Magnet for ARIES-CS

Magnet protection

Cooling of magnet structure

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Topics

- Cooling of large magnet structure in ARIES-CS

- Quench and magnet protection

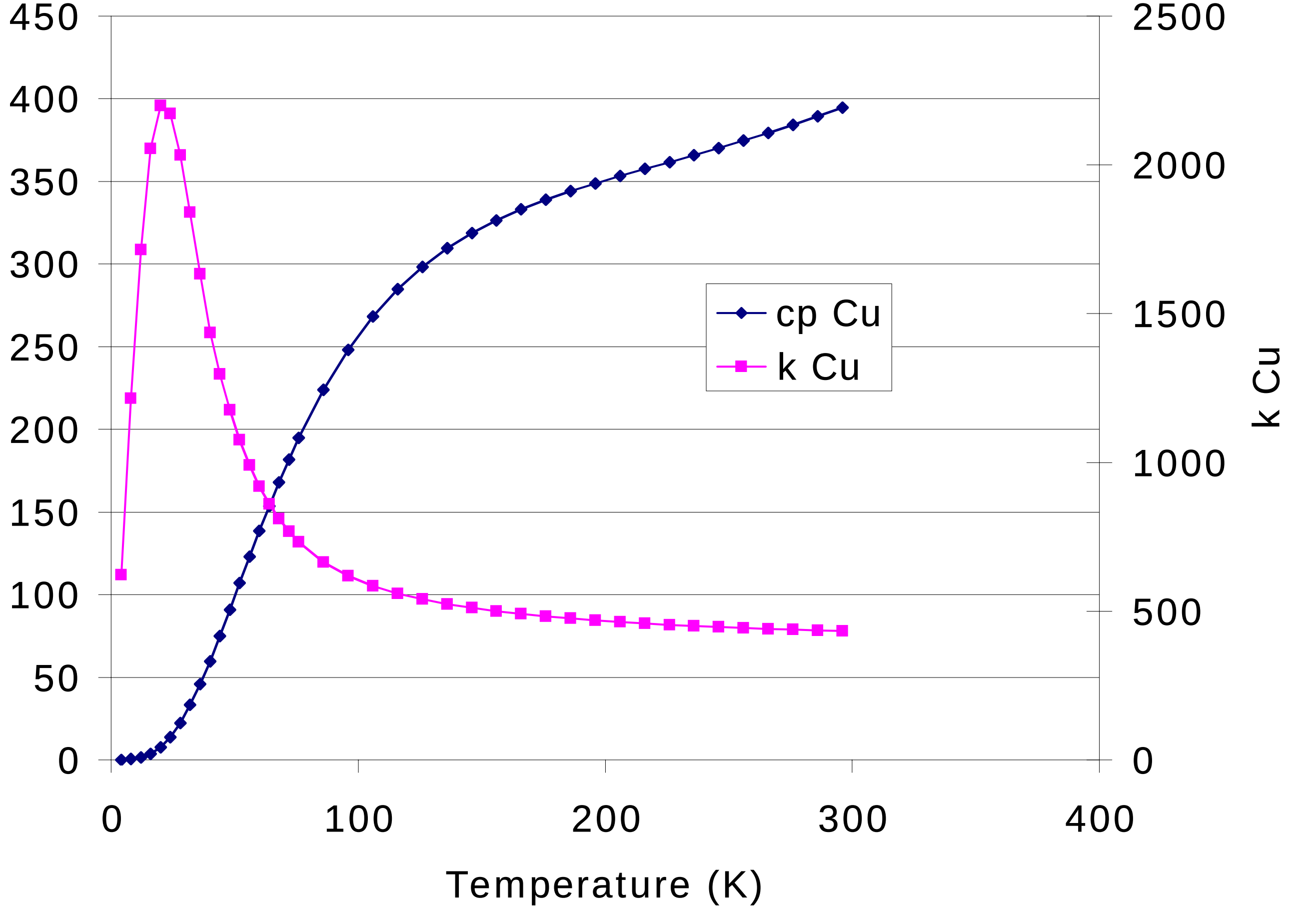
Cooling of magnet-structure

- Low temperature magnet operates near liquid He temperature
  - Complex shape of magnet requires structure surrounding magnets
  - “Continuous” structure represents large thermal load to the cryogenic system
  - Can higher temperatures be used to cool the magnet structure, with coil winding at lower temperatures?

