MS&T Pulsed Magnet Projects

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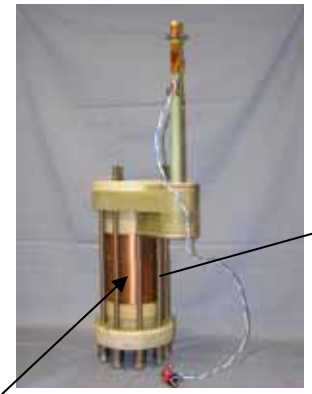
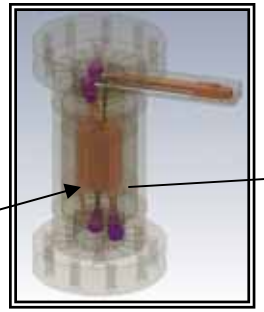
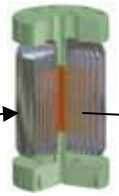


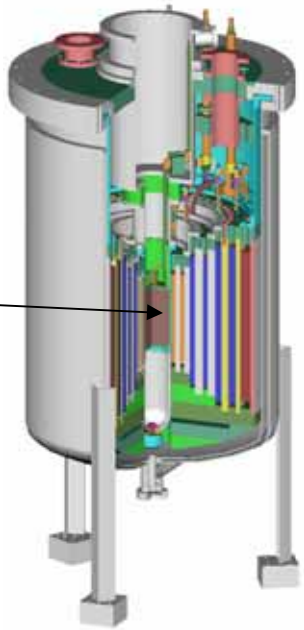
75 T Prototype



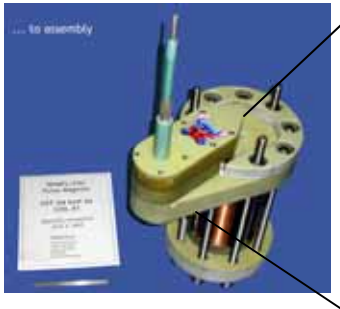
80 T Project



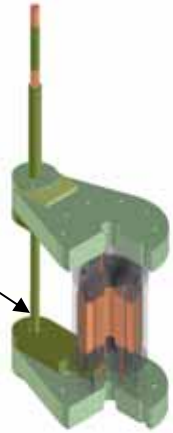
90 T Insert



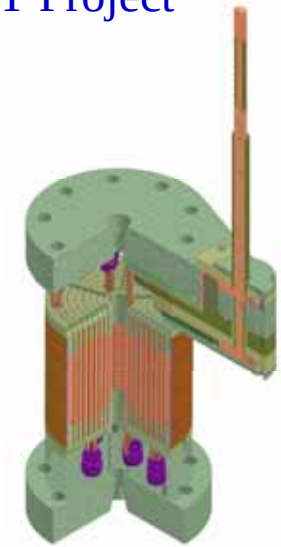
NHMFL 100 T



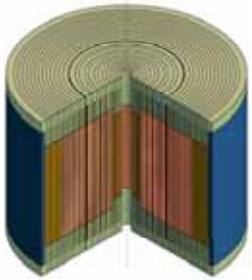
65 T Prototypes



24 mm Bore 59 T



24 mm Bore 55 T Quick Cool



60 T Midpulse

NHMFL Pulsed-Field Science Facility

User Facility Capacitor Bank

Present Configuration
1.4 MJ, 10 kV, 32 mF
4 mF/module

NHMFL Planning Upgrade
4.0 MJ, 16 kV, 32 mF
4 mF/module

Cell #4

65 T User

Cell #3

65 T User

Cell #2

50 T Mid-Pulse

Cell #1

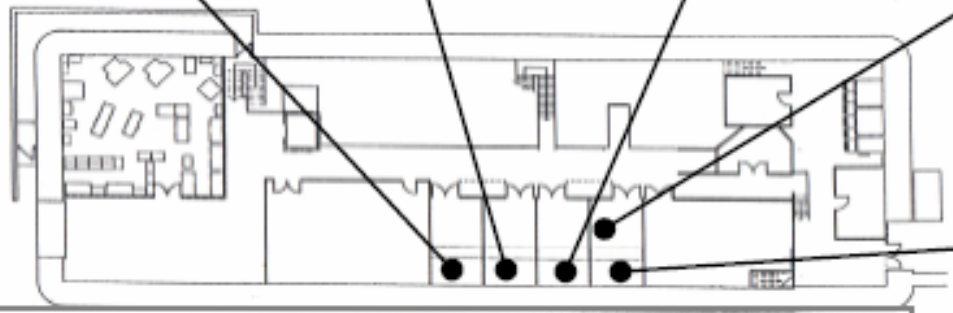
50 T Mid-Pulse

Cell #1

50 T Short-Pulse

Experimental Hall

High-Energy Experimental Hall



100T Multi-shot

60T Long Pulse

Power Supplies

RPM Power Supply & Model Magnet

100 T Capacitor Bank Now Operational

18kV, 3 modules
15.2 mF
(45.6mF/module)
16 caps/module

100 T Small Coil Program:
75 T Prototype
Started Testing

11/8/04 Passed
High Voltage
Test Protocol

NHMFL - Pulsed Groups

FOCUS
The development of the Pulsed Field Facility For Scientific Research

Capacitor Driven Pulsed Magnets

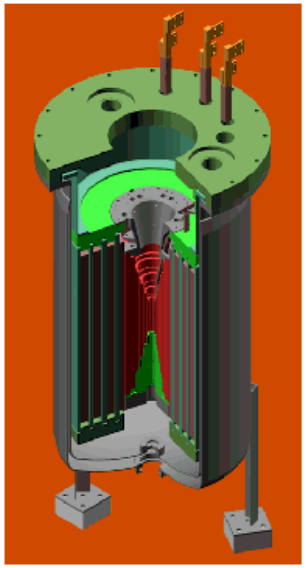
C.A. Swenson, W.S. Marshall, E.L. Miller, K.W Pickard, A.V. Gavrilin, K. Han, R.W. Walsh NHMFL-FSU

100T Insert Technology

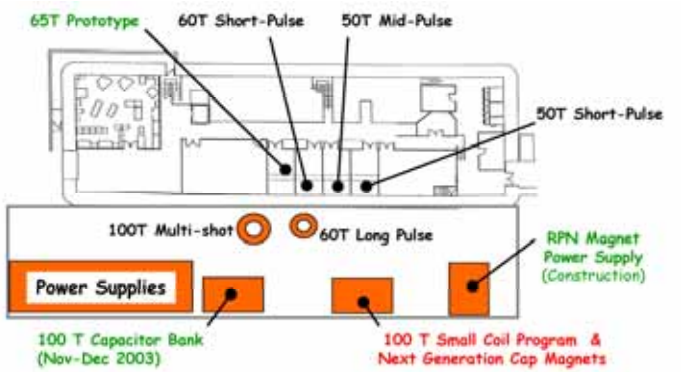
LANL Design Engineering Group

NSF 60 T Long Pulse

DOE-NSF 100 T Multi-Shot Magnet Outsert Coil Assembly



NHMFL Pulsed Field Facility



D. Rickel, P. Ruminer, C. Mielke, J. Schillig, J. Sims, A. Lacerda, and G. Boebinger NHMFL-LANL

Roadmap for Pulsed User Magnets

Goals:

