BNL Pulsed Magnet

Magnet System Cooldown and Structural Analyses
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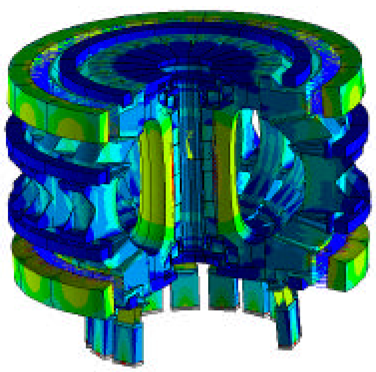
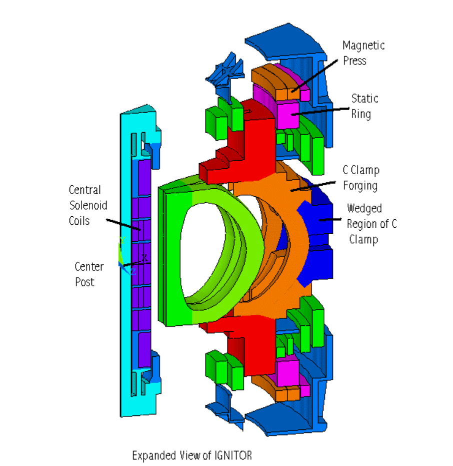
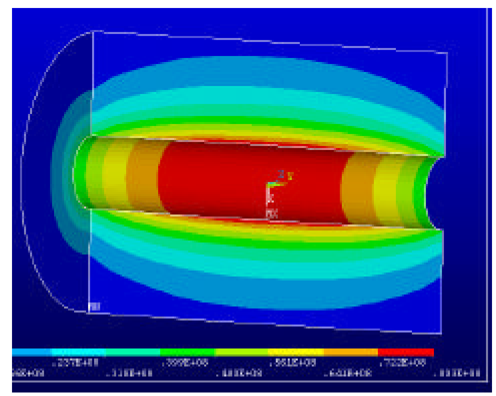
The Collaboration is Useful with Other PSFC Projects:



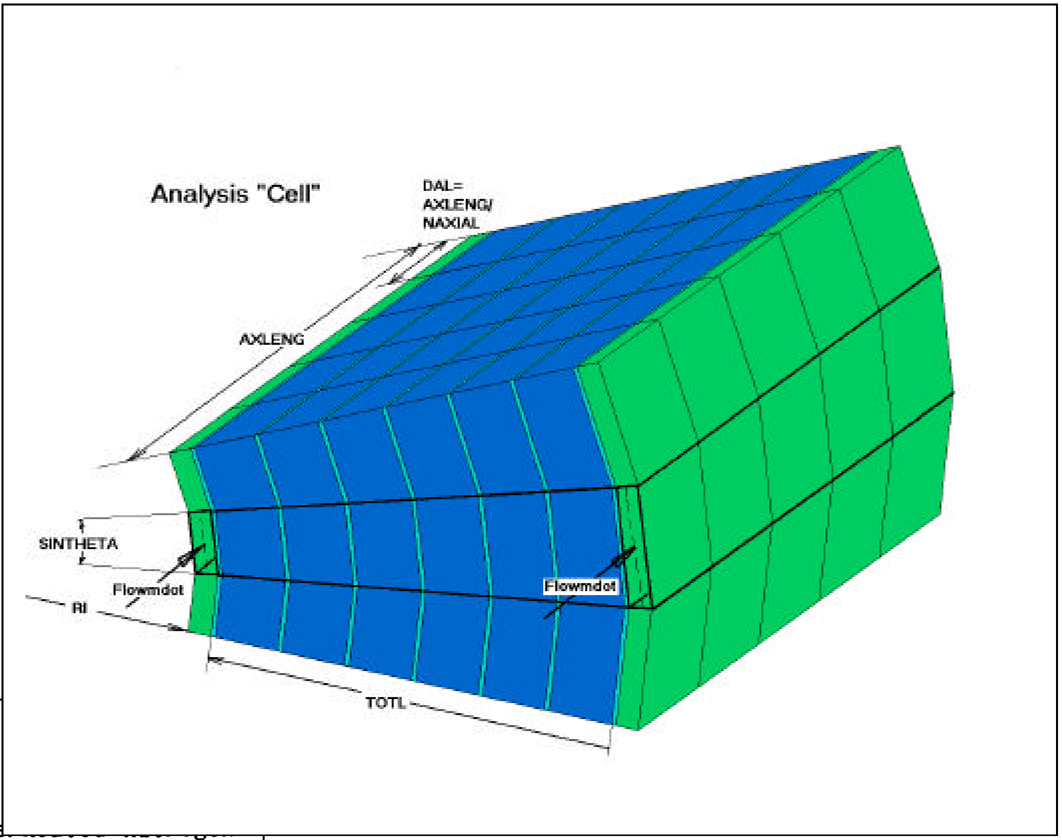
FIRE – Preconceptual Design and Snowmass Review. Inertially Cooled Be Copper , LN2 Cooling Between Shots, with a Helium Purge to Limit Activation