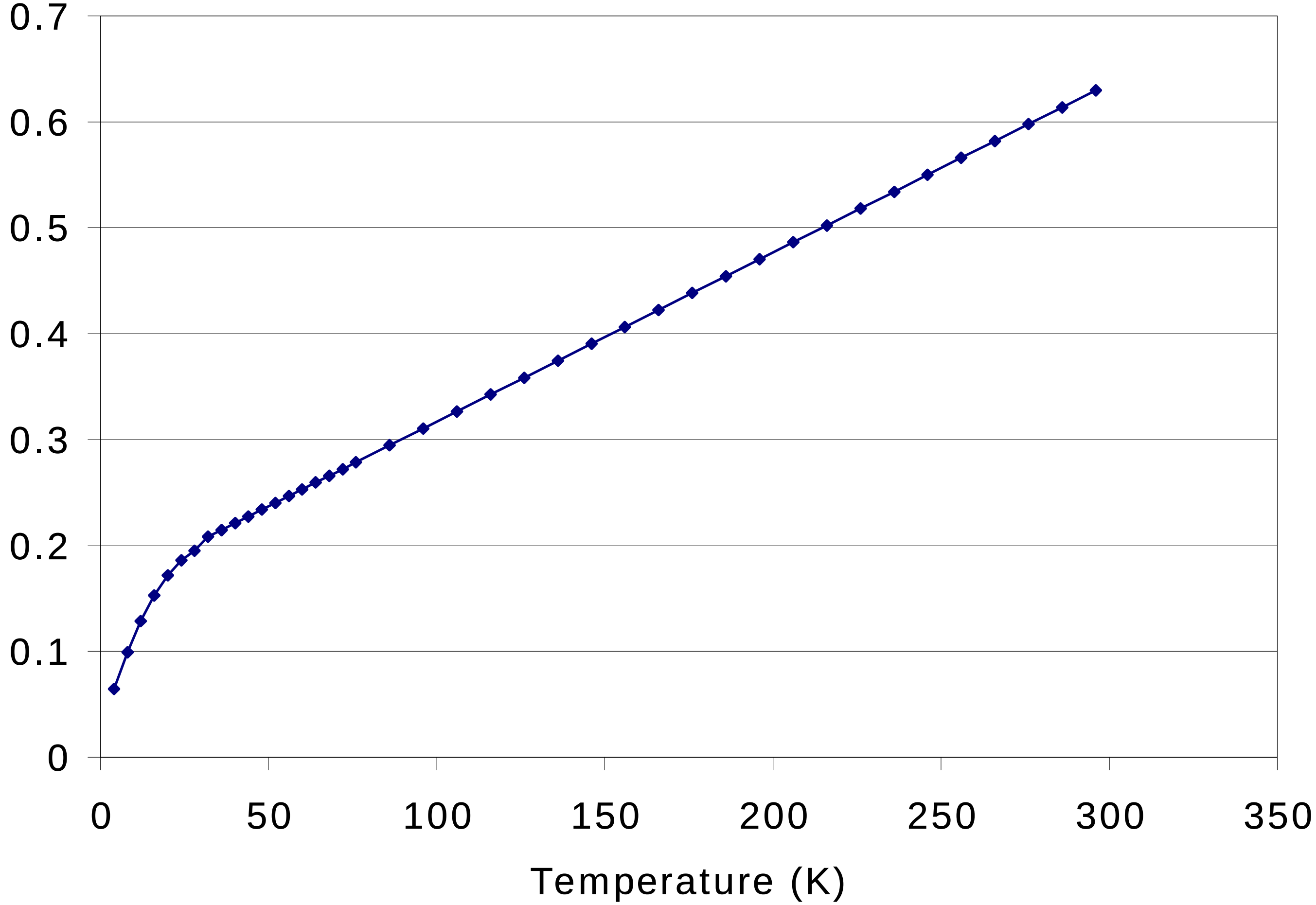
Model

- 2-D thermal analysis
  - Steel structure,
    - 0.10 m thick, outside of shield
  - Outer region of reactor, with coil spacing determined by constant toroidal width (that is, same toroidal width as inboard region)
  - Variable thermal loading
    - What is it?
  - 2 mm insulation between structure and coil winding
  - Non-linear thermal heat transfer due to strong dependence of thermal conductivity on temperature

