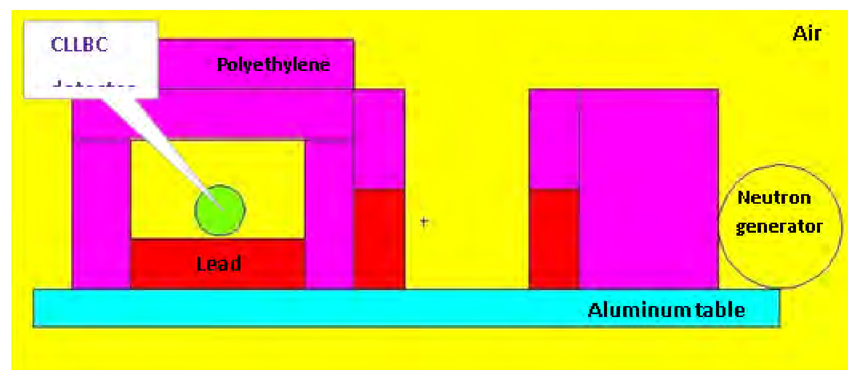
Technical Approach

MCNPX Model



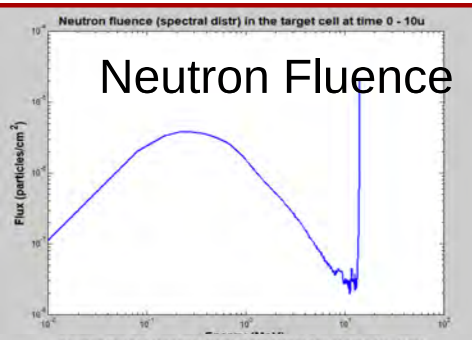


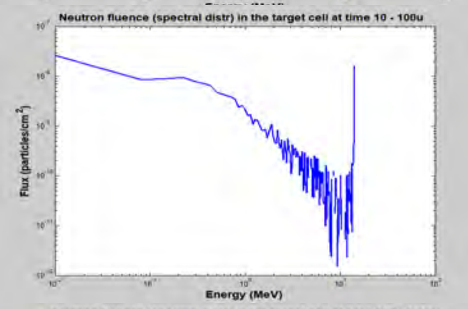


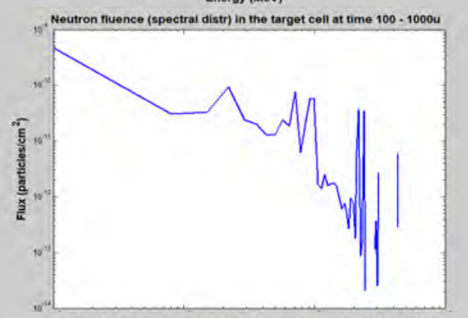


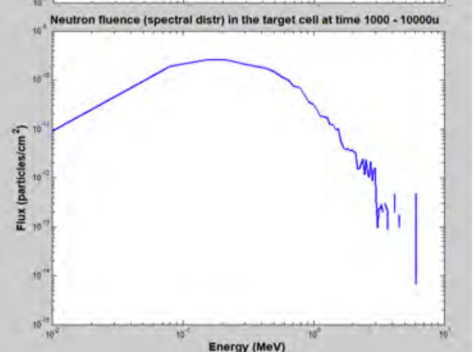
A1 Source Range

Results









0-10 μs

Left Neutron Fluence - Model 1 – DU

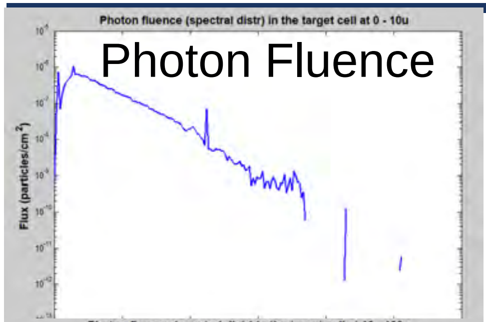
Right Photon Fluence - Model 1 – DU

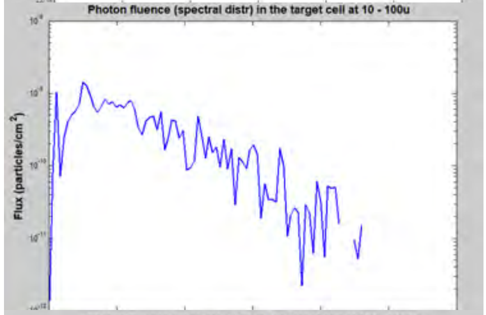
10-100 μs

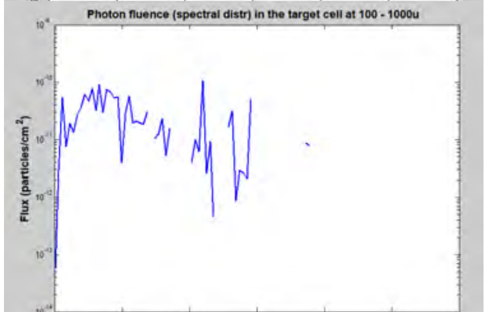
100-1000 μs

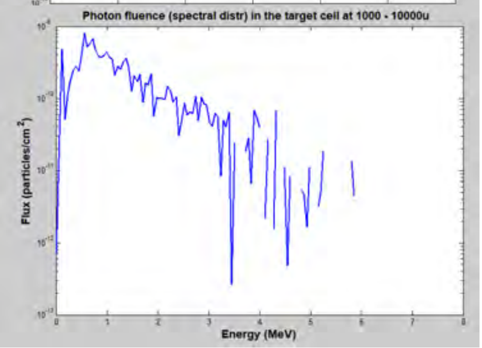
