UK Atomic Energy Authority

ASC 2024

Quench protection analysis and strategy for the STEP TF coils

4th September 2024

Sam Tippetts

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Spherical Tokamak for Energy Production (STEP)

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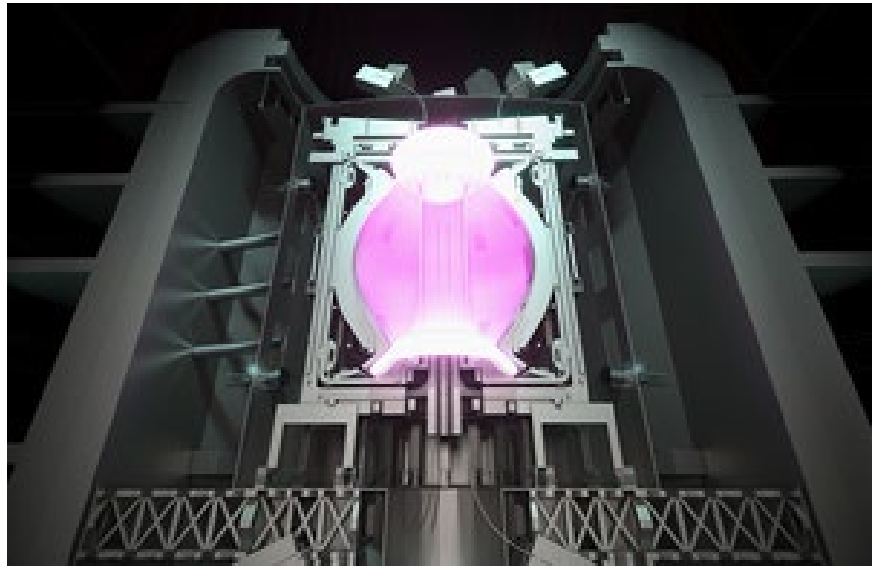
- Fusion Power Plant planned for operation in 2040s
- Fusion power: ~1.6 GW
- To be built at West Burton



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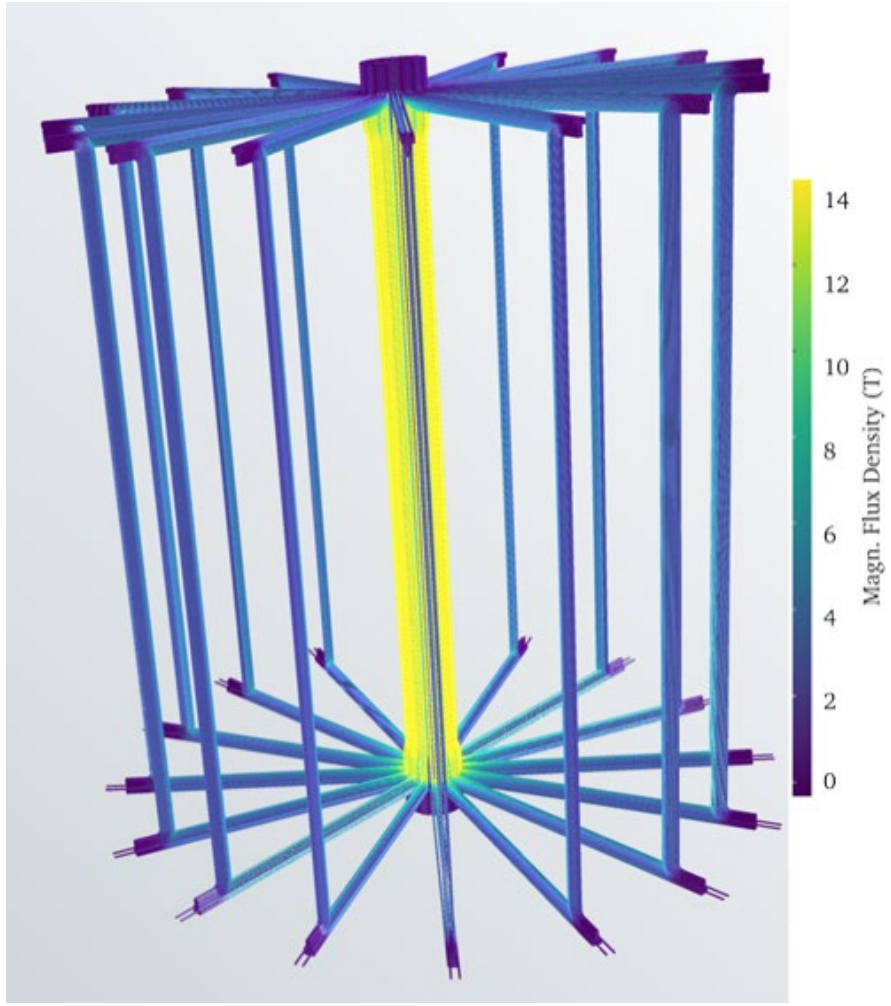
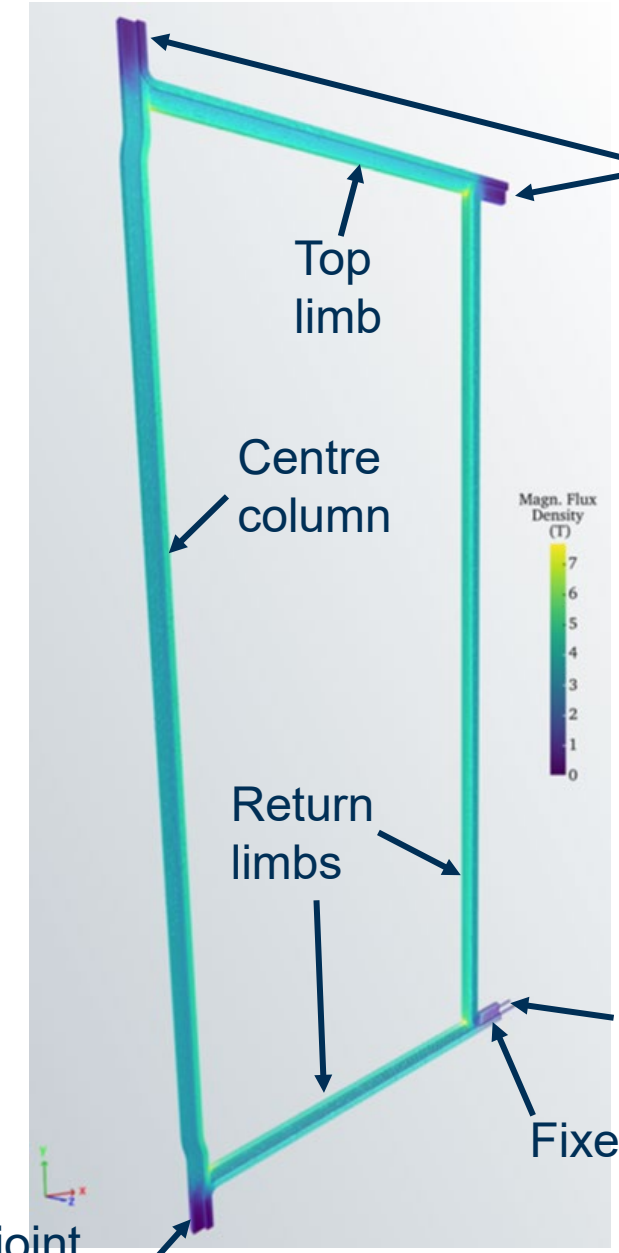
STEP TF Overview

