Monte Carlo Simulations for Time-of-Flight Epithermal Neutron Activation Analysis for Isotopic Signatures

MTV Workshop, 2021

March 31, 2021

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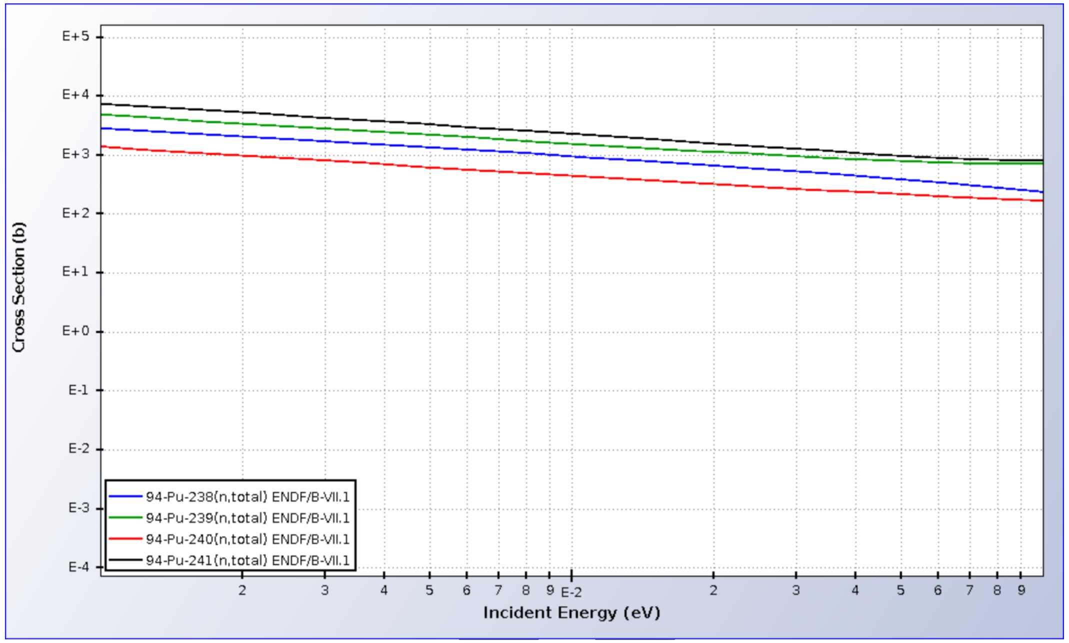
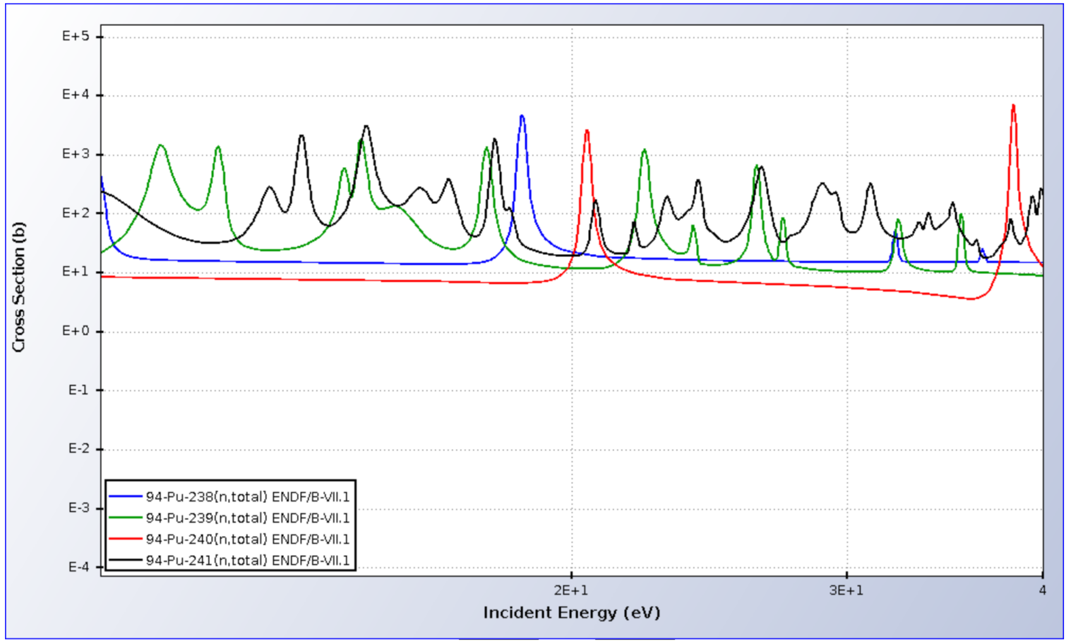
Introduction and Motivation

- There is a need for a fast, non-destructive technique to monitor nuclear material throughout the fuel cycle.