1. Improve User Facility

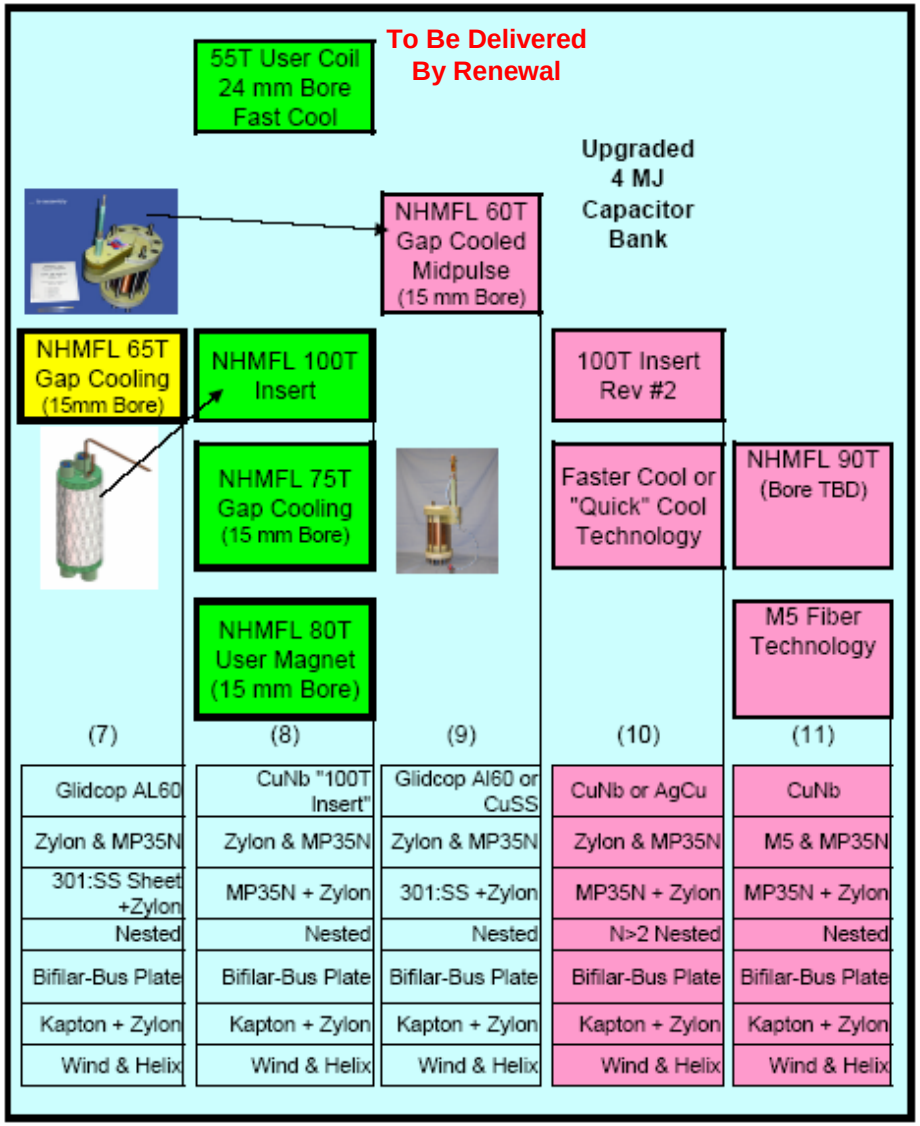
- Reliability – shot Life
- Higher fields
- Increased pulse width
- Minimum recovery time
- Minimize magnet noise

2. Develop 100 T-MS insert

- Reliability goal > 100-200 Shots

3. Structured Dialog

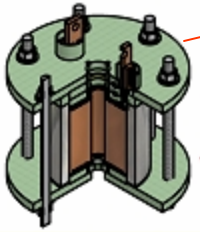
- Determine development goals based on science drivers
  - Pulsed Facility Input
  - User Community Input

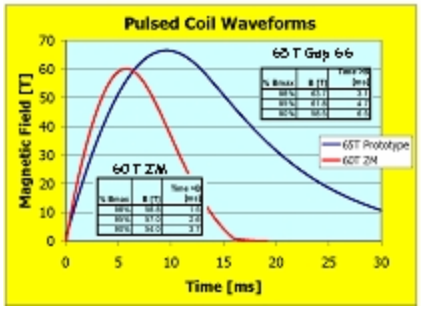


100T-MS Insert Hardware Developments

65 T Project

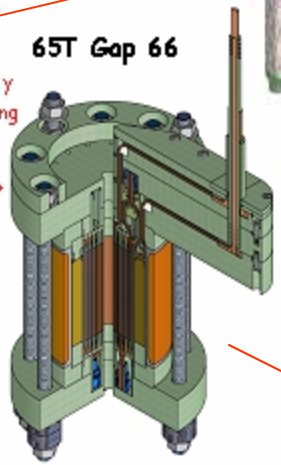
60T ZMD
E = 0.5 MJ





Reliability Engineering

65T Gap 66



Energy = 1.3 MJ

Poly-Layer Assembly Process Development

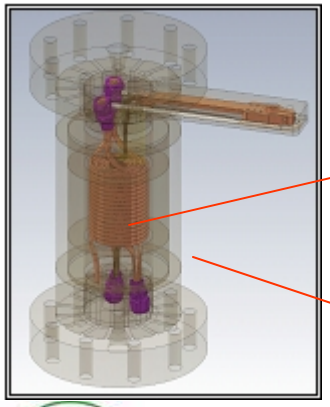
Insert Prototype Operation

65 T Project Accomplishments:

- Accumulated > 650 full field science shots on prototype #3 (Two assemblies are in operation)
- Accumulated ~ 460 full field science shots on Prototype #4 (First failure)
- Proven insert design template for CuNb work with 75T prototypes
- Operated magnets with reinforcement stress levels equivalent to operation at 95 T.
- Developed production capability.

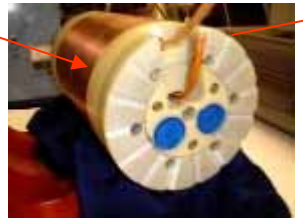
75 T Project

Design Concept



Insert Prototype CuNb Conductor

Nested Coils



75 T Prototype Assembly

75 T Project Objectives & Status:

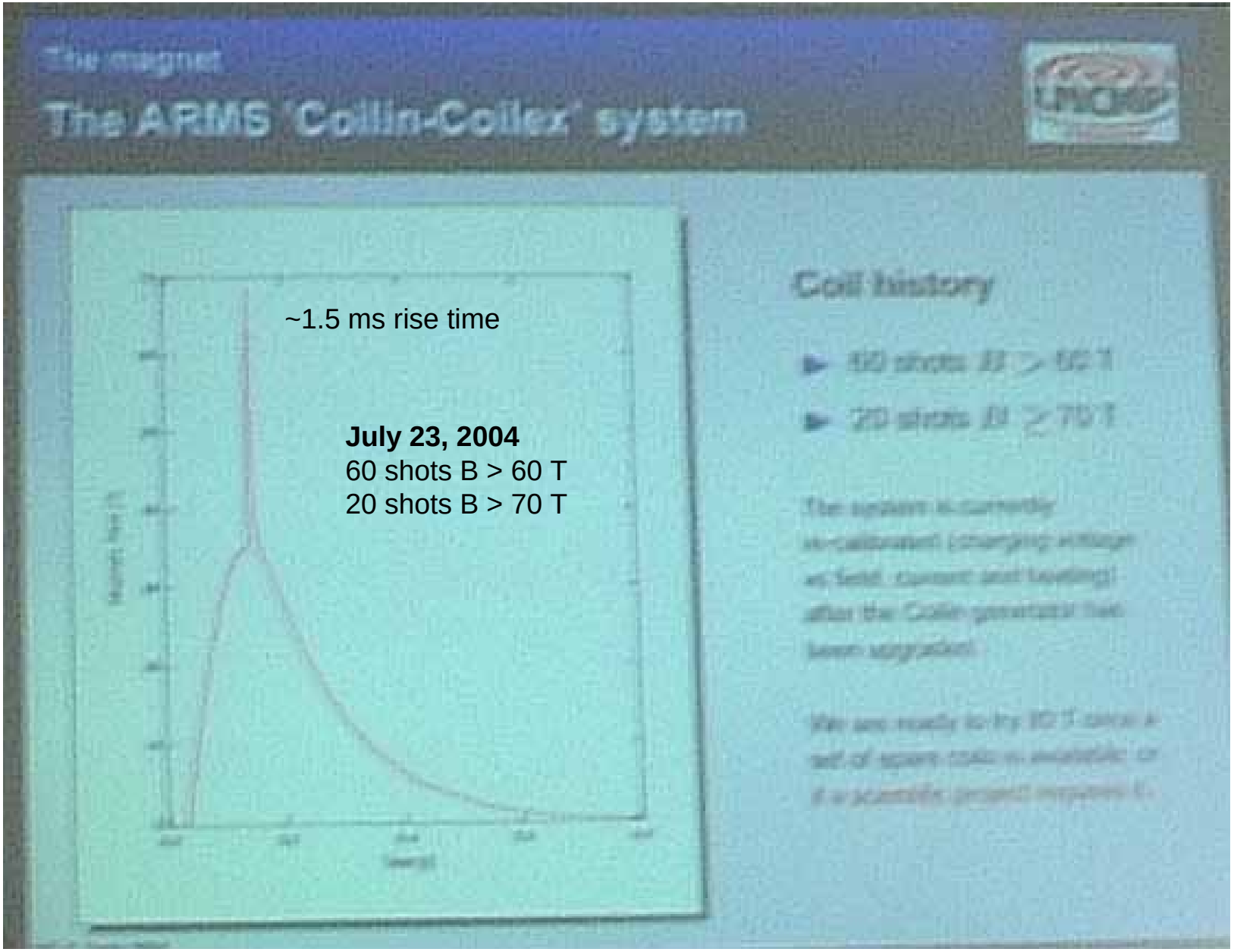
- Operational test of Bochvar CuNb wire
- Refine Poly-Layer Assembly Process
- Validate operation at 100 T stress levels
- Evaluate cryogen free operation
- Investigate high field operation

