

# BNL Capabilities for Supporting Fusion R&D

Ramesh Gupta, Superconducting Magnet Division



**BROOKHAVEN**  
NATIONAL LABORATORY

*a passion for discovery*

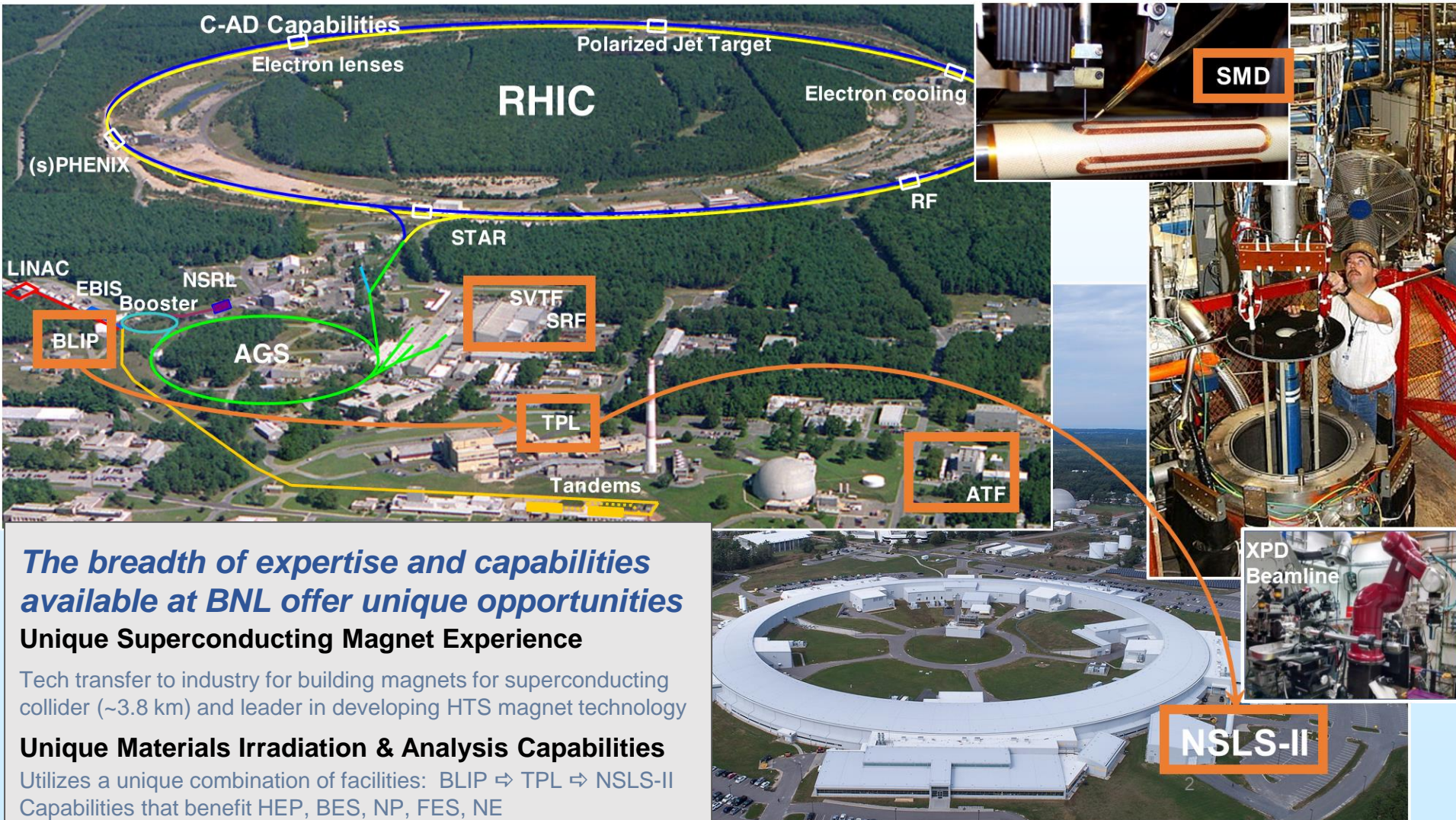


1st Annual INFUSE Workshop 11/22-23/19





# Unique BNL Capabilities for Fusion R&D





# Working with Industrial Partners



- Superconducting magnets were developed at the laboratory and built in the industry with a successful tech transfer
- Magnets are working reliably with no failure in two decades
- Core team of engineers, technicians and scientists still available

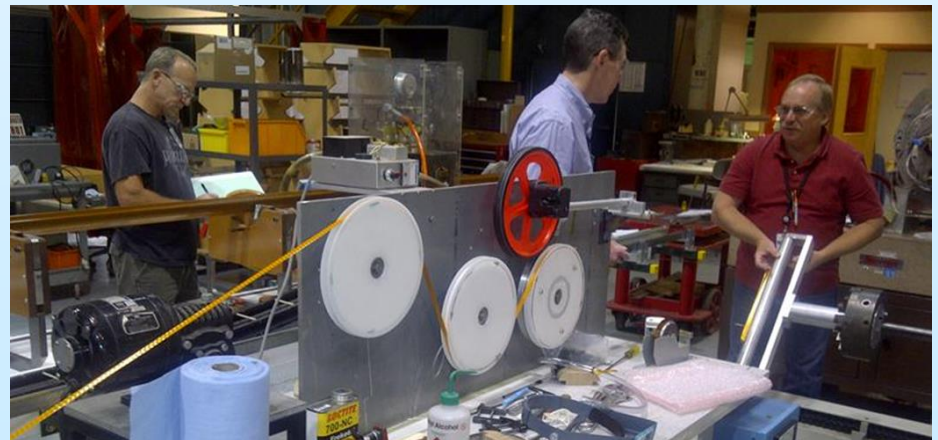
# A Pictorial Tour of Superconducting Magnet Division



# Coil Winding Machines



Semiautomatic coil winding with 10 m coil. The spool of cable used in the coil winding is in the foreground.





