Towards a Conservative 50 T HTS Magnet for Final Muon Collider Cooling

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- Starting Magnet Parameters
- More realistic Design
- Quench protection
- Conclusion

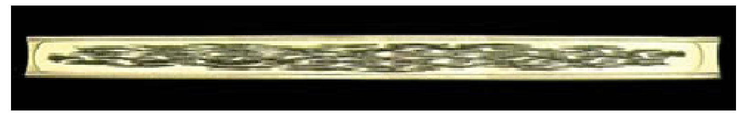
Choice of HTS Material

- American Superconductor tapes advantages:
  - Pre reacted as will 2nd Generation YBCO
  - Available with ss cladding, strong and hermetically sealed against cryogens
  - Relatively cheap (20$/m)
  - BNL has experience using it
- Other materials now have somewhat higher current capacity
  and should be investigated in parallel

High Strength Plus Wire

- Designed for use in applications where the wire must be mechanically strong and have high current density such as many coil and magnet applications
- Tolerant to small winding diameters or bend radii
- High tensile strength
- High engineering current density

$133\ A/mm^2$



Compression Tolerant Wire

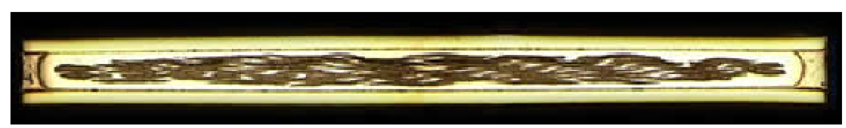
- Designed for use in applications where the wire may be subjected to compressive strains such as in some rotating machines
- Withstands compressive strains
- High tensile strength
- High current

$100\ A/mm^2$

Hermetic Wire

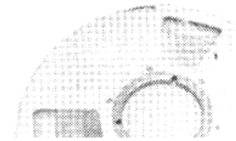
- Designed for use in applications where the wire is exposed to pressurized liquid cryogens such as power cables
- Hermetically sealed
- High tensile strength
- High current

$85\ A/mm^2$



YBCO from IGC

Second-Generation High Temperature Superconductor

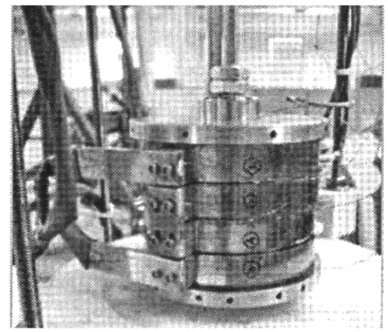


SuperPower has been developing YBCO-based second-generation (2G) HTS wire at its manufacturing plant in Schenectady, New York since 2000 and is now producing long lengths of high performance wire and **taking orders**.

Once SuperPower™ 2G HTS wire has been slit into device-specific widths, **Surround Copper Stabilizer (SCS)** is applied to completely encase the wire. Overcurrent capability in SCS wire can be tailored to the specific application. The stabilizer protects the conductor and produces rounded edges that are beneficial for high-voltage applications. Further, the probability of failure in the device due to voltage breakdown is reduced in conductors with SCS. SuperPower's SCS has been successfully implemented and tested on continuous lengths of hundreds of meters of wire.

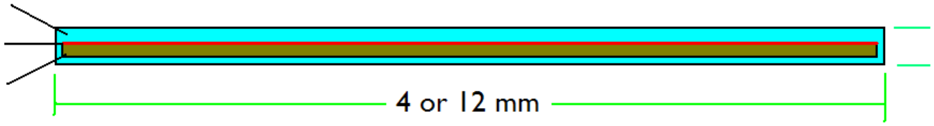
SPEC	SCS 4050	SCS 12050
	SCS = Surround Copper Stabil	
Width	4	12
Thickness	0.095	0.095
Silver Overlayer Thickness	2	2
Copper Stabilizer Thickness	0.04	0.04
Substrate Thickness	0.05	0.05
Critical Tensile Stress	>550	
Yield Strength	1200	1200
Bend Diameter in Tension	11	

- New high field coils fabricated with 2G HTS wire have achieved a record magnetic field of 2.4 Tesla at 64K.



