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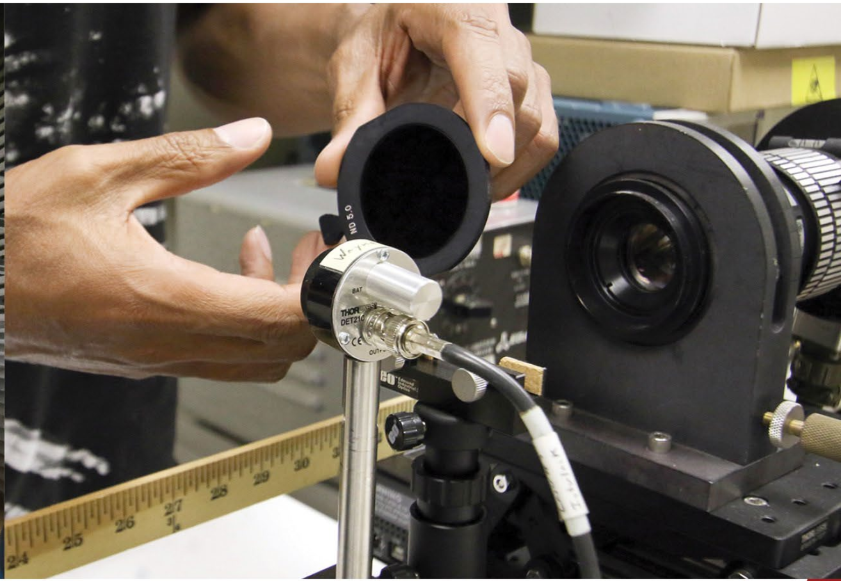
Photoneutron Production Using an Electron Linear Accelerator for Applications in Neutron Imaging

Kevin Yim

Ph.D. Dissertation Proposal

Department of Mechanical Engineering

University of Nevada Las Vegas

Nevada National Security Sites is managed and operated by MSTS under contract number DE-NA0003624.

This work was done by Mission Support and Test Services, LLC, under Contract No. DE-NA0003624 with the U.S. Department of Energy, the National Nuclear Security Administration's Office of Defense Programs, and supported by the Site-Directed Research and Development Program. DOE/NV/03624--2008.

Agenda

Introduction

- Photoneutron Physics
- Neutron Imaging and Radiography
- Research Questions and Objectives

Objective 1

Objective 2

Objective 3

Proposed Timeline

Introduction

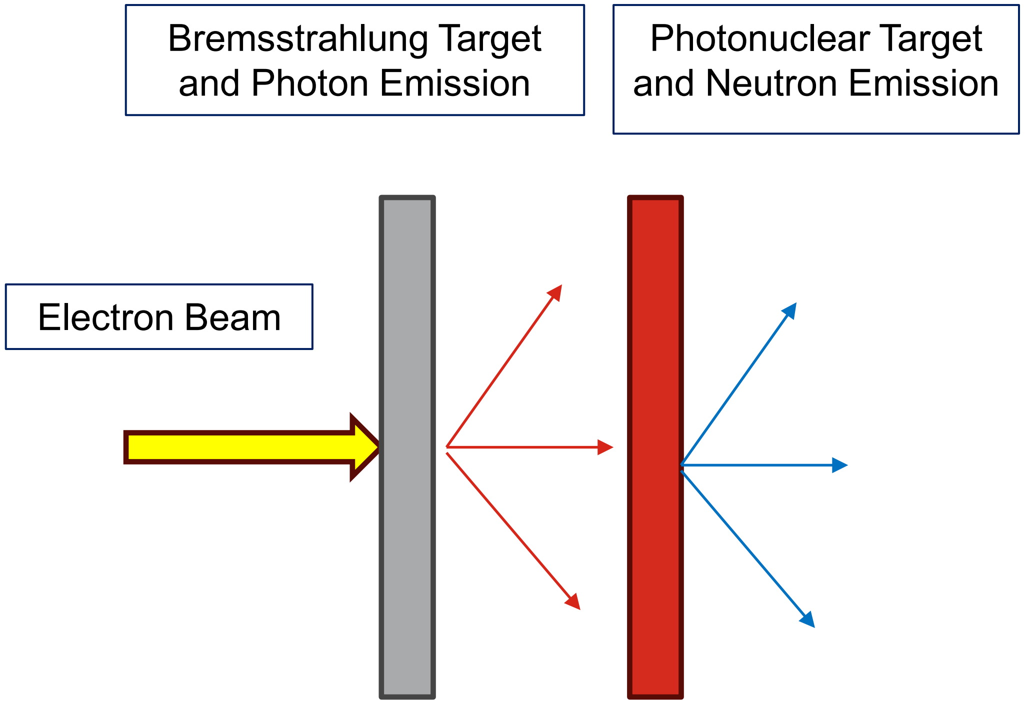
Photoneutron production is not a unique concept, but intentional photoneutron production for applications have yet to be explored with the anticipated NNSS Scorpius electron linear accelerator[1,2,3,4,5,6]

Photoneutrons can be produced using an electron linear accelerator quipped with a Bremsstrahlung target and a photoneutron converter[2]

Short pulse neutron sources can be used for neutron imaging applications of fast events such as dynamic experiments[7,8,9,10]

Introduction - Photoneutron Physics

- Mechanism of photoneutron production
  - Loss of energy by the electrons hitting a Bremsstrahlung target
    - Photons are generated
  - Photons interact with target nuclei causing instability resulting in neutron emission



Introduction – Neutron Imaging

- Neutron imaging, like x-ray imaging, is a radiographic testing method using neutrons[11]
- Neutron imaging is a non-destructive experimental method that enables viewing the inner structure of object of interest[12]
- Neutrons have high-penetration depth in metal and rock materials with high-sensitivity to elements such as hydrogen and lithium[12]

Radiograph of a camera – neutrons (top) and x-rays (bottom)[11]

Introduction – Research Questions

Can the neutrons produced from photonuclear reaction using a 20 MeV electron linear accelerator (Linac) be used to produce bimodal neutron and x-ray imaging?