- Epithermal neutrons can allow for more information to be extracted compared to thermal activation analysis.





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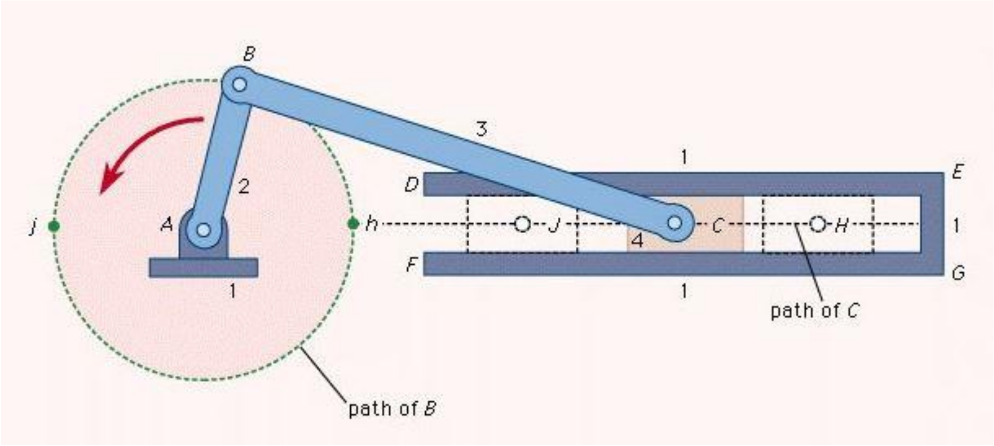
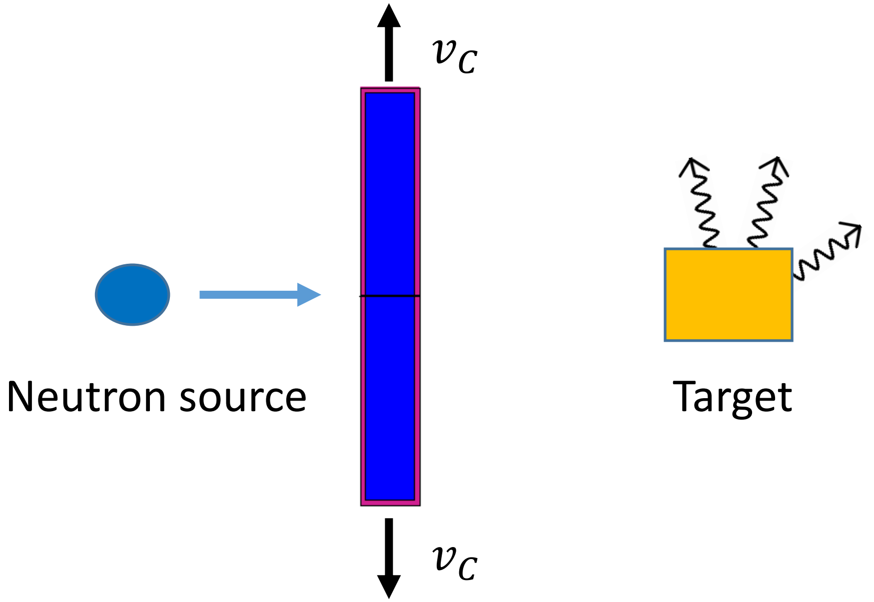
Mission Relevance

- There is a need for new tools and techniques to monitor nuclear material at various stages of the fuel cycle: mining and milling of uranium, conversion and fabrication of fresh fuel, enrichment, and plutonium separation from irradiated fuel at reprocessing facilities.
- This research is relevant to the NNSA mission by complementing the current state of the art in the area of Signals and Source Terms for Nuclear Nonproliferation.