IGNITOR – Snowmass Review. - Inertially Cooled Copper , 30K He Gas Cooled Between Shots



BNL Pulsed Magnet –Inertially Cooled , 30K He Gas Cooled Between Shots



2.1.3 Convective Heat Transfer

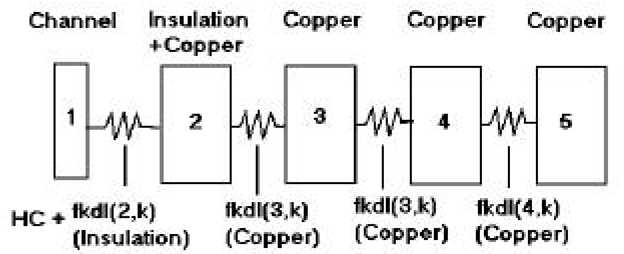
It is important to estimate how much heat the supe

gas (T > 77 K) could absorb before exiting the cooling channel. The convective heat transfer coefficient, h, could be obtained from[9]

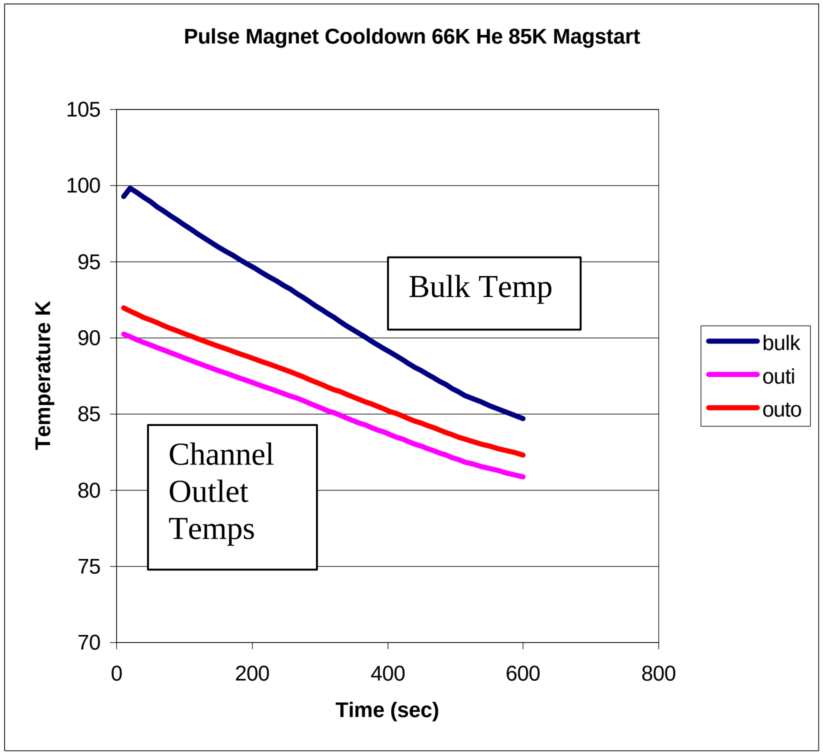
$$h = \frac{KNu}{D_e} = \frac{0.023Re^{0.8}Pr^{0.4}K}{D_e} \quad . \qquad (14)$$

This coefficient is about 21×10^{-3} W/cm^2 K at a vapor temperature of 200 K, vapor velocity of 40 m/s, and hydraulic diameter of 2 cm. It drops to 17×10^{-3} W/cm^2 K at a vapor temperature of 100 K, keeping the mass flow rate constant. It is interesting to note that the heat transfer coefficient for film boiling at 200 K from Fig. 4 is about 12×10^{-3} W/cm^2 K, which partially justifies the third assumption in Sect. 2.1.