# Coil Curing and Coil Reaction Furnace



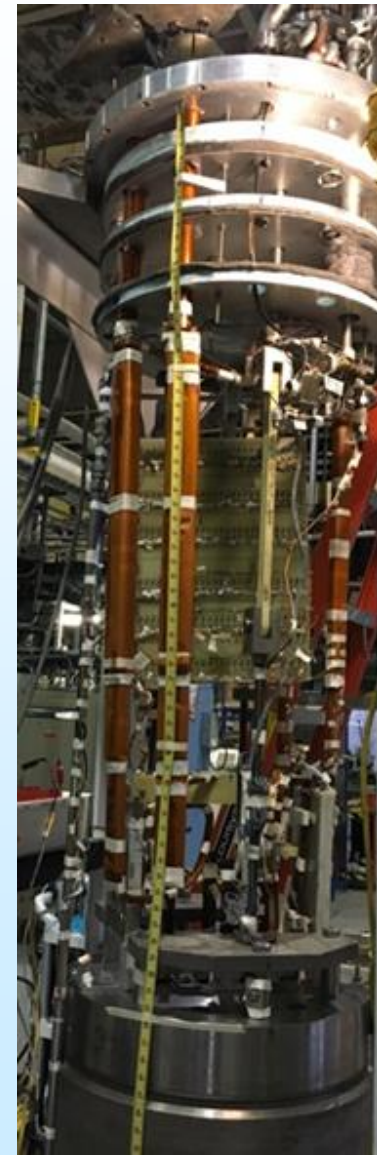
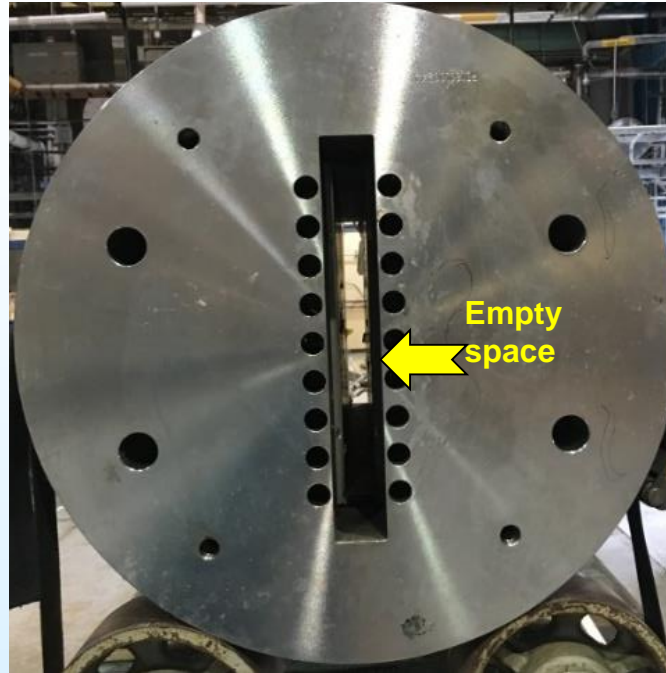
The coil, inserted in the form block, is heated electrically to set the epoxy that fixes the coil size. Heating is done inside an array of heavy copper (foreground) that minimizes heat loss.



# A Few Slides on Test Facilities



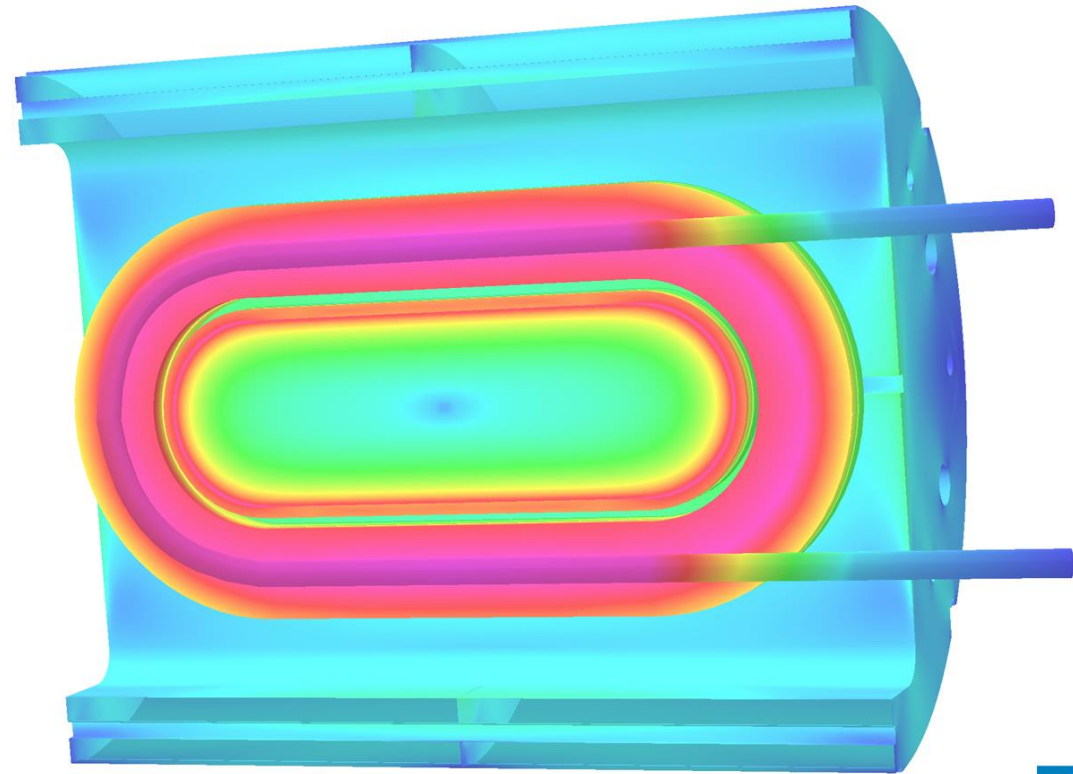
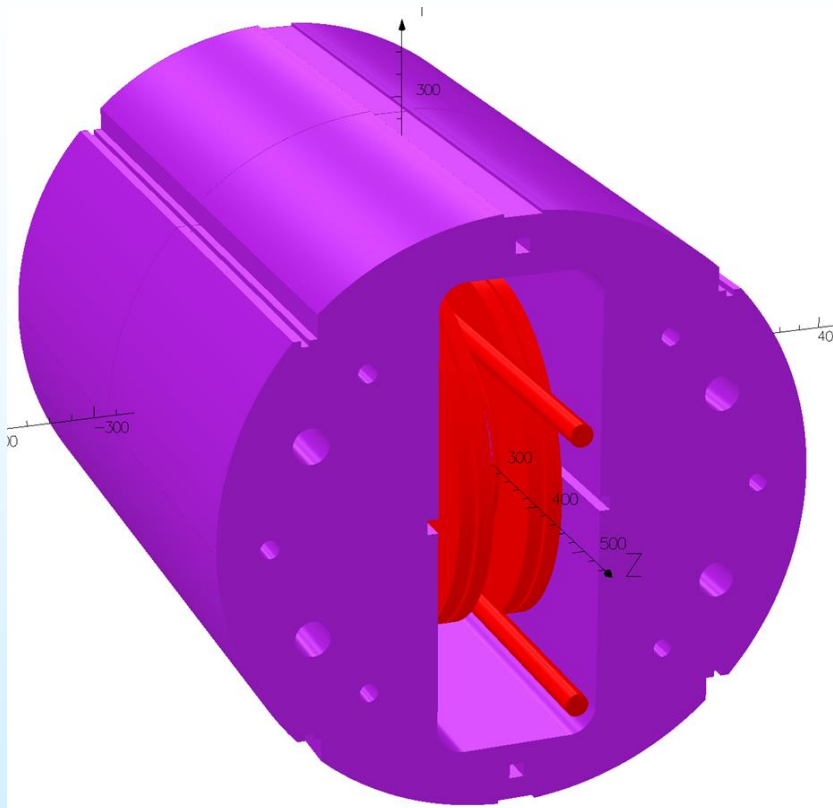
# A Unique Test Facility for Fusion R&D