Technical Approach

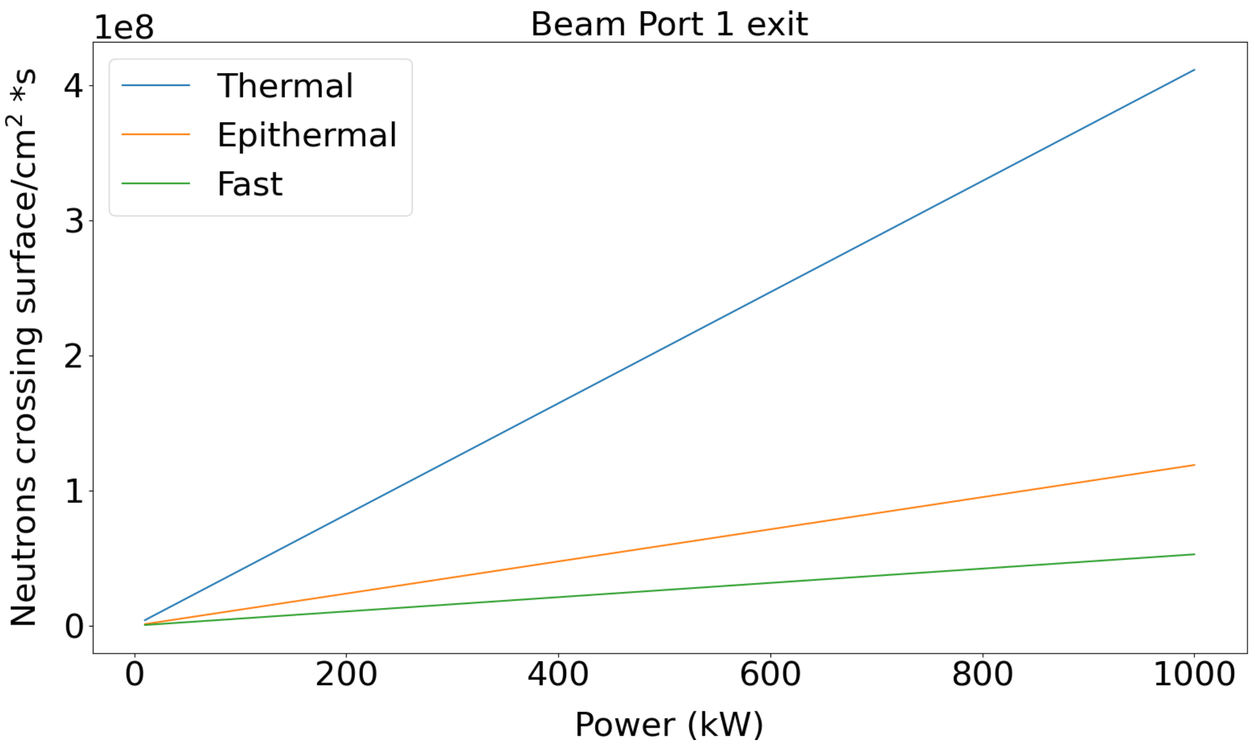
- We are developing a prompt and delayed-gamma neutron activation analysis system based on thermal and epithermal neutrons.
- This will provide the capability to perform ENAA to complement TOF measurements to assess elemental and isotopic signatures of specific nuclear-fuel manufacturing processes.
- To do this, we are developing a novel piston-based mechanical neutron chopper to create a source of nearly monochromatic epithermal neutrons.
- Monte Carlo simulations are being used to characterize the source of neutrons and quantify the mechanical chopper’s utility for ENAA.
- We are building simulation tools to optimize the chopper design and experimental parameters, as well as inform sample selection.