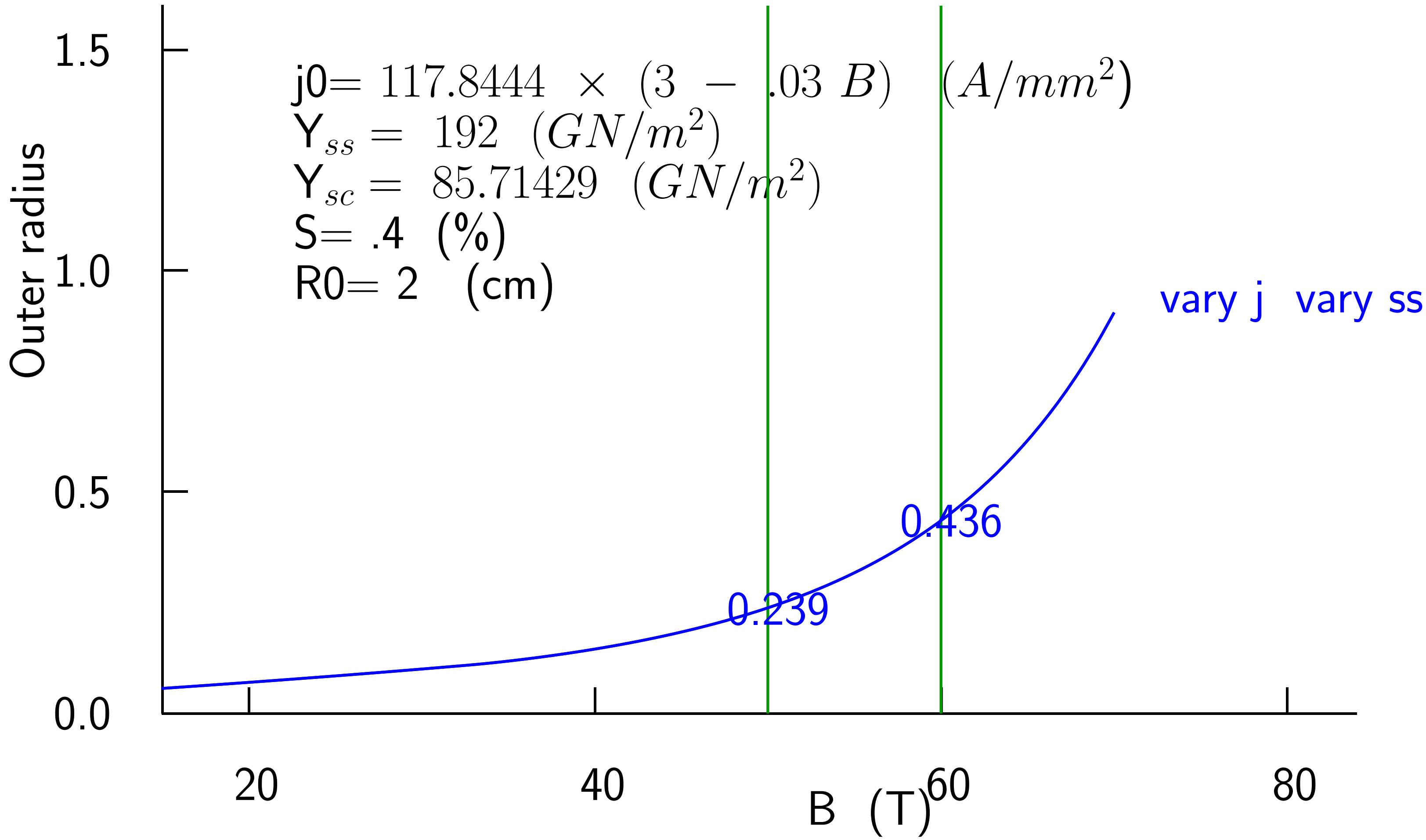
*** Uniformity in long lengths of SuperPower 2G HTS Wire is better than 5%**
*** Piece lengths of up to 300 meters are available**
*** Ic values range from 60 – 100 Amps at 77 K in 4 mm width**
*** Engineering Current Density (Je) = 16 – 26 kA/cm²** 160-260 A/mm^2
***** Other custom configurations are also available. *****

