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U.S. DEPARTMENT OF ENERGY

FY27 NPP LDRD Type B Pre-Proposal

Enabling Integrated Cryogenic Materials Characterization and Modeling for Next Generation Superconducting Magnet Systems

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@BrookhavenLab

FY27 NPP LDRD Type B Pre-Proposal

Proposal title: Enabling Integrated Cryogenic Materials Characterization and Modeling for Next Generation Superconducting Magnet Systems

Primary Investigator: Racquel Lovelace, Peng Xu

Other Investigators:

Indicate if this is a cross-directorate proposal: Yes ___ No_x__

If yes, identify other directorates/organizations:

Proposal Term: From: Oct 2026 To: Sept 2028

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Proposal title and brief abstract: **Enabling Integrated Cryogenic Materials Characterization and Modeling for Next Generation Superconducting Magnet Systems**

ABSTRACT: This project establishes an integrated experimental and modeling platform at BNL to study how structural and insulation materials behave at cryogenic temperatures down to 4 K. New test data will be used to build improved material models and incorporate them into finite-element simulations of superconducting magnets. The results will directly support EIC magnet design and enable future high-field accelerator and fusion magnet technologies.

Program: HEP, Accelerator R&D, Multiprogram

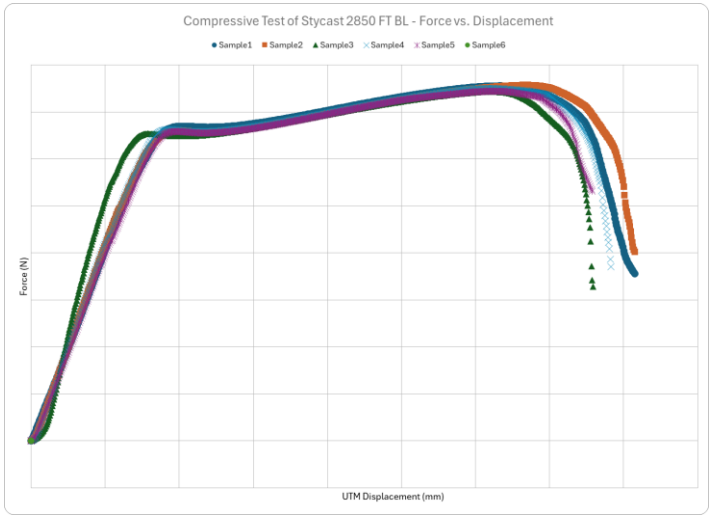
Return on Investment: Foundational research capability that positions BNL to compete for DOE funding in multiple strategic areas: HEP/EIC, Fusion Energy Sciences, Advanced Accelerator & Technology Programs, Materials and Engineering Science

Broader impact on the activities at the laboratory: Enables predictive magnet design, strengthens fusion and high-field magnet R&D, establishes a unique institutional capability, enhances scientific leadership, supports workforce and collaboration for students, postdocs and cross-departmental engagement. Overall, the project bridges materials physics, structural mechanics, and large-scale magnet system design, strengthening BNL's role as a hub for next-generation cryogenic technology development.

Total planned funding per year in FY27 and FY28: FY27: $200k - $250k (testing machine upgrade, custom cryostat design and fabrication, initial material testing at 293 K and 77 K, preliminary FEM framework). FY28: $200k - $250k (4K testing, constitutive damage model development, integrated FEM simulations, dissemination and proposal development)

Material Data at Varying Environments is Lacking

- Critical risks for superconducting (SC) magnets from extreme cryogenic environments include:
  - Mechanical failure
  - Insulation degradation
  - Stress-induced performance limits
- Proposal Experimental Component:
  - Upgrade existing universal testing machine to characterize commonly used polymers in SC magnets down to 4 Kelvin
  - Polymeric and composite materials exhibit non-linear and temperature-dependent damage and failure mechanisms not captured by current design assumptions



Preliminary, unpublished, compression data for Stycast 2850FT BL, tested at room temperature.

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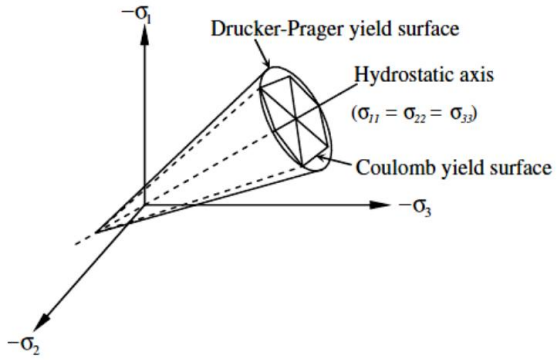
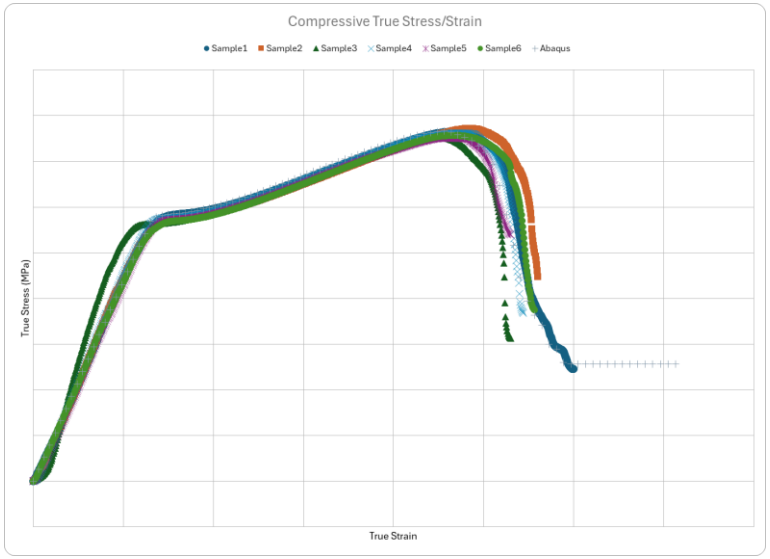
Constitutive Damage Model for FEM

- Temperature-dependent constitutive damage model will be constructed from the experimental data
- Damage model will be implemented in finite element models of SC magnet components to more accurately simulate:
  - Stress redistribution
  - Insulation integrity
  - Performance margins under realistic Lorentz force loading





Good comparison between Abaqus single element model using Drucker-Prager damage model and uniaxial compression data at room temperature

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Project Requirements

- Key Deliverables
  - Validated cryogenic mechanical property database (293 K, 77 K, 4 K).
  - Temperature-dependent constitutive & damage models.
  - Integrated FEM workflows for superconducting magnet structural analysis.
  - Publications, internal design tools, and datasets for future DOE proposals
- Personnel
  - Racquel Lovelace – 0.125 FTE
  - Peng Xu – 0.125 FTE
- Procurement
  - Instron universal test machine retrofit-upgrade
  - Custom cryostat
  - Test equipment (e.g. material samples, sensors, instrumentation, liquid helium, fixtures…)

Summary Slide

- Proposal funding will establish a unique institutional capability at BNL and strengthen scientific leadership in materials characterization for extreme cryogenic environments.
  - Leverages existing laboratory infrastructure to create a cost-effective, high-impact research platform.
  - Directly enables EIC magnet structural design, reducing uncertainty in stress, strain, and reliability margins.
  - Provides first-of-its-kind cryogenic mechanical data for polymers and composites used in superconducting magnet systems.
  - Integrates experiments with constitutive and damage modeling, enabling more accurate finite-element simulations of magnet structures.
  - Positions BNL for future DOE funding in accelerator technology, fusion energy, and advanced cryogenic systems.