A Method for Confirming the Operation of the ACC coils on ITER HNBs

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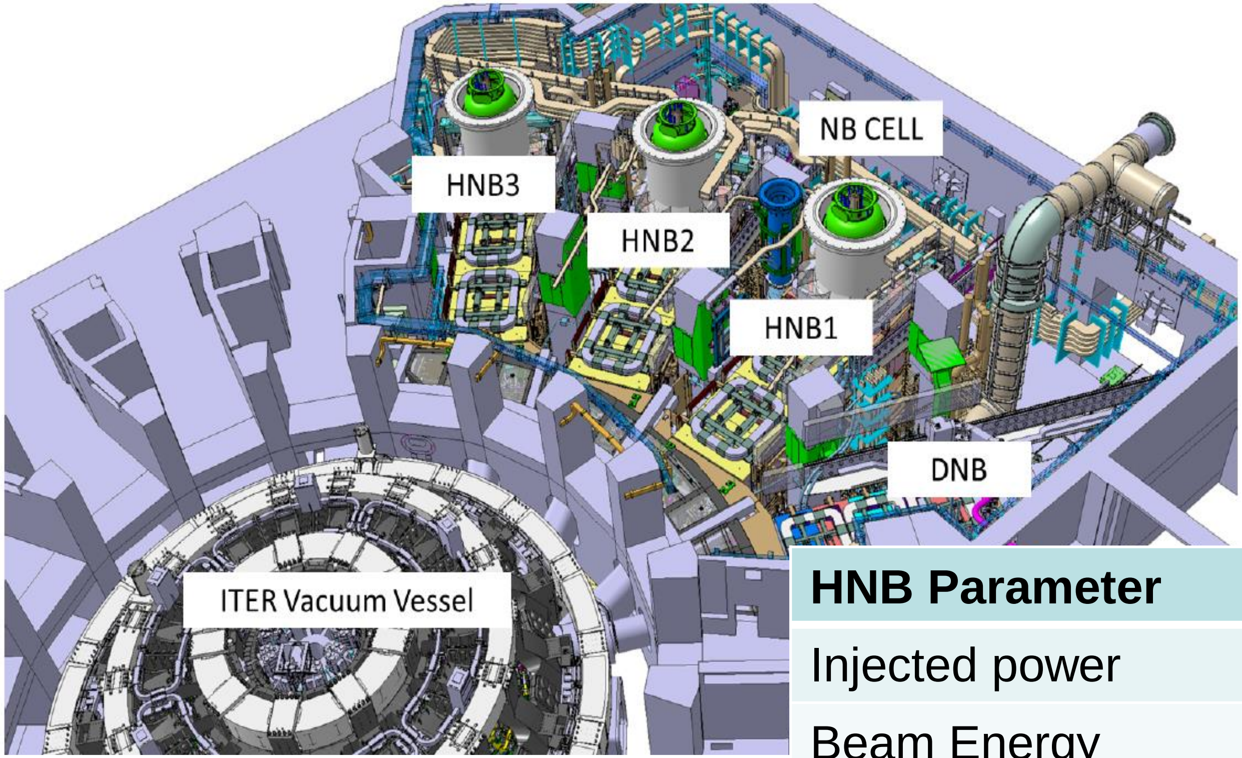
ITER Organisation

Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization

Contents

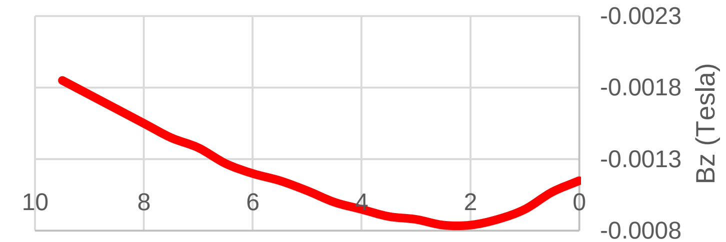
- ITER HNBs, and the Active Compensation and Correction Coils (ACCC)
- Thermal diagnostics on the Beamline Components
- BTR simulations
- Results