Objectives:

1. Create computational model using MCNP6 code to analyze photoneutron production and predict neutron yield for experimental proof of concept.
2. Conduct measurements of neutrons at the Idaho State University's Accelerator Center (IAC) using current mode neutron time-of-flight (nTOF) detectors. Compare the computational data with the experimental data.
3. Carry out proof of concept computational modeling using MCNP6 code of an object imaged by the neutrons produced by the photoneutron target.

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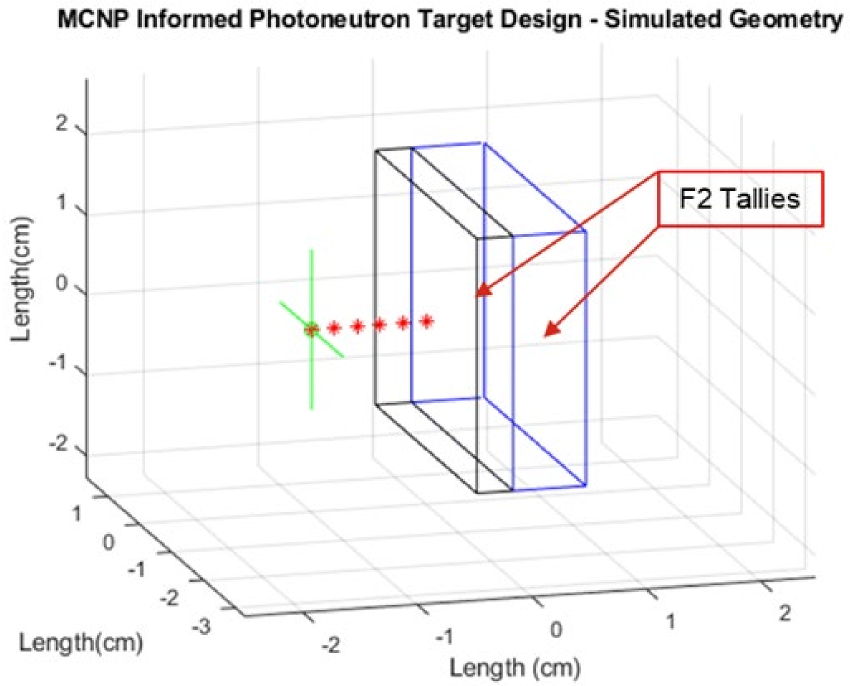
Objective 1

- Computational models in this study use a Monte Carlo code MCNP6
  - The code was developed by Los Alamos National Laboratory (LANL)[16]
  - Used to track particles through a system based on a series of inputs including material properties, cross-section libraries, source properties[18]
  - F2 tallies are the primary tallies for these simulations[17]:

$$\mathrm{F2} = \frac{1}{\mathrm{A}} \int_A dA \int_E dE \int_{4\pi} d\Omega\, \phi(r_s, E, \Omega)$$

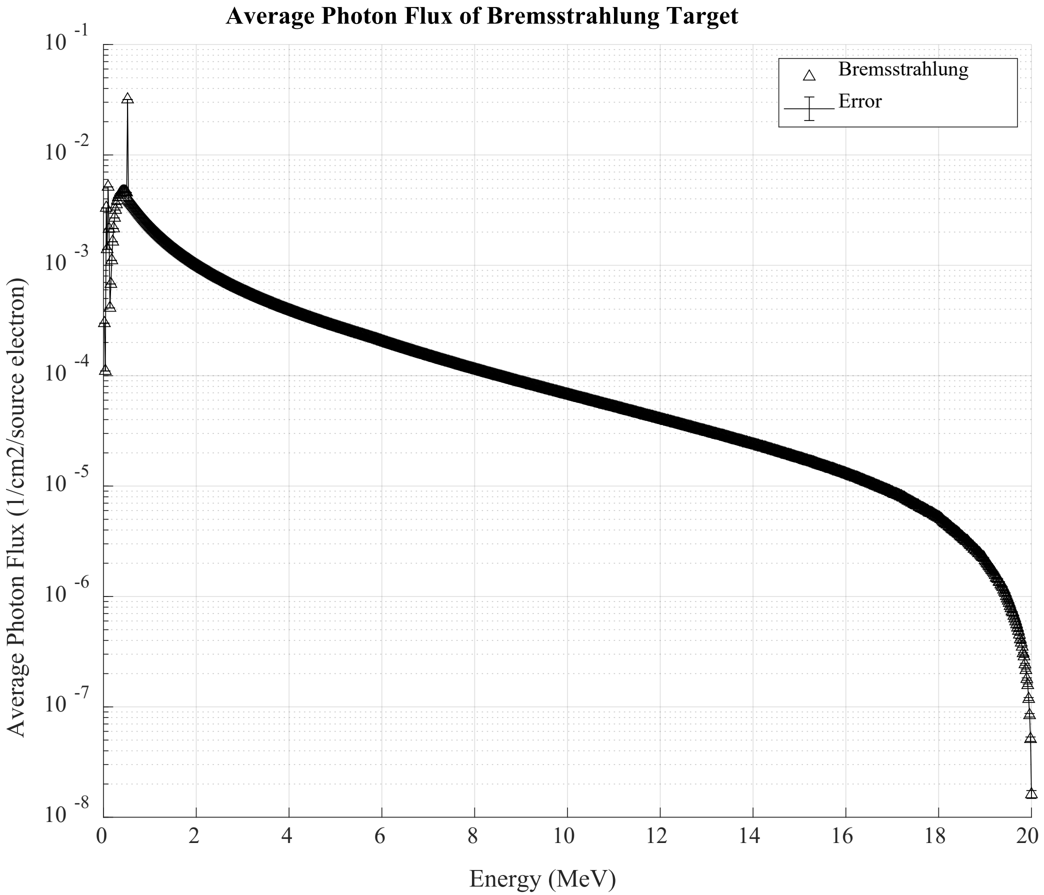
Objective 1 – Proof of Concept Model Setup