Picture frame coils, 16 coil arrangement:





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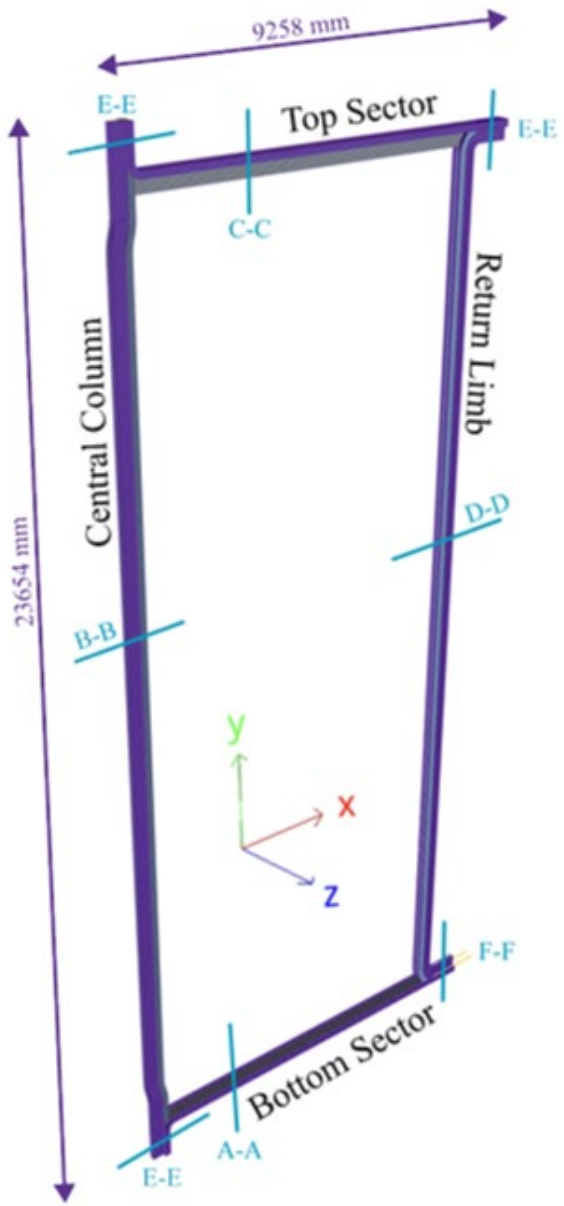
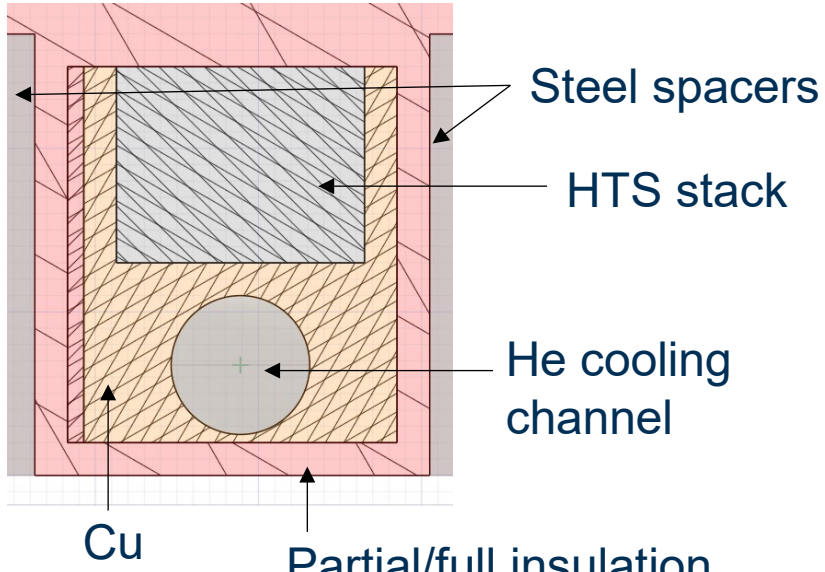
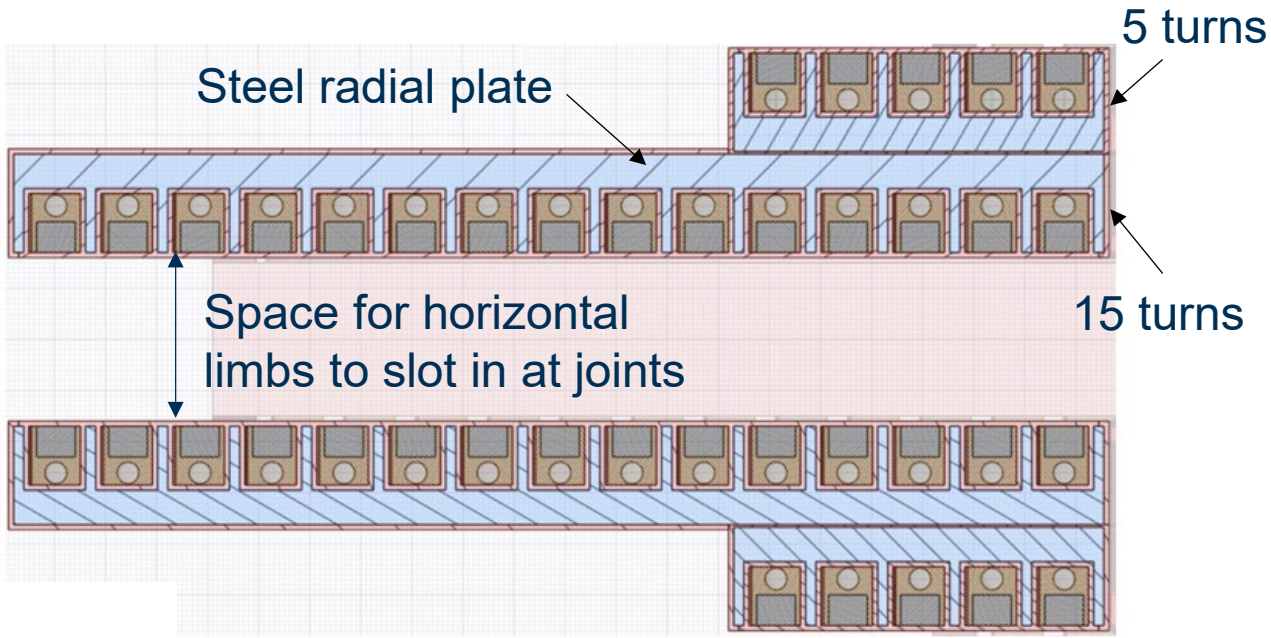
Overview