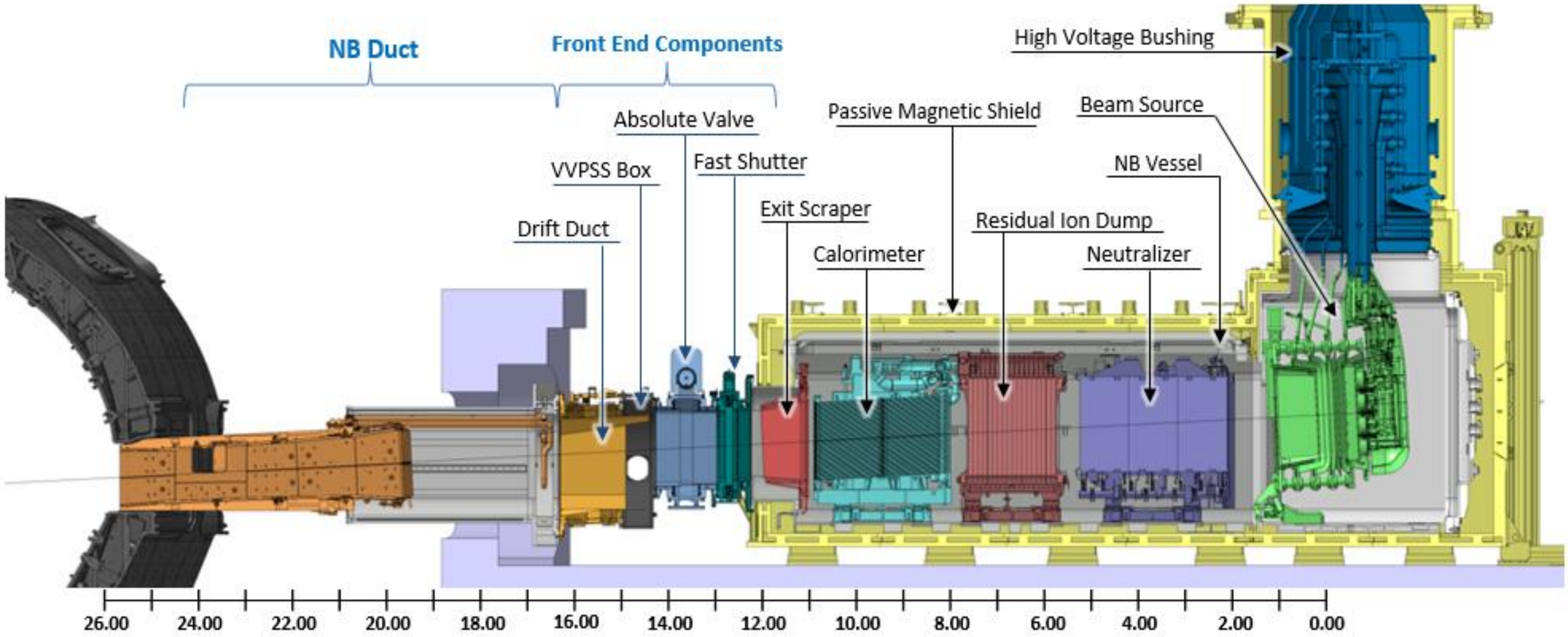
ITER HNB



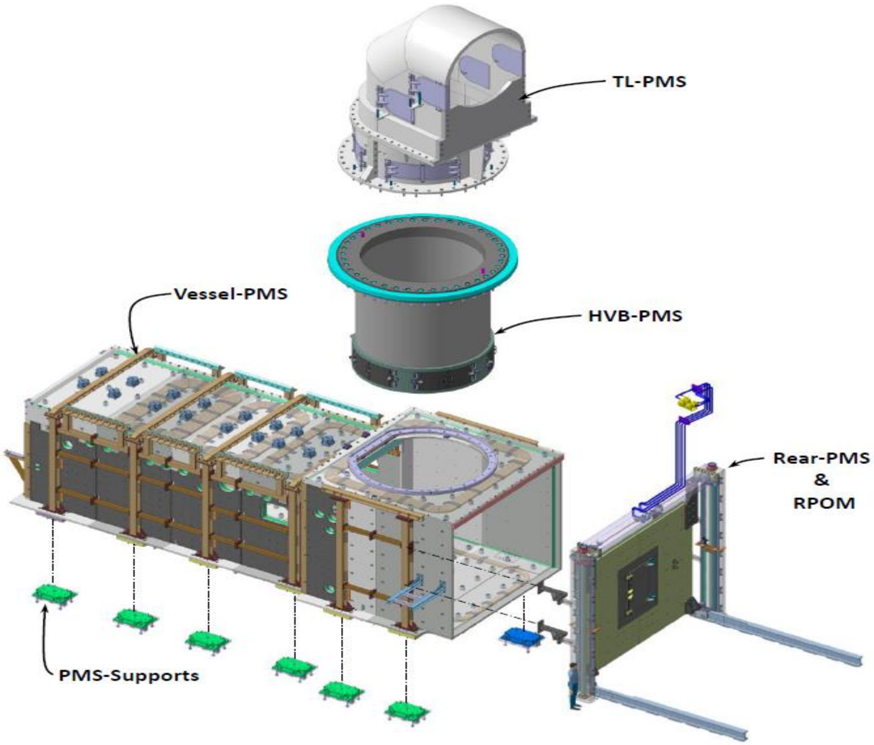
HNB Parameter	H phase	D phase
Injected power	16.5 MW	16.5 MW
Beam Energy	0.87 MeV	1 MeV
Accelerated Current	46 A	40 A
Divergence	3-7 mrad	3-7 mrad
Pulse Length	1000 s	3600 s

