COVER PAGE

Project Title: Fast-Neutron Source Localization using a Single-Photon Camera	
Federal Award Identification Number: DE-SC0025802	
Agency Code: 8900	**Organization:** Office of Fusion Energy Sciences
Recipient Award Identification Number: 207763	**Project Period:** 01/01/2025 - 12/31/2027
Reporting Period: 01/01/2025 - 12/31/2025	**Budget Period:** 01/01/2025 - 12/31/2025
Report Term: Once per Budget Period	**Submission Date and Time:** 10/15/2025 04:54 PM ET
Principal Investigator Information: Prof. Erik J Sanchez	**Recipient Organization:** Portland State University MailStop Code: SPA 1600 SW 4th Avenue, 210 210 Portland, OR 97207-0751 Country: USA **UEI:** H4CAHK2RD945

ACCOMPLISHMENTS

We proposed to fabricate a novel fast-neutron imaging camera for localizing and reconstructing the source of D-D energetic neutron emission within a reaction vessel in three dimensions by determining the neutron tracks back to the source. This detection system would be universal for D-D neutron generation in plasmas (or target-based systems) in any form of fast neutron reactor. The most immediate need for this imaging system is motivated by our recent paper in which we determined that, contrary to what has been believed for an inertial electrostatic confinement (IEC) device, many of the D-D fast-neutrons originate not in the central plasma, but rather at the walls or grid (cathode) within the reactor. Our neutron camera relies on a novel 3D reconstruction algorithm that leverages physics-based machine learning to reconstruct neutron traces from just a handful of scintillation photons in extremely photon-starved settings. The use of such a detection system would not only help other groups working with D-D or D-T reactions for the study of neutron scattering and plasma diagnostics, but also more broadly for neutron scattering and neutron radiography with a wide range of applications from medical imaging to border security.

Key Accomplishments

Key accomplishments during the first year include the development and testing of a prototype optical system and scintillation cube, advancement of Geant4 simulations, development of a machine learning framework with synthetic data generation capabilities, and acquisition of critical instrumentation including the TPX3CAM camera system.
Over the past year we have fabricated most of the physical camera setup. We have advanced our required physics modeling using Geant4, with preliminary physical models showing initial validation of the approach. We have also advanced our machine learning model in order to be prepared for simulated input from Geant4 as well as physical real-world data. Additionally, we performed trial runs at a local research reactor site (Reed College) using their plutonium-beryllium source as a source of high-energy neutrons.

Progress Relative to Timeline

According to our original timeline from our proposal, we are on schedule. The initial fabrication and modeling efforts are on time, and are even somewhat ahead of schedule. The IEC reactor (neutron generator) for testing with high-energy D-D neutrons is nearly completed. The work at Reed College was performed with a less capable camera than what was proposed due to delays in acquisition of the TPX3CAM system. The proposed camera has now been delivered and we are currently integrating it into our physical setup, including proper radiation shielding around the detector assembly.

Plans for Next Reporting Period

For the next reporting period we will fully integrate the TPX3CAM into the physical setup. In addition, we intend to characterize the neutron generator for testing with the camera system and further advance our Geant4 and machine learning modeling. The modeling combined with the physical camera and reactor will facilitate the acquisition of physical data for analysis and validation of our reconstruction algorithms.

Student Training and Development

Four graduate students have been directly involved in the progression of this work (part-time and full-time). One student has focused on the Geant4 modeling working with the PI, while another student has concentrated on machine learning model development working with the Co-PI. The physical construction of the IEC reactor and the camera setup involves two additional graduate students working part-time in close collaboration with the PI. The students performing the computational modeling have learned advanced simulation and machine learning techniques, while the students working on the physical setup have gained hands-on experience with soldering, machining, design software, 3D printing, electrical wiring, and experimental system integration.

Dissemination Plans

At this point in the work, no data or results have been disseminated. We plan to merge the Geant4 and machine learning modeling results into a simulation paper for publication first, before we report on the physical experimental data. This approach will allow us to provide further validation of our computational methods prior to presenting experimental results.

PRODUCTS

The products shown below include only Publications with a 'Published' status and Intellectual Properties with a 'Granted' status. Products with other statuses are not included in this report. The Revision Type indicates whether a product is New (newly added), Updated (existing product modified), or No Change (existing product reported without modifications) during the current budget period. Note that 'Updated' statuses may appear more frequently as products progress through the publishing process. All products listed have been reported for the current project period of this award.

PUBLICATIONS

There are no publications to report.

INTELLECTUAL PROPERTIES

There are no intellectual properties to report.

PARTICIPANTS AND OTHER COLLABORATING ORGANIZATIONS

The table below only contains participants who have identified an affiliation with the Awardee Institution. Participants from any associated subawards may not be included in this count.