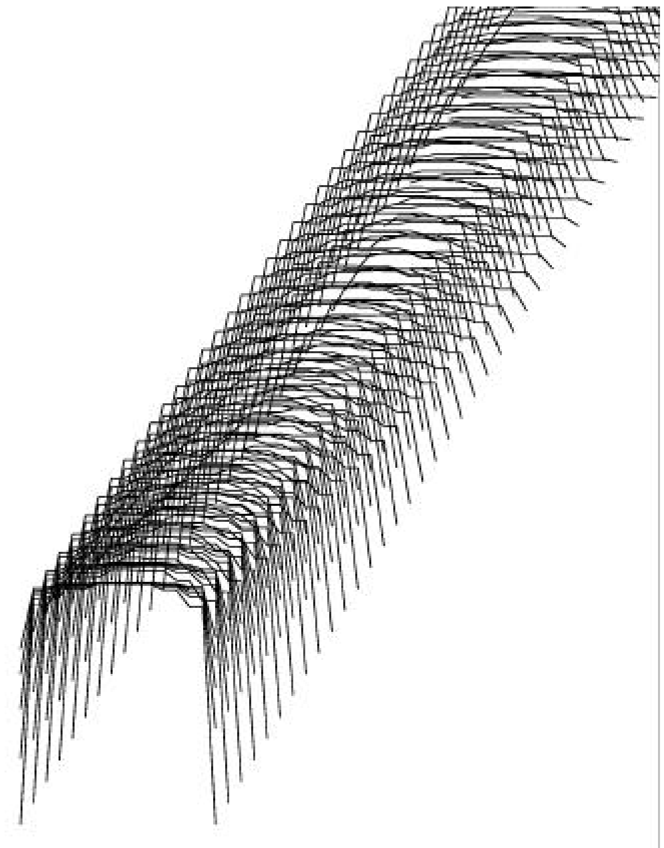
excerpt from: ORNL/FEDC-85-10 Dist Category UC20 c,dated October 1986



Channel Edge Thermal Model



66K inlet temperature, Time Step =.0001 sec – 100 K after Pulse Temp, The bulk temp is computed at a mid -axial slice. Time to 85K is about 600 sec or 10 min. Exclusive of time to flatten temp distribution.