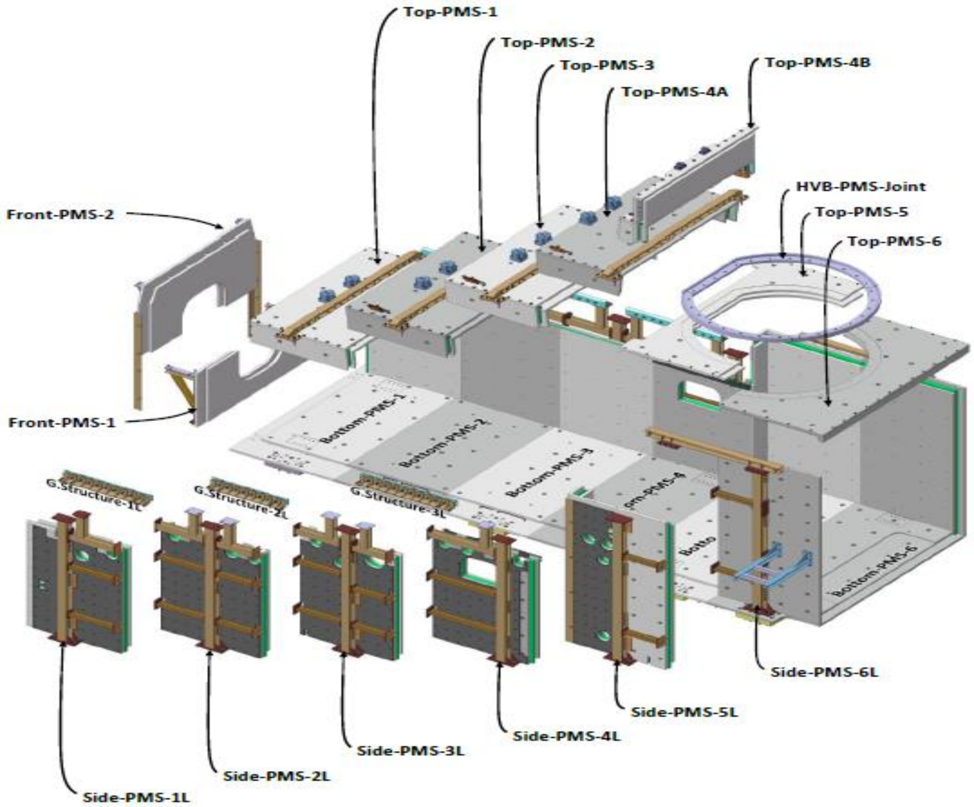
Heating Neutral Beam





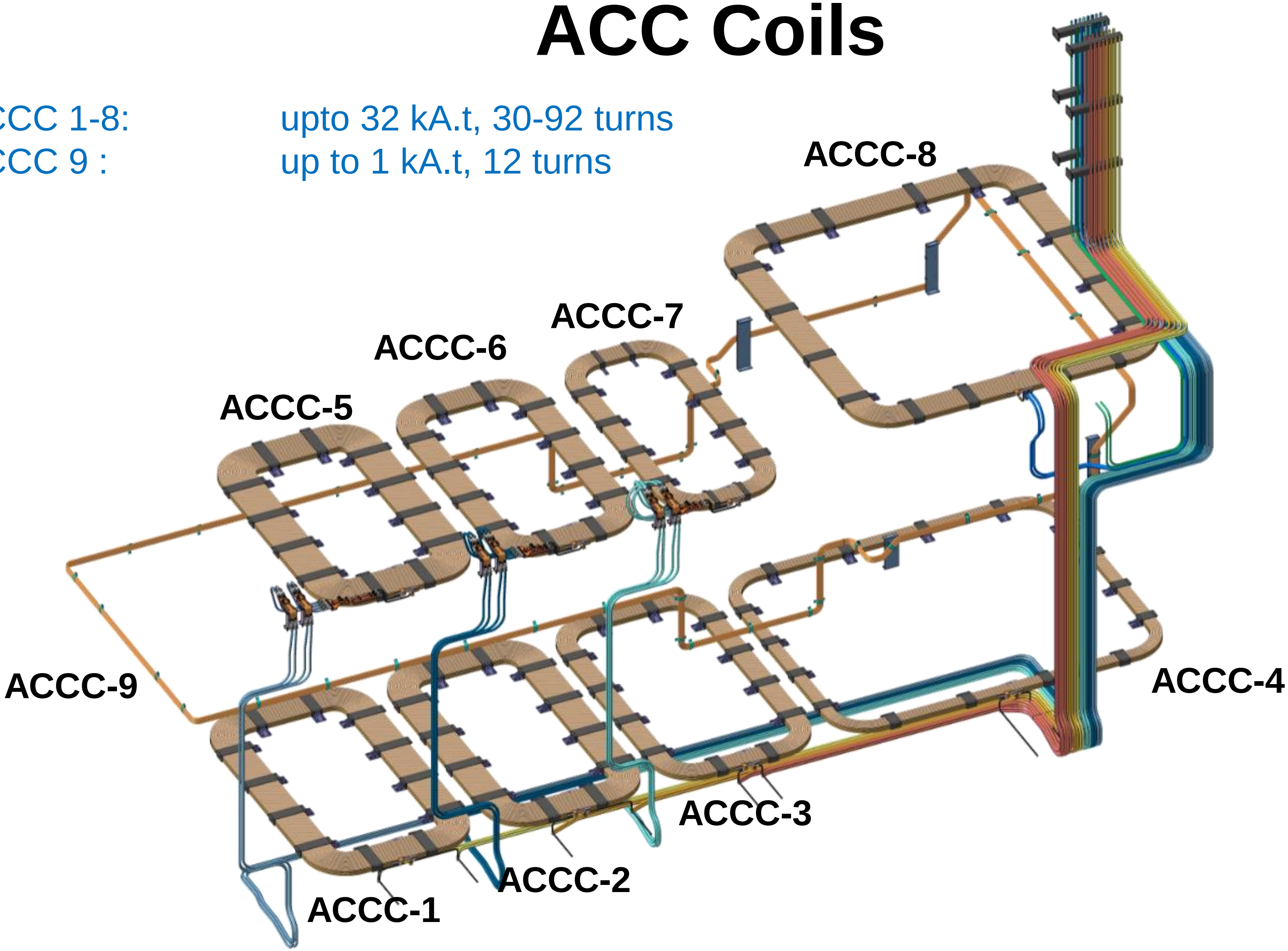
Passive Magnetic Shield





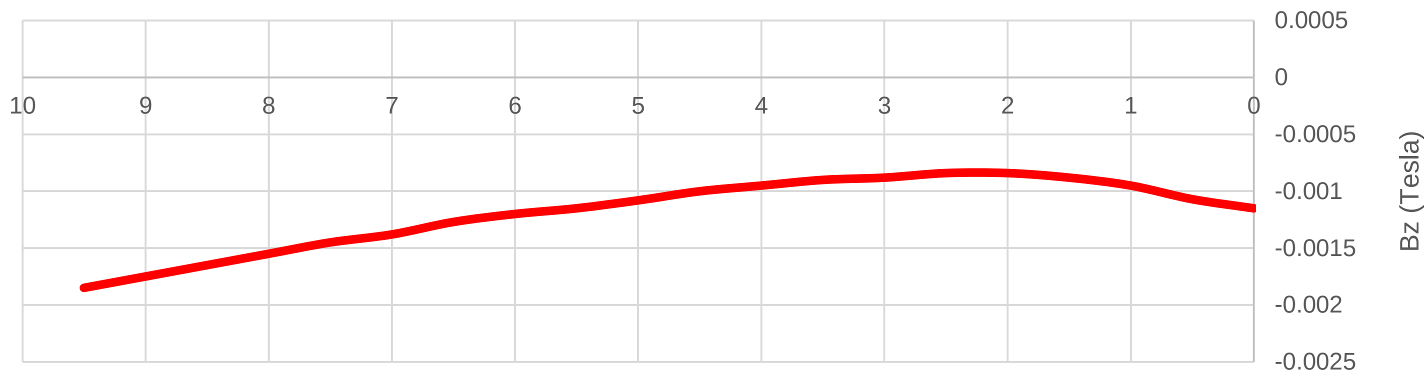