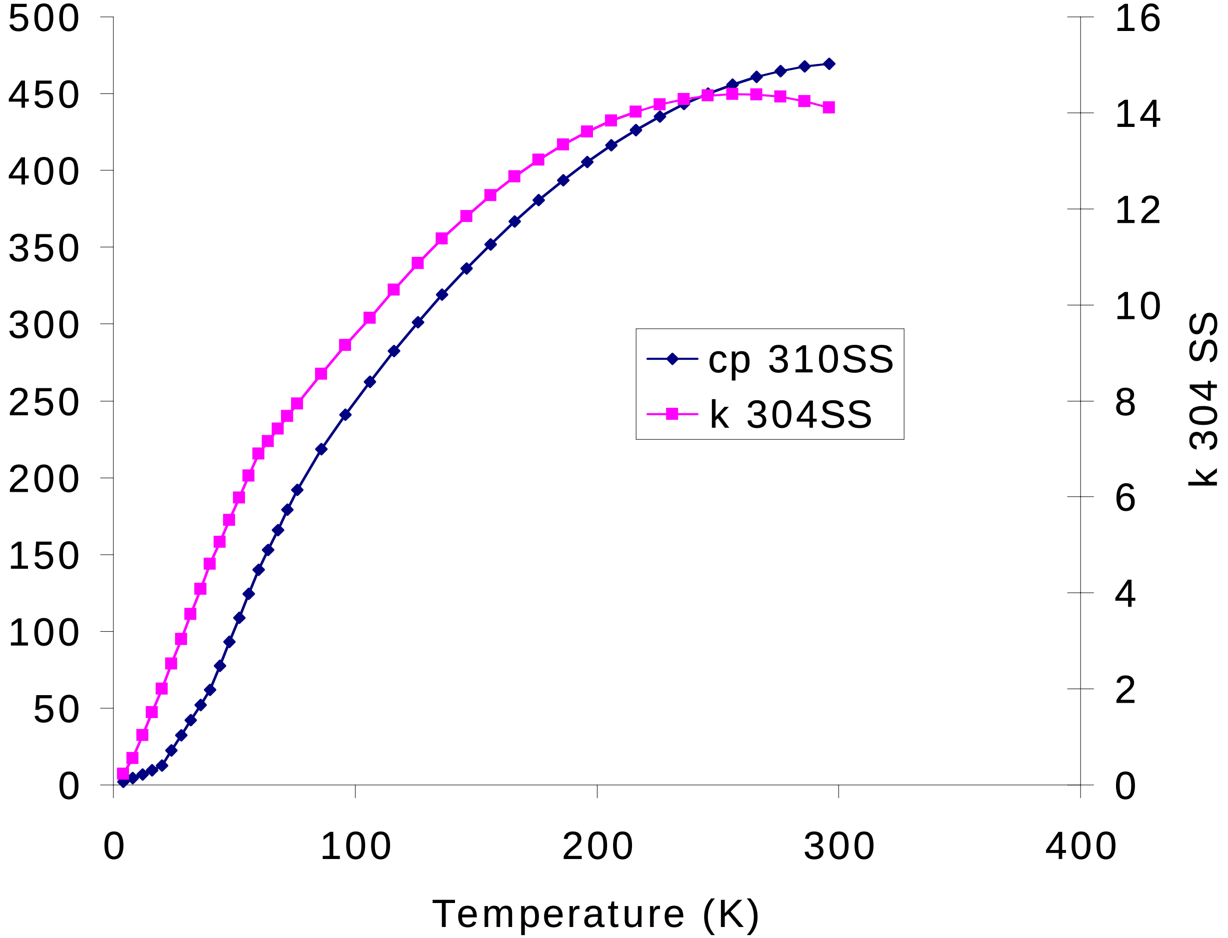
Material properties: Copper



Material properties: Insulation (G10)

