NEUP Nuclear Energy University Program
U.S. Department of Energy

Computer vision and machine learning for microstructural qualification

PI:
Elizabeth A. Holm
Carnegie Mellon University

Program:
CT-5: Nuclear Materials Discovery and Qualification Initiative R&D

Collaborators:
Amra Peles – PNNL
Andrew Casella – PNNL
Danny Edwards – PNNL
Daniel Schreiber – PNNL
David Senor – PNNL
Ziqing Zhai – PNNL
Mitra Taheri – JHU

ABSTRACT:
Materials in nuclear reactors face extreme environments, and the microstructural defects that develop under these operating conditions limit nuclear materials performance. Thus, quantifying and understanding microstructure is a key driver for performance-based materials qualification. A preponderance of microstructural data is visual, so data science methods such as computer vision (CV) and machine learning (ML) offer promising directions for microstructural analysis, both technologically (efficient tools) and scientifically (capturing richer microstructural information). In this project, we leverage our strengths in materials science, computer vision, and machine learning to build new, quantitative deep learning frameworks to accelerate and enable qualification of nuclear materials based on microstructural features. With that mission in mind, our objectives are as follows:

- **Data collection:** Select, collect, and process microstructural image data to maximize knowledge extraction.
- **Method development:** Develop CV methods to systematize the relationship between image complexity and CV representation.
- **Classification:** Devise classification approaches to discover and exploit the materials science knowledge in the "hidden" visual signals in microstructural images
- **Autonomous evaluation:** Use autonomous evaluation to quantitatively, repeatably, and objectively assess, characterize, and qualify microstructures.
- **Segmentation and measurement:** Develop and train objective, consistent, and reliable image segmentation methods that replicate human judgment while increasing productivity and throughput.
- **PSP connections:** Create black box and interpretable ML methods to predict materials performance and discover its underlying physics.

Adding CV/ML tools to the microstructural analysis pipeline promises to accelerate and enable nuclear material qualification based on microstructural features. Autonomous evaluation will identify structures associated with desirable outcomes, improving the quantification process workflow and enabling control of materials reproducibility. CV/ML segmentation and measurement will extract quantitative information from microstructural data more efficiently and thoroughly, making the most of our experimental investments. Finally, CV/ML will enable new, quantitative PSP connections to predict material performance and gain scientific understanding. Together, these efforts comprise a new paradigm for qualification based on microstructural features.