Started Testing Nov. 2004

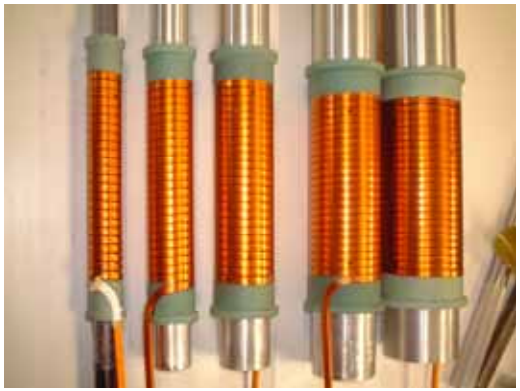
90T Insert Specifications

Coil Parameter	Attribute
Conductor	Bochvar CuNb 3.0 x 5.8 mm
Insulator	Kapton + Zylon Serving
Metal Reinforcement	2.5 GPa MP35N Alloy
Fiber reinforcement	5.0 GPa Zylon
Number of Layers	8
Turns per Layer	27
Bore	15.5 mm
Height	~ 300 mm Flange to Flange
Outside Diameter	199.5 mm
Outsert Field	43 T
Insert Field	50 T
Max Current	36.7 KA
Inductance	0.828 mH @ 20 Hz
Pulse Shape	Rise Time ~5.2 ms Decay Time ~ 8 ms
Cooling Time	~ 45 min between pulses

Insert reinforcement structure with zylon removed to illustrate metal placement

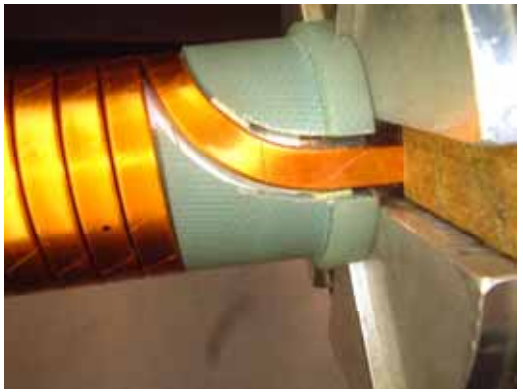

The magnet
The ARMS 'Collin-Collex' system
~1.5 ms rise time
July 23, 2004
60 shots B > 60 T
20 shots B > 70 T
Coil history

Poly-Layer Assembly Process

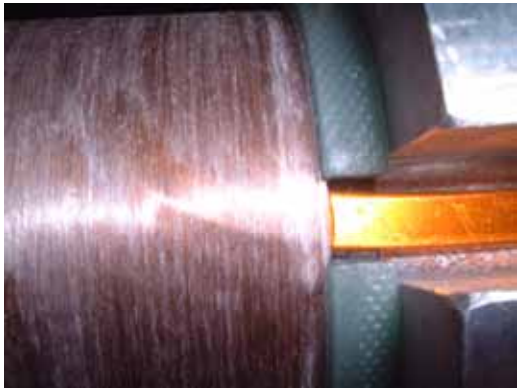


Layer Helix Coils

Winding Mandrel

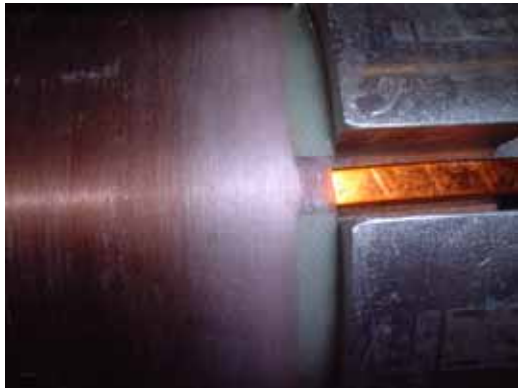


Detail End Spool



Zylon & S2 Interlayer

MP35N Sheet



Primary Zylon Reinforcement

Pulsed Magnet Upgrades

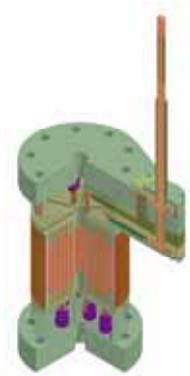
24 mm Upgrade
59T

Max Field [T]	59
Bore [mm]	24
Rise Time [ms]	9
Decay Time [ms]	11
Recovery Time [min]	25

Operates with
Existing User Bank

65 T Tooling for
Fabrication

24 mm Upgrade
55T Quick Cool

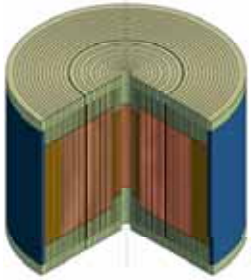


Max Field [T]	55
Bore [mm]	24
Rise Time [ms]	9
Decay Time [ms]	19
Recovery Time [min]	3