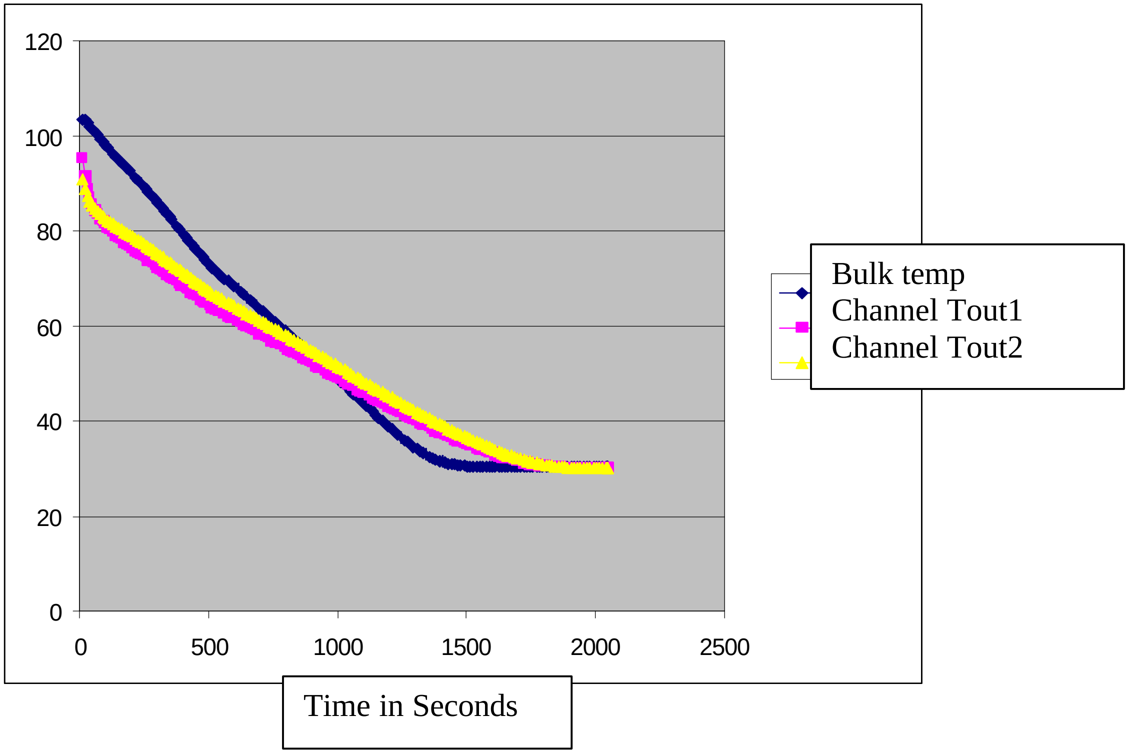


"Cell " Temperature profiles. Time is diagonally to the right. “Bunched” lines represent the axial temperature distribution.

Present Operational Scenarios:

Case #	Peak Field	T after pulse	T coolant	Start Bulk Temp	Guestimated Time
1	5T	90K	66K	84K	~200 sec
2	10T	96K	66K	74K	~800 sec
3	15T	78K	22K	30K	~1500 sec

30K Coolant, Cooldown from 100K



Bulk Temp Is Computed Mid Axial Build - It Bottoms out before the down stream end.

tout 1 and tout2 are Outlet Temperatures

Analyses to date: Time to target bulk temp. ½ inch Copper Conductor, 100K ,

	T after pulse	T coolant	Cond Layers	Time to 85K sec	Time to 30K sec
Equiv 5 Kapton .001in wrap	100K	66K	6 layers	600	
Equiv 5 Kapton .001in wrap	100K	66K	8 layers	>850	
Equiv 3 Kapton .001in wrap	100K	66K	8 layers	450	
Equiv 5 kapton .0001in wrap	100K	30K	6 Layers		2000