Section through centre column

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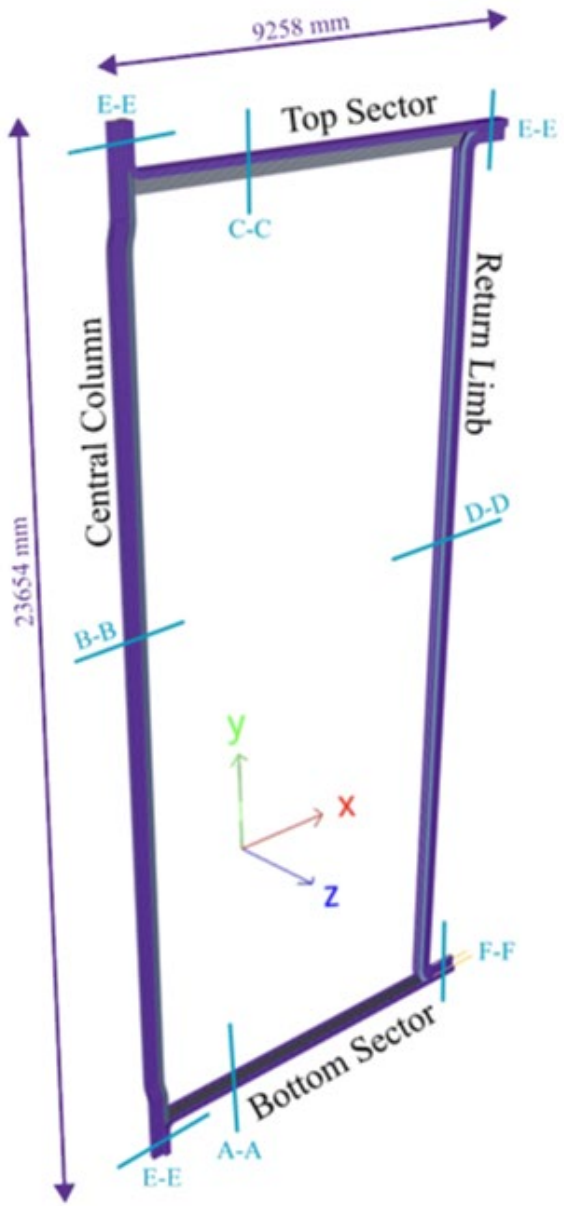
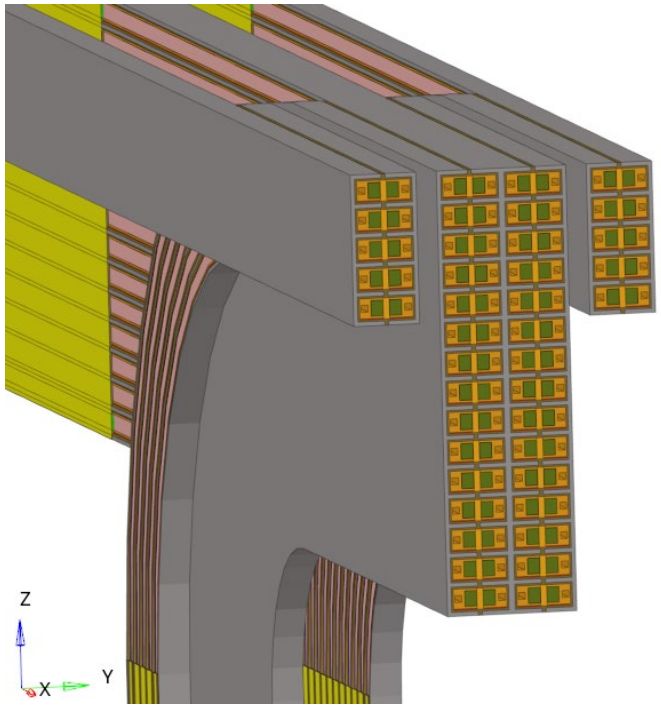
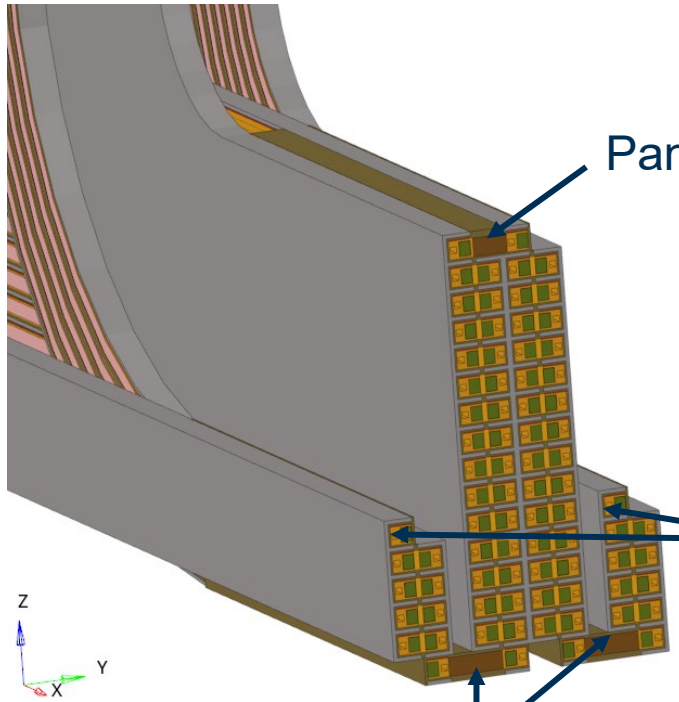
Joints



Re-mountable joint (x3)



Fixed joint



Pancake bridge

Terminals

Pancake bridges

Unlocking Maintenance – Architecting STEP for Maintenance and Realising Remountable Magnet Joints - Phil. Trans. R. Soc. A