Operates with
New User Bank

Midpulse
Upgrade

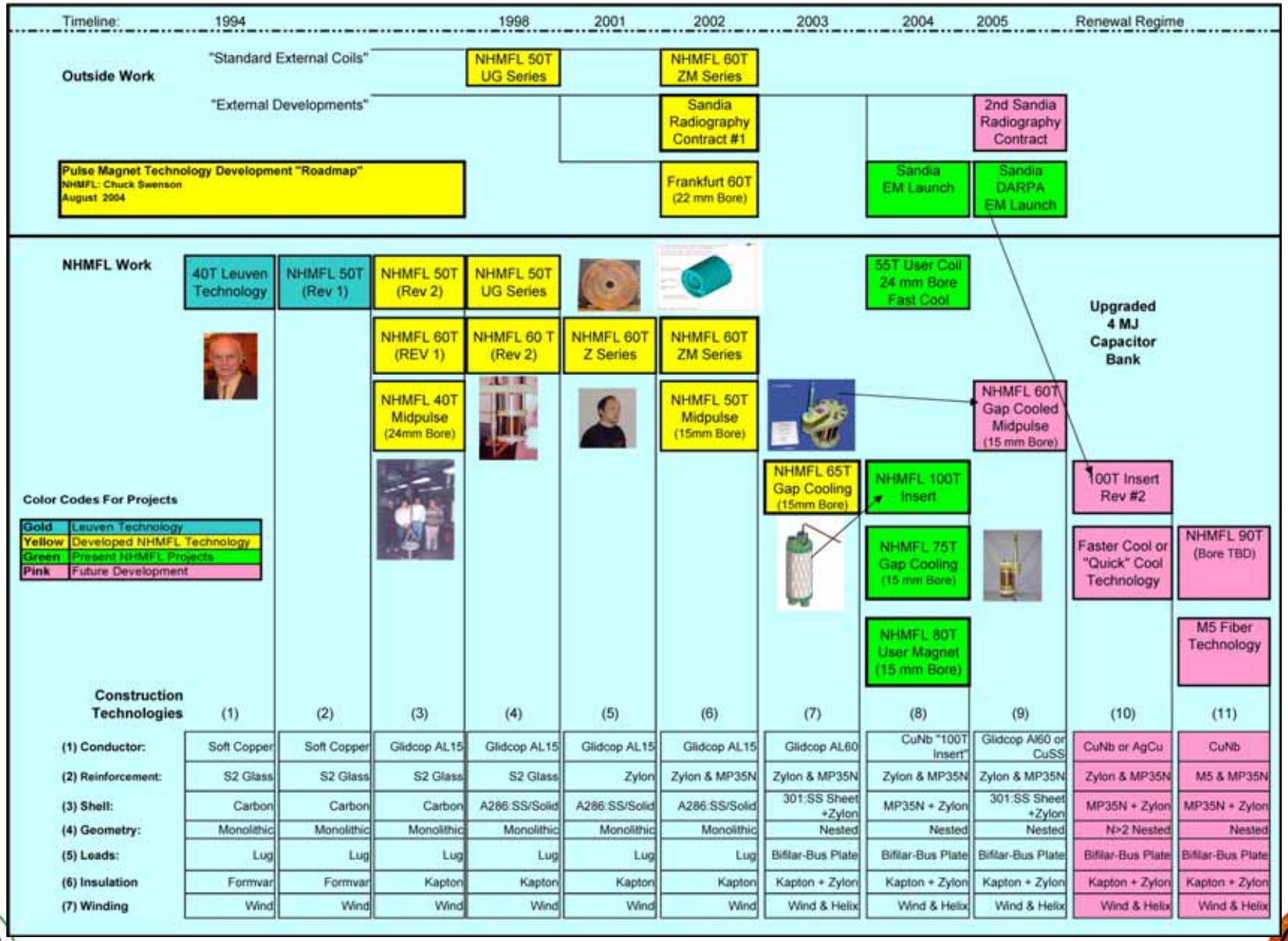
60 T



Max Field [T]	60
Bore [mm]	15
Rise Time [ms]	~ 35 -38
Decay Time [ms]	57
Recovery Time [min]	> 60

Operates with
New User Bank

Entire Roadmap for Pulsed Magnets



External Pulsed Magnet Collaborations

Projects	Funding Organization	Location	Year	Status
60 T Science Coils *	Institut für Festkörper- und Werkstofforschung	Dresden, Germany	2001	Completed
Sandia Radiography	Sandia National Laboratories	Albuquerque, NM	2002	Completed
55 T LV-Prototype	Physikalisches Institut, Johann-Wolfgang-Goethe Universität	Frankfurt, Germany	2002	Completed
Sandia LDRD EM Launch**	**Sandia National Laboratories**	**Albuquerque, NM**	**2004**	**Y1 Completed**
Sandia LDRD EM Launch**	Sandia National Laboratories	Albuquerque, NM	2005	Y2 Funded
Sandia DARPA**	DARPA & Sandia National Laboratories	Albuquerque, NM	2005	Funded

*** First observation of pulsed NMR made by Hasse in a NHMFL pulsed magnet at IFW Dresden.**

**** This activity is a team collaboration between the NHMFL, Sandia, and Los Alamos ESA-WDS**

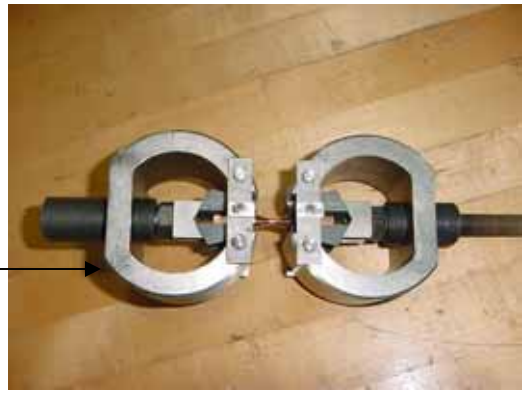
Collaborations Support Materials Testing and Development

- MP35N material developed
  - Mechanical Properties: UTS 2.5 GPa, 77 K Mod 226 GPa

- CuNb conductor program now starting coil testing. (Nov 2004)
  - Developed compressive cyclic fatigue apparatus and analysis methodology to evaluate risk. Now Standard!
  - Structuring Procurements for Both User & 100 T Programs

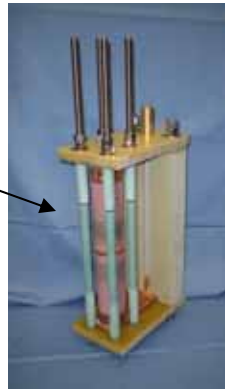
- Composites program underway. (Sandia Collaboration)
  - Performed Tensile Fatigue Lifetime Measurements on zylon composite. (10,000 Cycles @ 3.5 GPa Achievable.)
  - RT Mechanical Properties: UTS ~5.2 GPa, Mod ~215 GPa
  - Plan to study new M5 fiber
  - New tooling for evaluation of improved materials.

- Developing reinforcement test coils for lifetime measurement
  - Experiments to measure strain and conductor lifetime
    - **Thermal Cycle (77 K – 400 K)**
    - **Electric fields**
    - **Magnetic fields**
    - **Mechanical Stress**
    - **Strain (~ 1% - 2 %)**