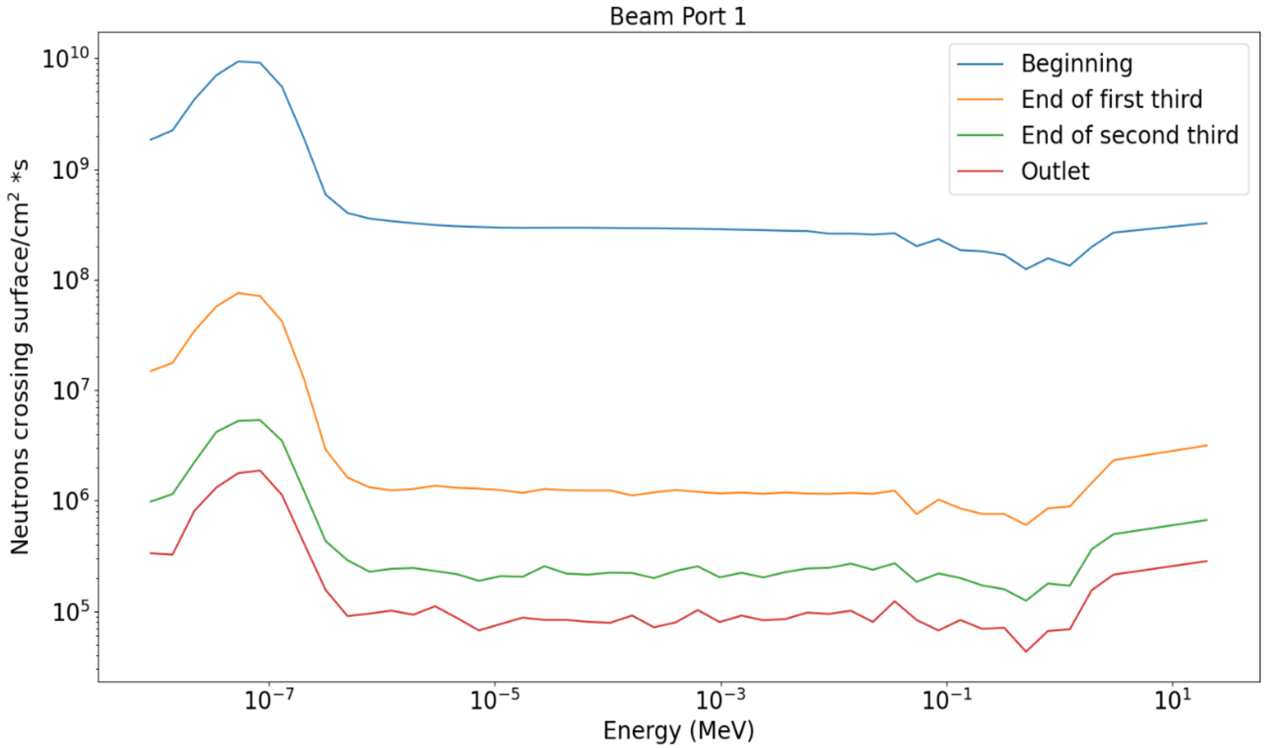
Beamport Characterization

- The Penn State Breazeale Reactor (PSBR) has recently undergone renovations which included new beamports and a D20 tank.
- Monte Carlo simulations have been used to characterize beamport 1 to define the neutron source.
    - Informs the design of the neutron chopper, filter and experimental parameters.



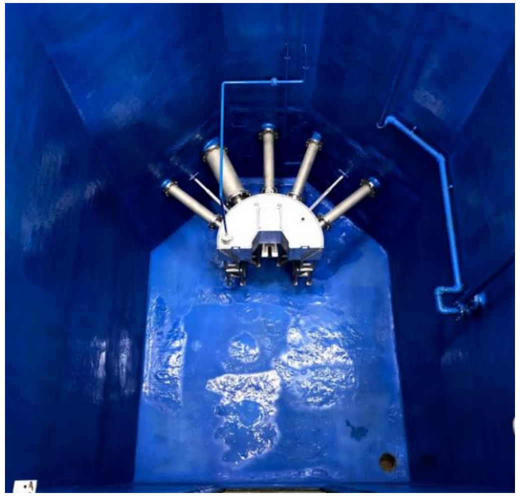
Beamport Characterization

- Simulations efforts have been used to optimize neutron activation analysis experimental parameters.
- Argon-41 production in the beamport has been estimated.
  - $7.5 \frac{\text{nCi}}{\text{mL}}$ after 18.8 minutes at 20 kW
- The production of Argon-41, along with activity predictions and dose estimates have been optimized for safety and efficiency in experiments.