- A  $\text{Nb}_3\text{Sn}$  dipole providing a background field up to 10 T
- Large open space: 31 mm wide and 335 mm high
- Cable with large bend radius can be easily accommodated
- Cable can be looped inside the high field region for a long length in-field test
- To be used in the CFS INFUSE HTS cable quench studies



# Model of Cable Test in 10 T Background Field Magnet

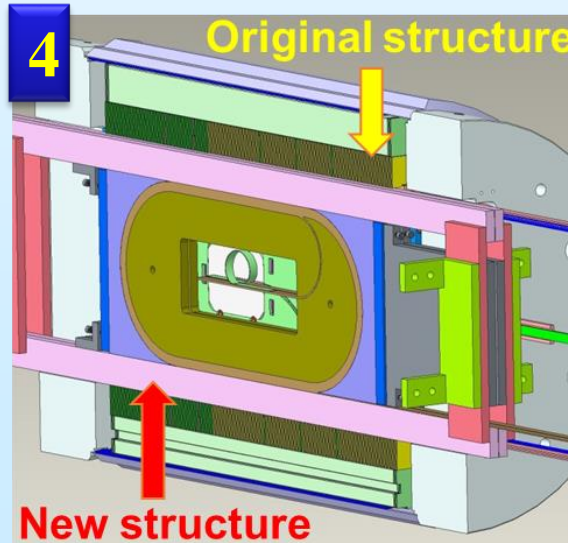
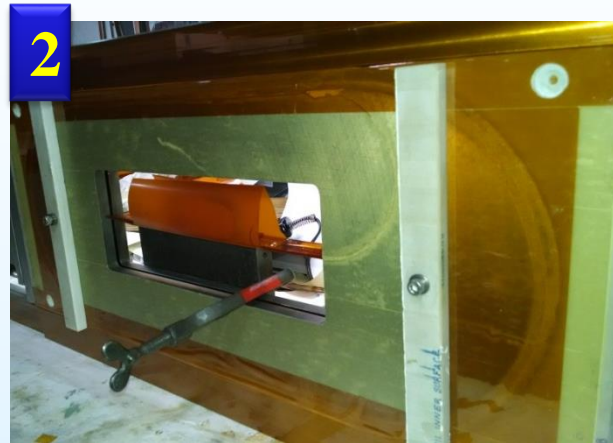
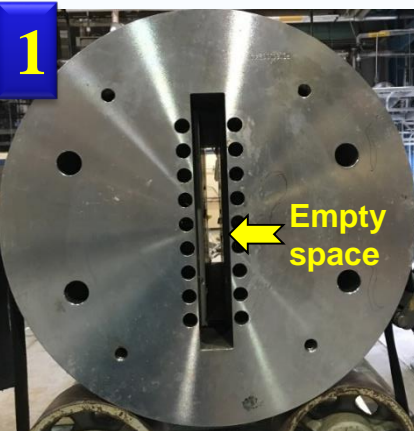


Cable can be bent in a large bending diameter  
(~140 mm to ~300 mm) and stays in a high field region

# Rapid turn-around, Low-cost Tests of R&D HTS Coils (total field: ~15 T)

## Five Simple Steps/Components

1. Magnet (dipole) with a large open space
2. Coil for high field testing
3. Slide coil in the magnet
4. Coils become an integral part of the magnet
5. Magnet with new coil(s) ready for testing





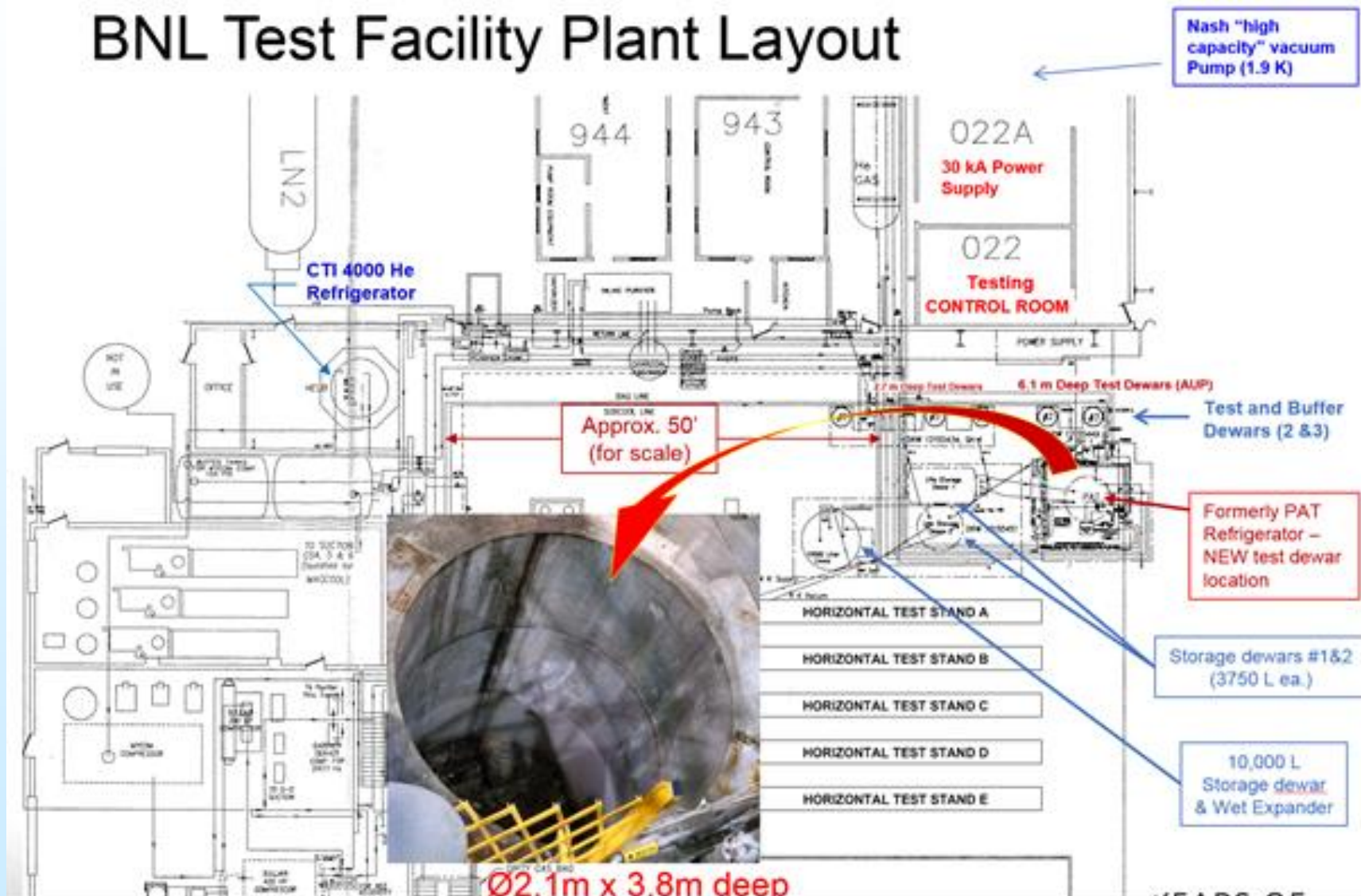
# Six Dewar at Vertical Test Facility (up to 4.5 m, 1.9 K)