- Cells
  - Bremsstrahlung Target
    - 5/8 in x 5/8 in x 1/4 in
    - Tungsten
  - Photoneutron Target
    - 5/8 in x 5/8 in x (1/4-1 in)
    - Tungsten and Depleted Uranium (DU)
- Tallies
  - F2 tally on target surfaces facing away from the source
  - Units: particles/cm^2/source electron
- 20 MeV electron point source that moves along y-axis
- Mode (N P E) – the model tracks neutrons, photons, and electrons
  - Photonuclear physics is turned on for this computation



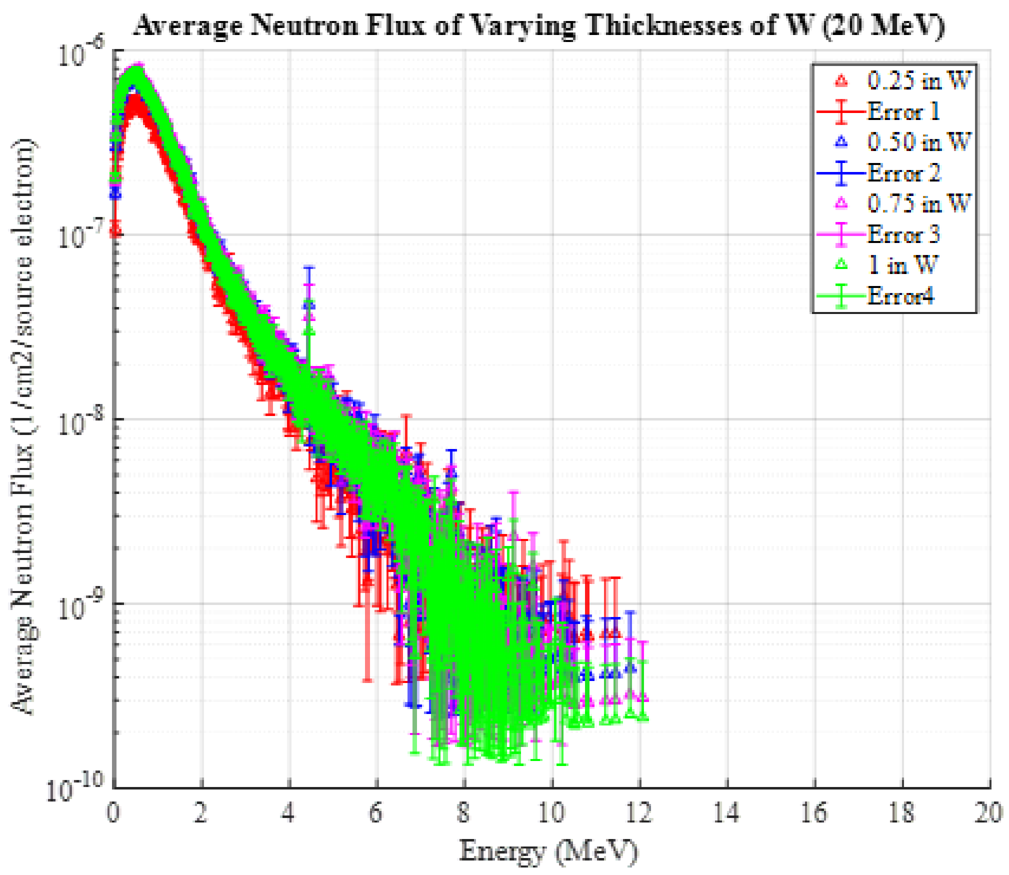
Objective 1 – Preliminary Results - Photons