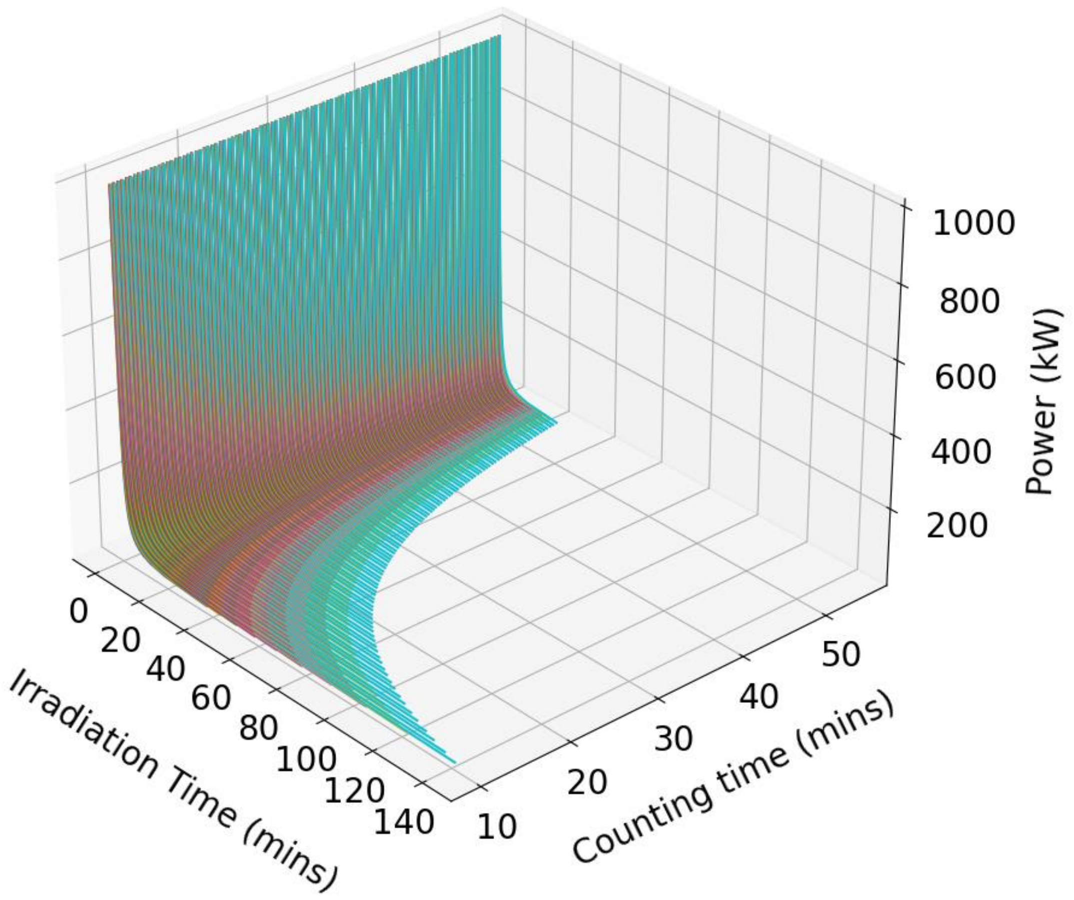
Beamport Characterization

- These simulations will be experimentally validated through a set of foil activation experiments and neutron spectrum unfolding software (STAYSL).
- Foils/wires sensitive to fast neutrons:
  - In
  - Fe
  - Ti
  - Ni
  - Mg
  - Au-Al
- Foils/wires sensitive to thermal neutrons:
  - In
  - Fe
  - Cu
  - Au
  - Co
  - Sn



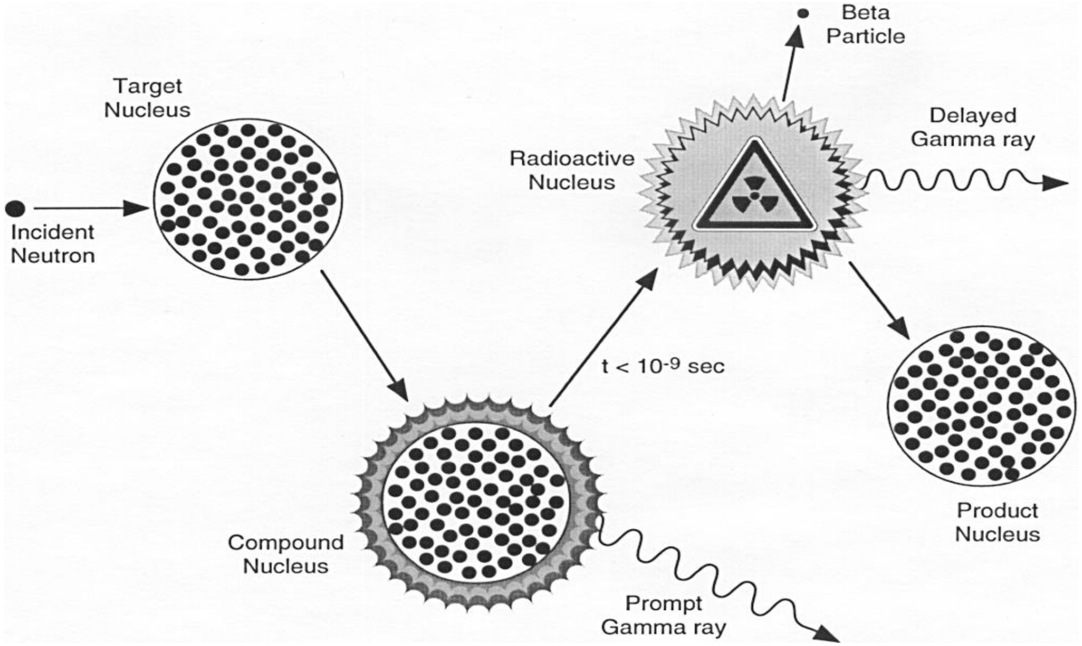
Optimization Tool for Experimental Parameters