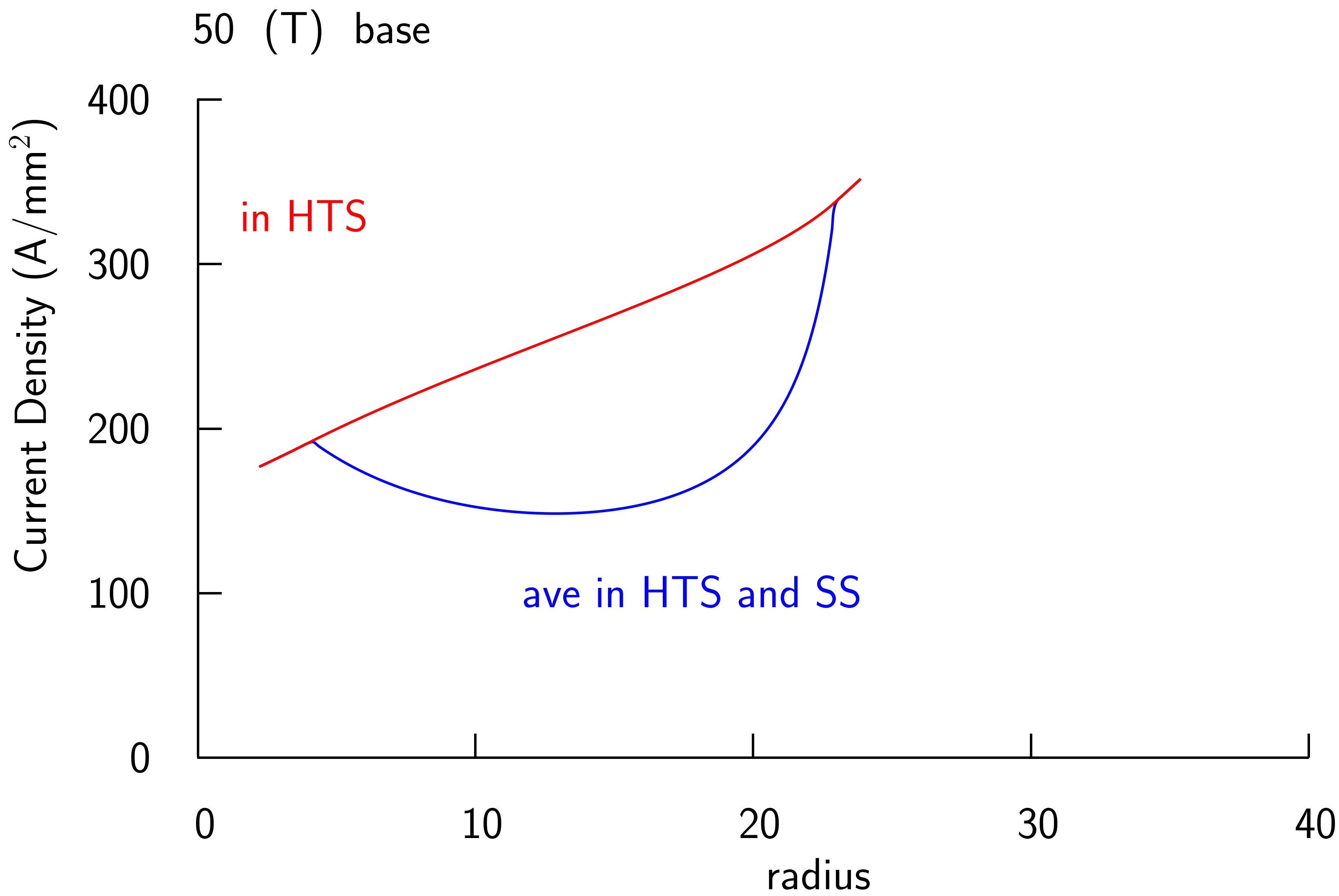
Additional product details available on our website: www.superpower-inc.com