Cyclic Fatigue Fixture

Zylon Tensile Test Form

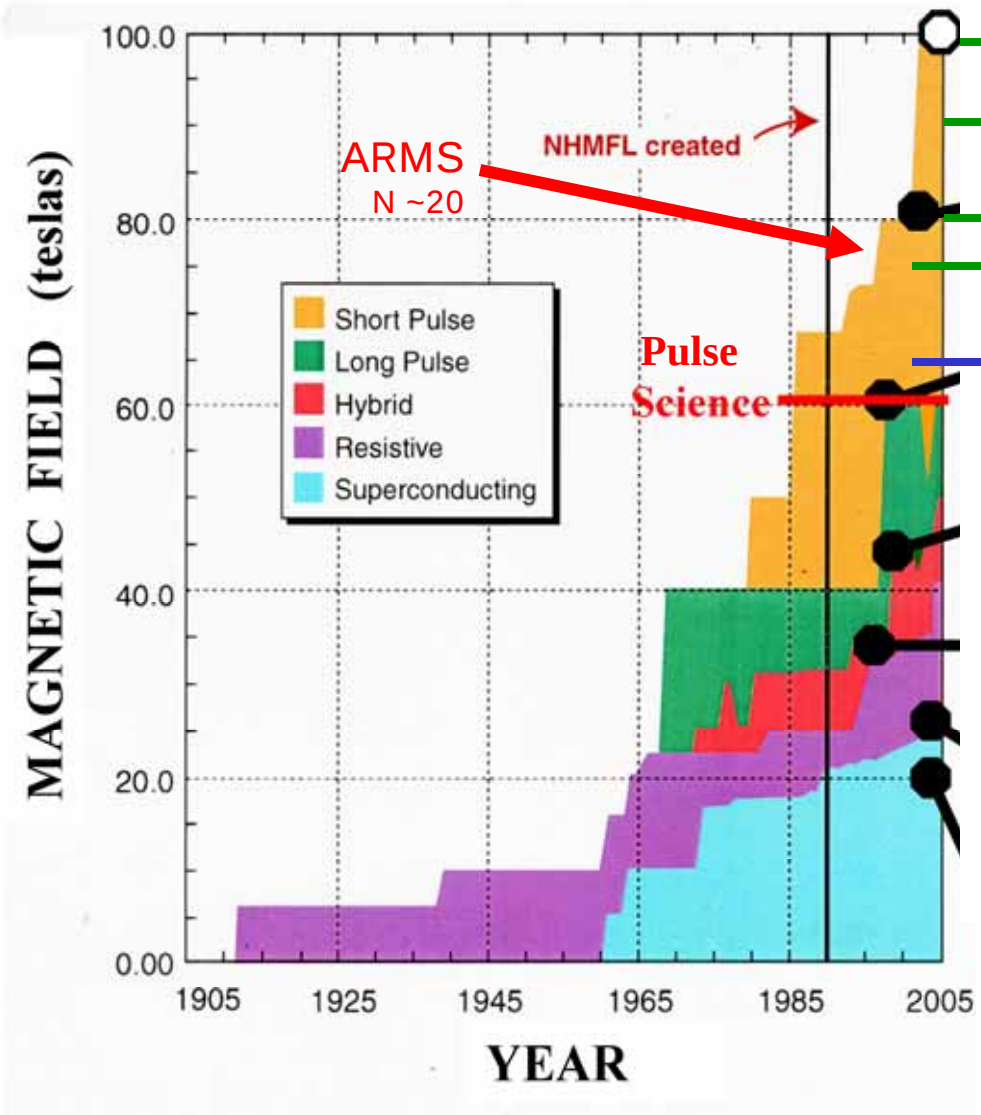


RPM Test Assemly

Reality

USER SCIENCE FIELDS HAVE INCREASED TO 65 T

There are significant challenges associated with high fields!



Our WORK

100 T Insert

90 T Insert

80 T Limit Study

75T CuNb Study

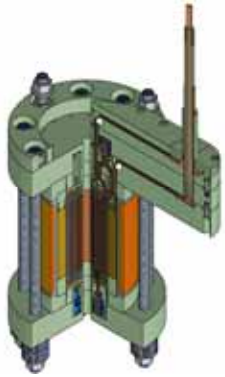
65T: P3: N > 650
P4: N = 460

Concurrent

Development Programs Increased SCIENCE Fields

This Involves EFFORT

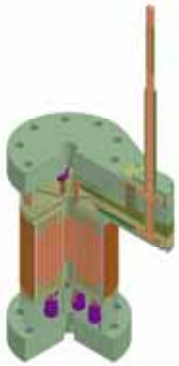
Conclusions



65T

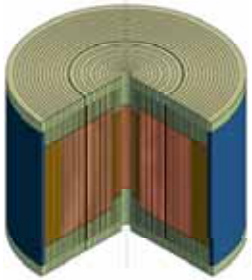
- Upgrading user magnets with new design templates
  - **Logical Progression:** **65 T, 70 – 75 T, 80 T, 100T Insert**
- Improving science opportunities at pulsed user facility
- Successfully structuring well funded external collaborations within U.S. National Labs
- Collaborations support our technical base and improve pulsed technology for user magnets
- Identifying upgrade options for new user bank