# A 2.1m diameter x 3.8m deep pit (a future test-stand to share)

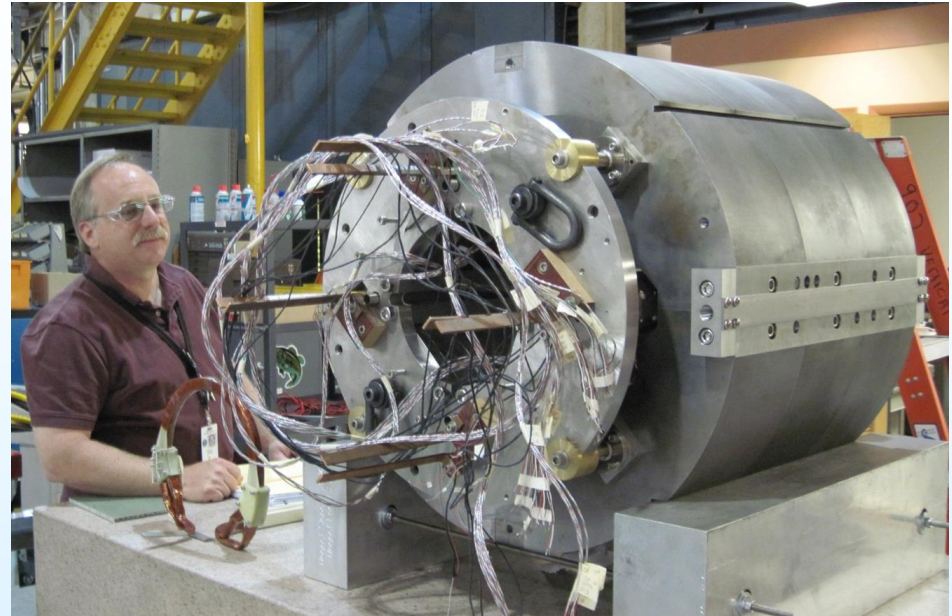
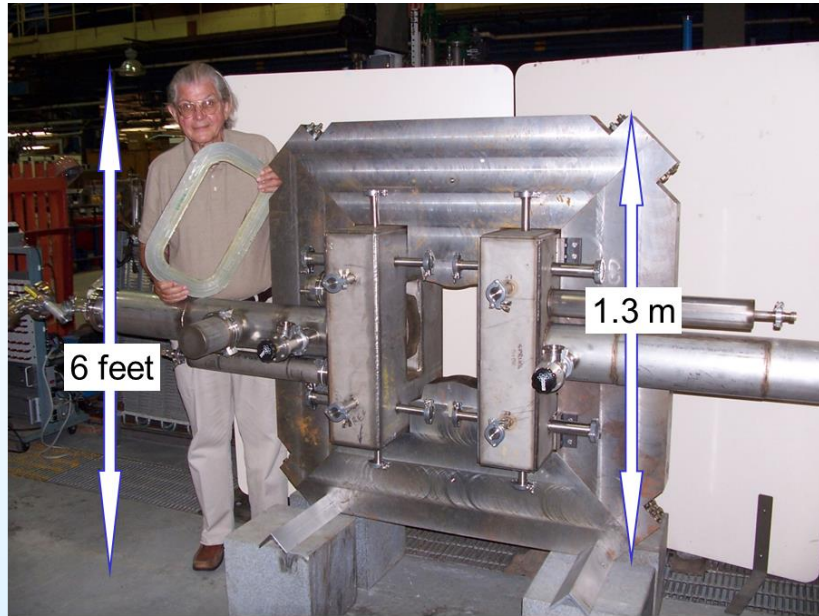
## BNL Test Facility Plant Layout





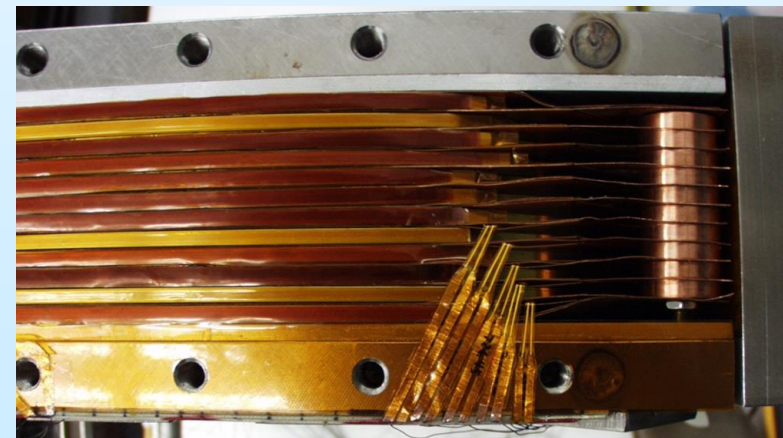
# Unique Experience and Capabilities with the HTS Magnet Technology