Starting Design

High Strength HTS and SS insulation

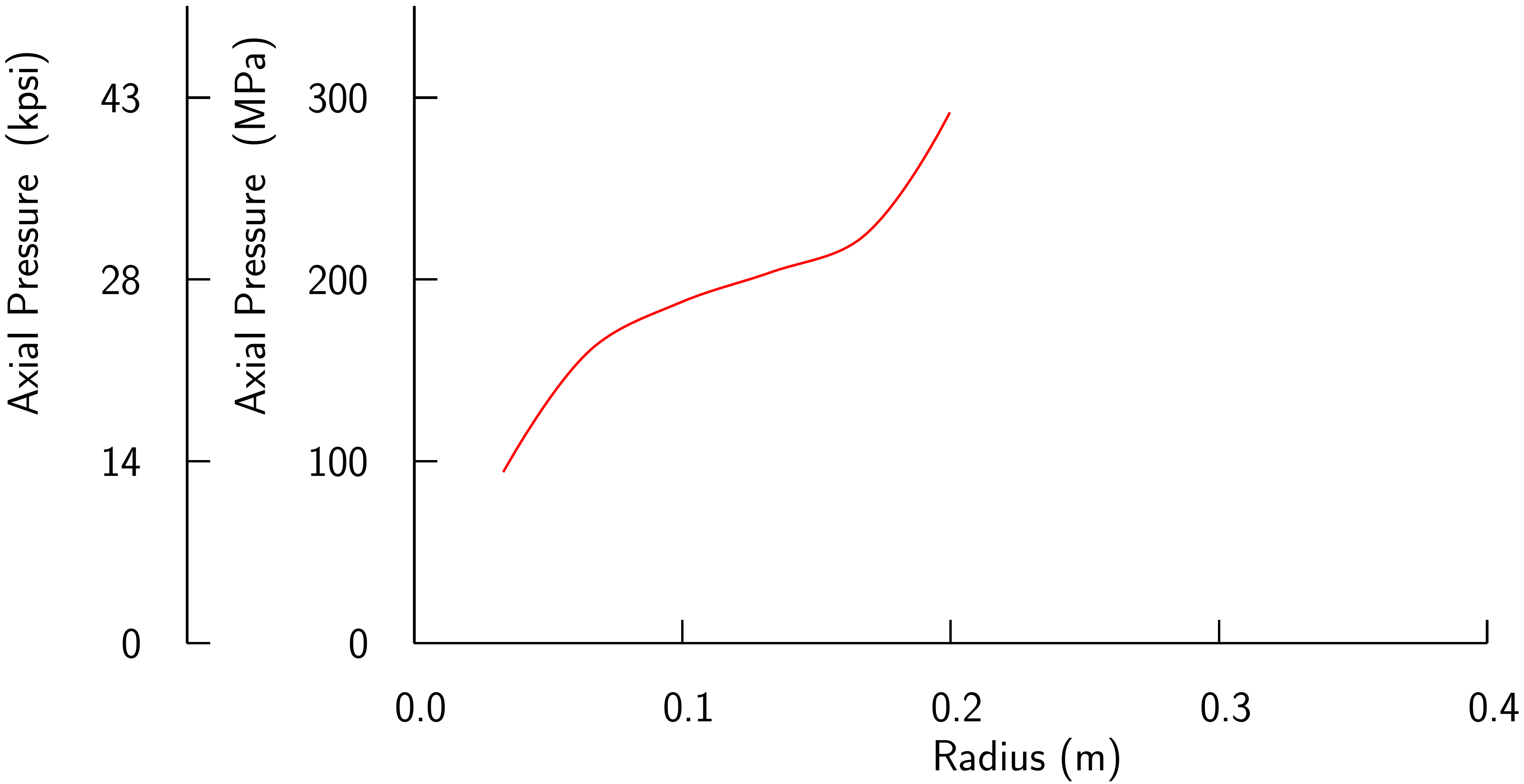




Note very high current densities

Stored Energy = 29 MJ

Calculation of sideways (axial) pressure on layers

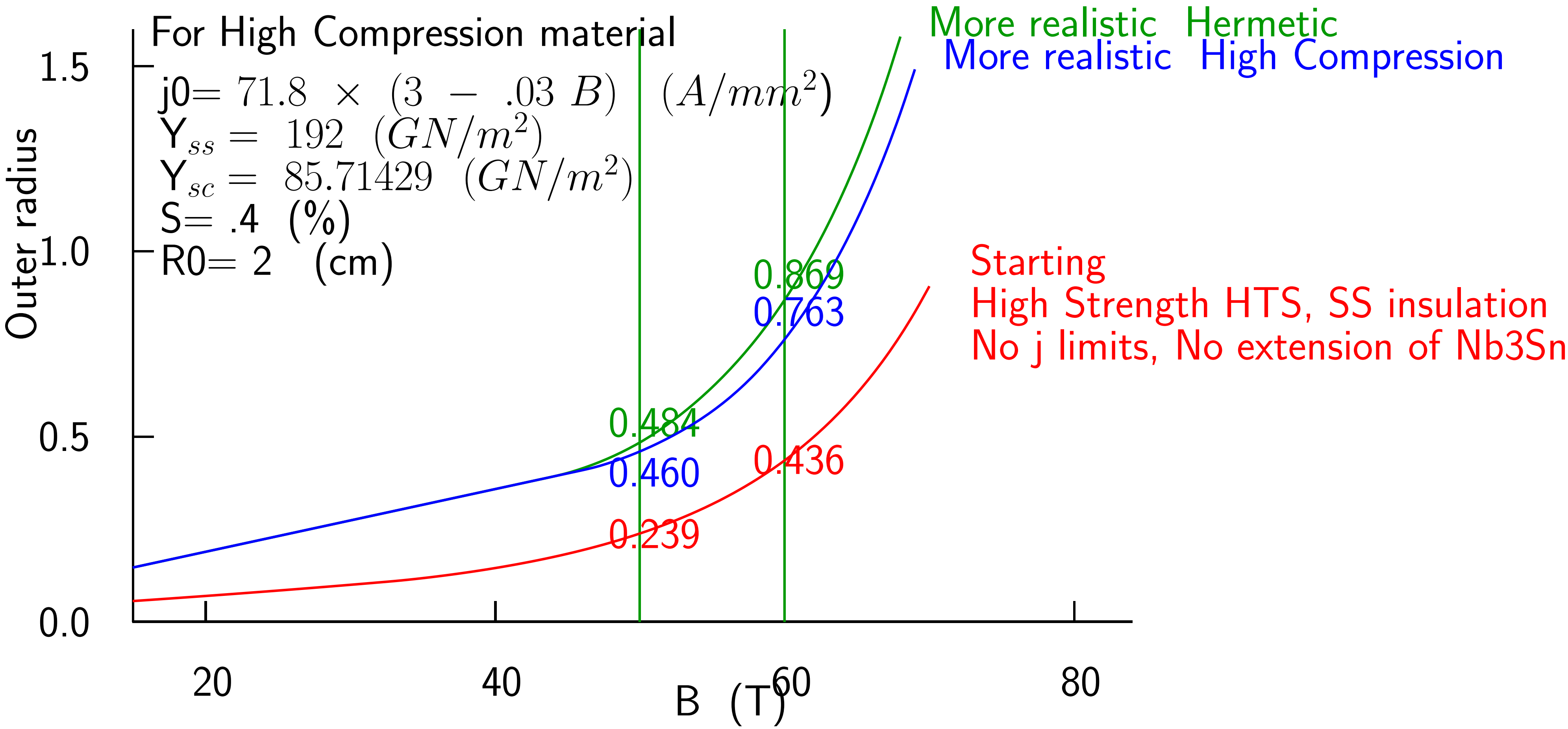


Note: these are very high (of order 40 k psi)

Steps towards a more conservative Design

- Add 25 μm insulation around all conductors
- Use American Superconductor "High Compression" tape
  This has less current density, but can probably stand more sideways pressure
- Add copper to limit current densities to about 100 Amps per mm^2

- Limit axial loads in Nb3Sn to $<$ 70 MPa (10 kpsi)
- Limit axial load in HTS to $<$140 MPa (20 kpsi)