- The results of the Monte Carlo simulations have been used to optimize activation experiments.
- The following parameters are considered:
  - Allowable power level of reactor for unplugged beamport configuration
  - Three group flux and associated cross sections
  - Gamma and beta dose from target
  - Decay during irradiation, cooling and counting times
  - Detection efficiency and counting statistics
  - Argon-41 production
- Using this information in conjunction with chopper metrics; dose, irradiation time, and power can be minimized .



Expected Impact

- Prompt and delayed gamma activation analysis will complement neutron TOF measurements.
- TOF measurements can be made to spatially resolve and identify isotopes in bulk samples, but may not quantify or identify trace isotopes.
- NAA is an analytical technique with very high sensitivities – detection limits of ppm-ppb.
- A chopper system that can effectively monochromatize neutron pulses will allow for preferential activation of isotopes while mitigating undesired activation from thermal or off-resonant energy neutrons.
    - Will enhance signal to noise ratio of measured photons of interest.



MTV Impact

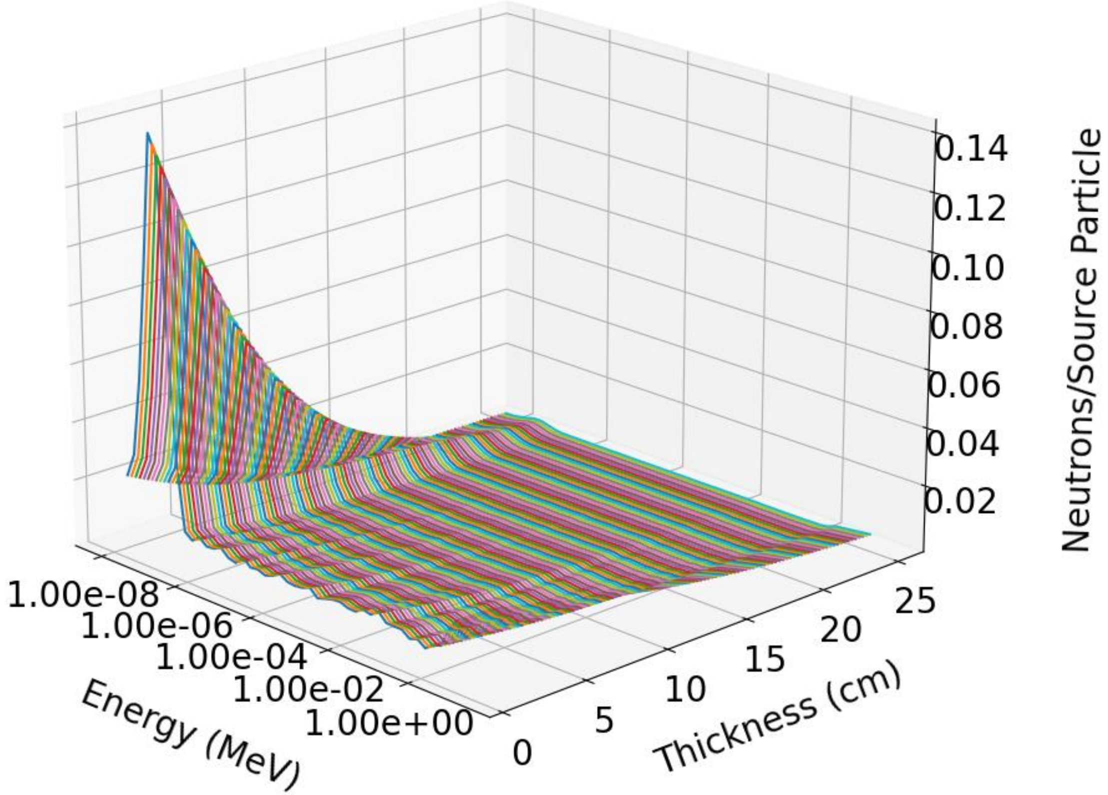
- The MTV has allowed for useful networking with experts in TOF measurements, mechanical velocity selection, and the nuclear fuel cycle.
- There is an interest from a national lab regarding the novel piston-based mechanical neutron chopper for designated use at a TRIGA reactor.
- The mechanical neutron chopper is interdisciplinary by nature and its design is being aided by Daniel Cortes, Assistant Professor of Mechanical Engineering at Penn State.