# HTS Magnet Technology for High Radiation and Large Heat Loads



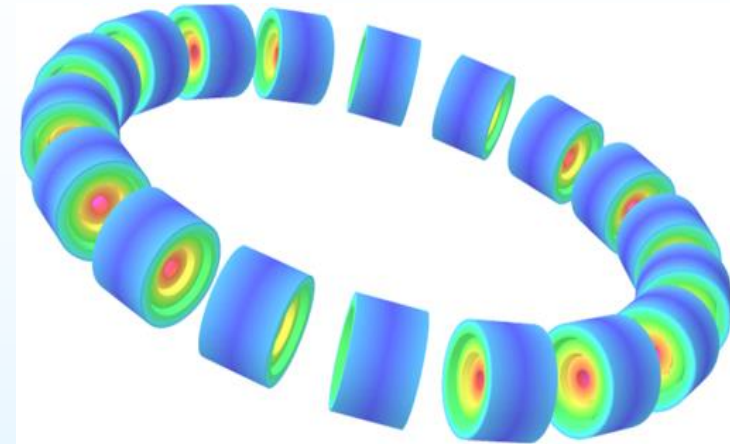
**Radiation : ~10 MGy/year**

**Large heat load environment. Stable operation with 5kW/m<sup>3</sup> at ~30 K**

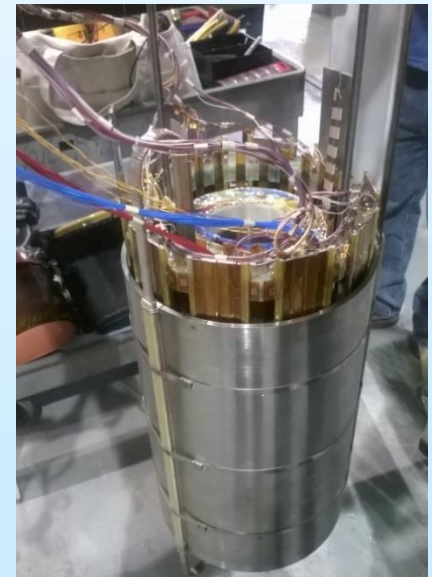
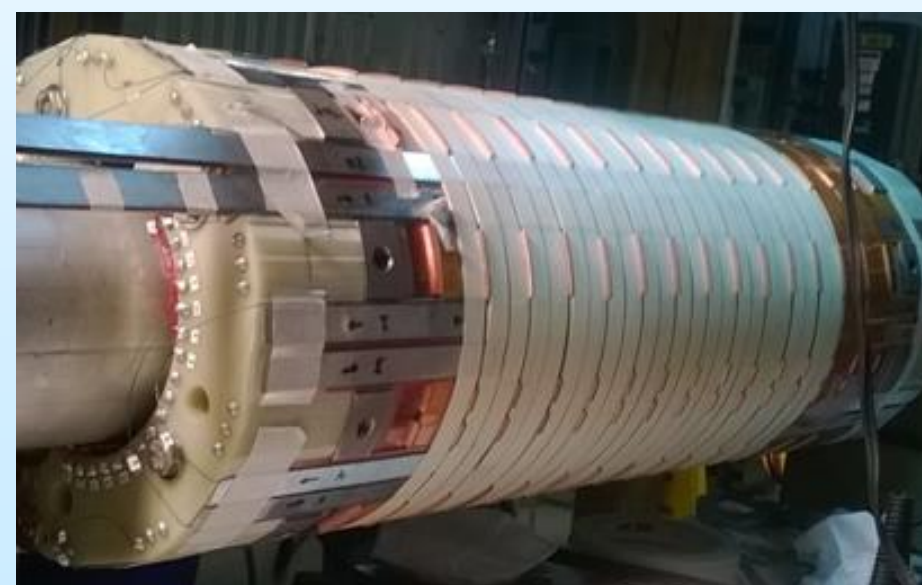




# Record HTS SMES Performance (12.5 T at 27 K in 100 mm aperture)



- High risk, high reward - funded by arpa-e
- HTS: >6 km, 12 mm wide from SuperPower
- Design field : 25 T at 4 K (12.5 T at 27 K)
- Design Hoop Stresses: 400 MPa
- Run terminated after 27 K test because of the arcing in the leads (HTS coils ok)
- ✓ **These results (12.5 T at 27 K) may be relevant to HTS magnet R&D for fusion**



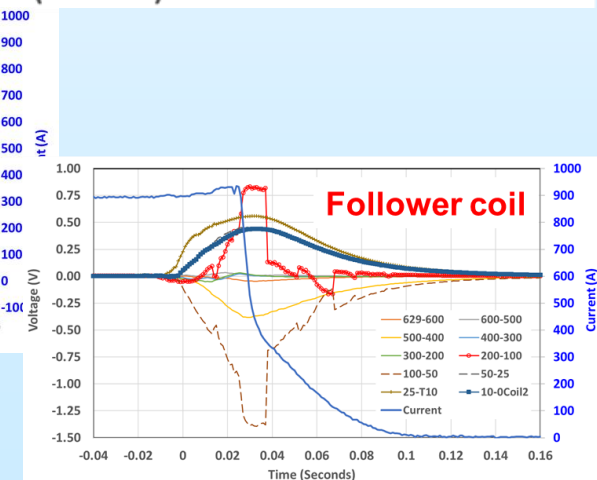
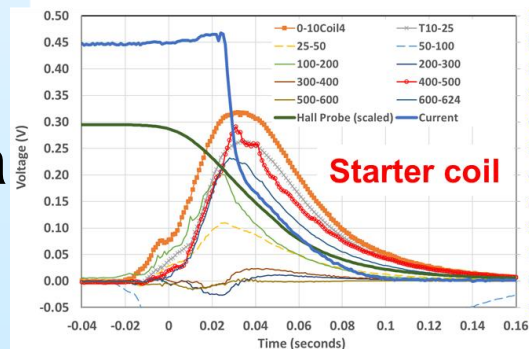
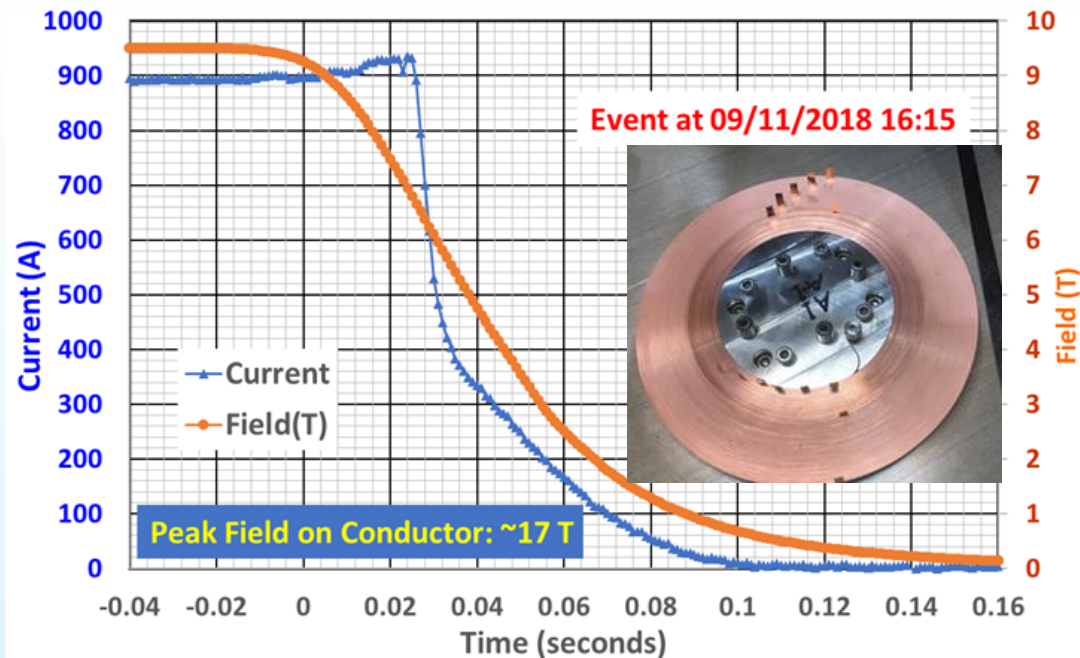
# No-Insulation Coil Technology @4K for High Field and Large Aperture