1-10 ms

Model 1: DU
Fluence (spectral distribution) in the target cell

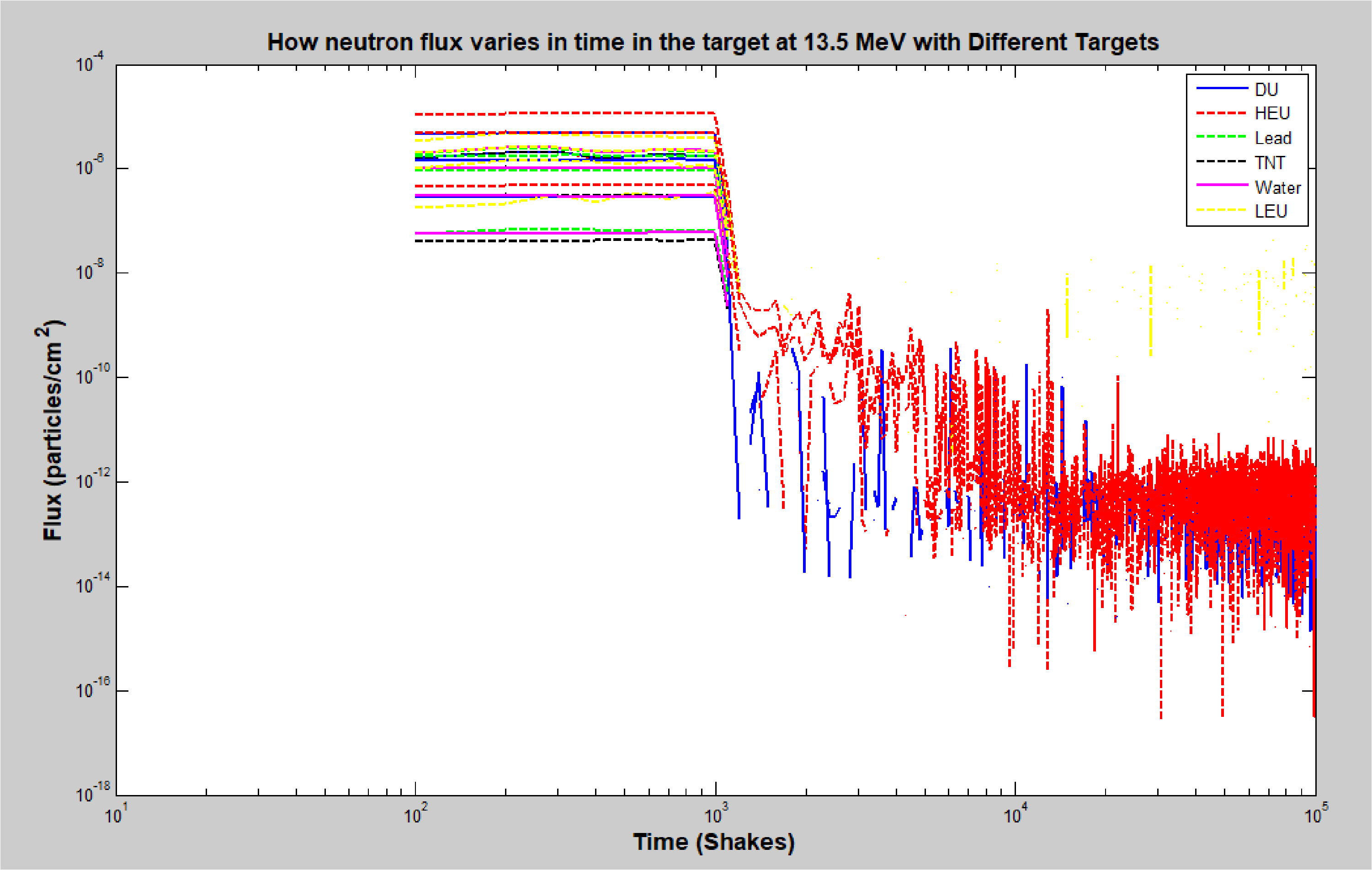






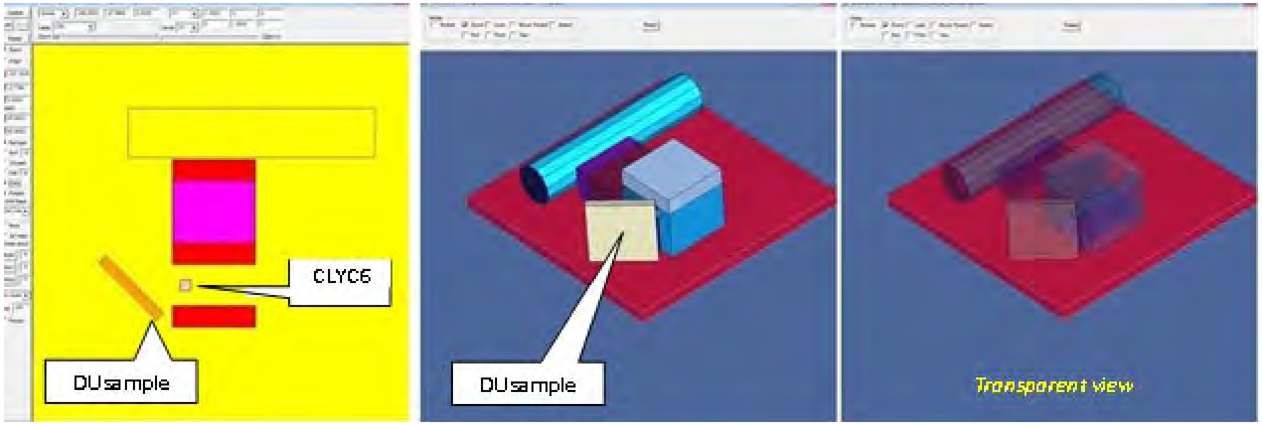


Results

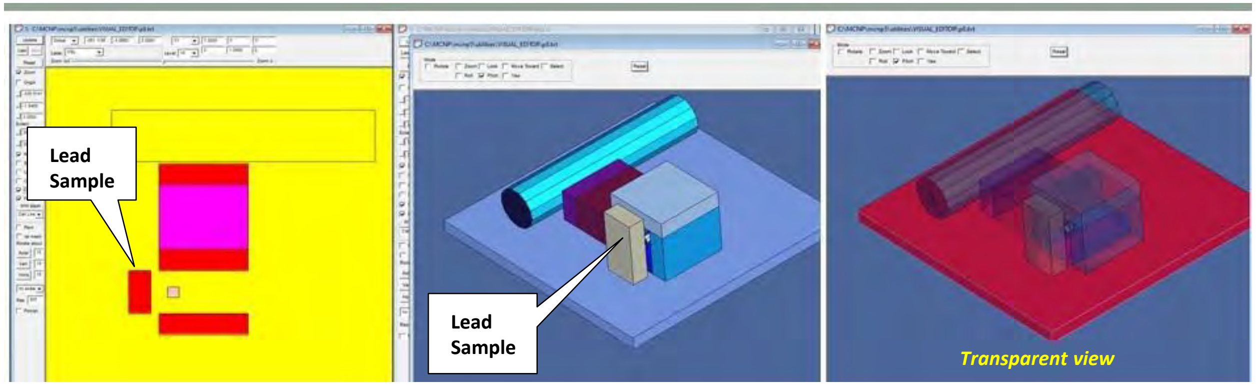


Model 1: DU
Neutron flux varies in time in the target

Results

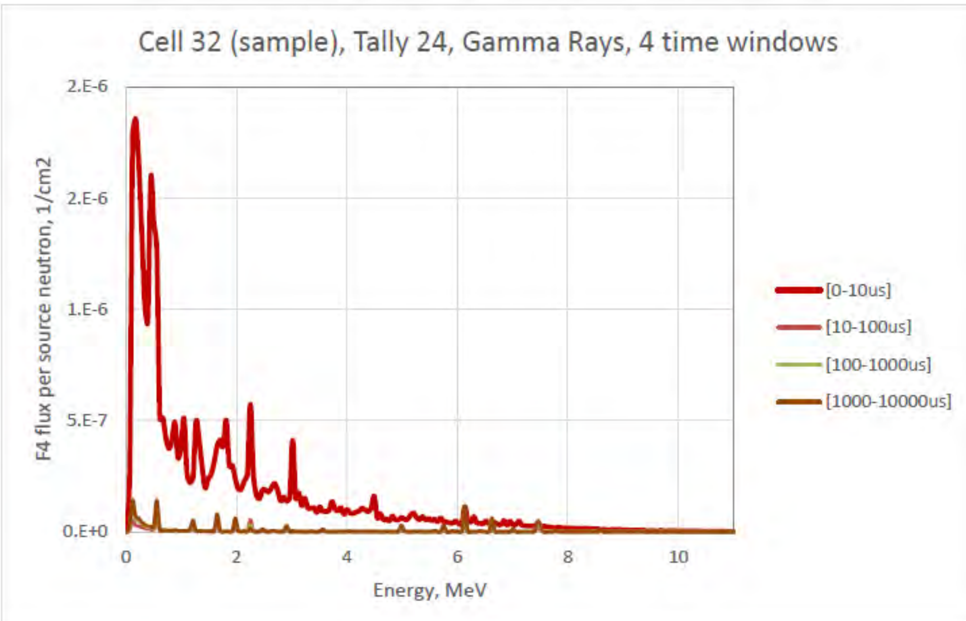


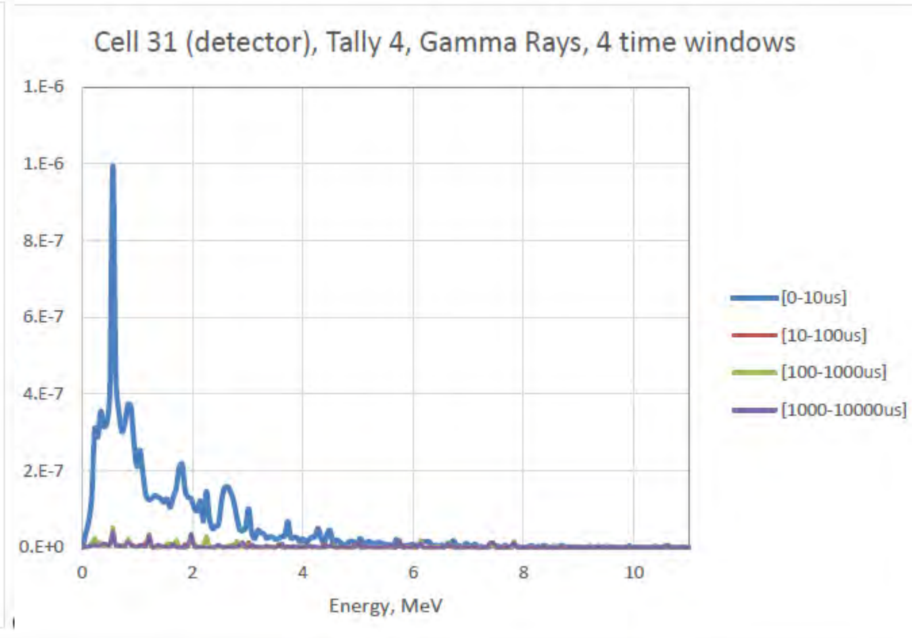
VizEd views of the updated MCNP model of the neutron assay setup in the MSTS source range, with a DU sample positioned near the multi-mode detector at 45 degrees.