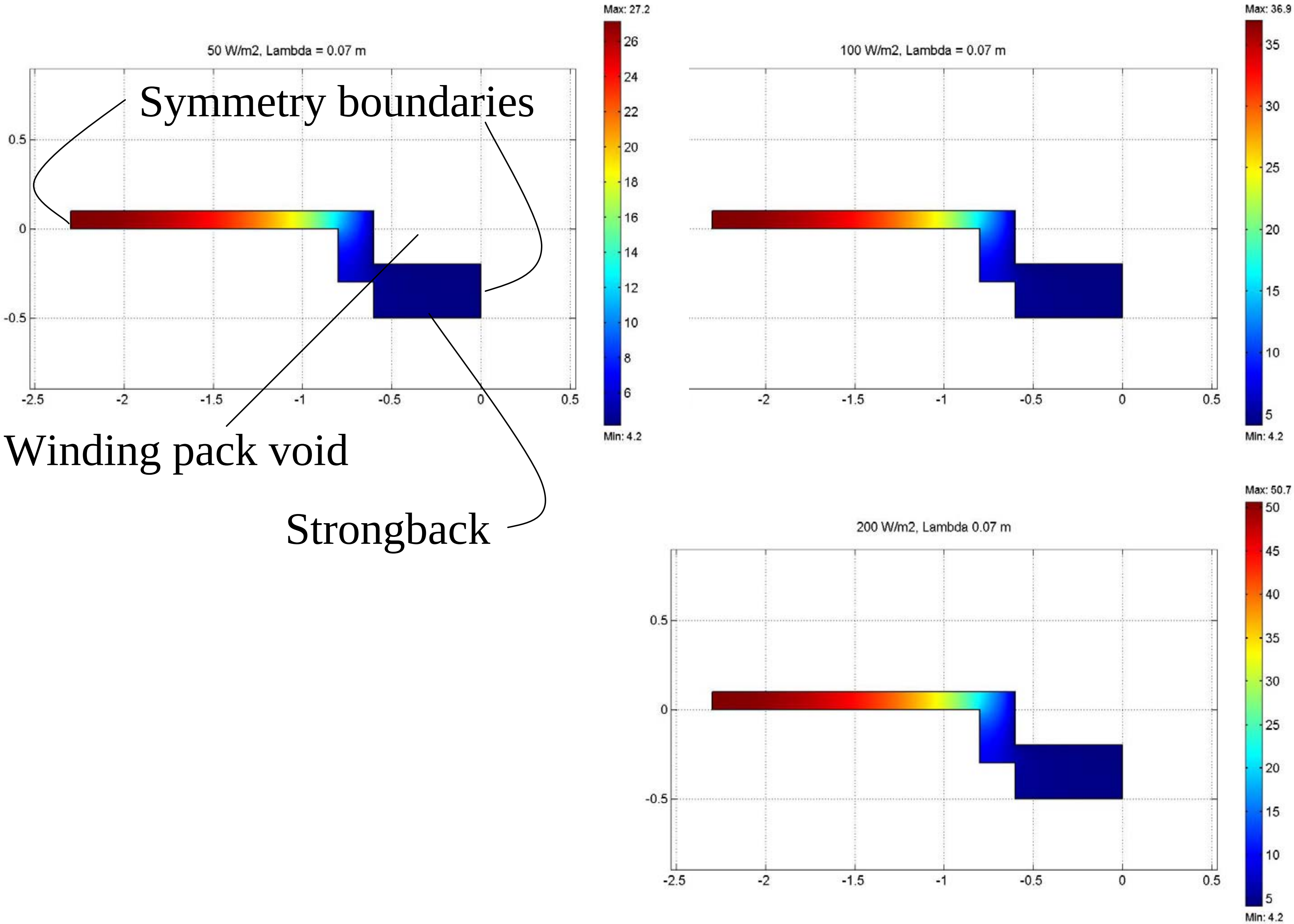


Material properties: steel



Model

- Peak thermal loading
  - 50, 100, 200 W/m^2
- Dimensions of NCSX-like with 5 MW/m^2 peak wall loading (6.83 m plasma major radius)
- e-folding distance of heating is 0.07 m