## Magnet Design

- 105 mm, 25 T design
- Hoop stresses ~480 MPa
- Conductor: SuperPower  
~6 km, 12 mm

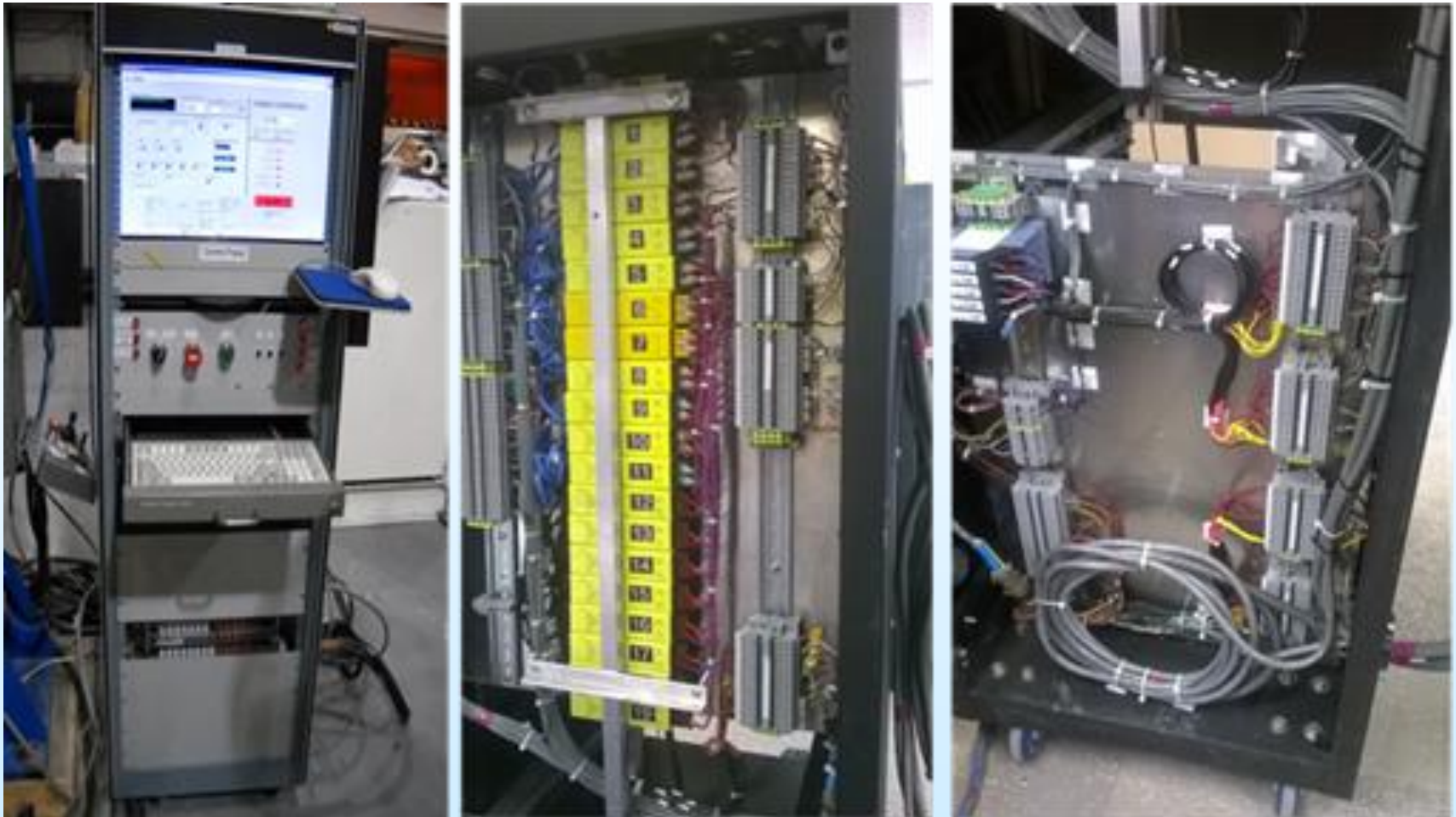
## Quench Test @4 K

- Peak field: 17 T, double  
pancake
- Hoop stresses ~400 MPa
- Several quenches
- Accident scenarios  
tested





# Advanced Quench Protection Electronics



**Detects onset of pre-quench voltage at  $< 1\text{mV}$  and with isolation voltage  $> 1\text{kV}$  allows fast energy extraction**