Views of the updated MCNP model of the neutron assay setup in the MSTS source range, with a lead sample positioned near the multi-mode detector.

Results

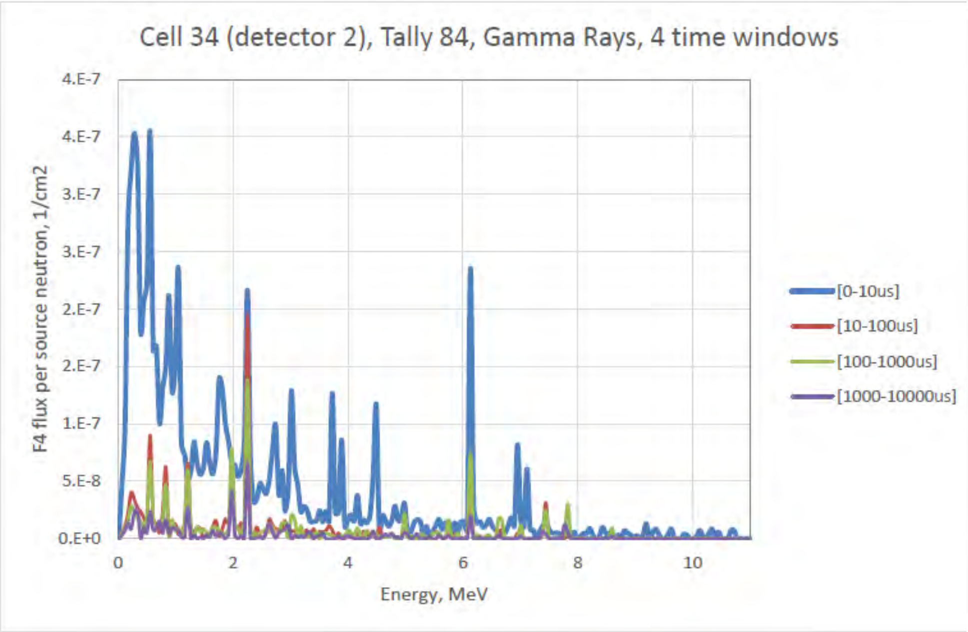


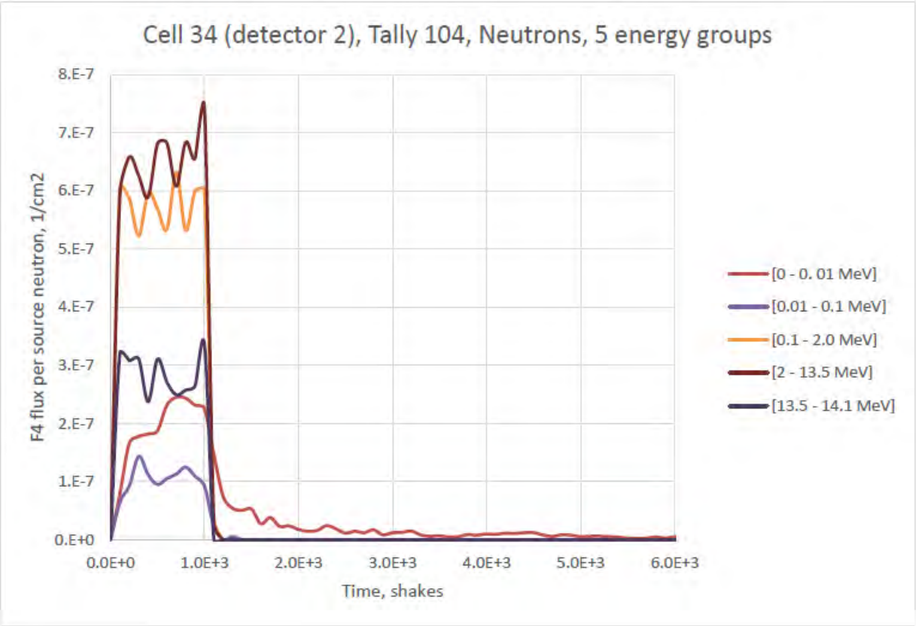


NaCl

Lead

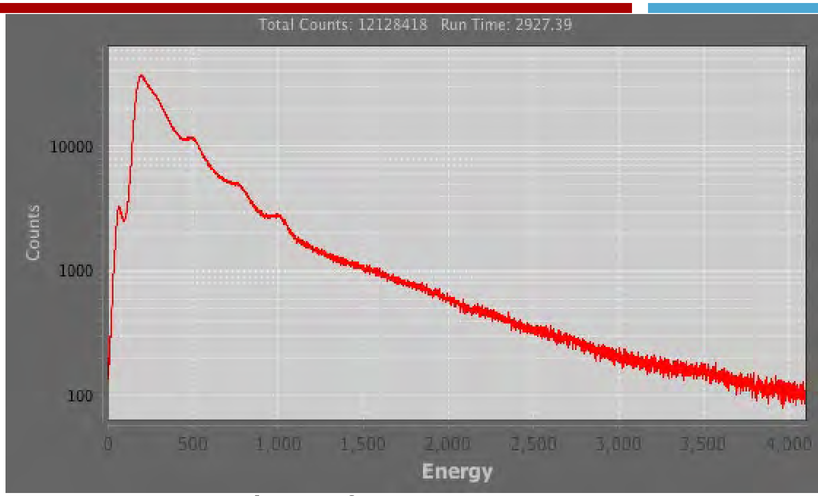
Results



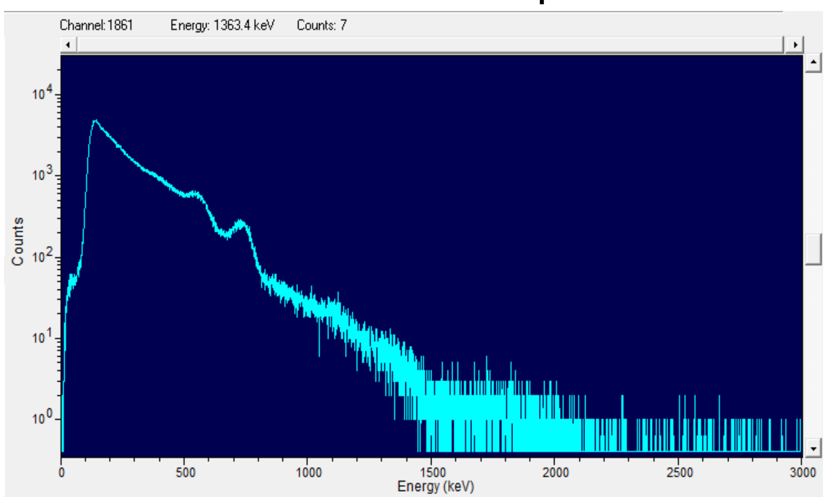


Water

Results



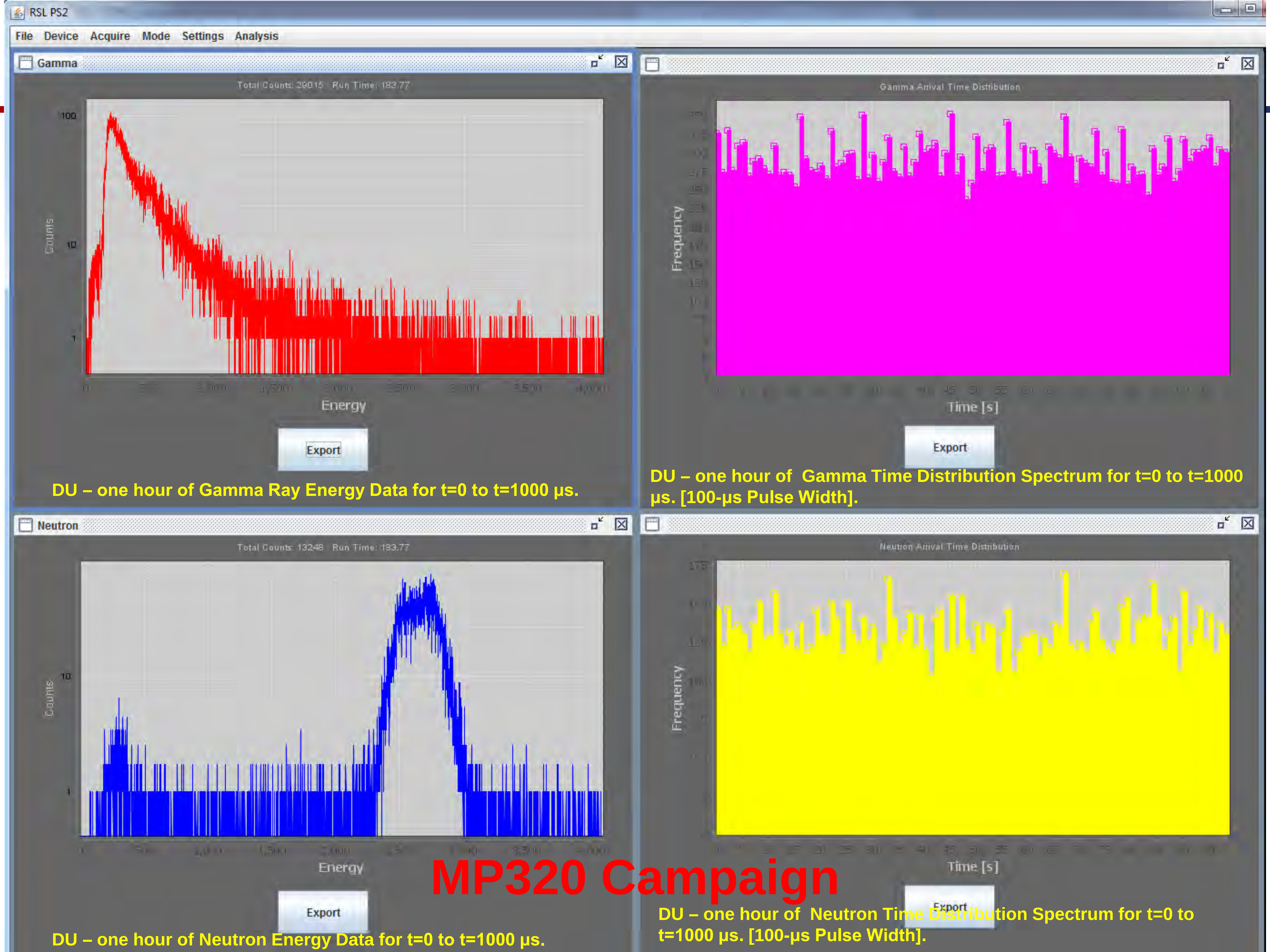
DU – one hour of Gamma Ray Energy Data for t=1000 to t=3300 μs



DU Background for 10 minutes

DU Plate – 9 kg, 172 mBq

MP320 Campaign Energy Spectra



MP320 Campaign

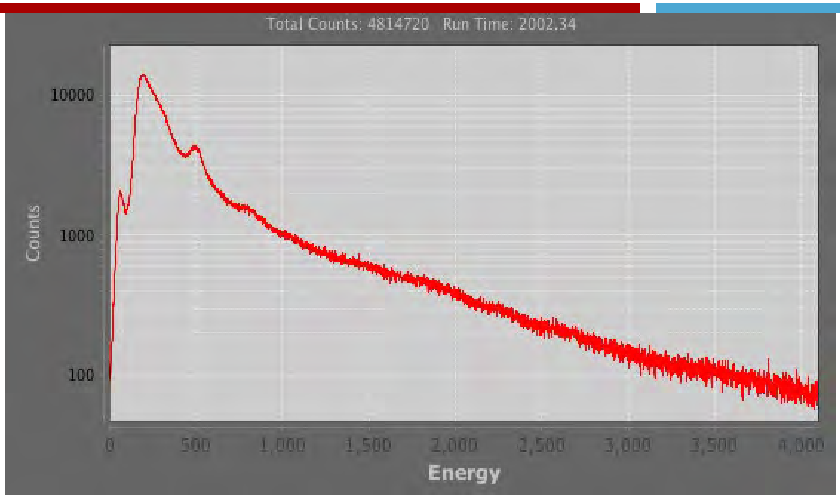
DU – one hour of Gamma Ray Energy Data for t=0 to t=1000 μs.