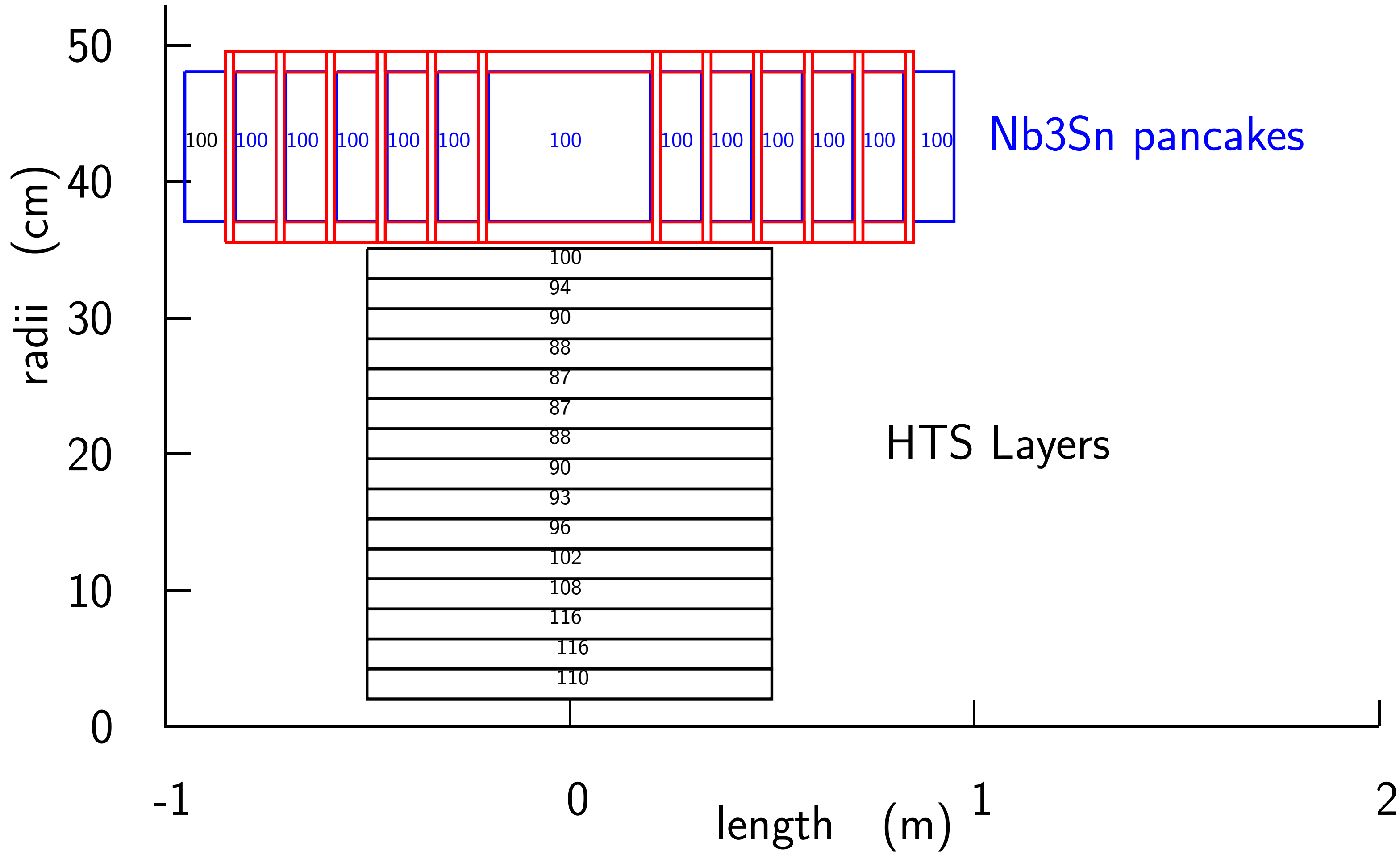


Following calculations use "High Compression" material specs

But use of "hermetic" material increases rad by only 2 cm

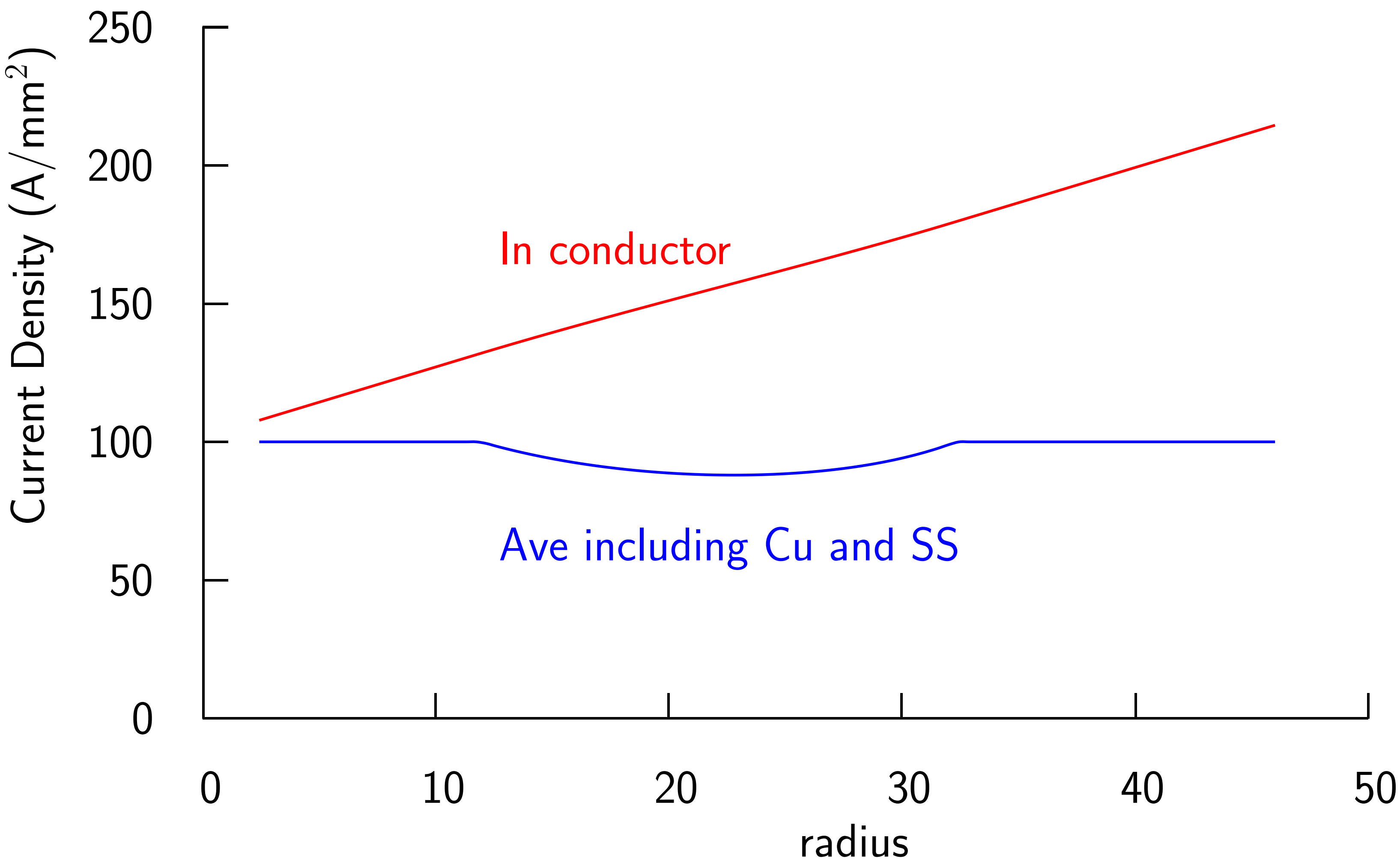
Cross section of coil Blocks

- current densities in A/mm2
- Red structure supports axial loads on Nb3Sn coils
- Extended Nb3Sn reduces B⊥ on HTS