# Materials Irradiation & Analysis Capabilities

**Utilizes a unique combination of facilities:  
BLIP ⇒ TPL ⇒ NSLS-II**

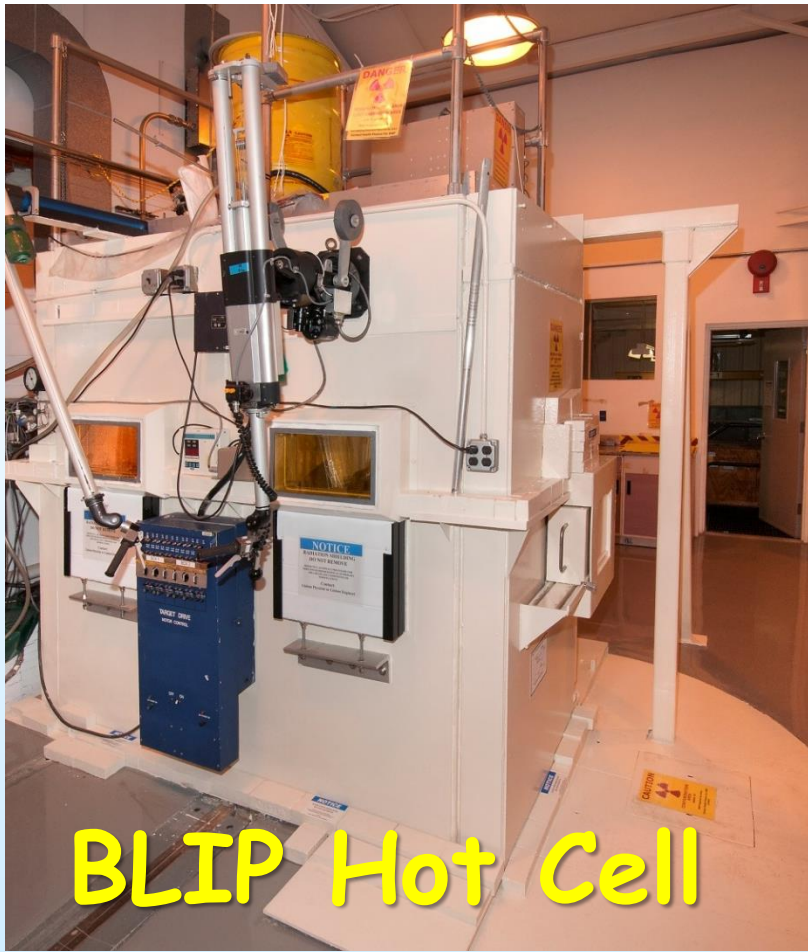
BLIP: Brookhaven Linac Isotope Producer

TPL: Target Processing Laboratory

NSLS II: National Synchrotron Light Source II



# Irradiation Facilities at BNL BLIP and NSLS-II



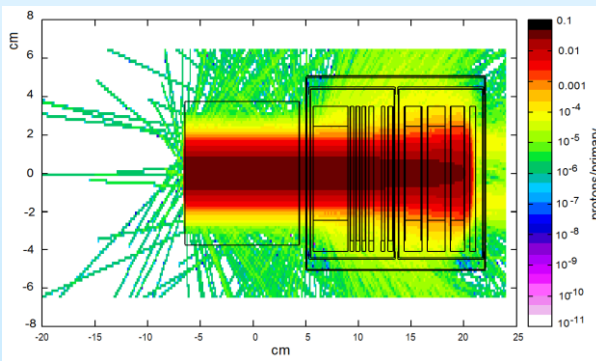
**BLIP Hot Cell**

BLIP uses 145  $\mu$ A proton beams of up to 200 MeV

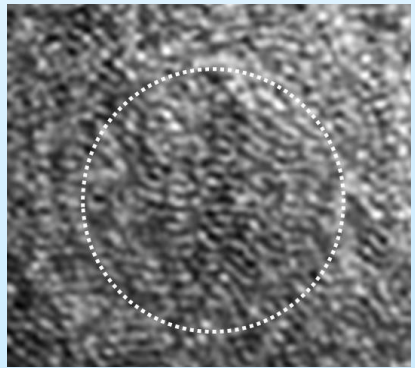


**NSLS II**

NSLS-II is a state-of-the-art 3 GeV electron storage ring



Irradiation with BNL Linac protons

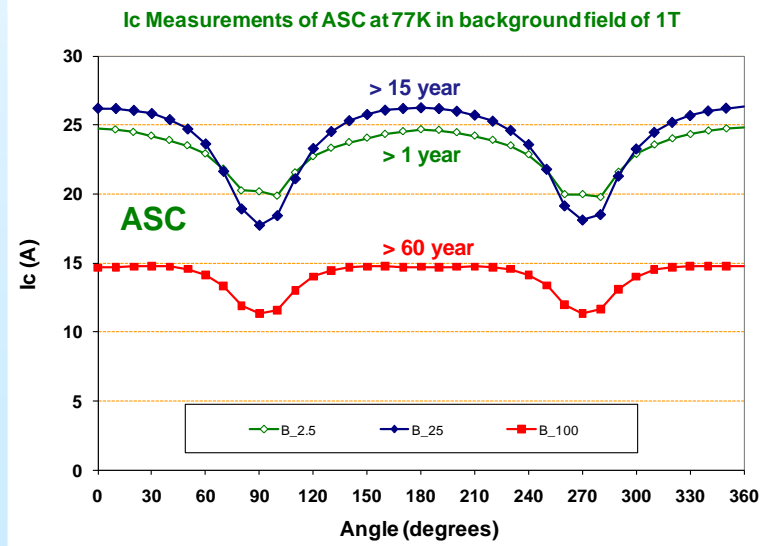
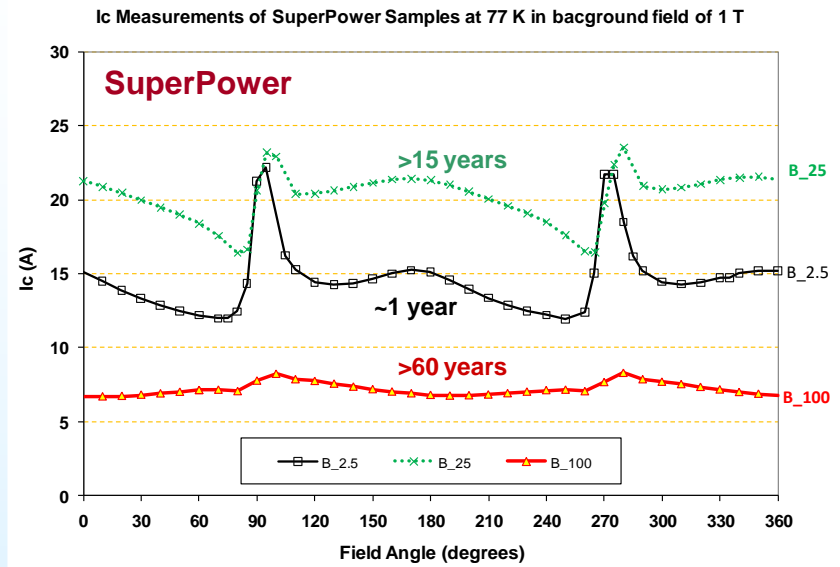
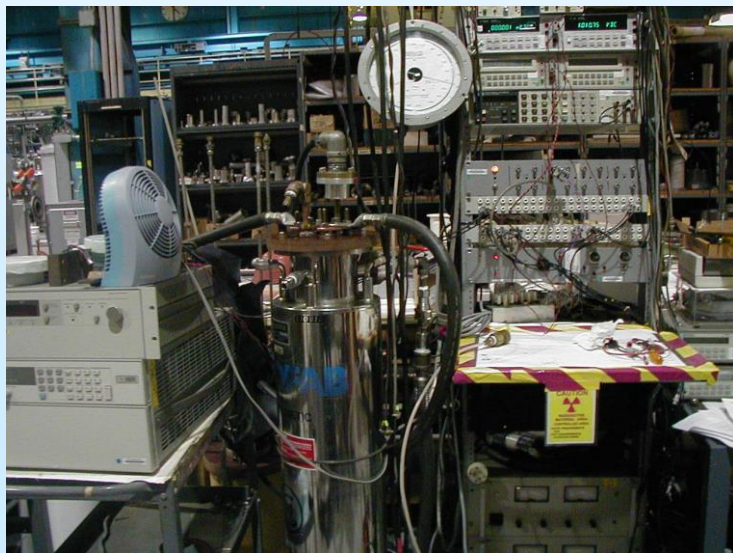
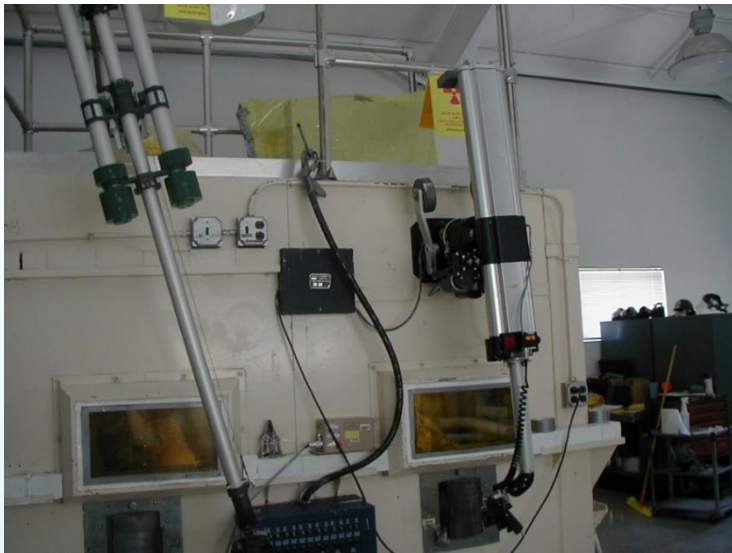