DU – one hour of Gamma Time Distribution Spectrum for t=0 to t=1000 μs. [100-μs Pulse Width].

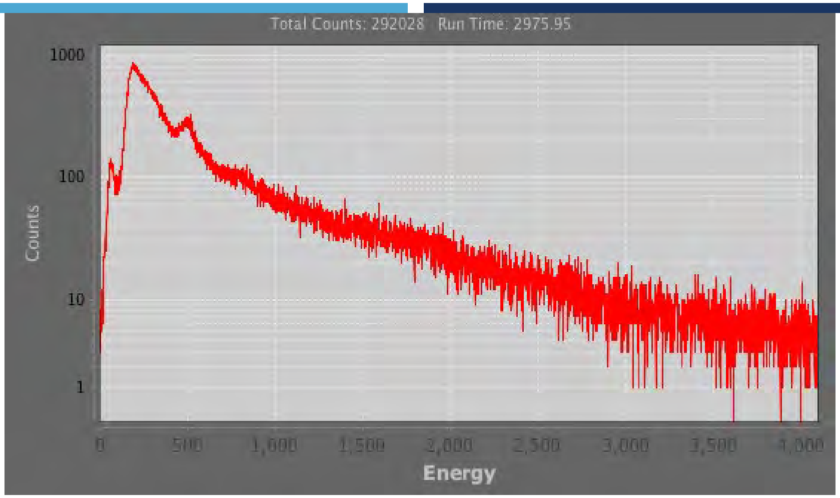
DU – one hour of Neutron Energy Data for t=0 to t=1000 μs.

DU – one hour of Neutron Time Distribution Spectrum for t=0 to t=1000 μs. [100-μs Pulse Width].

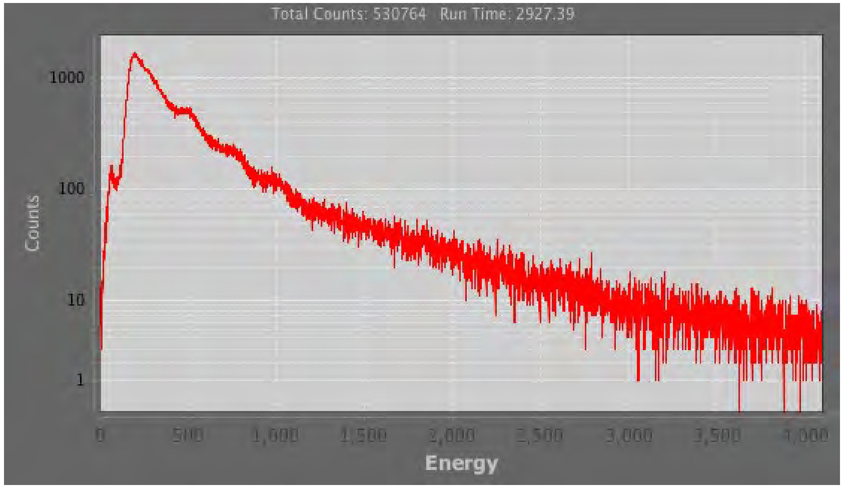
Results



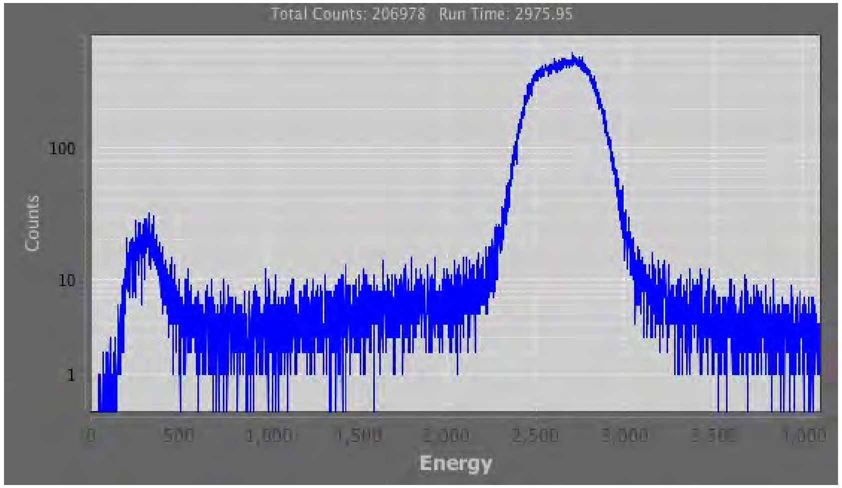
DU – one hour of Gamma Ray Energy Data for t=1000 to t=3300 μs



Gamma Ray Energy Data for no target for t=0 to t=100 μs [100-μs Pulse Width]



DU – one hour of Gamma Ray Energy Data for t=100 to t=200 μs



Neutron Energy Data for no target for t=0 to t=100 μs [100-μs Pulse Width]