24 mm Upgrade

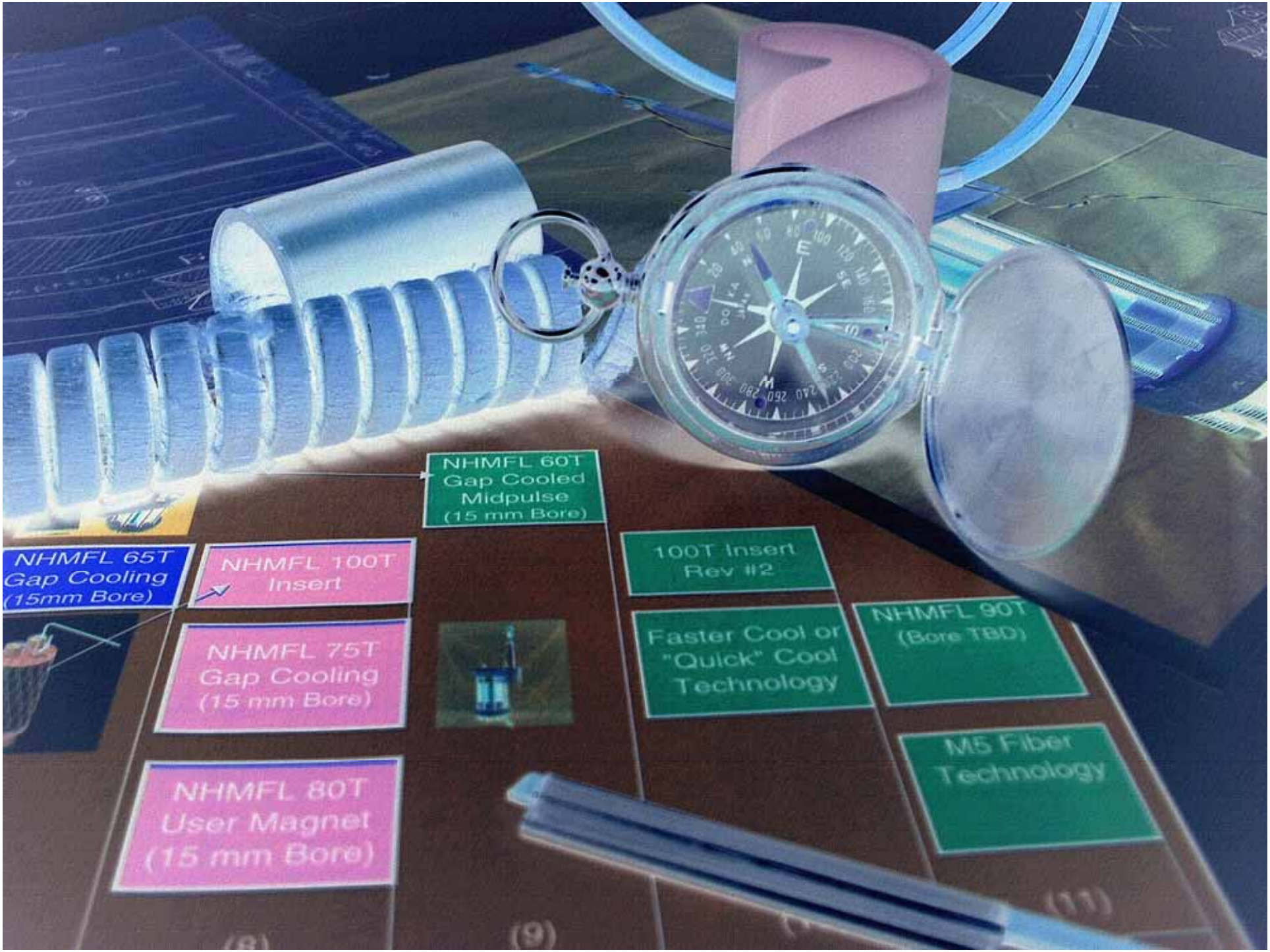


Quick Cool

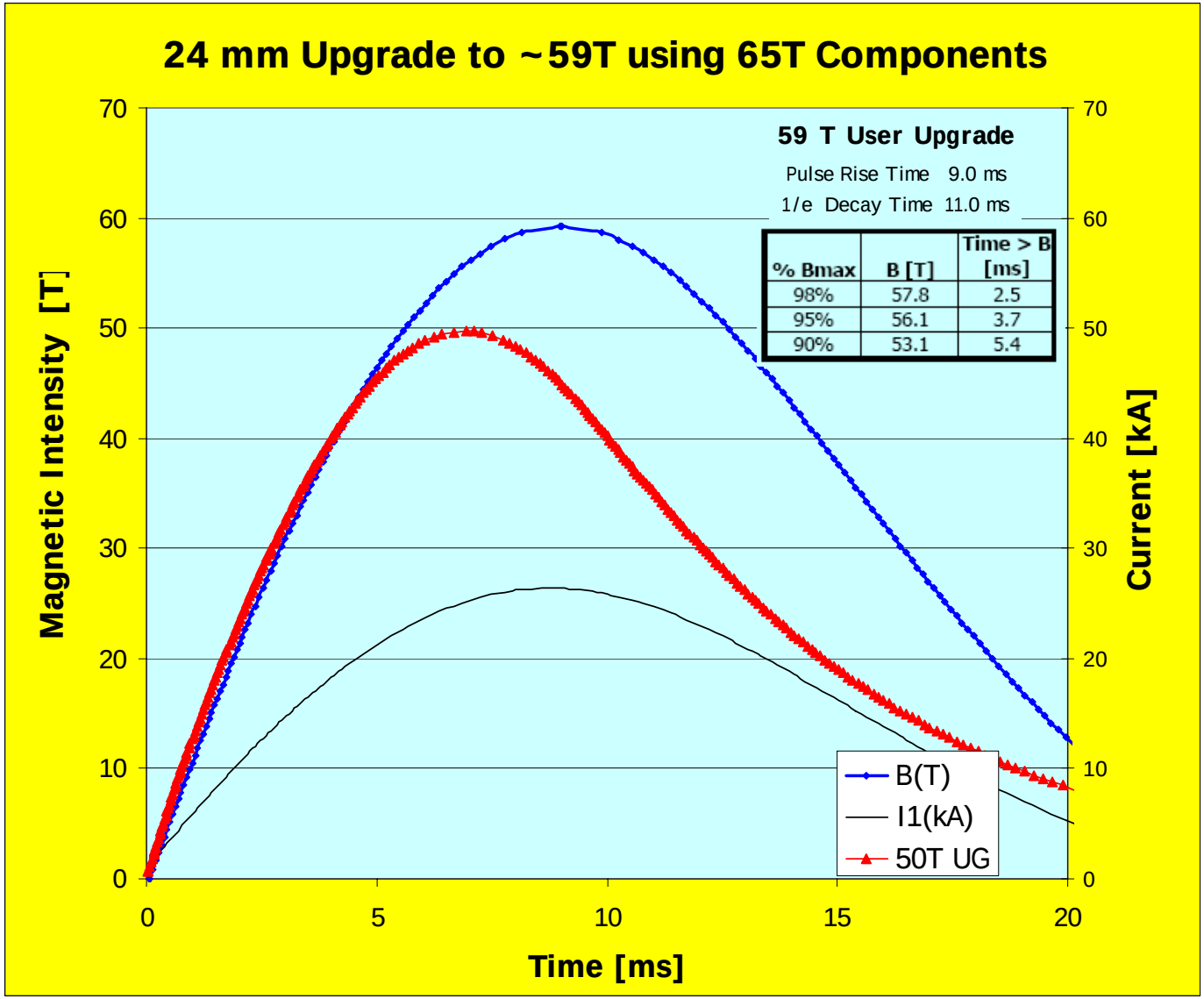
Insert

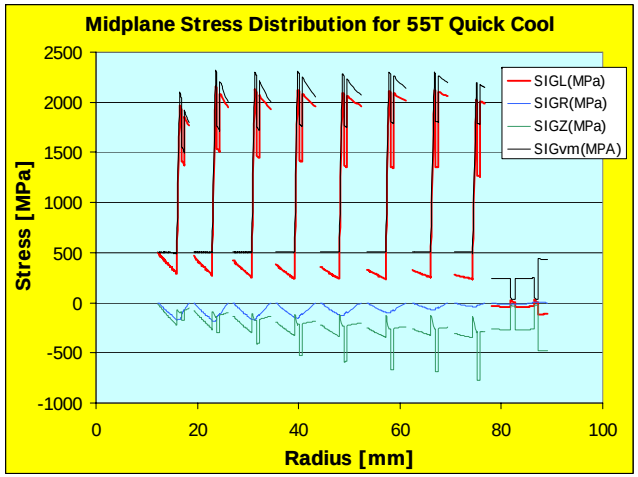


Midpulse

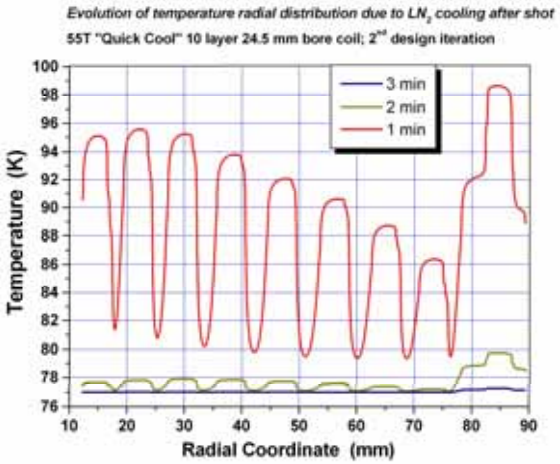

NHMFL 60T
Gap Cooled
Midpulse
(15 mm Bore)
NHMFL 65T
Gap Cooling
(15mm Bore)
NHMFL 100T
Insert
100T Insert
Rev #2
NHMFL 75T
Gap Cooling
(15 mm Bore)
Faster Cool or
"Quick" Cool
Technology
NHMFL 90T
(Bore TBD)
M5 Fiber
Technology
NHMFL 80T
User Magnet
(15 mm Bore)
(9)
(11)