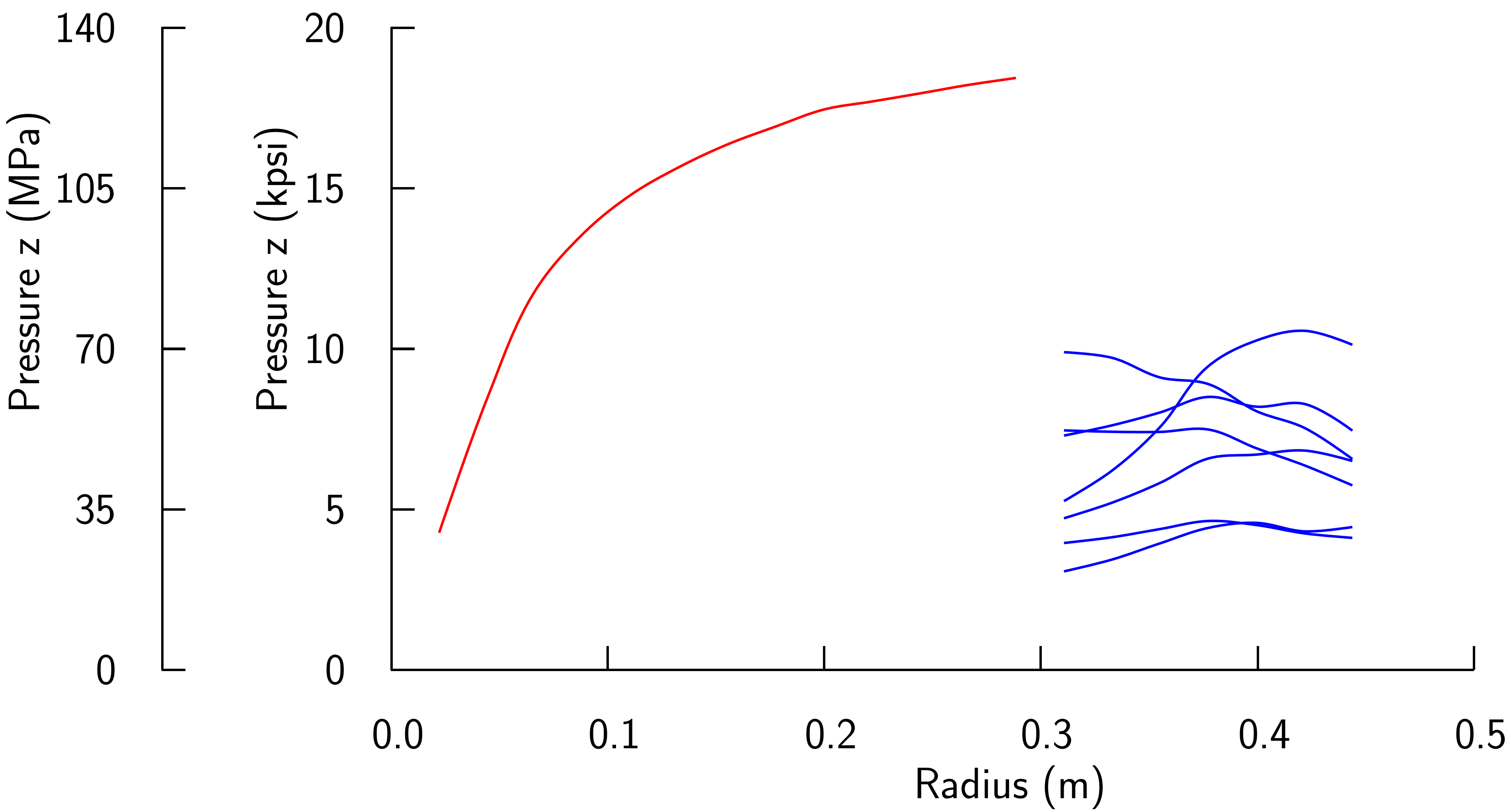


Stored Energy = 109.6 MJ 4 times starting design

Current Densities



Axial pressures



Quench protection

If the magnetic stored energy were dumped uniformly in the magnet (wt $\approx$ 5 tonnes) then the temperature rise would be only 40 degrees, but

Problem:

- At local spot where quench starts, ignoring heat conduction, the local heating causes temperature to rise until current is stopped.
- There will be a critical $\int I^2 dt$ allowable before the temperature rise is excessive.
- In a high field solenoid the inductance is so high that a rapid turn off requires high voltages.
- The coupled inductance is so large that it is hard to drop the current in only one block or layer, unless a conducting loop is present to take up that current