MP320 Campaign Energy Spectra

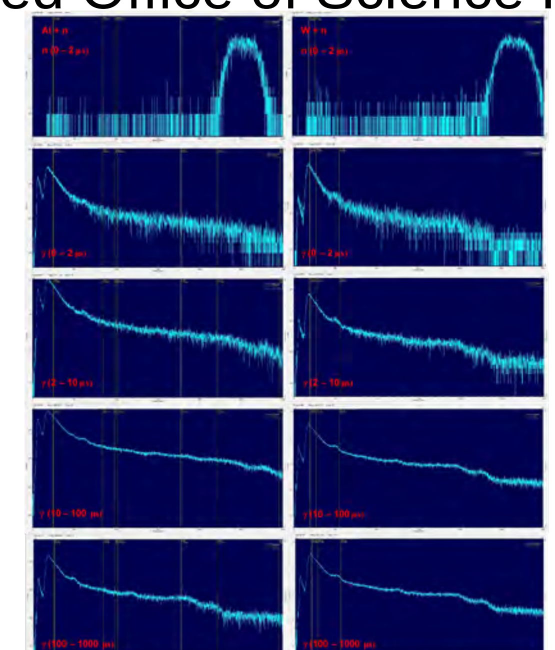
Summary of Results, Path Forward

- Successfully launched research study
  - UNLV, WKU subcontracts are in place
  - Neutron generator from WKU at A1 Building
  - Tested system with STL API-120
  - Tested system with Falcon Mobile DPF at RNCTEC
  - Tested system with MP320 at A1 Building
  - Performed Monte Carlo modeling for study
- Set up the Neutron Generator.
- Set up Neutron Generator authorization basis.
- Set up 4-detector system.

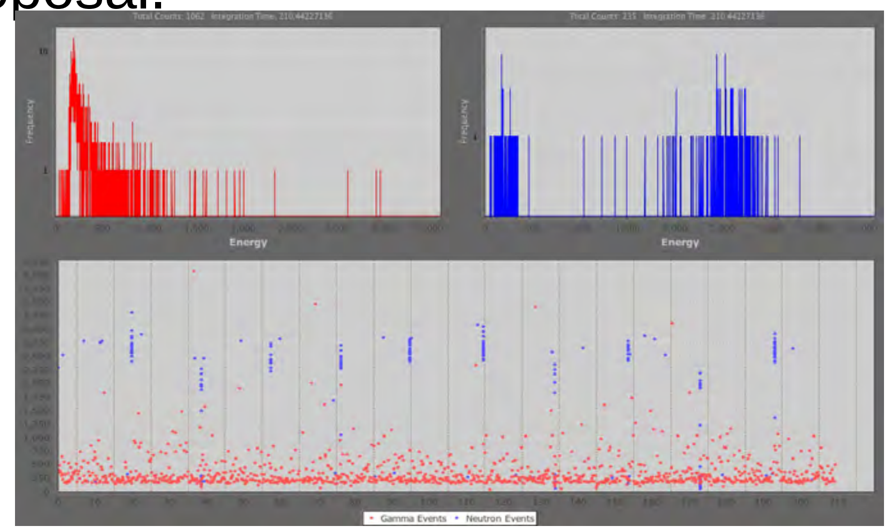
Impact

- Task Order with UNLV Department of Mechanical Engineering.
- Supported a UNLV Graduate Student.
- Established tie with Western Kentucky University.
- Mark Adan UNLV paper "Dual-mode Interrogation System with Irradiation Markers"
- Leveraged on NA-22 DFEAT Program.
- Submitted Office of Science Proposal.

API-120 Data



Energy spectra (0 – 3 MeV) for detected neutrons (top row) and gammas in time windows of 0-2 µs, 2-10 µs, 10-100 µs, and 100-1000 µs following the neutron start for Aluminum target (left) and Tungsten target (right).



Spectra for the neutron irradiation of DU. Top left: Gamma Energy Spectrum 0-4 MeV. Top right: Neutron Energy Spectrum 0-4 MeV. Bottom: Combined Neutron (blue) and Gamma (red) Waterfall Energy Spectra.

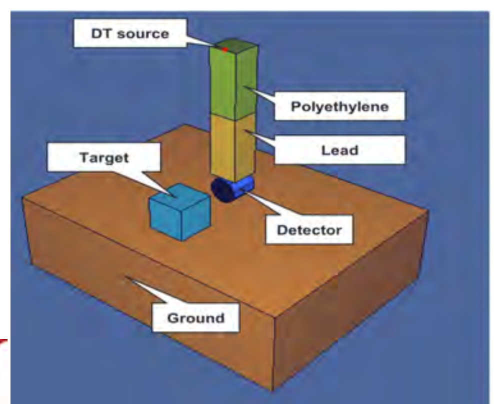
DPF Data

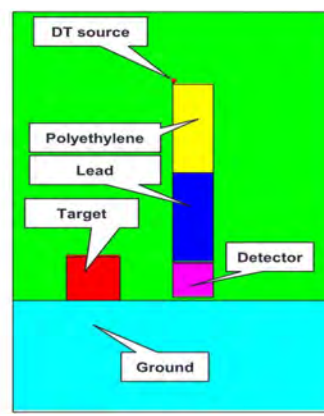
Impact

- The UNLV team assisted MSTS team in modeling of the multi-modal, multi-energy approach for neutron interrogation of spent fuel using the MCNP6 code. The Monte Carlo model of the neutron assay experiment was created. The UNLV team assisted and advised the MSTS. The SDRD project also funded the UNLV graduate students Monia Kazemeini and Jean Chagas-Vaz, whose degree research work is related to this SDRD project.
- Western Kentucky University has provided the Thermo Fisher Scientific MP-320 Neutron Generator, a computer-controlled DT neutron generator MP-320.

WKU provided the Thermo Fisher Scientific MP-320 Neutron Generator.

UNLV produced the software and MCNP input file for the geometry for the project active interrogation experiment.