50 W/m2, Lambda = 0.07 m
Max: 27.2
Min: 4.2
Symmetry boundaries
Winding pack void
Strongback
100 W/m2, Lambda = 0.07 m
Max: 36.9
Min: 4.2
200 W/m2, Lambda 0.07 m
Max: 50.7
Min: 4.2

Structure cooling

- Cooling of the structure can be achieved at reduced refrigeration power by removing the thermal load at higher temperature
  - For 20 K, 0.1 W/cm^3 and higher can result in a reduction of the 4 K thermal load in the structure by about a factor of 3.
  - For lower power densities, temperature must be lower than 20 K
  - Need closure on the thermal loadings from neutronic analysis

Quench constrains

- For the High Tc case (with YBCO superconductor, generation 2)
  - No-quench postulated
    - It will not be possible to monitor a quench, even if one occurred
    - Large heat capacities, coupled with conductor placed in intimate contact with structure (no conductor motion).
- For low Tc conservative engineering design, quench quickly monitored, with dump in a few seconds.

Magnet energy dump

- Properties given to system code assumes a 2 s energy extraction
  - Aggressive
  - If external dump (baseline):
    - High voltage, high current many parallel circuits
    - 20 kV, 50 kA, 20-40 circuits (*i.e.*, more than one per coil)
    - High current requires large cross section conductor
      - Wind and react [Previous baseline]
      - Ceramic braid insulation, epoxy impregnation after heat treatment
  - Internal dump?

Internal dump

- Externally induced quench of magnet
  - Easily achieved by the externally activated heaters
  - Heaters, in principle, could be passive
    - However, active heaters would provide better protection
    - Low thermal capacity of magnet at low temperature implies to power requirements for the externally activated circuits
  - Advanced thermal quench desired
    - Fiber-optics based.
    - Idea is to uniformly deposit magnet energy throughout the magnet winding pack.

Internal dump

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

- Initial temperature of winding pack ~ 150 K
- Final time ~ 20,000 s (~ 6 hours)
- No cooling
- Internal dump of ~ 40 GJ

Recool issues

- Need to determine reactor implications of magnet quench
  - Of course, no power.
  - How will the blanket/balance of plant handle off-normal event (scram?)
  - Requirements for restart
  - Refrigeration requirement for recool:
    - Remove energy from magnet with flowing He gas, as cooling power scales inversely with temperature (I.e., do not want to cool a magnet at 100 K with 4 K He).