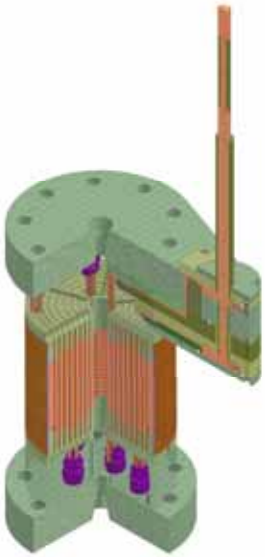
59T Gap 5-6
Fast Cool
Al60 Conductor



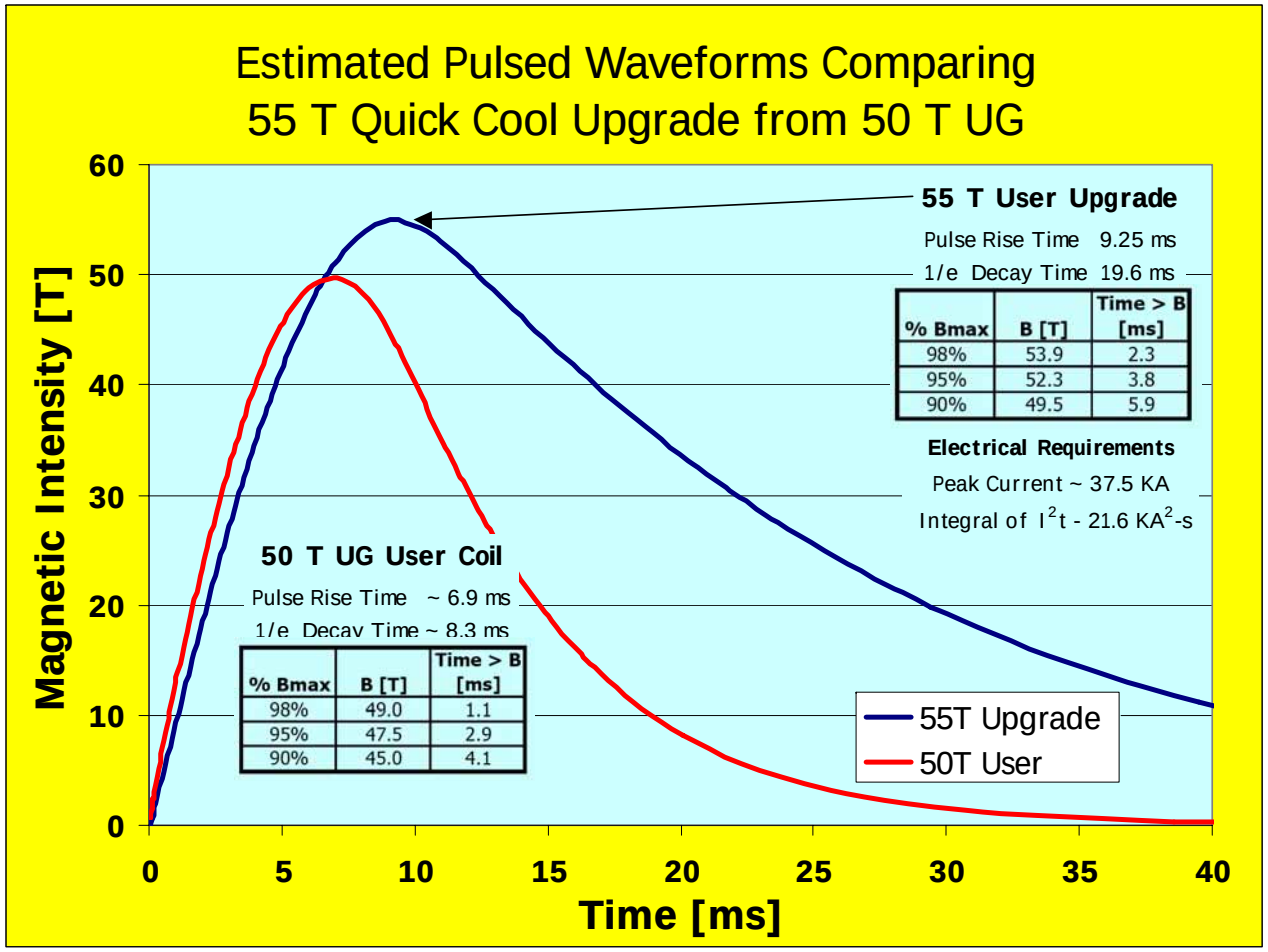


Quick Cool Windings AL15

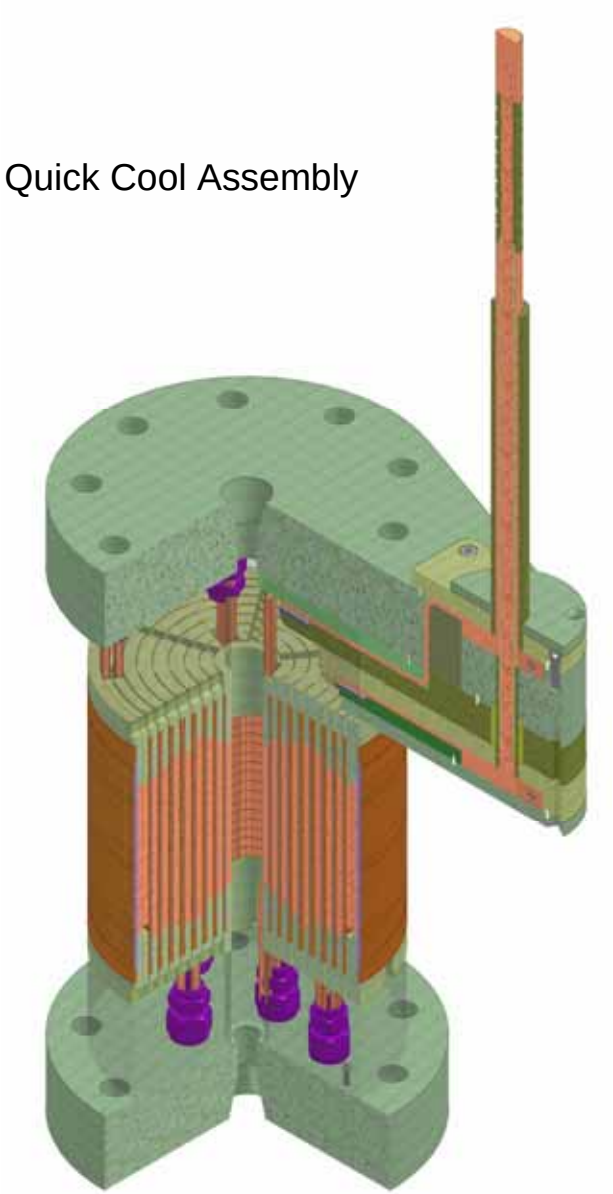


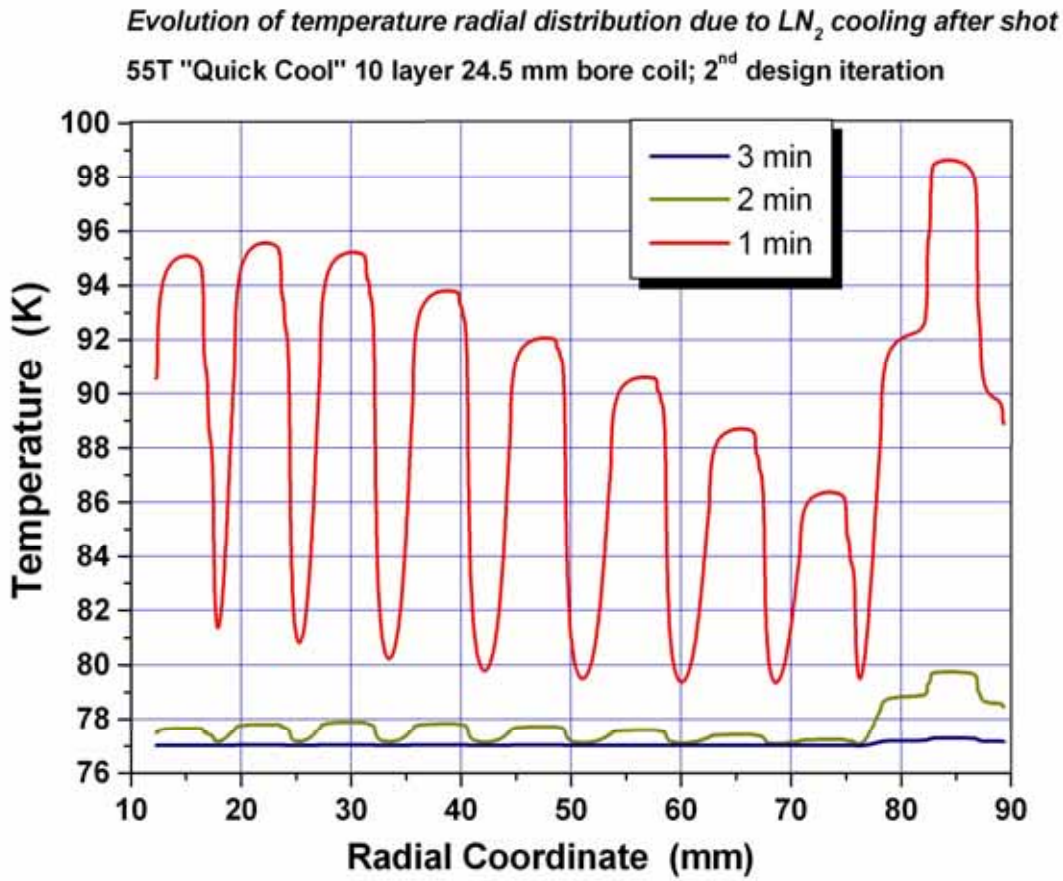


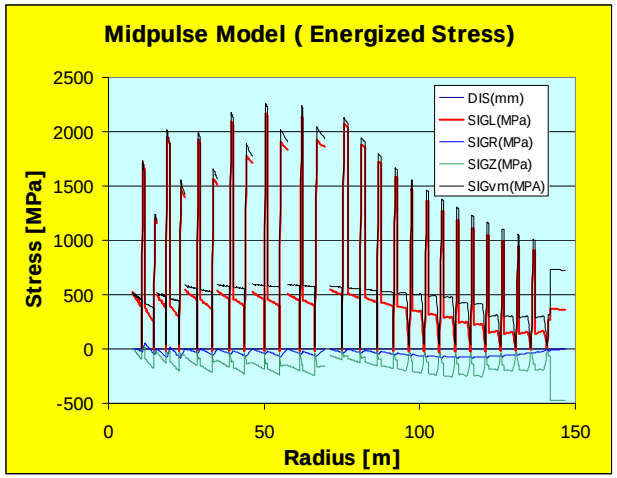
Quick Cool Assembly

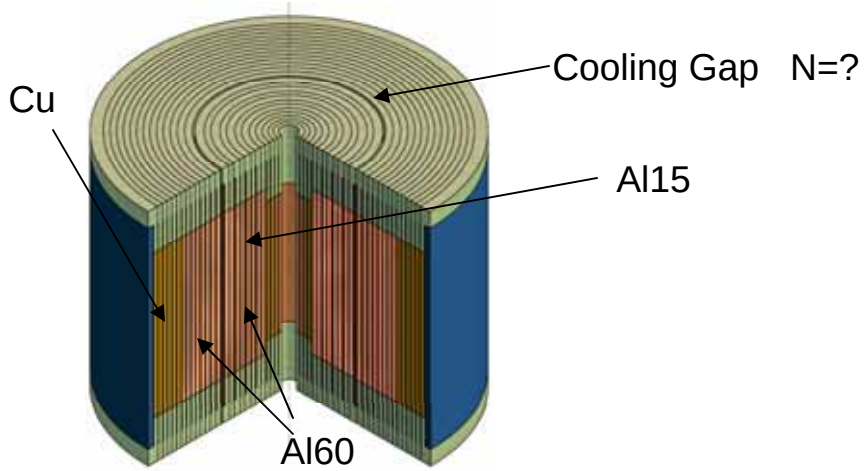


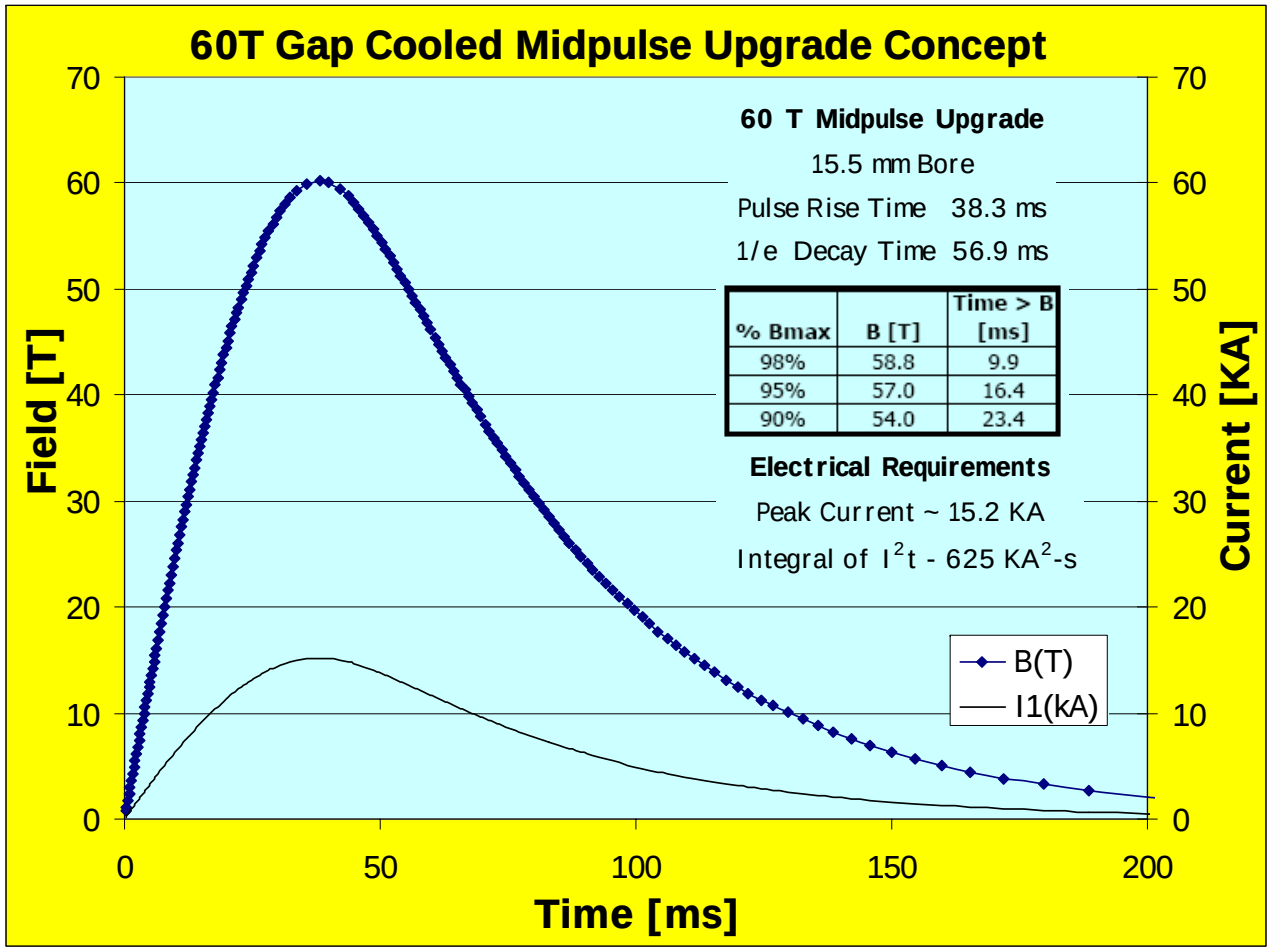
Quick Cool Assembly






Midpulse Model (Energized Stress)
Stress [MPa]
Radius [m]
DIS(mm)
SIGL(MPa)
SIGR(MPa)
SIGZ(MPa)
SIGvm(MPA)
2500
2000
1500
1000
500
0
-500
0
50
100
150


Cu
Cooling Gap N=?
Al15
Al60


60T Gap Cooled Midpulse Upgrade Concept
Field [T]
Current [KA]
Time [ms]
0
10
20
30
40
50
60
70
0
50
100
150
200
60 T Midpulse Upgrade
15.5 mm Bore