Ongoing Work– Filter Design and Optimization

- Monte Carlo simulations are being used to optimize a neutron filter that will be retrofitted at the end of beamport 1.
- These simulations are being automated to maximize a defined Figure of Merit (FOM).

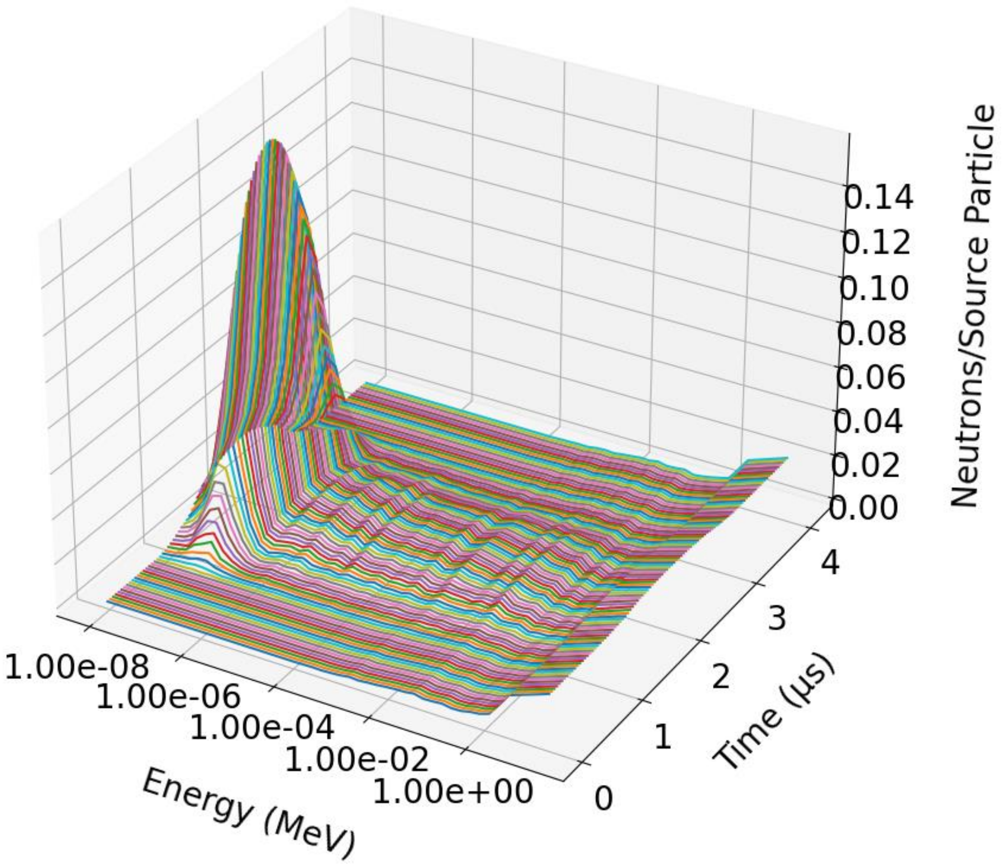
$$FOM = \frac{neutrons\ between\ 0.1 - 40\ eV}{neutrons > 40\ eV}$$

- Automation process involves testing permutations of materials and thicknesses to maximize the intensity of neutrons in the desired energy range.
- It is assumed that neutrons below 40 eV are effectively removed by the absorbing material contained in the chopper.