Recool time

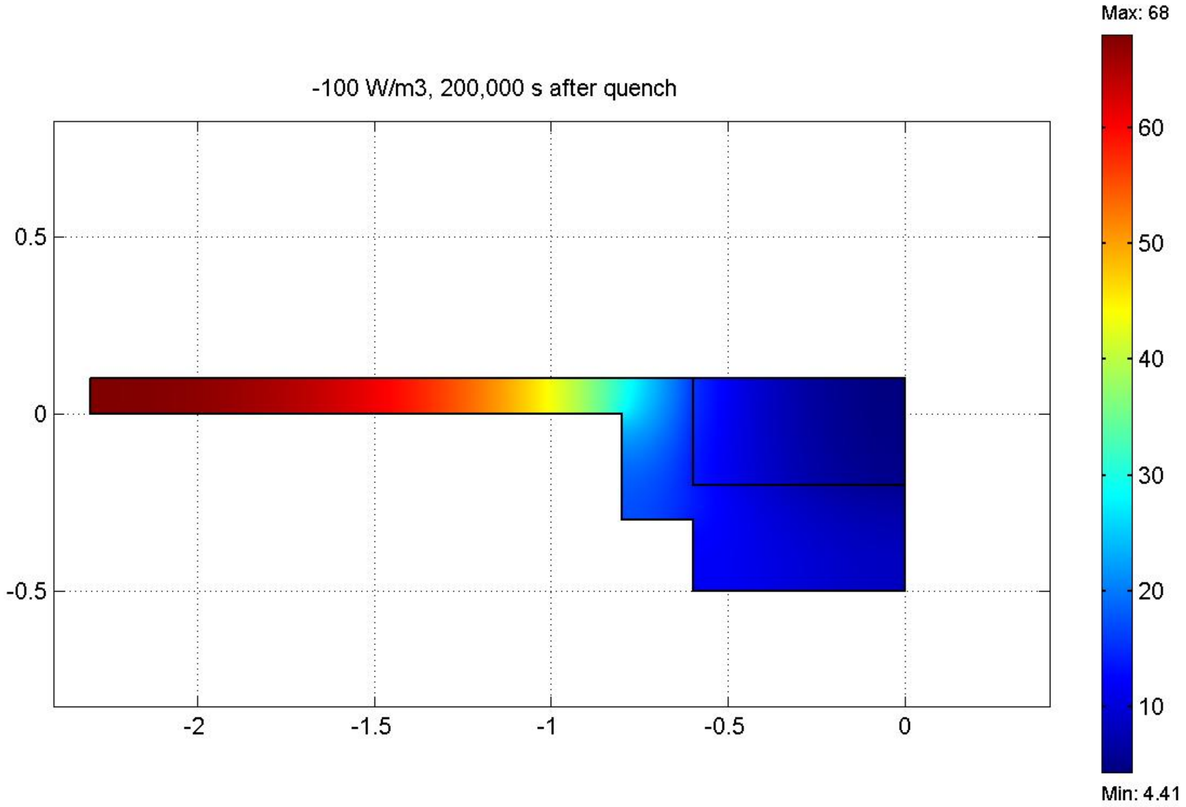
- Assume that 40 GJ are released to the magnet, uniformly distributed over the winding and structure (about 4000 tonnes)
  - rising the average temperature of the magnet to about 100 K
  - Cooling power ~ 10 kW at 4 K
    - Refrigeration power scales ~ T
    - 1 ton cooled down in 24 hours with 4 W from 77 K with 3 W

Recool

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

- 10 kW recool (-100 W/m^3)
- 200000 s
- Only winding pack is being recooled

Recool -- 200,000 s (~ 2.5 days)