Pulse Rise Time 38.3 ms
1/e Decay Time 56.9 ms
% Bmax | B [T] | Time > B [ms]
98% | 58.8 | 9.9
95% | 57.0 | 16.4
90% | 54.0 | 23.4
Electrical Requirements
Peak Current ~ 15.2 KA
Integral of I²t - 625 KA²-s
B(T)
I1(kA)

Commercial Product

Zylon - PBO

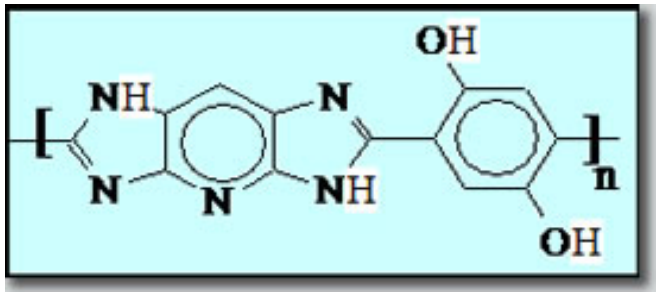
poly(p-phenylene-2,6-benzobisoxazole)(PBO).

Fiber Modulus	280 GPa
Fiber UTS	5.8 GPa
Packing Fraction	90% - 95%
Composite Hoop Modulus	200 GPa – 220 GPa
Composite UTS	5.2 GPa

Industrial Development

M5 - PIPD

Poly(diimidazo pyridinylene (dihydroxy) phenylene) (PIPD)



Fiber Modulus	350 GPa	450 GPa
Fiber UTS	5.8 GPa	~7 GPa
Packing Fraction	65% - 70%	65% - 70%
Composite Hoop Modulus	~250 GPa	~ 300 GPa
Composite UTS	~4.2 GPa	~5 GPa