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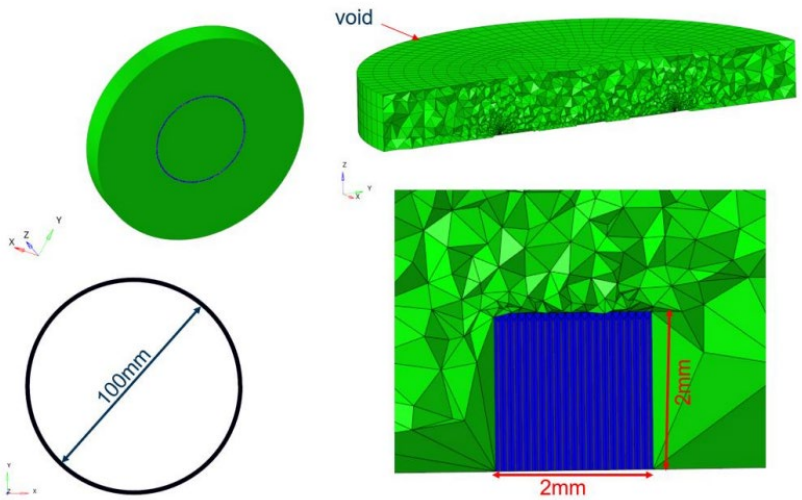
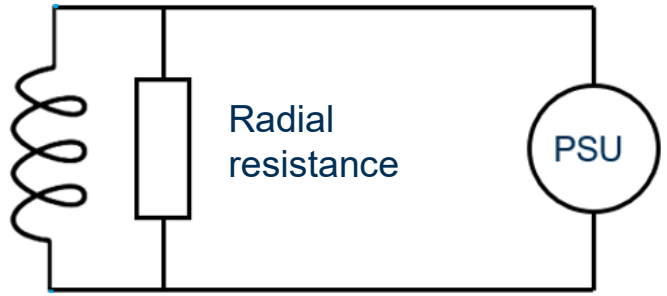
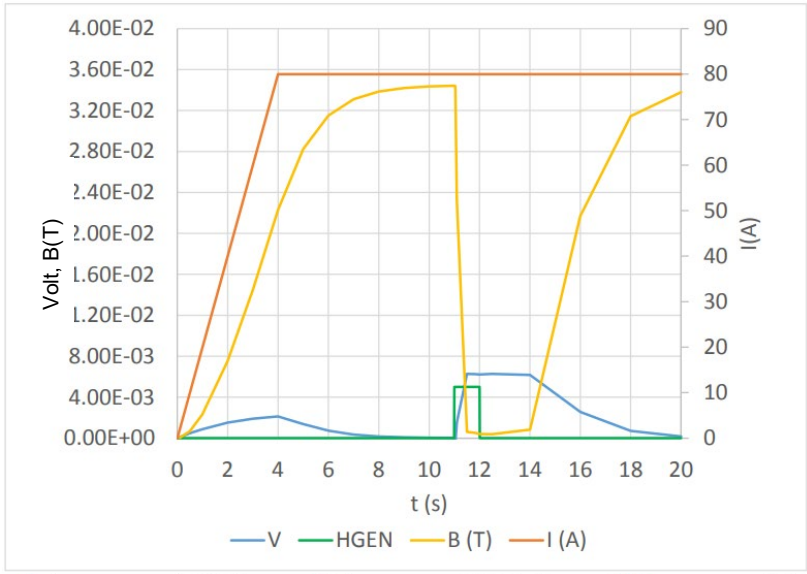
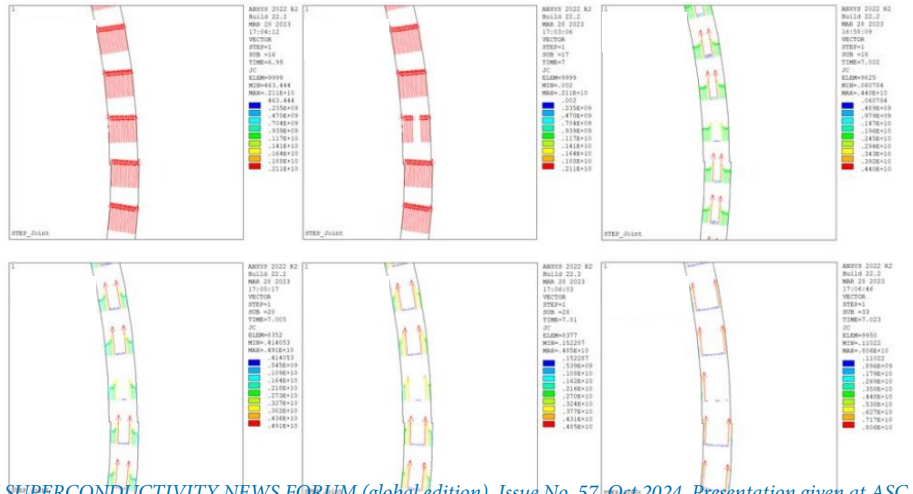
Non-insulation concept and passive ‘self-protection’

- Passive quench protection has been demonstrated on small coils made from individual HTS tapes wound into coils.









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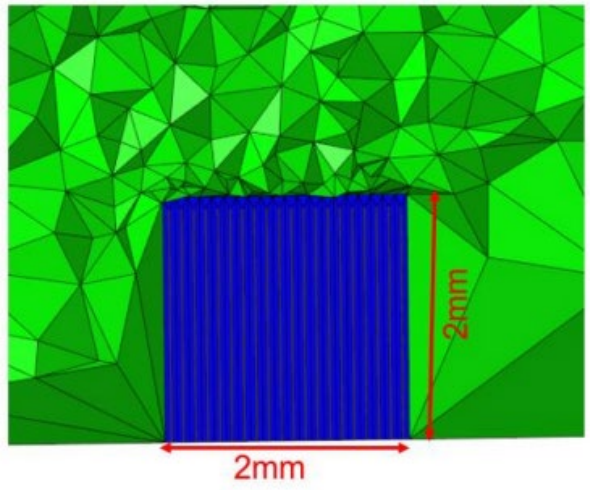
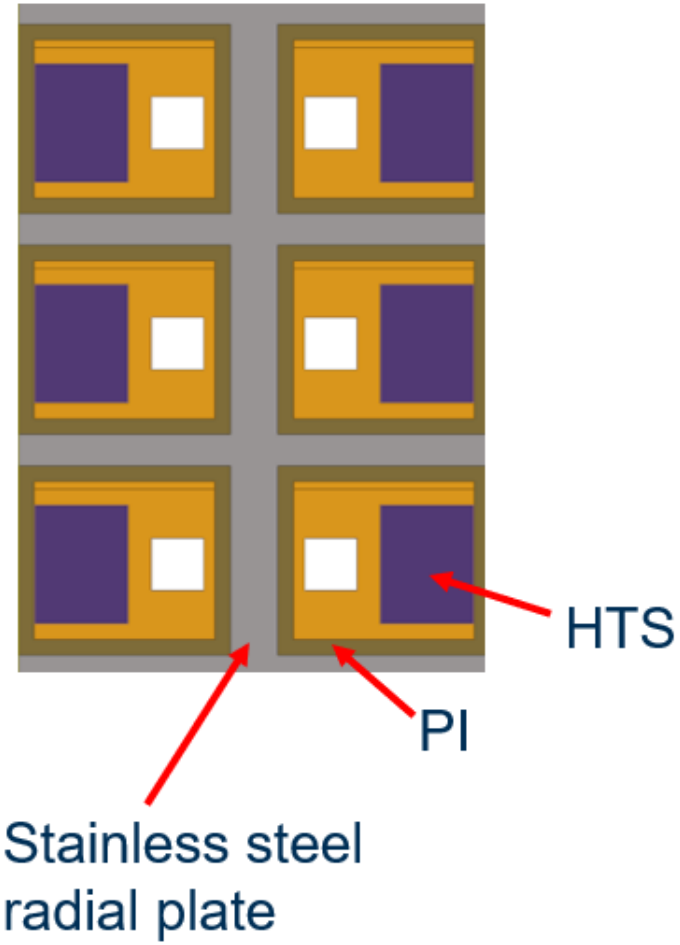
Partial Insulation

Scaling up to STEP coil size, PI needed to achieve sufficient radial resistance, contact resistance or steel resistance is insufficient.



$$\frac{R_{azimuthal}}{R_{radial}}$$

Needs to be low, say <0.05



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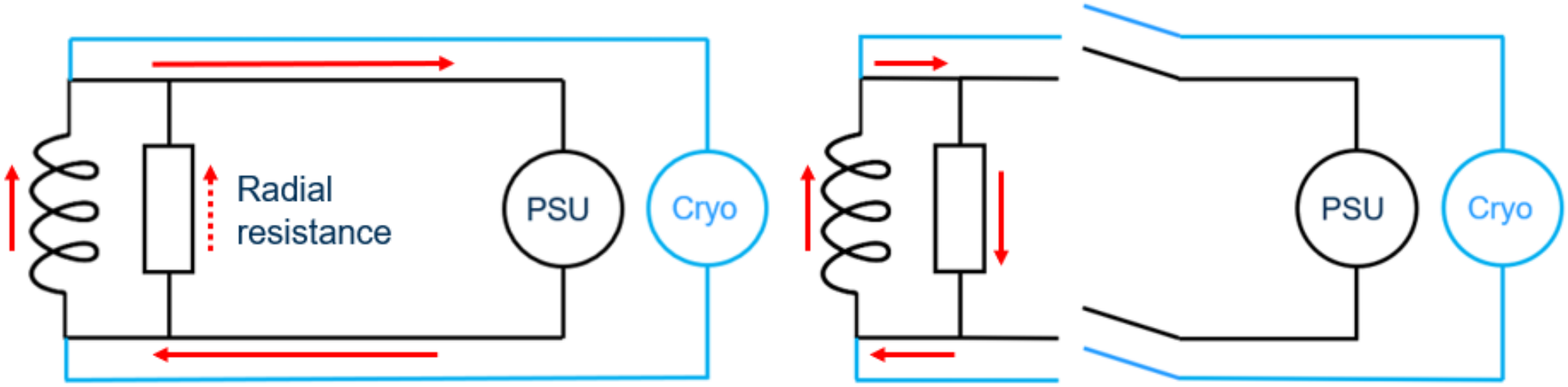
Open circuit discharge

- Local heat pulses are not the only case to be considered. Another, potentially much more severe case, is that of open circuit discharge, which would occur in the event of a PSU failure. A simultaneous cryo failure would exacerbate the situation.