Coil Stress Estimate

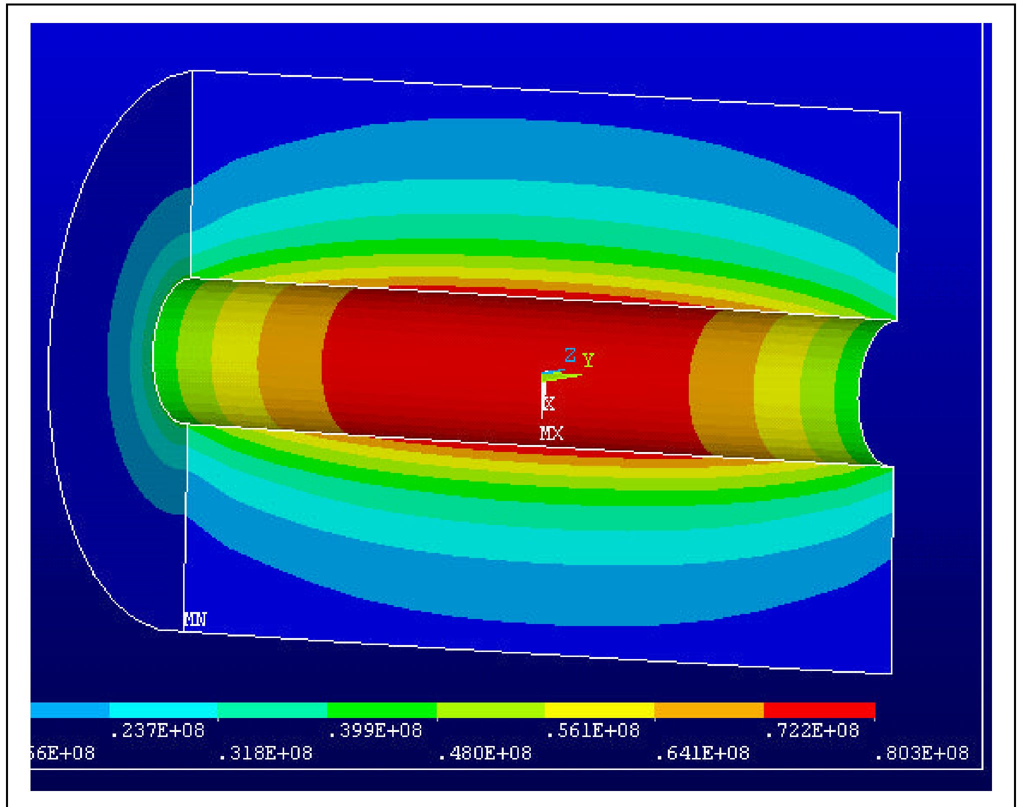
R	z	dr	Dz
.20425	0	.2415	.97

Stresses for this coil, MPa:

Field	Smeared Hoop	Smeared VM
10T	80.3	82.6
15T	180.7	186

Stresses for this coil with .85 packing fraction, MPa:

Field	Smeared Hoop	Smeared VM
10T	94.5	97.2
15T	212.8	218.8



Interpolated values:, Work hardened copper-, OFHC c10100 60% red

temp deg k	77	90	100	125	150	200	250	275	292
yield	374	369.	365.	356.	347.	328.	317.	312.	308.
ultimate	476.	466.	458.	439.	420.	383.	365.	356.	350.

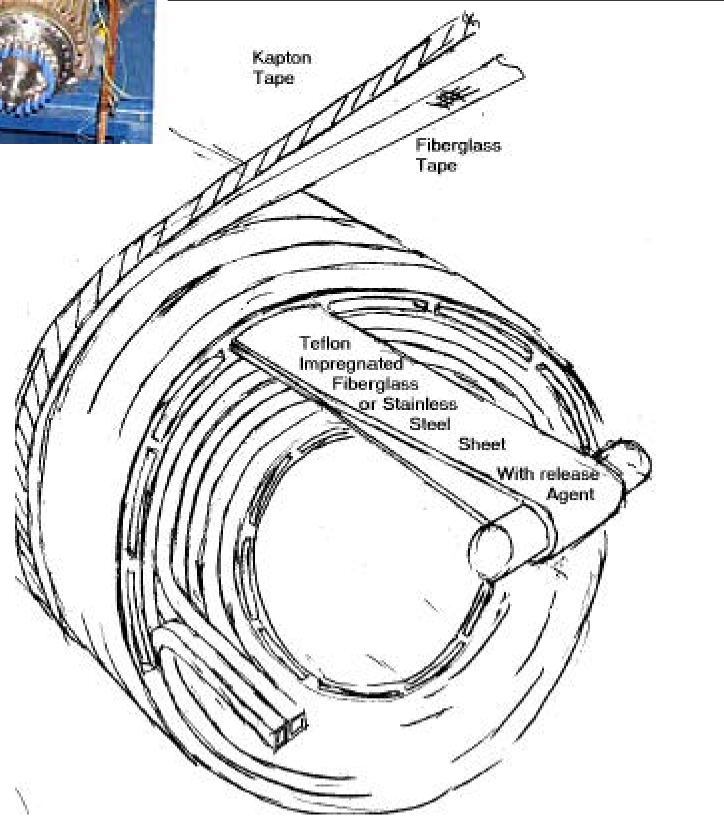
Stress Will be Lower for the 14,5T .8m OD

Engineering Tasks

- Identify Voltages for All Operating Scenarios - Choose Insulation Systems. Determine where Kapton is used.
- Stress Analysis, Assess Radial load on Channel Ligaments, Necessity for Outer Ring, Operation with Inner Modules Energized, No Current in Outer Module
- Confirm Cooldown and Pressure Drop Calculations
- Thermal Contraction/Shock of Channel – Avoid Separation and Loss of Conduction
- 10 atm He Can Design
- Mandrel and Flow Plenums Design
- Cryostat Design. Is this a Vacuum Cryostat with LN2 Shield, or a Gaseous N2?
- Break-outs and Leads Penetration design – Support in radial Field
- Eddy Currents in He Can.
- Cryogenic Electrical Breaks
- Design Supports, Break-outs, He can and Cryostat to Allow Phased Construction