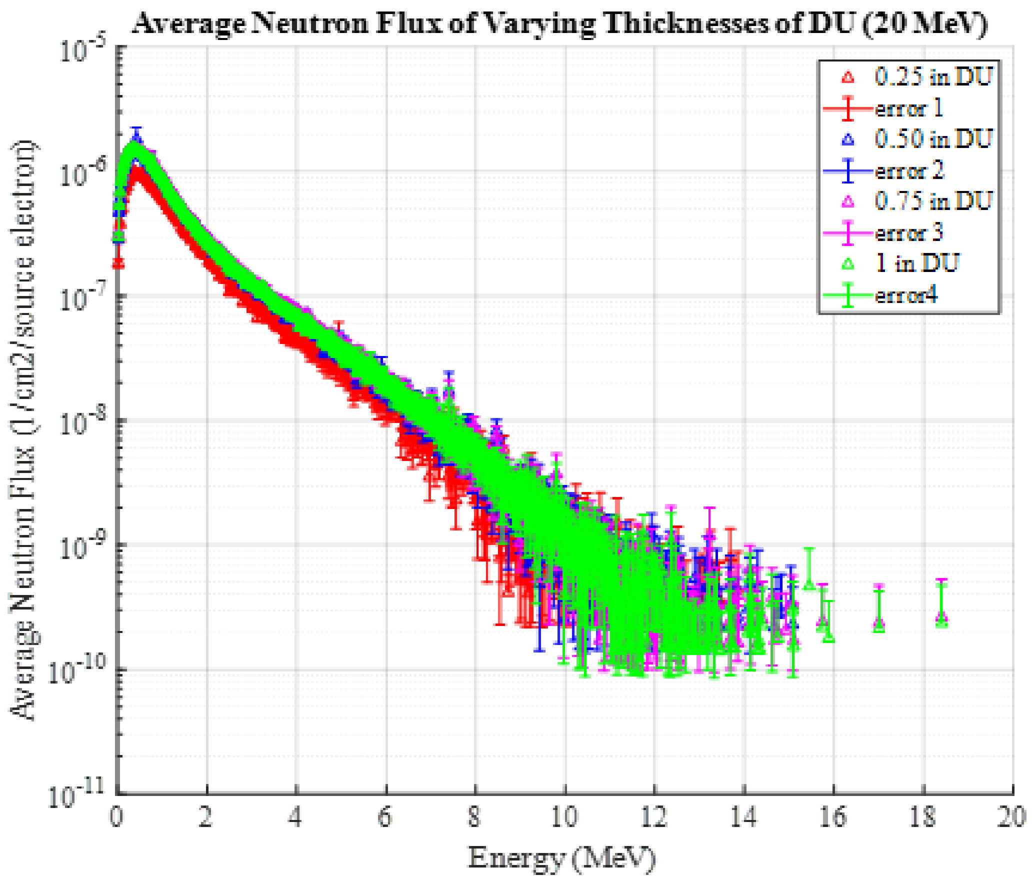
- F2 tally at the Bremsstrahlung target's surface
- Shows average photon flux at each energy bin per a single source electron



Photopeak observed at 511 keV

Objective 1 – Preliminary Results - Neutrons





0.75 *in* thickness is observed to yield the most neutrons for both materials

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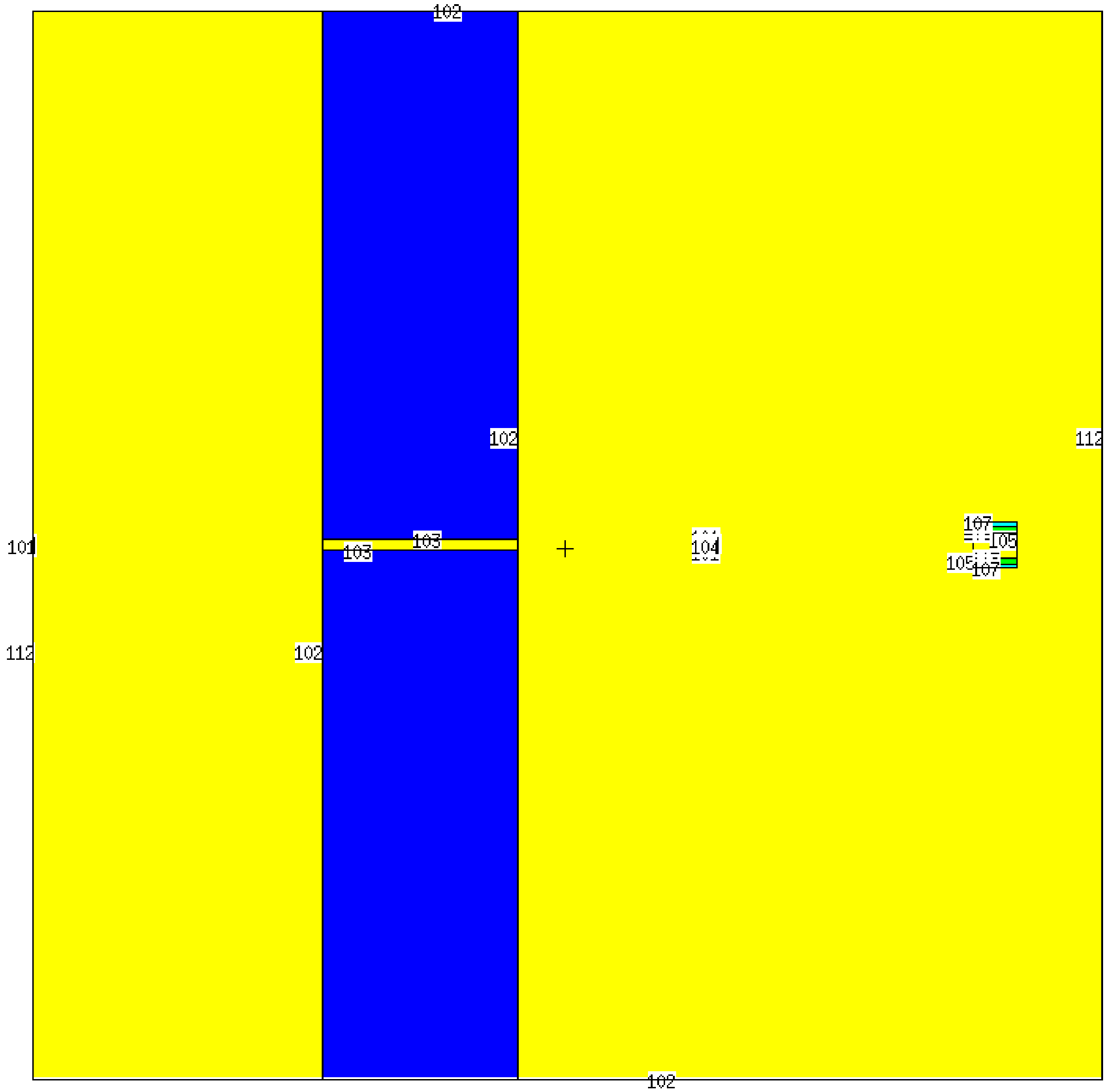
Objective 1 – Preliminary Results - Tabulated