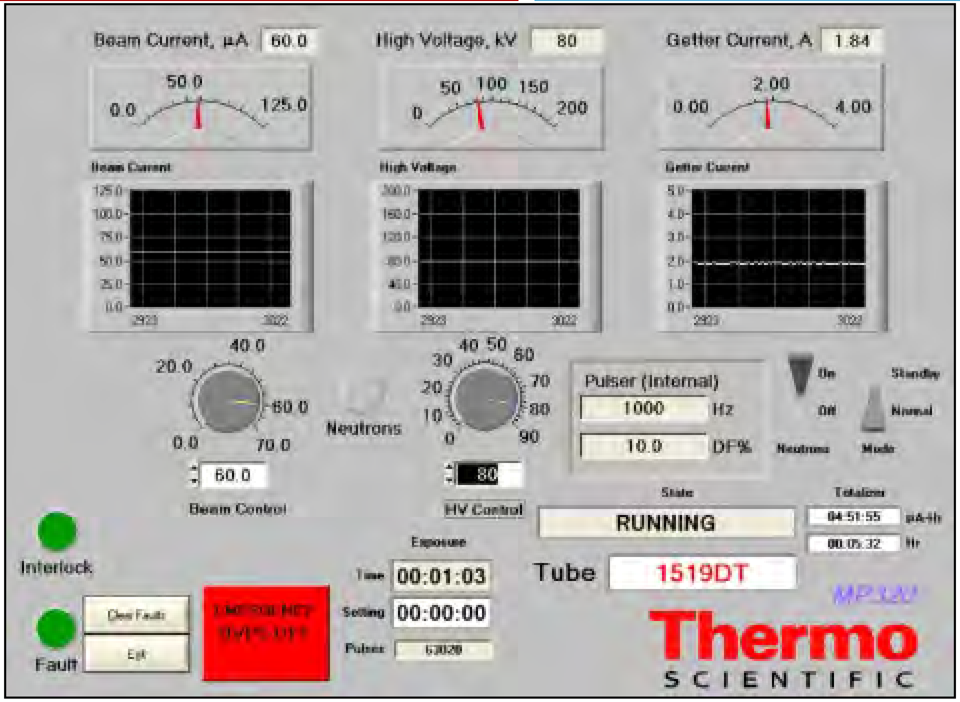


UNLV

WKU

Backup Slides

Technical Approach

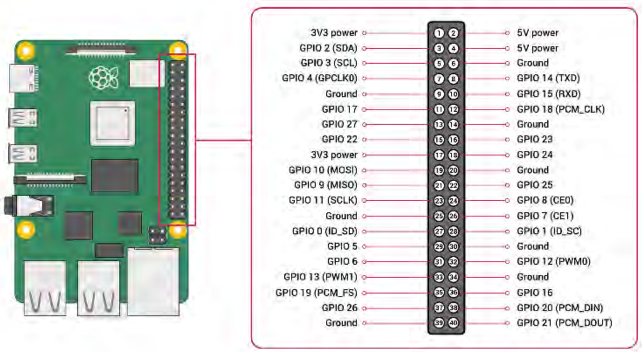


MP320 Neutron Generator - Operations

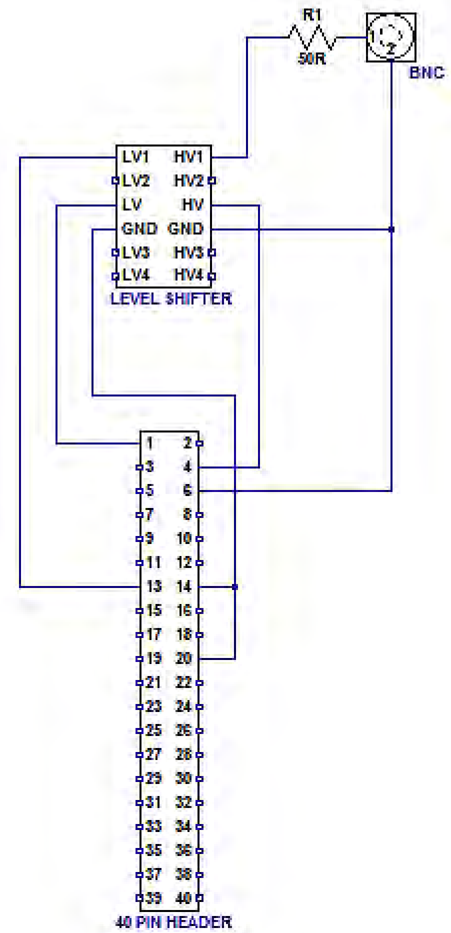
A Thermo Fisher Scientific Model MP320 Neutron Generator was used in the D+T mode to produce 14 MeV neutrons via the following nuclear fusion reaction:

$$^{2}D + ^{3}T \rightarrow ^{4}He\ (3.5\ MeV) + n^{0}\ (14.1\ MeV)$$

Technical Approach – MCA Acquisition



GPIO Header.
The wiring diagram for the GPIO header GPIO connectors on the Raspberry Pi for proper placement and termination



External Trigger Circuit

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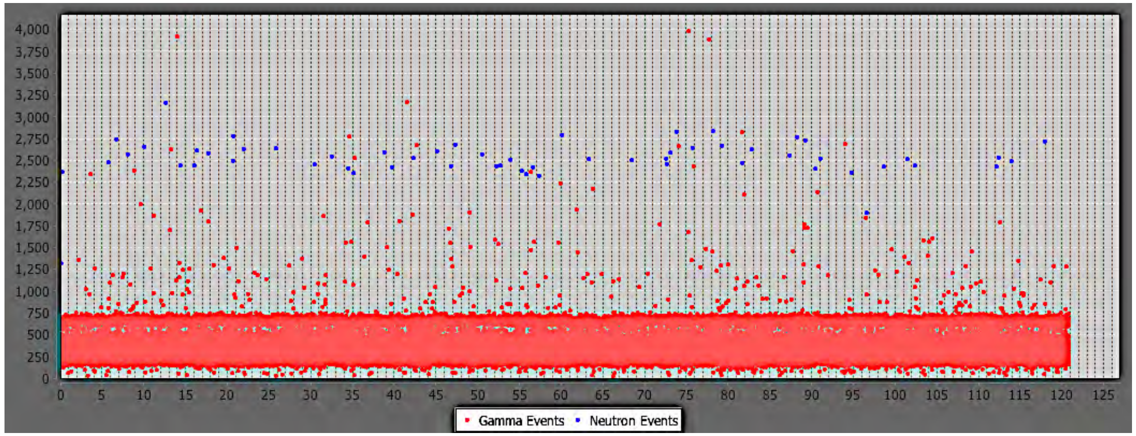
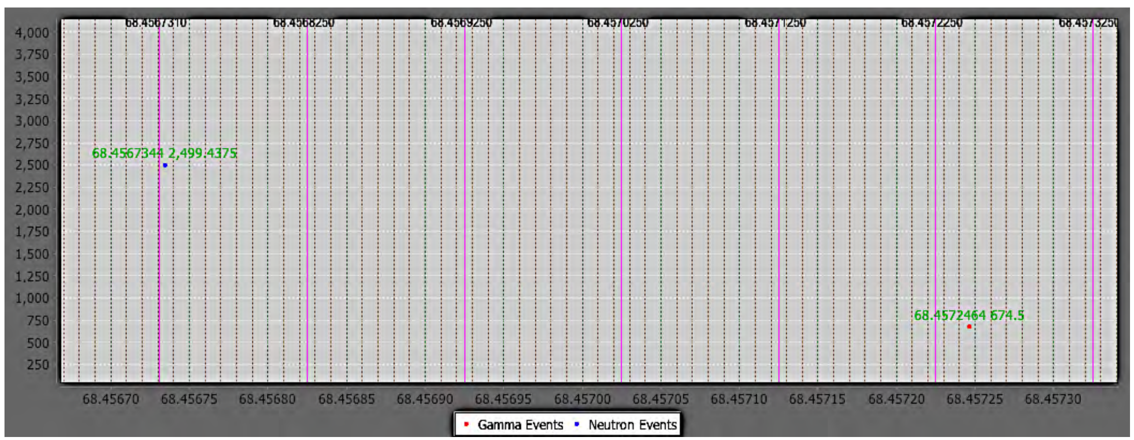
SDRD SITE-DIRECTED RESEARCH & DEVELOPMENT

Technical Approach – MCA Acquisition





List Mode Energy-Time plots with External 10 kHz Triggers

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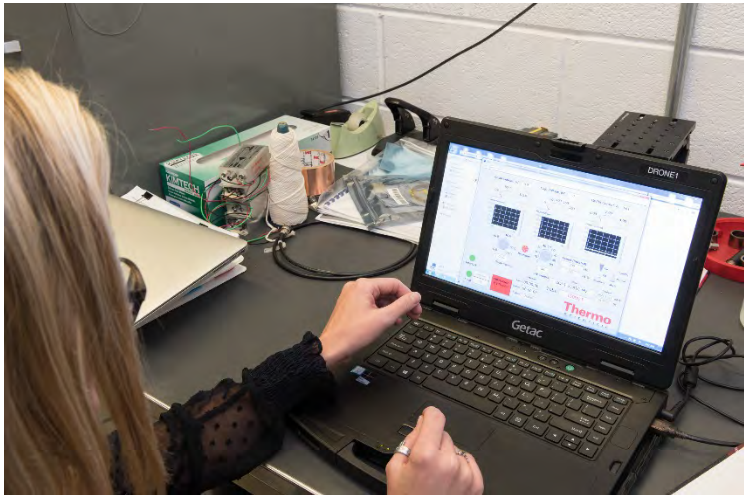
Technical Approach – MP320 Campaign

June 2020 Campaign

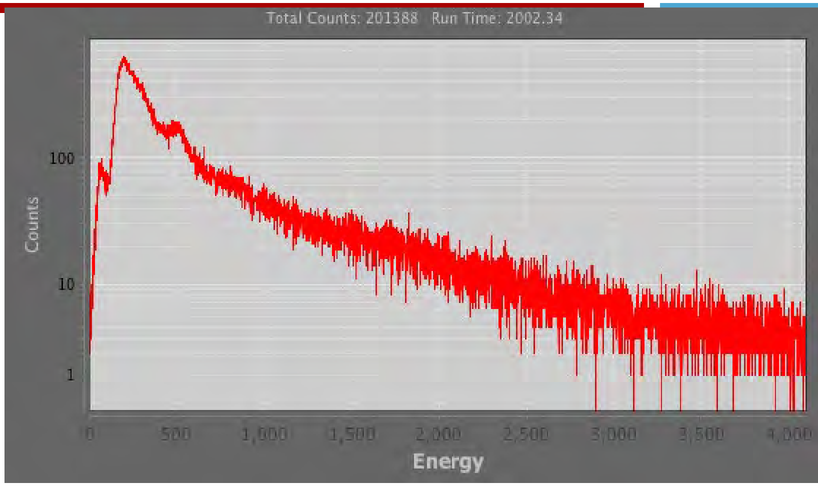
Technical Approach – MP320 Campaign



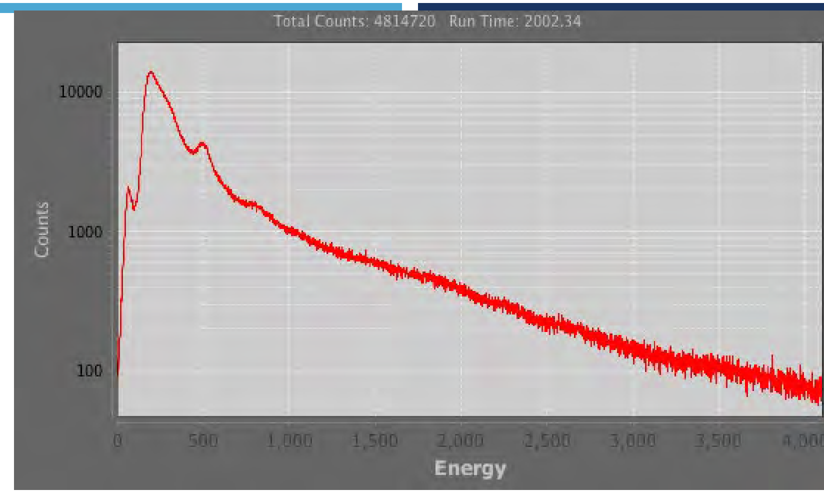
Left. Neutron Source control console.