- This is considered to be a worst-case operational scenario, so it was decided that this would be the case initially analysed by LBE.

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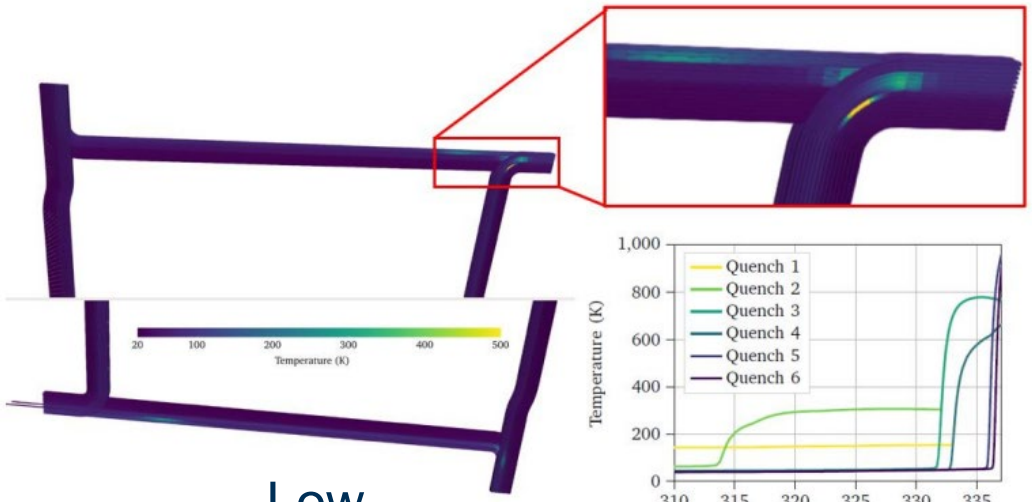
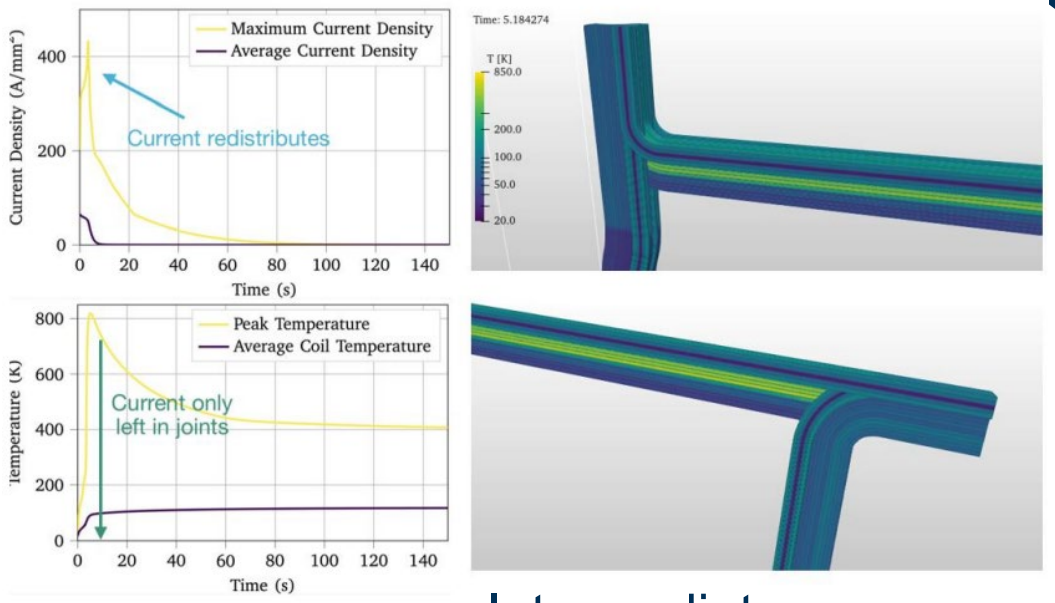
Analysis of Partially Insulated Coil