Material	Thickness (in)	Total Surface Flux $\left(\frac{\frac{neutrons}{cm^2}}{electron}\right)$	Total Error (%)
Tungsten	0.25	3.70×10^{-5}	0.53
	0.50	4.86×10^{-5}	0.38
	0.75	$\mathbf{5.12 \times 10^{-5}}$	**0.34**
	1.00	4.94×10^{-5}	0.31
Depleted Uranium	0.25	7.09×10^{-5}	0.3
	0.50	9.97×10^{-5}	0.51
	0.75	$\mathbf{1.06 \times 10^{-4}}$	**0.22**
	1.00	1.03×10^{-4}	0.22

Total neutron surface flux drops between 0.75 *in* and 1 *in* thickness

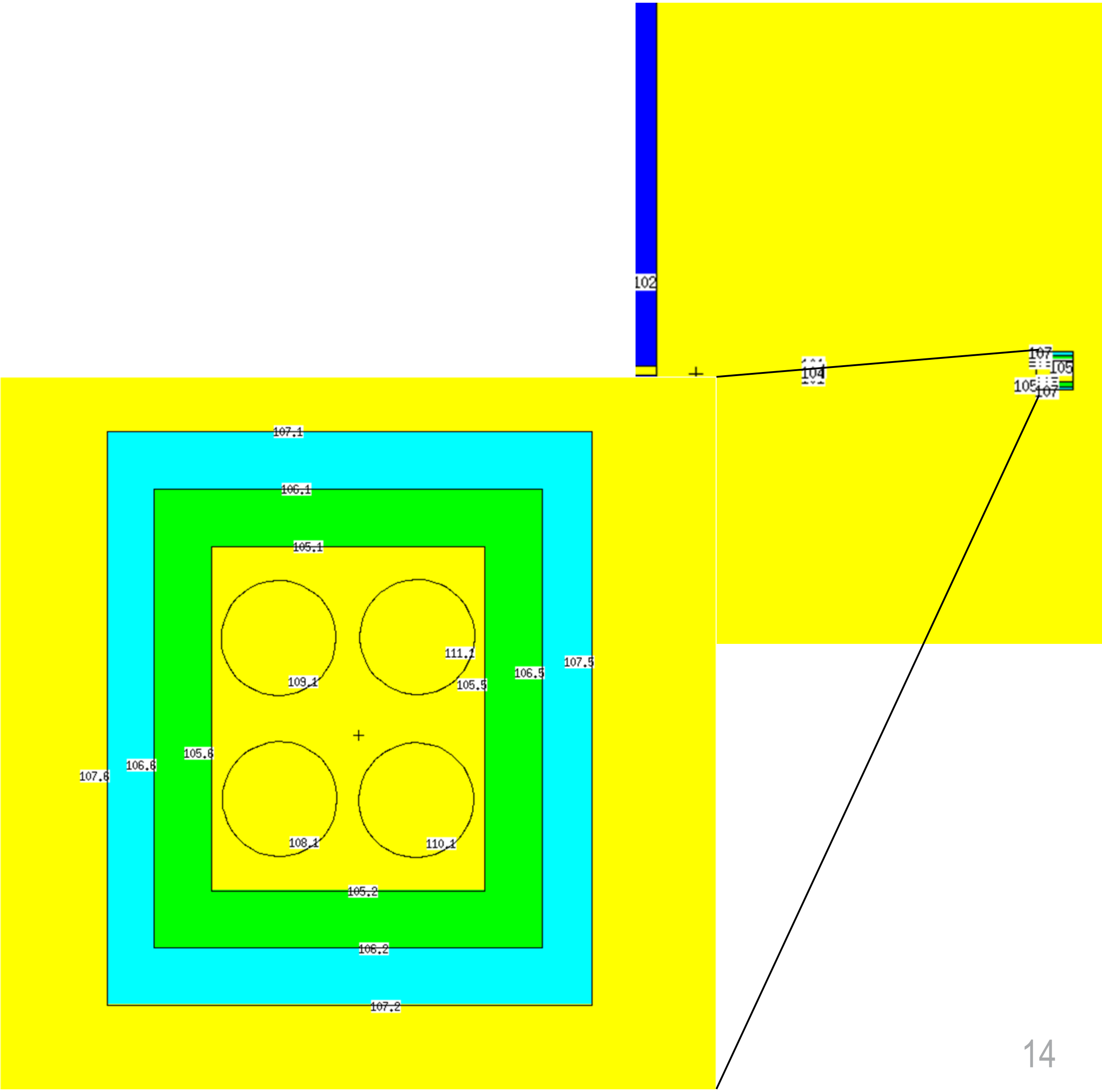
Objective 1 – ISU IAC Model Setup

- Surfaces
  - Room contains concrete walls, collimator, targets, detectors, and air
  - Bremsstrahlung Target
    - 1/10th in thick
    - Tungsten
  - Photoneutron Target
    - ¾ in thick, 252 in away from Bremsstrahlung target
    - Tungsten
- Same source, mode, and physics as proof-of-concept model