Quench protection methods

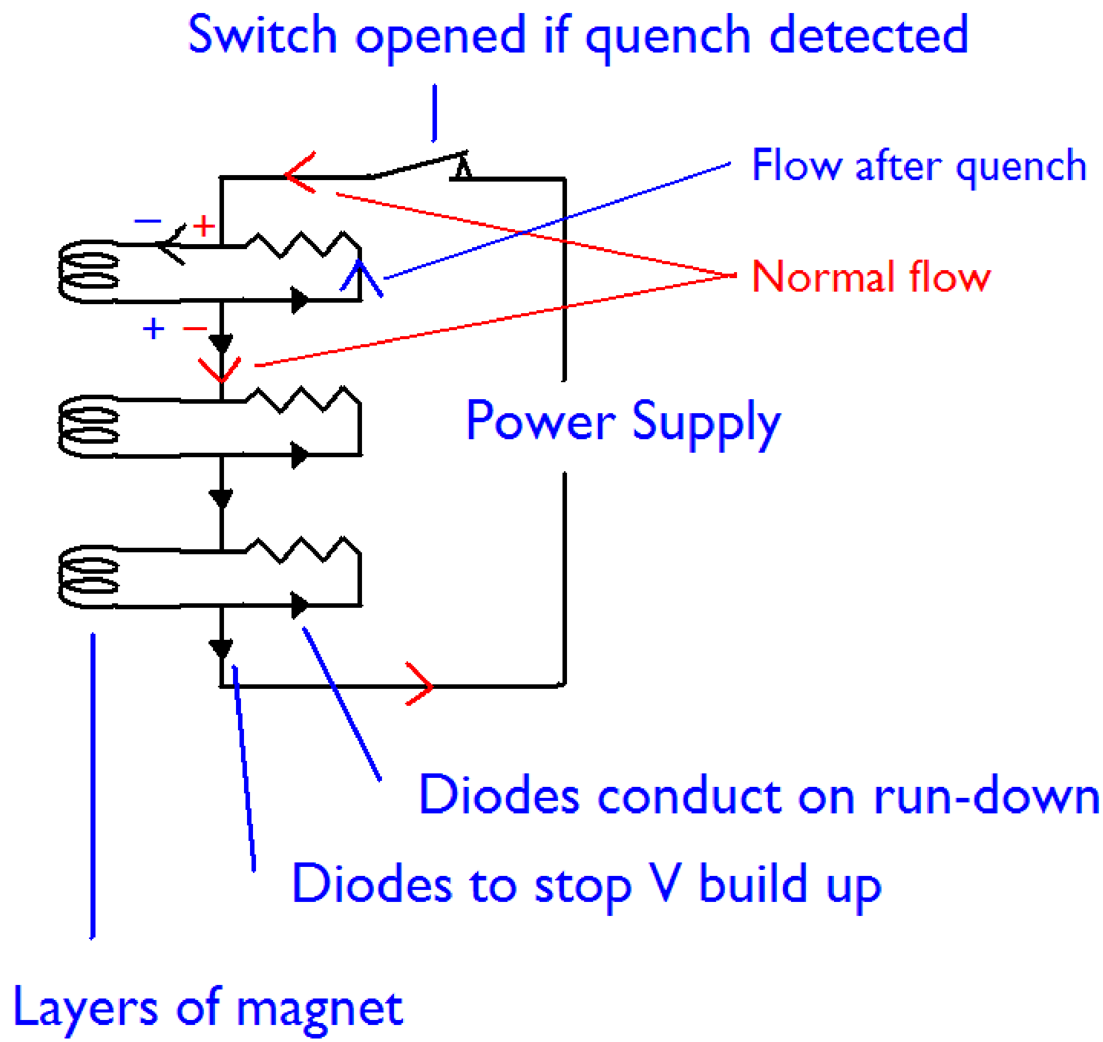
1. Passive
   If quench propagates fast enough then the magnet current drops before the local spot overheats
   Unlikely for HTS

2. Added closed conducting loops that will carry the current as the superconductor currents drop (Alvin's suggestion)
   Probably requires considerable copper thus decreasing average density and increasing required radius

3. Active heaters
   Detect any quench and actively fire heaters to quench entire magnet causing rapid ramp down without large external voltages
   A significant temp jump must be introduced to quench HTS making this probably hard

4. Active ramp down
   Detect any quench and actively ramp down magnet when observed
   Some technique must be employed to avoid very large external voltages

Voltage avoidance technique for method #4



Conclusion

For 50 T

- With the existing American Superconductor HTS tapes:
- The quoted "starting" parameters are probably unrealistic from current density, quench protection and force considerations
- Addressing these problems raises the overall magnet radius from 23 to 46 cm
- But his still looks reasonable

For 60 T

- With the existing American Superconductor HTS tapes:
- the required radius rises to near 90 cm
- This would be expensive, but possibly still possible
- But forces for this case have not been calculated yet