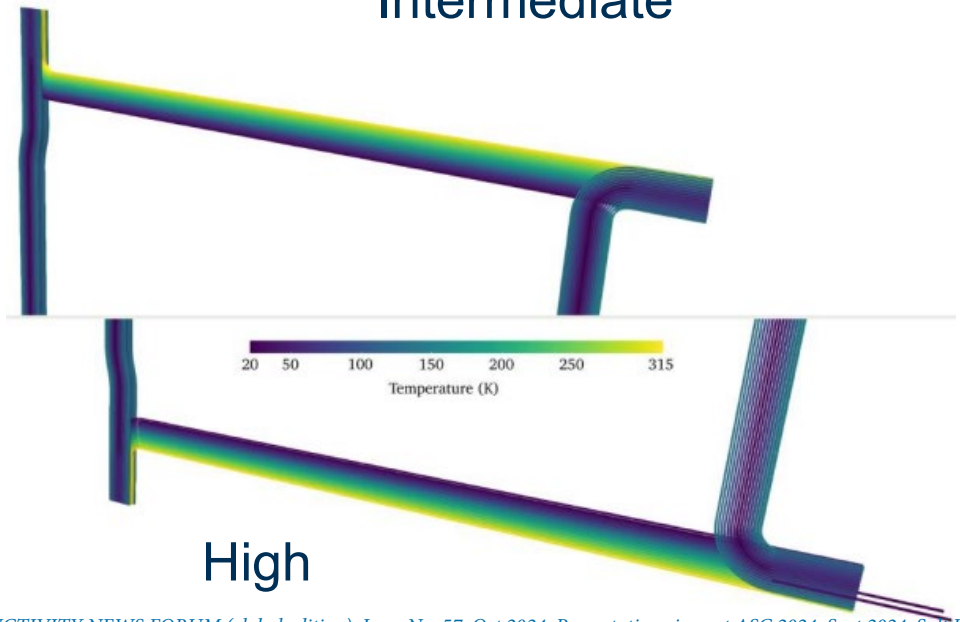


Low

Case	Resistivity (Ωm)
Low	0.003
Intermediate	3
High	400



Intermediate



High

We couldn't achieve acceptable behaviour with PI with the coil geometry

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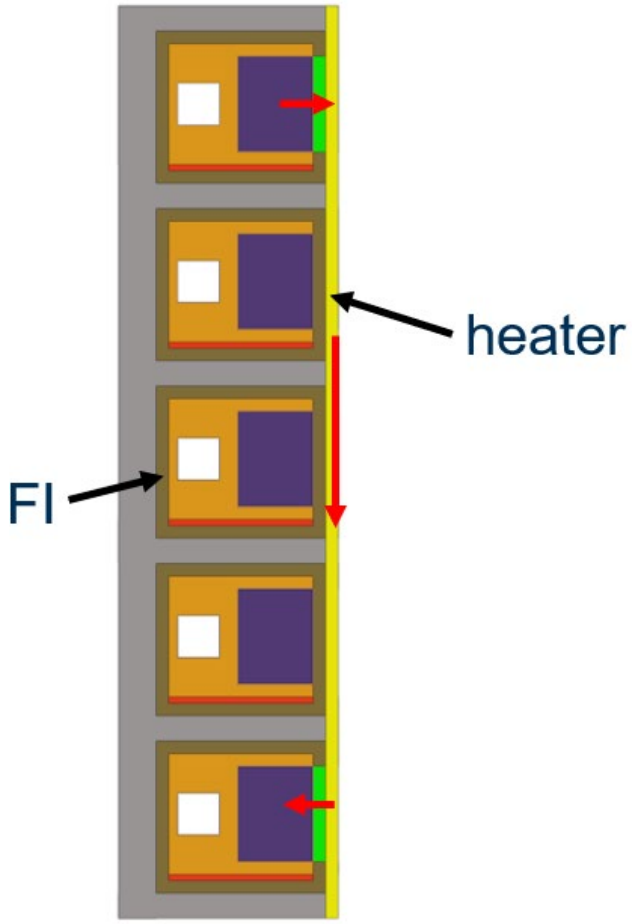
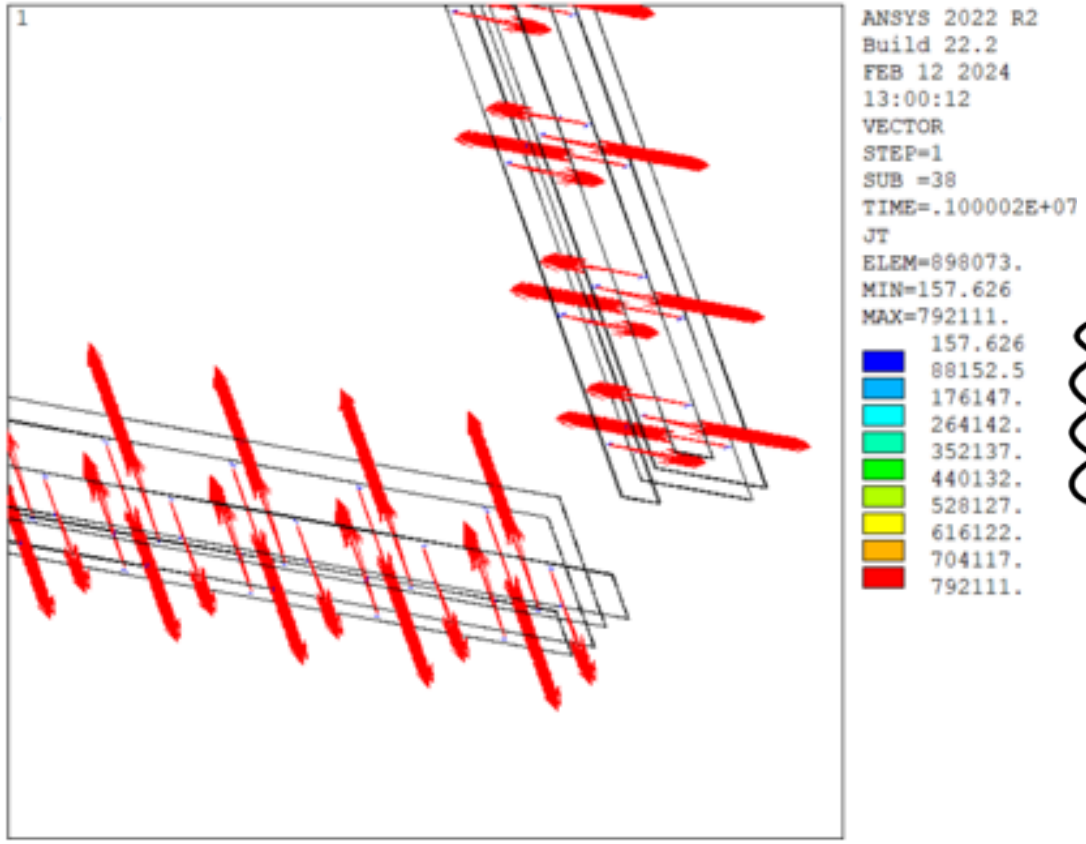
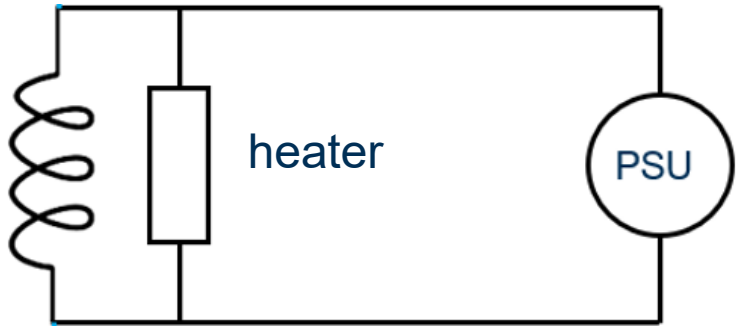
Fully Insulated Coil with Quench Heater