Diagnosis of Target Failure – NSLS-II

# Radiation Damage Studies at BNL from 142 MeV Protons on ReBCO Tapes for FRIB

**(77 K, 1T) Testing  
at Magnet Division**

**Irradiated at BLIP**





## Conceptual Design of MPEX Magnet System

Robert Duckworth\*, Thomas Bjorholm, Robby Hicks, Dean McGinnis, Arnold Lumsdaine, Michael Anerella, Ramesh Gupta, Joseph Muratore, Piyush Joshi, John Cozzolino, Paul Kovach, Andrew Marone, & Stephen Plate  
May 2, 2019

ORNL is managed by UT-Battelle, LLC for the US Department of Energy



MPEX Magnet Design - Partnership with Brookhaven National Laboratory utilized to address knowledge gaps in magnet design

- BNL Magnet Group worked with ORNL as strategic partner to evaluate design baseline in key areas and detailed assessment of ICH system
  - Previous experience on multiple superconducting solenoid geometries that have designed, fabricated, and commissioned.
- Areas examined for all MPEX coils
  - Axial/radial forces – all coils
  - Quench Protection – all coils
  - Current lead penetrations - ICH
  - Coil winding/mandrel construction - ICH

Goal is to have a conceptual design that identifies key issues and provide necessary information to develop effective specifications for MPEX magnet system

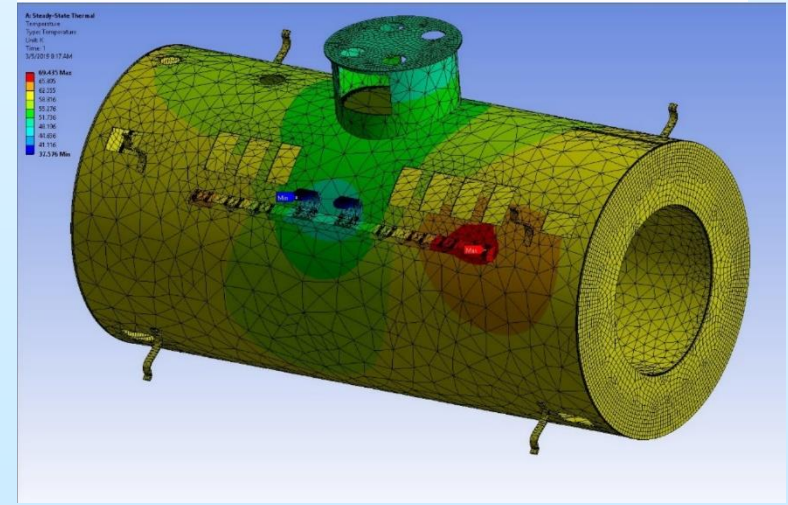
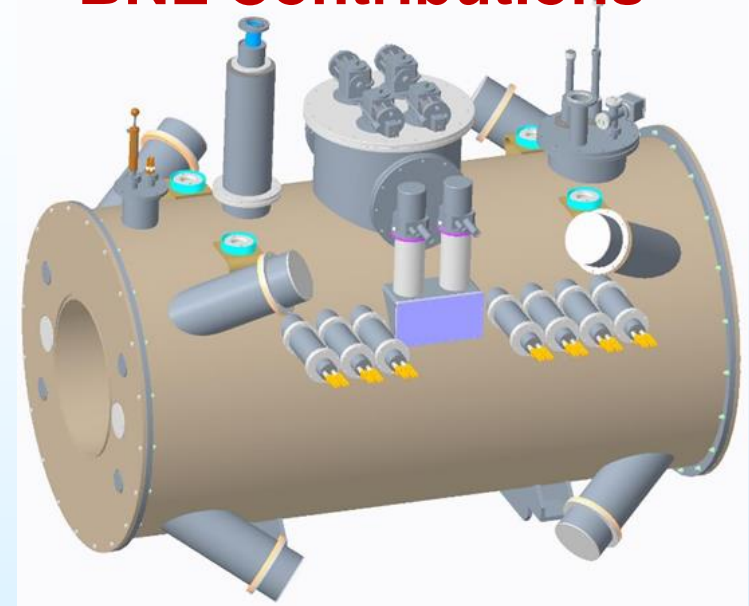


**BNL AGS Snake Magnet**  
(3 T max, 20 cm warm bore, LHe recondensing system)

MPEX magnets  
(0.2 T to 1.35 T max, 66 cm / 1.5 m warm bores, LHe recondensing system)

MPEX\_CDR\_4\_Magnets\_Duckworth\_External

## BNL Contributions



# Summary

- **BNL can help the fusion program in many ways**
- **A team of people who have worked with industry**
- **Unique experience with HTS technology**
- **Irradiation Capabilities**
- **We are looking forward to working with  
INFUSE industrial partners**