PARTICIPANTS DETAIL

Project Role	Number of People	Total Person Months Worked
Graduate Student (Research Assistant)	2	4
Principal Investigator/Project Director	1	0
Total Responses	**3**	**4**

PARTNERS DETAIL

Partner:	Brookhaven National Laboratory, Upton, NY, USA

IMPACT

We are presently in the first year of a three-year project to create a 3D imaging system for fast neutrons. We are nearly complete with the fabrication of the physical system for imaging fast neutrons. The IEC reactor serving as our neutron generator is almost complete, and we believe we will soon have neutrons available for preliminary physical data collection. The impact this work will have on other disciplines can be seen in the advancement of technology using state-of-the-art equipment for imaging and temporally resolving fast processes, which may be utilized in medical, material science, and other fields.

What was the impact on other disciplines?

During this first year, the project has advanced computational methodologies which are a combination of nuclear physics, machine learning, and optical detection that are relevant to multiple disciplines. The physics-based machine learning algorithms we are developing for extracting information from photon-starved imaging scenarios have potential applications in medical imaging (particularly low-dose radiation imaging), astronomy (detecting faint celestial signals), and quantum sensing. Our Geant4 simulation framework for modeling scintillation processes as a validated computational tool can assist other researchers studying particle detection and radiation physics. The synthetic data generation engine we are developing provides a template for training machine learning models in other data-limited experimental physics situations. While these are early-stage contributions, they could establish cross disciplinary methods.

What was the impact on physical, institutional, and information resources that form infrastructure?

This project has resulted in the establishment of new experimental infrastructure for neutron imaging research. The prototype optical system, scintillation cube assembly, and light-tight enclosure represent new physical research capabilities. The acquisition and integration of the TPX3CAM single-photon camera system adds state-of-the-art imaging capability to our institutional resources. Presently, such a device with this level of temporal and spatial collection is not at Portland State University. The near completion of the IEC neutron generator provides a controlled neutron source for experimental validation and training. These physical resources will serve future research projects beyond the current scope of this proposed research. On the computational side, we have developed Geant4 simulation code and flexible Python-based machine learning frameworks that represent reusable information infrastructure. The collaboration established with Reed College for access to their plutonium-beryllium (Pu-Be) neutron source represents an institutional partnership that enhances research capabilities for both institutions.

What was the impact on technology transfer?

As this is the first year of a three-year project, technology transfer activities are premature at this stage. However, the project is developing several components with potential commercial and public use applications. The 3D neutron imaging technology being developed has clear pathways to practical deployment in border security and non-proliferation monitoring, where rapid localization of neutron sources is critically important. The single-photon imaging techniques and machine learning reconstruction algorithms could be adopted by companies developing advanced medical imaging systems, particularly in radiation therapy planning and proton therapy dosimetry. We anticipate that by the completion of the three-year project, we will have demonstrated capabilities that warrant technology transfer discussions with government agencies responsible for security and non-proliferation, as well as commercial entities in medical physics and advanced manufacturing. At present, no formal technology transfer activities or startup initiatives have been initiated, but the introductory work completed this year makes the project available for such opportunities.

What was the impact on society beyond science and technology?

While direct societal impact is limited during this foundational development phase, the project addresses challenges with clear societal benefits. The advancement of fusion energy diagnostics contributes to the nation's long-term energy security. The potential applications in border security and nuclear non-proliferation serve national security interests. Medical imaging applications could eventually improve cancer treatment planning and reduce radiation exposure for patients. The project also contributes to scientific literacy and technical workforce development, training the next generation of researchers in advanced experimental and computational methods. These students will enter the workforce equipped with skills in cutting-edge technologies that support American competitiveness in high-tech sectors.

What was the impact on the development of human resources?

Four graduate students have been directly involved in this project during the first year, gaining valuable interdisciplinary training. One student has developed expertise in Geant4 radiation transport modeling and nuclear physics simulation, working closely with the PI. Another student has focused on machine learning model development and synthetic data generation for computer vision applications, working with the Co-PI. Two additional students working part-time have gained hands-on experience with experimental system construction, including soldering, machining, computer-aided design software, 3D printing, electrical wiring, vacuum systems, and high-voltage power systems. The students performing computational modeling have learned to integrate physics-based constraints into machine learning frameworks, a valuable skill set bridging traditional physics and modern data science. The hands-on fabrication experience provides practical engineering skills that complement theoretical knowledge. These students are developing the multidisciplinary skill sets increasingly demanded in national laboratories, advanced technology companies, and academic research institutions. The training encompasses the full spectrum from fundamental physics to practical engineering implementation, preparing these individuals to tackle complex technical challenges in their future careers.