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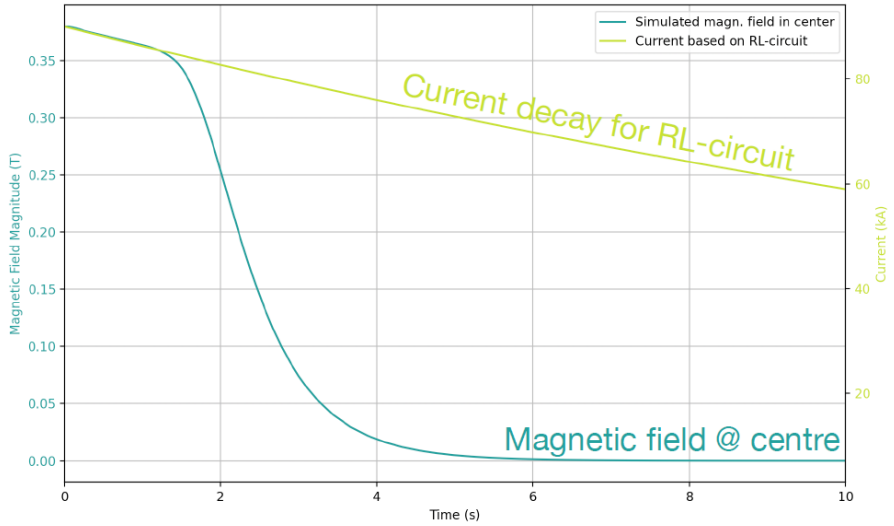
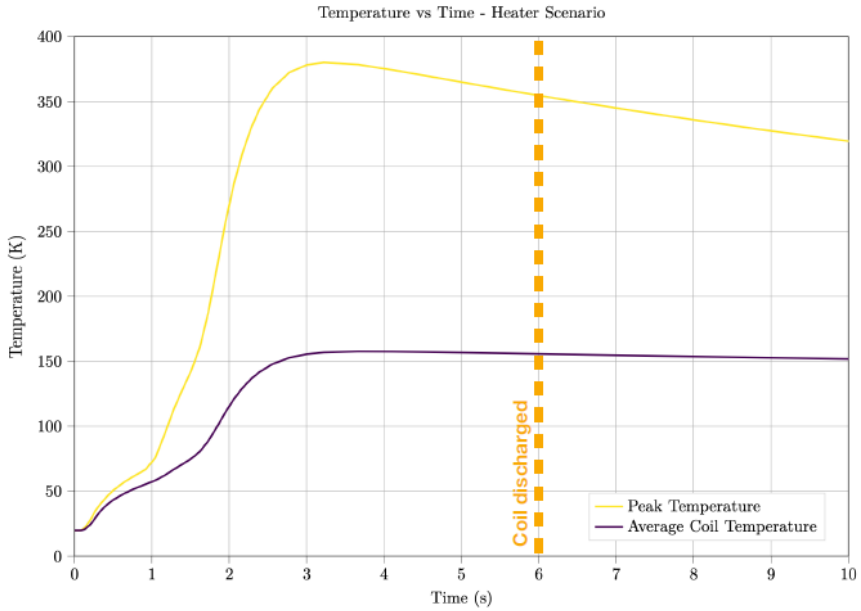
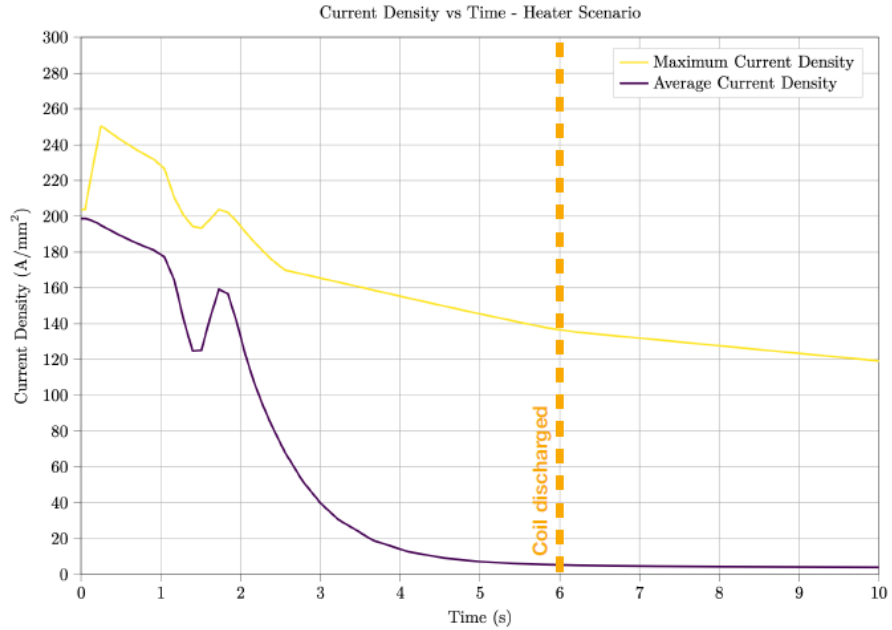
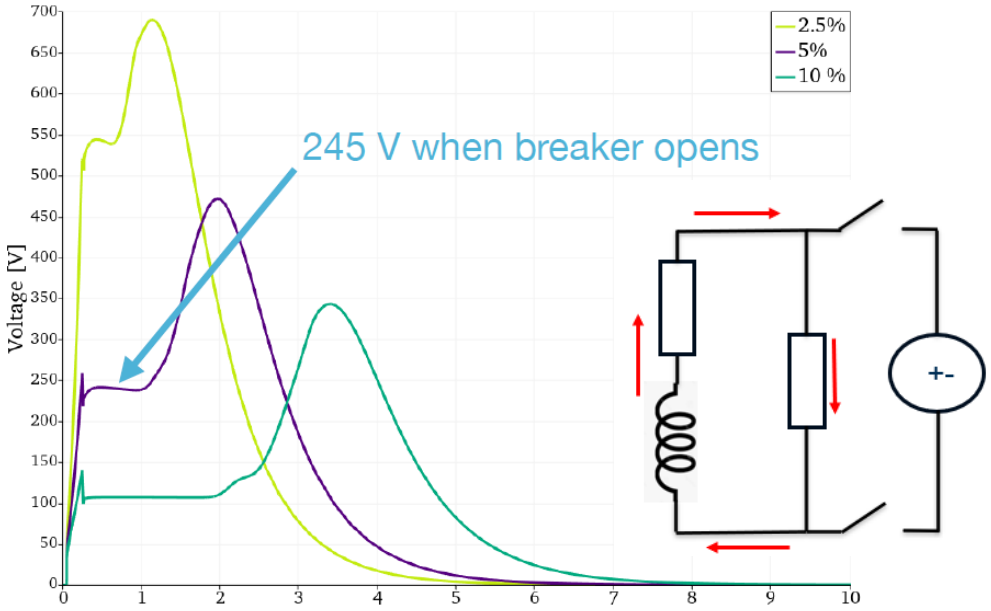
Analysis of Full Insulation with Quench Heaters









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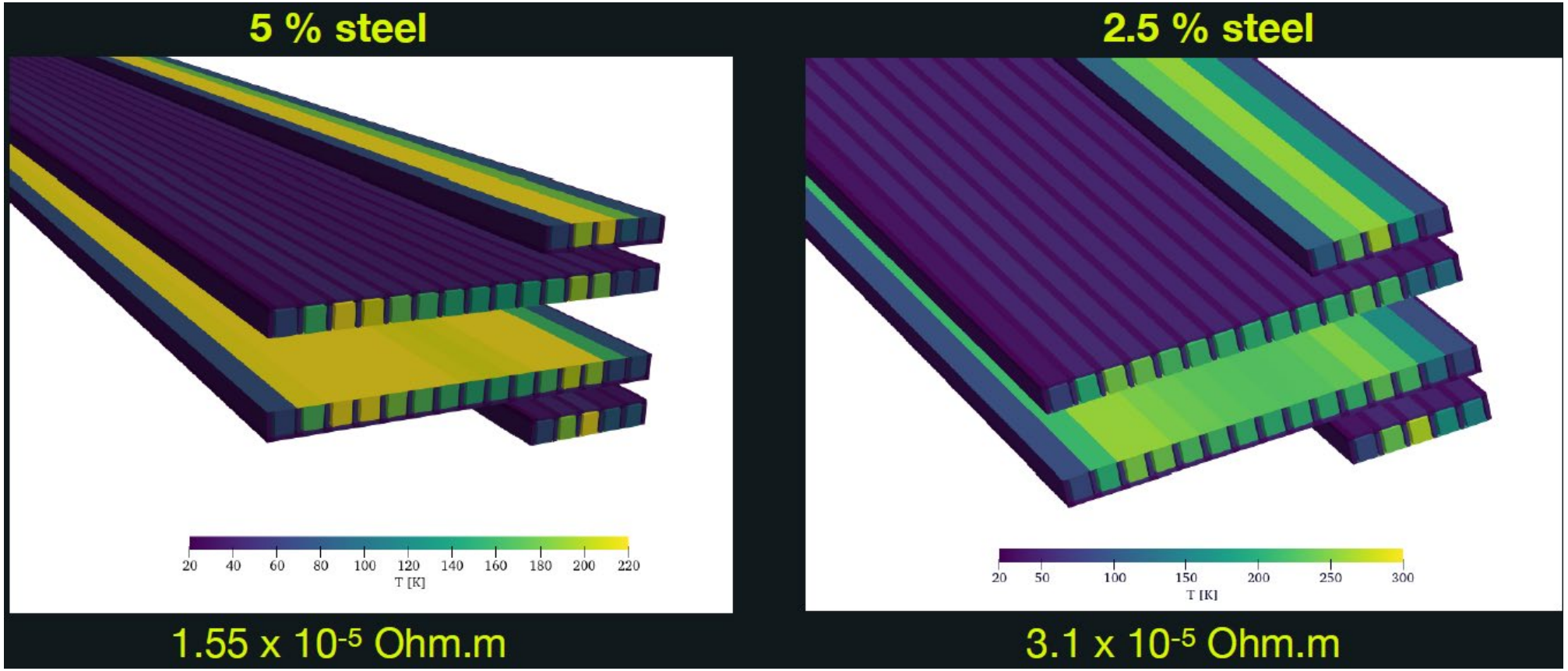