Layer Insulation and Forming the Channels

Mega Amp Spherical Torus (MAST) used Teflon impregnated fiberglass to form their gap between the post and winding .
C-Mod used a steel strip with release agent to obtain the gap between TF and CS



- Kapton is the limiting element in the thermal conduction through the coil.
- Kapton was expected to be wound around the conductor. This produced the equivalent of 5 mils of Kapton between layers.
- To improve conduction, Kapton is used only between the layers. Turn to turn voltage is lower than layer to layer. The turn to turn voltage is less than the rule of thumb for He breakdown voltage (1 volt/mil at 1 atmosphere) for the insulation thickness proposed.
- The layer to layer voltage exceeds this however, and would need the Kapton if there was an imperfection in the epoxy/glass insulation. Half lapps of kapton and fiberglass, similar to the CS model coil will retain some structural integrity.
- Once a layer of conductor is wound, a layer of Kapton/glass would be wound on the completed layer of conductor. This produces the equivalent of 3 mils of Kapton rather than 5 if the conductor is wrapped individually. only Every 8th layer some sort of preformed channel array would be layed on, then wrapped with glass/Kapton to hold it in place.

Table 1. Cost estimate for industry fabrication of pulsed copper coil and liquid nitrogen cryostat.

	Cost($1000) Inner Two Modules	Cost($1000) Three Modules
Materials - Dies (2) - Conductor - Kapton - Fiberglass	 4 30 14 4	 4 60 28 8
Tooling	10	10
**Labor	76	152
He Pressure Can, Mandrel and Fiberglass Cryostat	30	30
Total	**168**	**292**

* Conductor estimate: 1300 turns, total length of 833 meter, 1943 Kgs (used 1000 meter for estimate)

** Labor estimate: 1300 turns total, average of 20 turns winding per day
average of 65 days, at 5 days per week equals 13 weeks,
or 520 hours, at $60 / hour equals to $31.2 K
estimating one week of setup time $2.4 K
Plus two weeks of impregnation $4.8 K
Adds up to $38.4K rounded off to $38K

Original Cost Basis

R	z	dr	Dz
.20425	0	.2415	.97

Helium Cooling Not Costed, but Plenum and Channels are similar.

Contingency not included: recommend 10% or $9K

Table 2. Budgetary estimate for design, fabrication supervision, and testing and installation of pulsed copper magnets January 2, 2002 - October 31, 2002

	Person-Months			Funds			
	Phase One	Phase Two	Phase Three	Phase One ENGR	Phase Two FAB	Phase Three TEST	Summary
	Magnet Design	Fabr. Supervision	Acceptance Testing				
ENGINEERING PERSONNEL	3.2	2.54	1.7	$48,500	$37,000	$22,000	$107,500
OTHER PERSONNEL							
Designers	2.9	0	0	$26,000	$0	$0	$26,000
Technicians	0	0	2	$0	$0	$18,000	$18,000
Other(Allocated Admin. Support)				$5,000	$4,000	$4,000	$13,000
TOTAL OTHER PERSONNEL				$31,000	$4,000	$22,000	$57,000
TOTAL SALARIES, WAGES & FRINGE BENE FITS				$79,500	$41,000	$44,000	$164,500
TRAVEL 1. Domestic				$2,400	$13,000	$5,200	$20,600
OTHER COSTS							
1. Materials and Supplies				$800	$300	$750	$1,850
2. Liquid Nitrogen				$0	$0	$5,000	$5,000
3. Computer Services				$2,000	$450	$1,000	$3,450
4. Electrical Components				$0	$0	$2,000	$2,000
5. Mechanical Components				$0	$0	$1,800	$1,800
6. Other: Allocated Lab Expense				$300	$250	$250	$800
TOTAL OTHER DIRECT COSTS				$3,100	$1,000	$10,800	$14,900
TOTAL COSTS of PROJECT				$85,000	$55,000	$60,000	$200,000

Notes:

1) All costs are fully loaded
2) Phase I duration: 4 Months, Jan. 2, 2002 - April 30, 2002
3) Phase II duration: May 1, 2002 - August 31, 2002
4) Phase III duration: September 1, 2002 - October 31, 2002