Objective 1 – ISU IAC Model Setup

- Tallies
  - F2 tally taken at photoneutron target facing away from the source
  - F4 tally taken at four detector cells
    - Detector cells filled with air
    - Detectors surrounded by a cell filled with lead
    - Lead surrounded by a cell filled with polyethylene
    - Detectors are 94 *in* away from the photoneutron target



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Objective 1 – Preliminary Results – ISU Setup

Material	Thickness (in)	Total Surface Flux (neutrons/cm^2 /electron)	Total Error (%)
Tungsten	0.75	2.08 x 10^{-8}	1.62

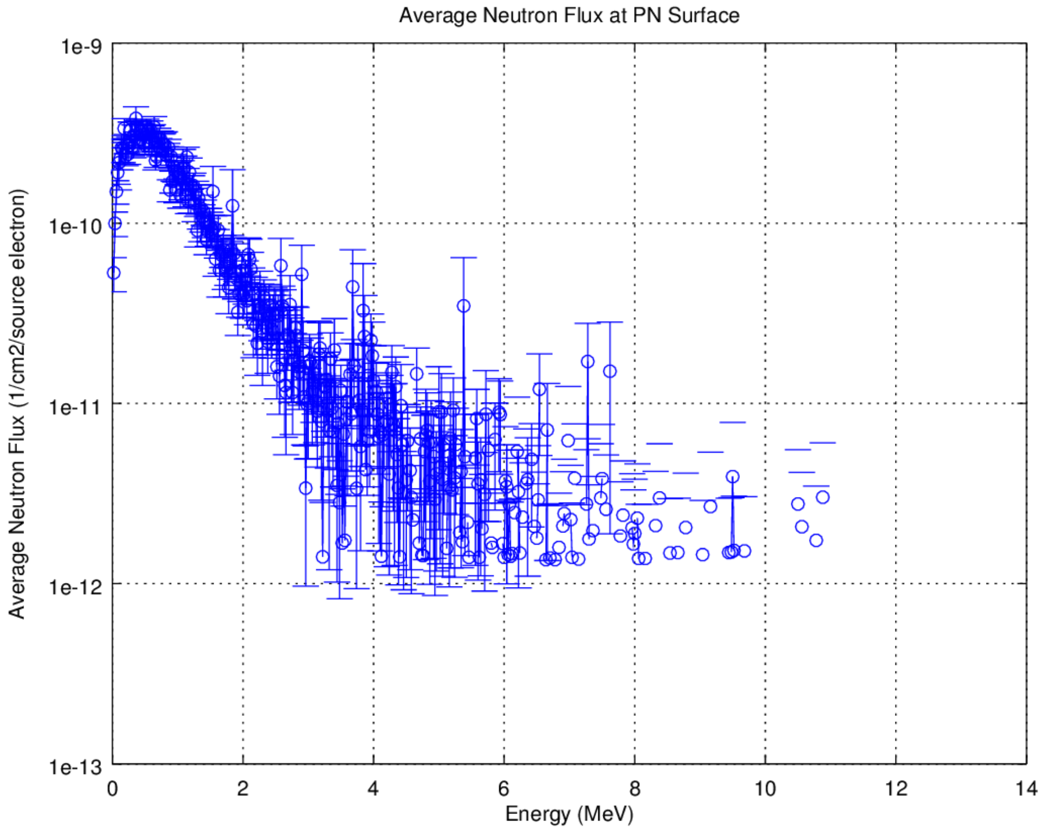
Estimated neutrons/pulse

Given I=25A, dt = 100 ps, f = 60 Hz[19]

$$\frac{e^-}{pulse} = 25\frac{C}{s}\ x\ \frac{1x10^{-10}s}{pulse}\ x\ 1.609\ x10^{-19}\frac{e^-}{C}$$

For neutrons:

$$\frac{\frac{n}{cm^2}}{pulse} = \left(4.03x10^{10}\frac{e^-}{pulse}\right)\left(2.08x10^{-8}\frac{\frac{n}{cm^2}}{e^-}\right) = \frac{838\frac{n}{cm^2}}{pulse}$$



50294 neutrons/cm^2/s generated at target surface

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Objective 2

- Since the neutron energies are anticipated to be less than 100 MeV, time of arrival to detectors can be estimated assuming non-relativistic neutrons:

$$E_n = \frac{1}{2} m_n v_n^2$$

  - Rearranging the equation in terms of time:

$$t = R_n \left(\frac{m_n}{2E_n} \right)^{\frac{1}{2}}$$

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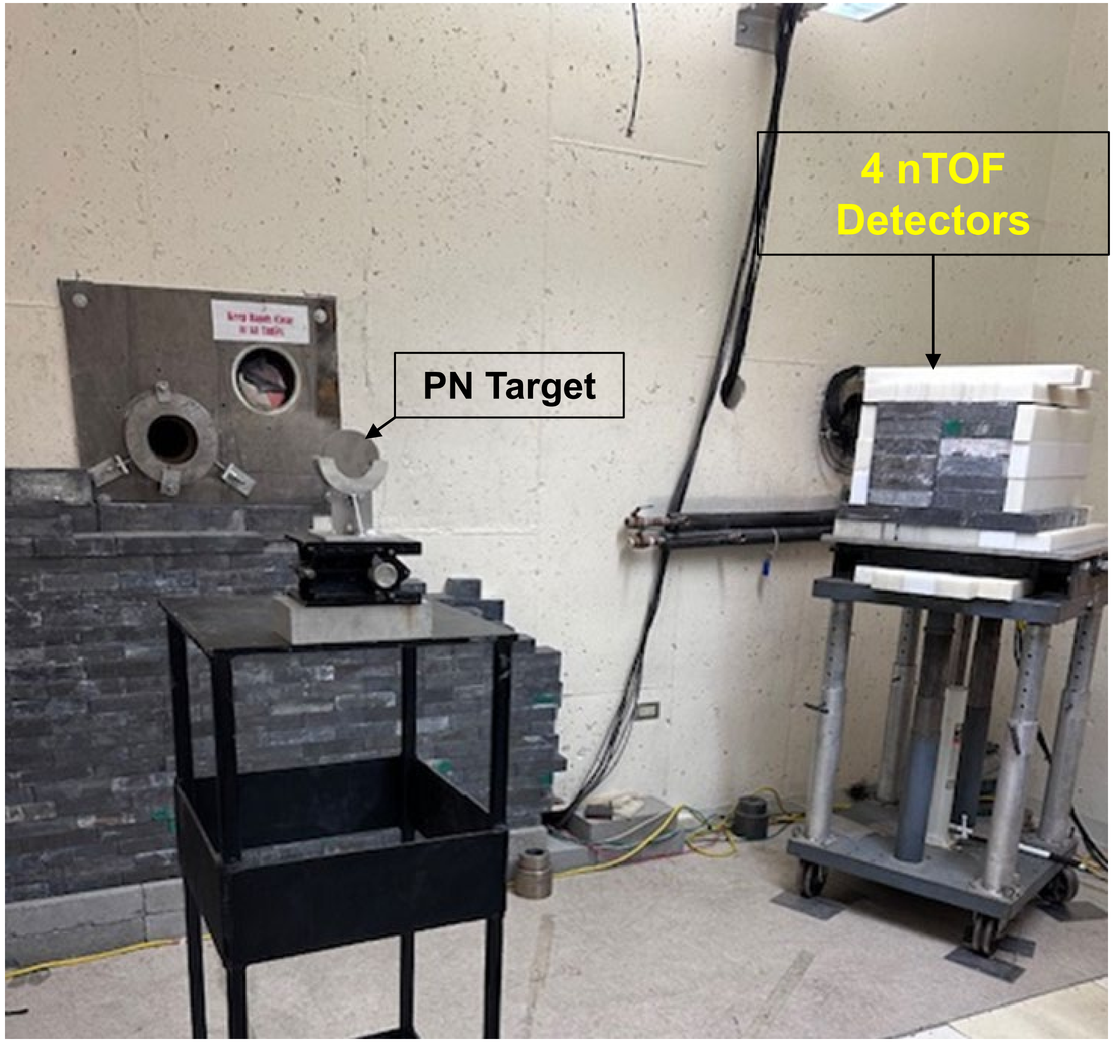
Objective 2 – Measurement Setup (A)

- Target and detectors setup in the detector hall
- Detectors are shielded with lead and polyethylene to shield them from gamma rays



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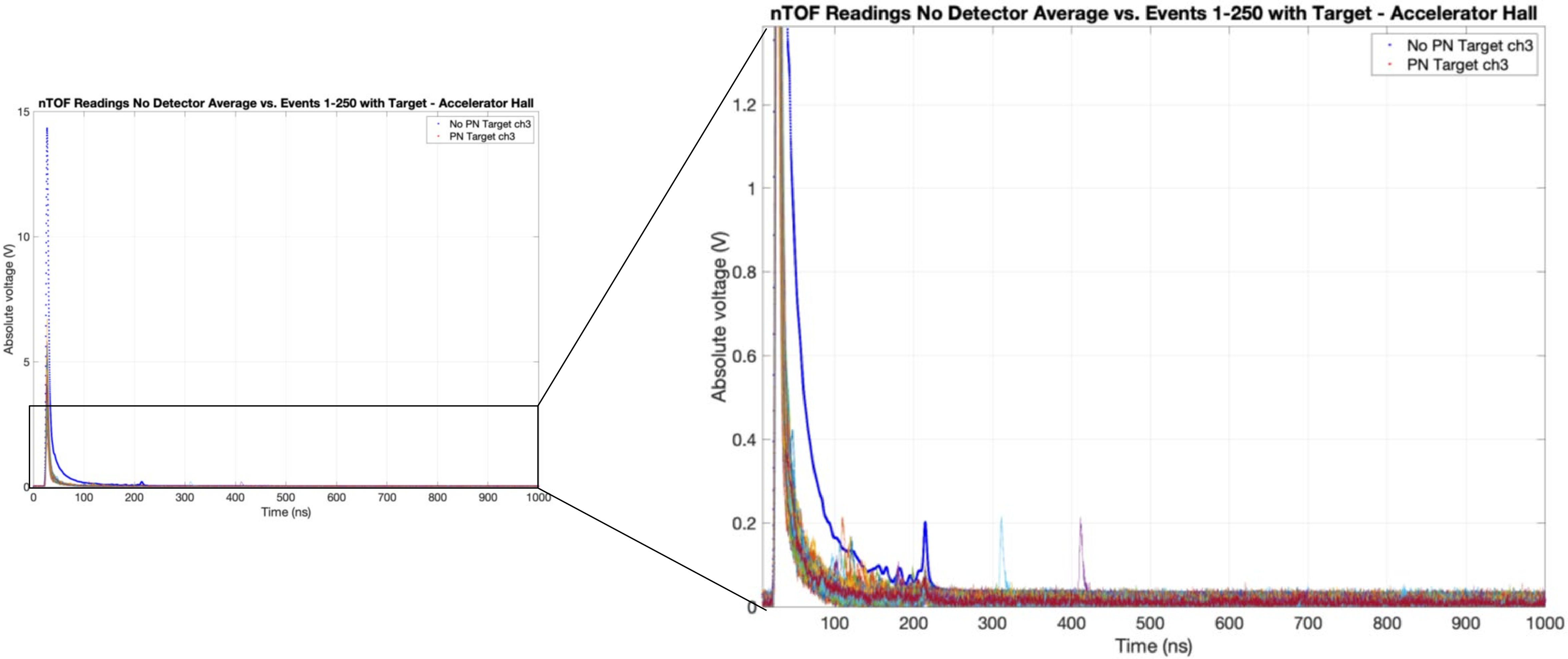
Objective 2 – Measurement Setup (B)