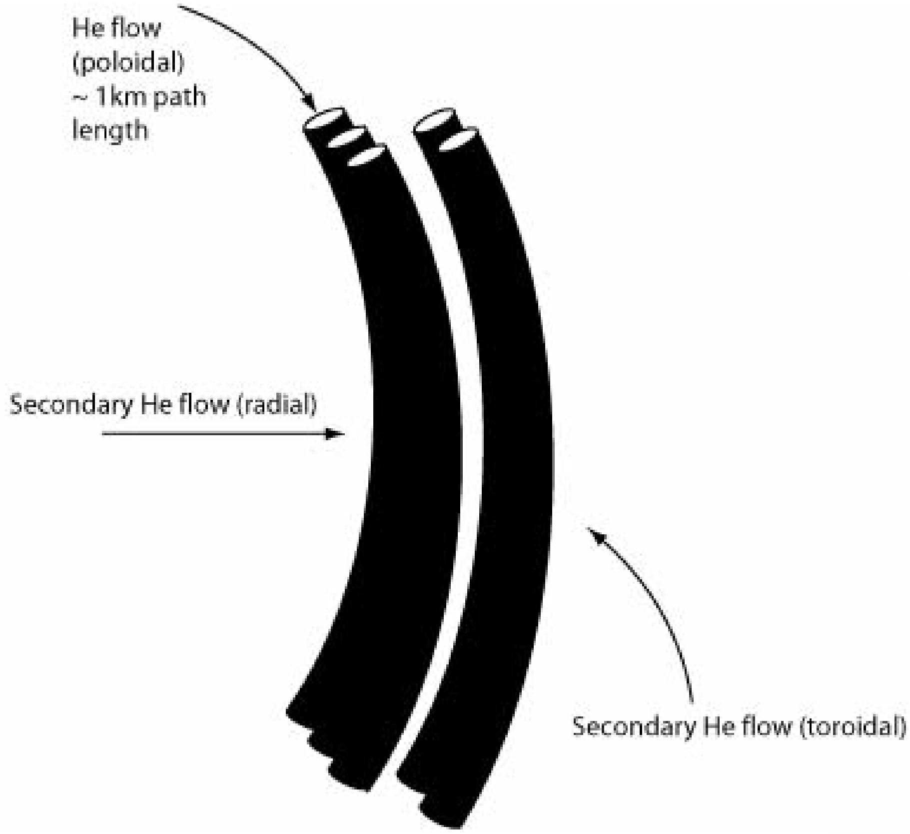


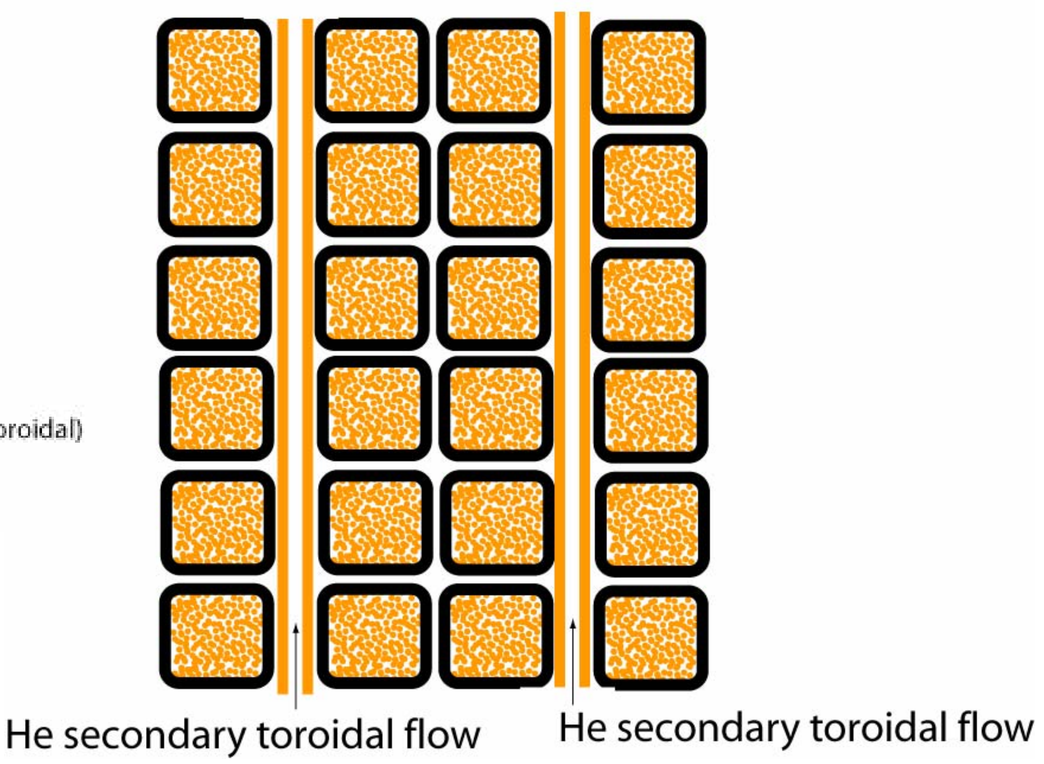
- ΔT substantial from structure to winding pack, but not in nearby coil structure

Recool

- 40 GJ
- If cooled nearly isentropically (with little ΔT), the recool can be completed in ~ 2 days
- Can it be accomplished with small ΔT across the coil
- Cooling can be performed by using two circuits, as in the blanket. A fast moving one that cools locally the coil, and a slow moving one that cools along the coil.

Multi-loop cooling





Summary

- Structure can be cooled separately from the winding pack of low-Tc magnet to reduce thermal load to refrigerator, if this load is high
  - Useful to calculate the radiation loading, especially in the other regions of the magnet
- Internally dumping the magnetic energy is an attractive means of protecting the magnet
  - Although it results in larger load to the refrigerator, how long does it take to restart a fusion reactor after a quench?
  - What determines the minimimum downtime after quench:
    - the balance of plant, the blanket, the magnet