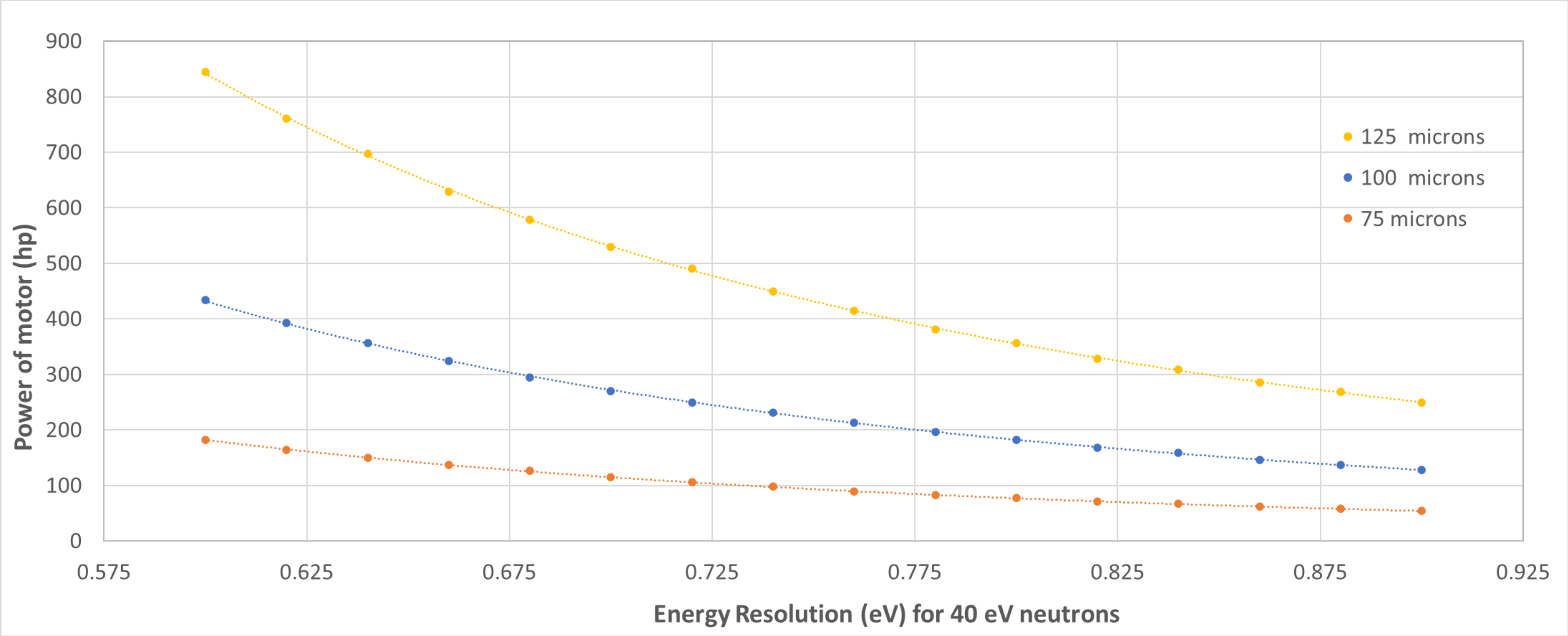
Ongoing Work– Time-Dependent Detector Response

- A Monte Carlo based tool is being developed to model time-dependent detector response from cyclic NAA.
- This simulation tool utilizes the simulated unfiltered neutron spectrum from the outlet of beamport 1 as a source for the chopper.
- Kinematics of the chopper are used to discretize time steps for neutron intensity and corresponding detector response for a full cycle of the chopper.
- Prompt and delayed are being modeled to assess the utility of different targets.



Ongoing Work– Iteration of Mechanical Parameters

- The stress state of various components of the chopper system is dynamic.
- Analytical approximations of the forces have allowed for estimated stress states, but a more detailed Finite Element Analysis (FEA) model is necessary before the chopper is constructed.
- Bearings, lubrication, connections and the motor need to be evaluated for reliability and operational lifetime.
- A detailed CAD model of this system will be drafted and parametrized for subsequent iterations.



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Conclusions

- We are developing Monte Carlo simulation based tools to analyze the quantitative performance of a piston-based mechanical neutron chopper for cyclic activation analysis.
- These simulation tools will be able to quantify detector response to undesirable, higher-energy neutrons transmitted while the chopper is in the closed position.
- These measurements will be used to complement TOF measurements such as transmission resonance analysis.
- This will allow for a fast, non-destructive, highly sensitive technique to analyze nuclear samples of interest.
- This work impacts the NNSA mission by serving as a verification technique for nuclear material related activities.

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