Right. Setup for the neutron active interrogation of aluminum.

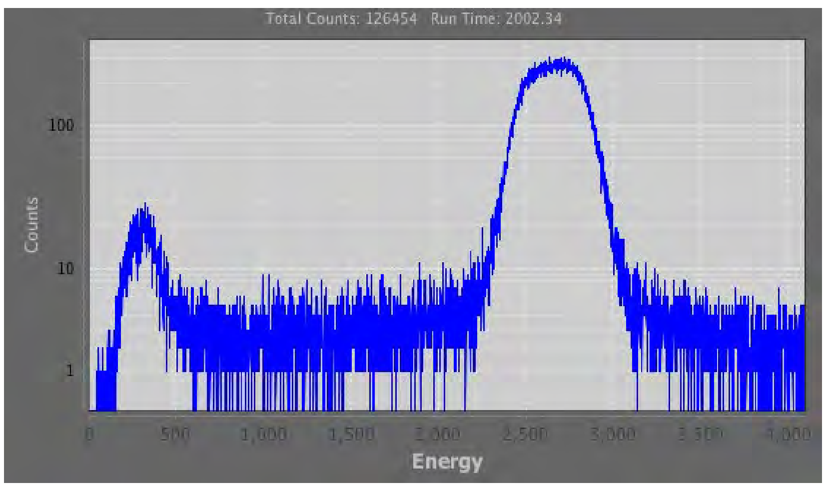
Results to Date



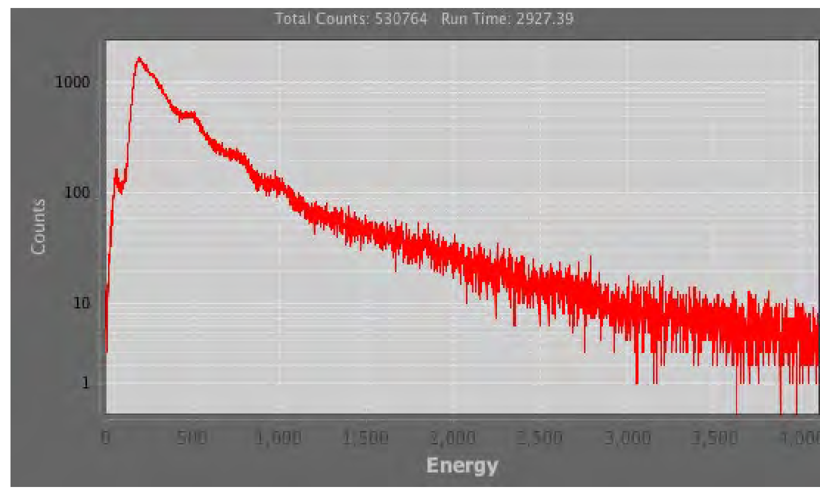
Al – one hour of Gamma Ray Energy Data for t=0 to t=100 μs [100-μs Pulse Width].



Al – one hour of Gamma Ray Energy Data for t=100 to t=3300 μs.



Al – one hour of Neutron Energy Data for t=0 to t=100 μs [100-μs Pulse Width].



DU – one hour of Gamma Ray Energy Data for t=100 to t=200 μs.

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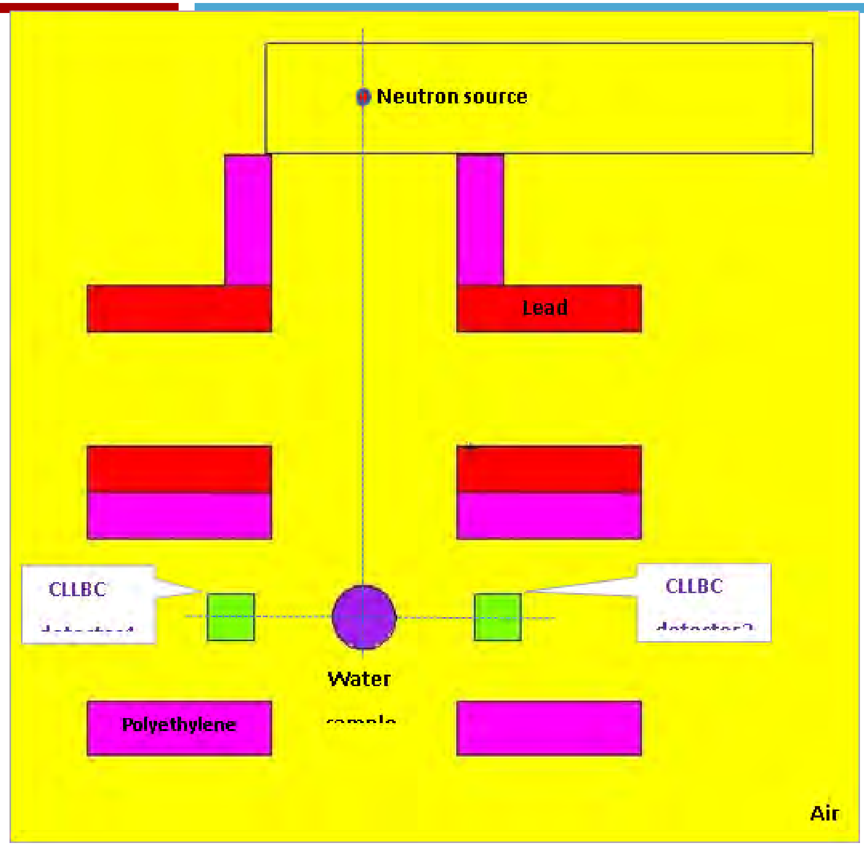
MP320 Campaign Energy Spectra