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Operation

- A Fully Insulated coil is not passive, in the event of a temperature excursion in the coil, a decision must be made at some point to discharge the coil to avoid a damaging quench.

- The Helium coolant will be monitored using radio-frequency time and frequency domain reflectometry. A temperature rise will cause the He density to drop, which will change the refractive index of the Helium. This method should be sensitive enough to pick up < 1K rise anywhere in the cooling loop.

- The question to be answered is how much of a temperature rise can be tolerated before a discharge must be initiated. If we wait until T_C it will likely be too late, we won't be able to discharge quickly enough to avoid damaging peak temperatures. But discharging after only a few K rise would be expensive if unnecessary.

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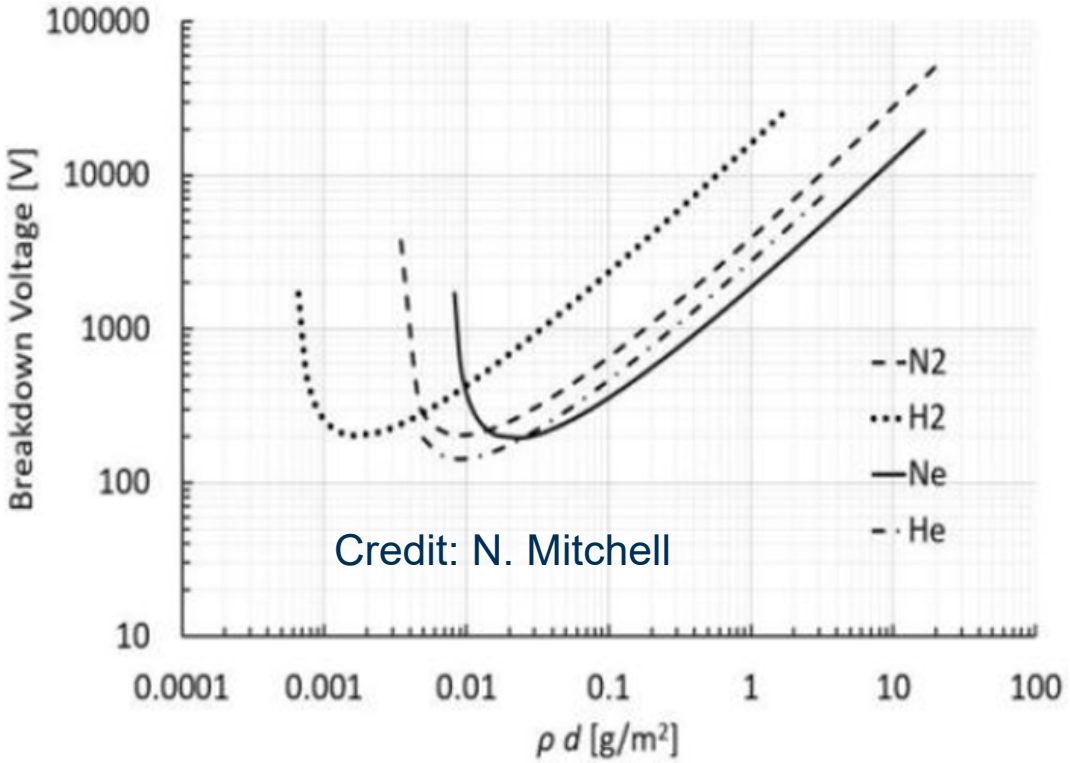
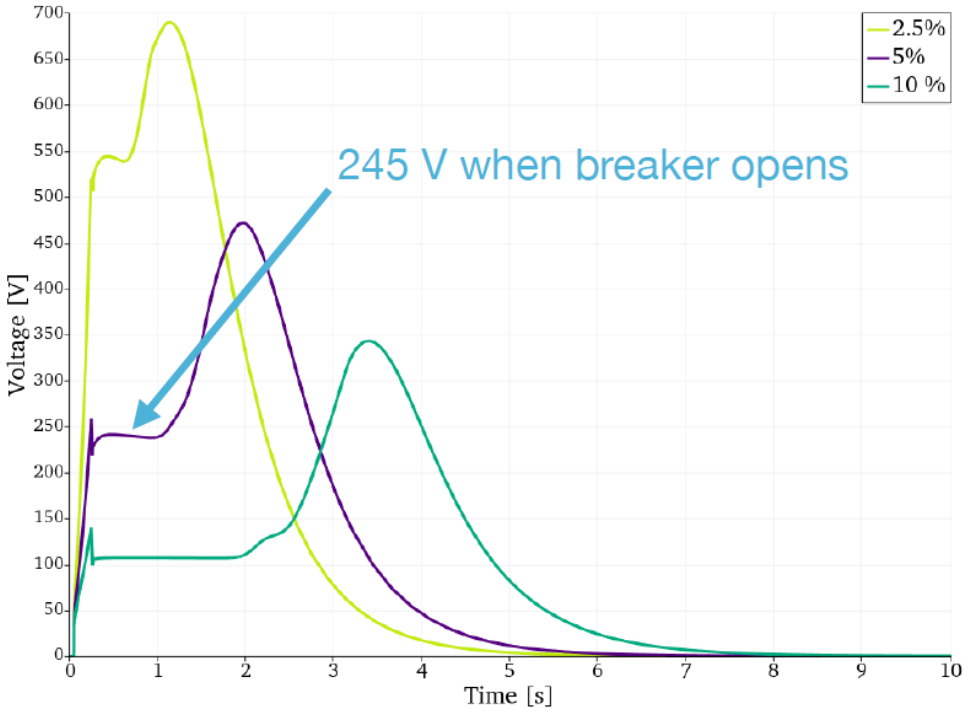
Paschen Breakdown



Such a low voltage might make the quench heater option non-viable, and so we are **revisiting the PI concept** with a revised radial plate arrangement.

Achieving a ‘Paschen tight’ re-mountable joint would be extremely challenging – so total voltage across coil set must be less than +/-140V, i.e. ~17V across each coil



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Summary

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- Both partial insulation and quench heaters are being explored as quench protection concepts for STEP TF coils.
- Partial Insulation concepts can be *passive* or *self-protecting* in the case of local heating, but quench heaters require an *active* response.
- Open circuit discharge must also be considered as a potential worst-case operating scenario.
- Paschen breakdown is a major concern – low voltage limit avoids risk
- Low voltage limit may preclude quench heaters – partial insulation may be our only option.

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Thank you for listening

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