DOE Funding Opportunity
DE-FOA-0001817

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Company Highlights

BWXT is one of the world’s most prolific nuclear technology innovation companies and the sole manufacturer of naval nuclear reactors for U.S. submarines and aircraft carriers.

- **6,250** highly skilled employees
- **$1.8 billion** USD in 2018 revenues
- **11** major manufacturing facilities totaling 3.8 million square feet
- **60+** years manufacturing naval nuclear components and reactors
- **300+** commercial nuclear steam generators manufactured
- **1.5 million+** Canada Deuterium Uranium (CANDU) fuel bundles provided
- **14** U.S. Department of Energy laboratories, environmental cleanup projects and NASA sites
- **8,000+** fuel elements delivered to U.S. national laboratories, universities and international customers

NYSE: BWXT

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We have been at the forefront of the commercial nuclear power generation and government nuclear industries for decades, achieving an impressive number of firsts along the way.

HISTORY OF INNOVATION
1850s
Our heritage dates back to the invention of the water tube boiler by Stephen Wilcox, who later founded The Babcock & Wilcox Company.

NUCLEAR FLEET
1950s
Our naval nuclear lineage began with the USS Nautilus, the world’s first nuclear-powered submarine.

EXPANDING CAPABILITIES
2000s
We completed key acquisitions and a successful spin-off of our power generation business while developing new, advanced technologies.
### BWXT, A Complete Life Cycle Provider – What We Do

#### Advanced Technologies
- Advanced Reactors Design
- Developmental Testing
- Manufacturing Development Including Additive
- Radioisotope Development

#### Commercial Nuclear Fuel
- CANDU Fuel
- Fuel Handling & Engineered Solutions
- Nuclear Non-Proliferation

#### Commercial Nuclear Components
- Steam Generators
- Heat Exchangers
- Reactor Vessels

#### Complex Operations Management
- Nuclear Facilities & Operations Management
- Nuclear Materials Management
- Environmental Safety & Health Management

#### Environmental Management
- Waste Management
- Facility Decontamination, Decommissioning & Demolition
- Remediation & Restoration

#### Laboratory Services
- Failure Analysis
- Nondestructive Evaluation & Inspection Systems
- Strategic Materials

#### Naval Nuclear Propulsion
- Design Engineering
- Precision Manufacturing
- Nuclear Fuel

#### Nuclear Services
- Steam Generator Services
- PWR Heat Exchanger Services
- Reactor Services

#### Radiochemistry
- Medical Isotope Production
- Research & Development
- Processing, Packaging & Delivery Services

#### Research Test Reactors
- Fuel Plates & Target Manufacturing
- Fuel Powder
- Low-Enriched Uranium Fuel Development

#### Space Applications
- Nuclear Thermal Propulsion
- Reactor Design & Fuel Development
- Ground Testing
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- **FOA Title:** U.S. Industry Opportunities for Advanced Nuclear Technology Development
- **Topic:** Establishment of an integrated, advanced manufacturing and data science driven paradigm for advanced reactor systems
- **Award (ID) Number:** DE-NE0008744
- **Awardee:** BWXT Nuclear Energy, Inc.
- **Awardee DUNS #:** 829891394
- **Collaborator:** Oak Ridge National Laboratory / Manufacturing Demonstration Facility (FFRDC)

Arcam Spectra H Installed at ORNL-MDF
DE-FOA-0001817 - Acknowledgements

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- Andrew Chern*
- Travis Fritts*
- Chris Folmar
- Danny Galicki*
- James Gallier
- Don Hill
- Russ Jensen

*Co-located at ORNL / MDF

**ORNL**
- Ryan Kitchen*
- Matt LeVasseur
- Travis McFalls*
- Matt Preston*
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- Dave Zilles
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- Betsy Ellis
- Michael Kirka
- Kory Linton
- Vincent Paquit
- Xin Sun
Objectives

ID4BT
- Rapid Development Paradigm
- Technology Driven
- Enabling the Commercialization of High Power Dense Nuclear Designs

Reactor Design
- GEN IV
- Compact
- Cost Effective
- Inherently Safe

Advanced Materials
- Technology Leap
- Not AM Today
- Increased Safety Margins

Additive Manufacturing
- Unique Geometries
- Improved Thermal Energy Management
- Customized Design
ID$^4$BT = Integrated 3D Design, Build, Test, & Data Science

Integrated Design
- Requirements Development
- Mechanical Design
- Core Physics
- Thermal Analysis
- VHTR Concept
- UHTR Concept

Build
- AM HAST® X
- AM Mo Alloys

Test
- Chemical Analysis
- Mechanical Tests
- Powder Characterization

Data Science
- In-situ monitoring
- 3D part reconstruction
Why Electron Beam Additive Technology?

- The benefits of EBM over other AM technologies:
  - Low risk of contamination due to processing in a vacuum
  - Pre/Post heating allows builds to be performed at elevated temperatures
  - Accurate and fast beam location control
  - Precision control over processing parameters and scan strategy
    - Precise pre/post heating during builds
    - Manipulate grain microstructure (equiaxed vs columnar)

- Arcam Spectra H
  - 6kW beam power
  - 250mm x 250mm x 430mm build volume
  - BWXT has the first operational unit in the U.S.
Hastelloy® X Build Overview – Spectra H

Accomplishments:
- 70+ Builds over 7 months
- Parameter Development
  - Arcam Algorithm Defects
  - Visual Defects
  - Surface Finish
  - Porosity and Microstructure

Tensile Tests:
- As-built Configuration
  - YS exceeds ASTM standards
  - UTS exceeds ASTM standards
    » In 2 of 3 configurations
- After Post-Processing Heat Treat
  - YS exceeds ASTM standards
  - UTS exceeds ASTM standards
    » In 2 of 3 configurations
  - % Elongation exceeds ASTM standards
Molybdenum Build Overview

○ Phase 1 Development
  ▪ Mini-vat builds of pure Moly on the Arcam S12
  ▪ Moly alloy melt tests on the Arcam S12

○ Phase 2 Development
  ▪ Large builds of pure Moly on the Arcam Spectra H
  ▪ Mini-vat builds of Moly alloys on the Arcam S12 or other

○ Phase 3 Development
  ▪ Large builds of Moly alloys on the Arcam Spectra H
Data Science Development and Digital Twins

- Machine learning algorithms for prediction of build effects and property prediction
- Develop accurate 3D *digital twin*
- GD&T
  - +/- 90um on edges
  - +/- 180um edge to edge
- Pore Detection
  - 100um or larger at 99.99% detection
  - ~15% false positives
- Working method for in-situ crack detection
**Summary**

- **Design**
  - Completed multiple design/analysis iterations
  - Continue developing the VHTR and UHTR concepts

- **Hastelloy® X Builds**
  - Builds complete
  - Excellent mechanical properties
  - Acceptable as-built surface finishes
  - Acceptable GD&T

- **Molybdenum Builds**
  - Successful crack free bulk builds
  - Moly alloy melt test reveal crack free melt pools

- **Data Science**
  - Accurately develop 3D digital twin of as-built part
  - 99.99% pore detection
  - Successfully providing feedback loop to build strategy
  - Working on feedback loop to design/analysis software