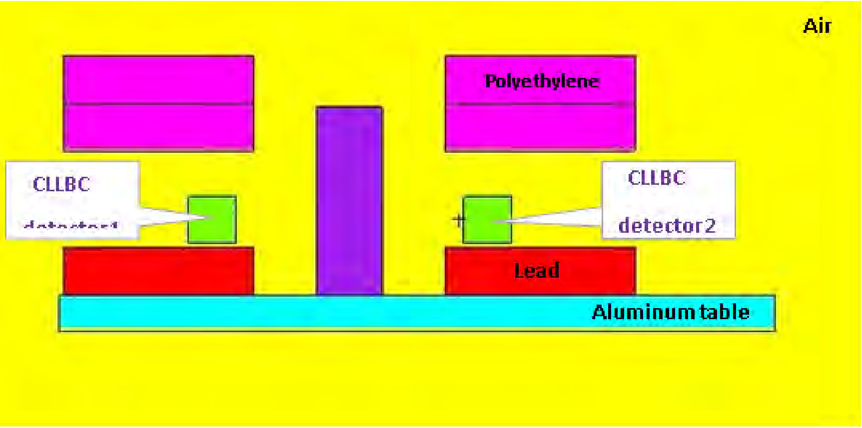
SDRD SITE-DIRECTED RESEARCH & DEVELOPMENT

Technical Approach

MCNPX Model

H_20





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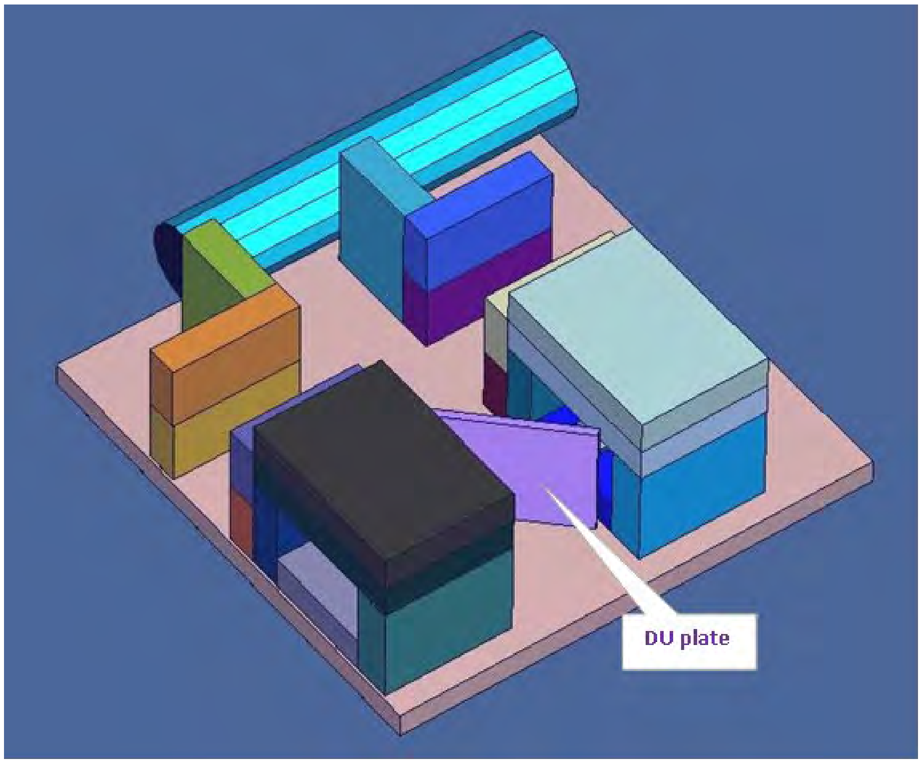
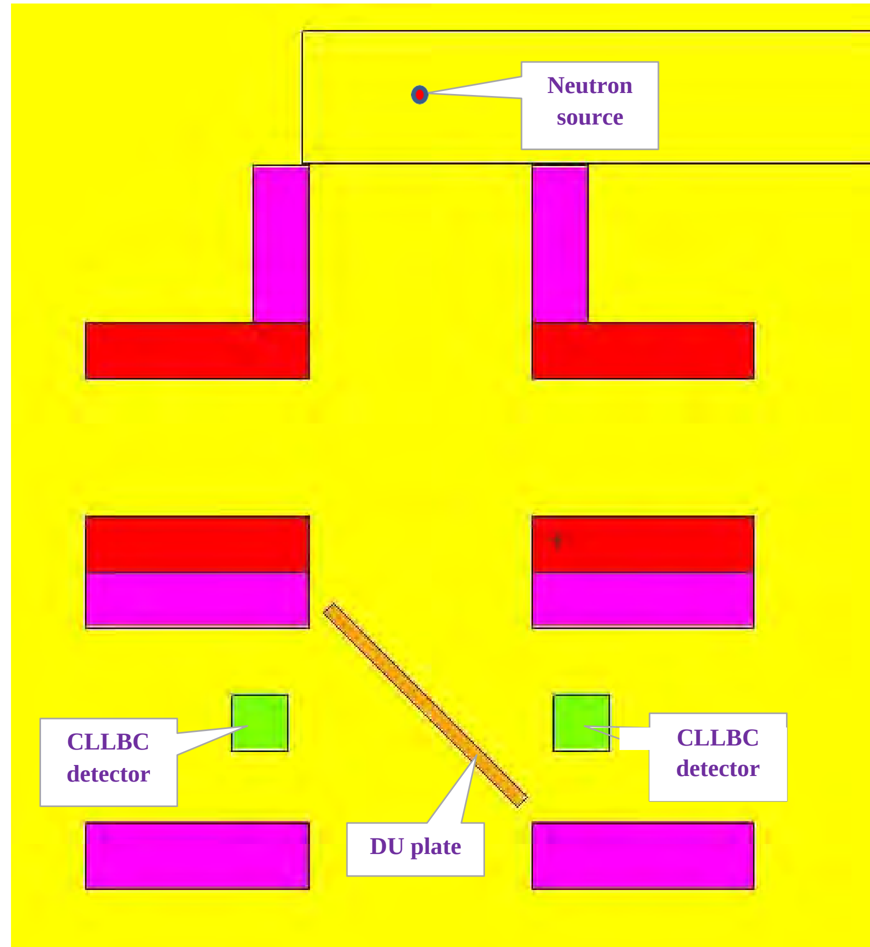
SDRD SITE-DIRECTED RESEARCH & DEVELOPMENT

Technical Approach

MCNPX Model

DU



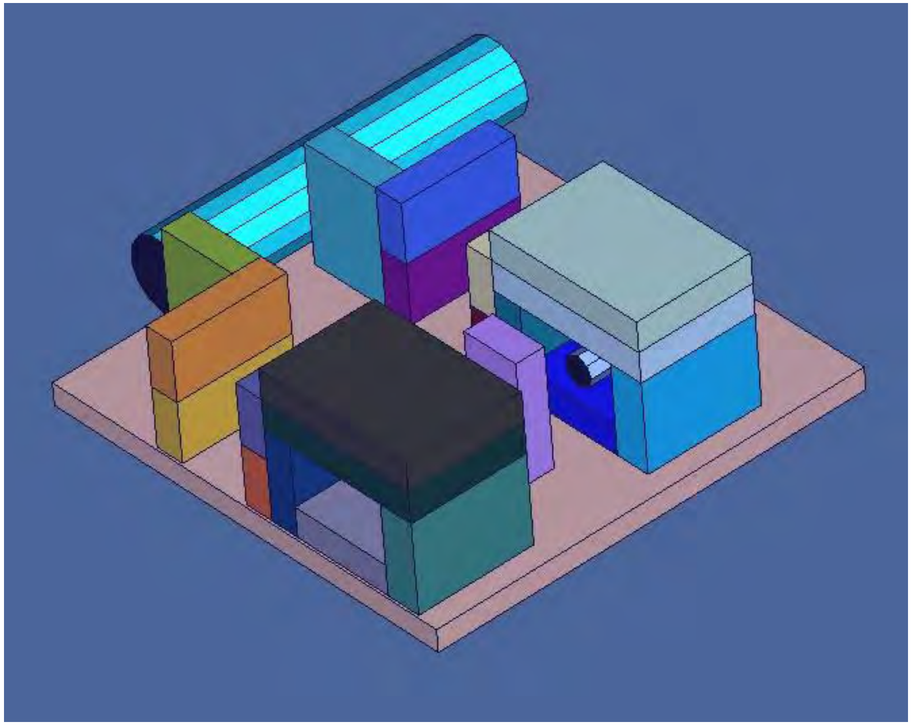


3D view of the model with the DU plate between two detectors;
2D view (XY) of a DU plate sample;

Technical Approach

MCNPX Model

Pb



Technical Accomplishments

- Mark Adan completed his experimental development on the 2-detector system. Mark Adan prepared a manual on his data acquisition system. The manual may serve as a core basis document for the publication.
- On April 28, at 10:30 AM, Mark Adan presented a seminar on his data acquisition system. Mark Adan prepared an equipment inventory for his engineering system supporting the project.
- On April 30, Ed Bravo retrieved all project equipment in custody of Mark Adan. On April 30, Ed Bravo met with Mark Adan to pick up experimental equipment on which he worked.
- On May 1, senior project engineer Mark Adan departed employment with MSTS.
- Exchanged drafts of SDRD FY21 Pre-Proposals with UNLV Professor Alex Barzilov. Completed and submitted the FY21 SDRD Pre-Proposal for year 3.
- Paul Guss presented the May 19 Science & Technology seminar.

Technical Accomplishments

- Conducted the June 3-11 A1 Source Range Campaign.
- Paul Guss commissioned Daniel Lowe and Irene Garza to find the Pu puck source in the NNSS MC&A program.
- Leslie Esquibel conducted a Financial Review of the Project with Paul Guss on May 13.
- Responded to the SDRD Project Office on the May 13 – Midyear Review on Project Financials.
- Acquired new computer for the project work with IT assistance.
- Prepared a new operator's manual covering the experimental development on the 2-detector system.
- Reviewed the new operator's manual covering the experimental development on the 2-detector system.
- FY21 SDRD Proposal for year 3 was approved.

Future Direction

- ▶ Set up the timing models.
- ▶ Set up the Neutron Generator for next campaign.
- ▶ Assess data acquired in the 4 campaigns.
- ▶ Advance the acquisition system set up for multiple detectors to perform time correlated event detections.