- Photoneutron target setup in the accelerator hall (top)
- Detector array setup in the detector hall by the collimator (bottom)

Objective 2 – Preliminary Results



Potential neutron candidates at 300 - 400 ns

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Objective 3

- Additional work is needed for this objective and will start upon completion of the objective one and objective two
  - This model will follow a similar concept to the model of the ISU IAC
  - French Test Object (FTO) will be added into the fold for imaging
  - Collimation for the neutrons
  - Imaging detectors will be accounted for and radiography tallies will be used

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Proposed Timeline

Objectives	Subtasks	Month	Year
Literature Review	Literature Review	Ongoing	2023-2024
Objective 1 - Computational Model	Proof of Concept Computational Model - 4 MeV	May	2023
	Proof of Concept Computational Model - 20 MeV	May	2024
	ISU/IAC Predictive Model	July	2024
	ISU/IAC Revised Model	August	2024
Objective 2 - Experiments	Proof of Concept Measurement - 4 MeV	June	2023
	ISU/IAC Measurement Campaign 1 - 20 MeV	March	2024
	ISU/IAC Measurement Campaign 2 - 20 MeV	August	2024
	nTOF Data Analysis	August/September	2024
	Model and Experiment Comparison	August/September	2024
Objective 3 - Neutron Imaging Model	Computational Imaging Model Developed	September/October	2024
Miscellaneous	2023 NNSS Detectors Workshop Presentation	May	2023
	2024 NNSS Detectors Workshop Presentation	May	2024
	CAARI-SNEAP 2024 Invited Speaker Presentation	July	2024
	Paper 1 - Computation Model	In Progress	2024
	Paper 2 - Neutron Measurements (co-author)	In Progress	2024
	Paper 3 - Neutron Imaging Using Photoneutrons	November	2024
	Dissertation Defense	November	2024

Course Completion

- Completed 9/9 required course credits
- Completed 12/12 elective course credits
- Completed 9/18 dissertation credits – enrolled for an additional 9 Fall 2024

PLAN OF STUDY - Part II
Doctor of Philosophy - Mechanical Engineering
- Post-Master's Nuclear Engineering

Complete this form and upload it into the Plan of Study – Part I available in your Grad Rebel Gateway student portal on the Forms tab under Required Forms. Once submitted, the form will route electronically for signatures. Upon approval by the Graduate College, the status of your form will be updated in the Grad Rebel Gateway.

Refer to the 2022-23 Graduate Catalog for degree requirements.

COURSE REQUIREMENTS

Required Courses – Credits: 9
Take three courses (9 credits) from the list displayed on the respective section of the catalog program page (linked above):

COURSE (Prefix & #)	CREDITS	GRADE (if completed)	SEMESTER/YEAR (Taken/anticipated)	COURSE (Substitution)	CREDITS (Substitution)	GRADE (Substitution)	INSTITUTION (Substitution)
ME 655	3	A	Fall/2023				
ME 757	3	A	Spring/2023				
ME 765	3	A	Fall/2023				

Elective Courses – Credits: 12
Complete 12 credits of 600- or 700-level coursework from within the College of Engineering. Courses from outside the College of Engineering may be taken with advisor approval.

COURSE (Prefix & #)	CREDITS	GRADE (if completed)	SEMESTER/YEAR (Taken/anticipated)	COURSE (Substitution)	CREDITS (Substitution)	GRADE (Substitution)	INSTITUTION (Substitution)
ME 705	3	A	Fall/2022				
ME 707	3	A-	Fall/2022				
ME 791	3	A	Spring/2023				
ME 754	3	A	Fall/2023				

Dissertation – Credits: 18

COURSE (Prefix & #)	CREDITS	GRADE (if completed)	SEMESTER/YEAR (Taken/anticipated)	COURSE (Substitution)	CREDITS (Substitution)	GRADE (Substitution)	INSTITUTION (Substitution)
ME 799	9	X	Spring/2024				
ME 799	9		Fall/2024				

TOTAL CREDITS 39 Minimum credits required for graduation = 39

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