ACC Coils

ACCC 1-8: upto 32 kA.t, 30-92 turns
ACCC 9 : up to 1 kA.t, 12 turns

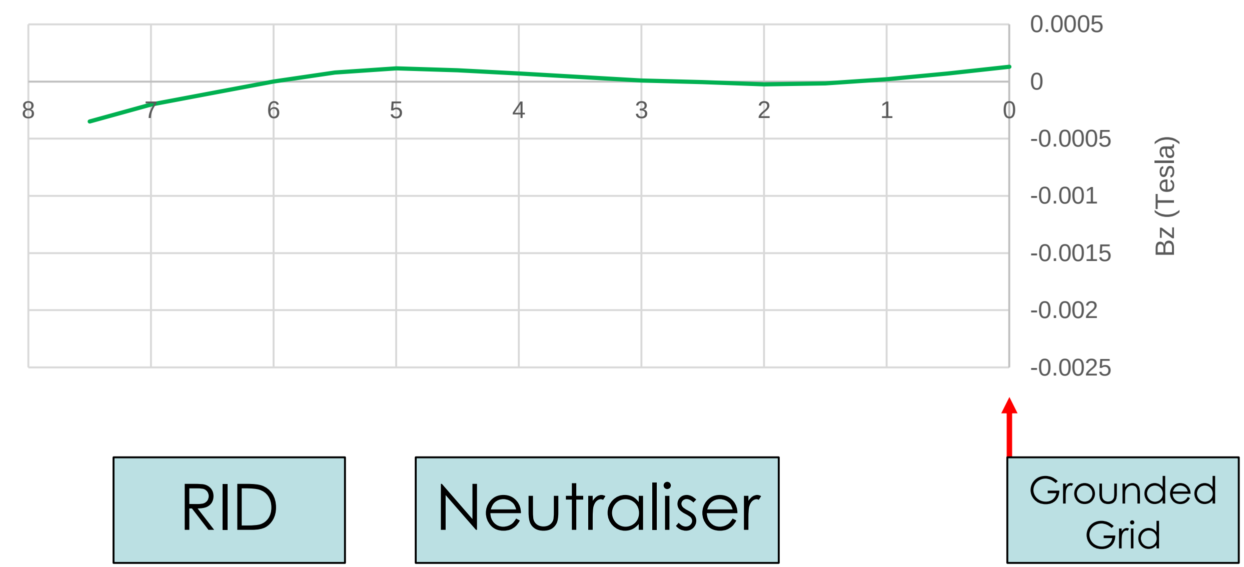


Magnetic fields

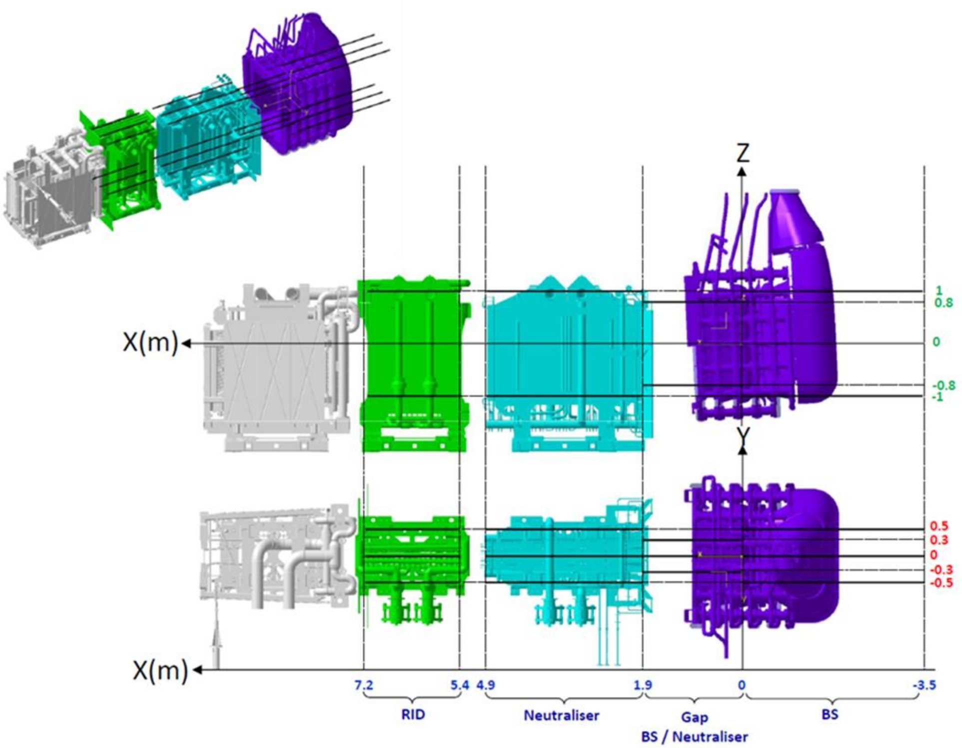
B Field with only Passive Magnetic Shield (PMS)



Standard residual field used in design process (PMS + ACCC)



B Field requirements



Beam Source (-3.5< x < -0.6):

$|B| < 10^{-3}$ T

Accelerator: (-0.6 < x < 0)

$|B_z| < 2 \times 10^{-4}$ T

Gap between BS and Neutraliser:

$|B_z| < 3 \times 10^{-4}$ T and $\int B_z dz < 2 \times 10^{-4}$ T.m

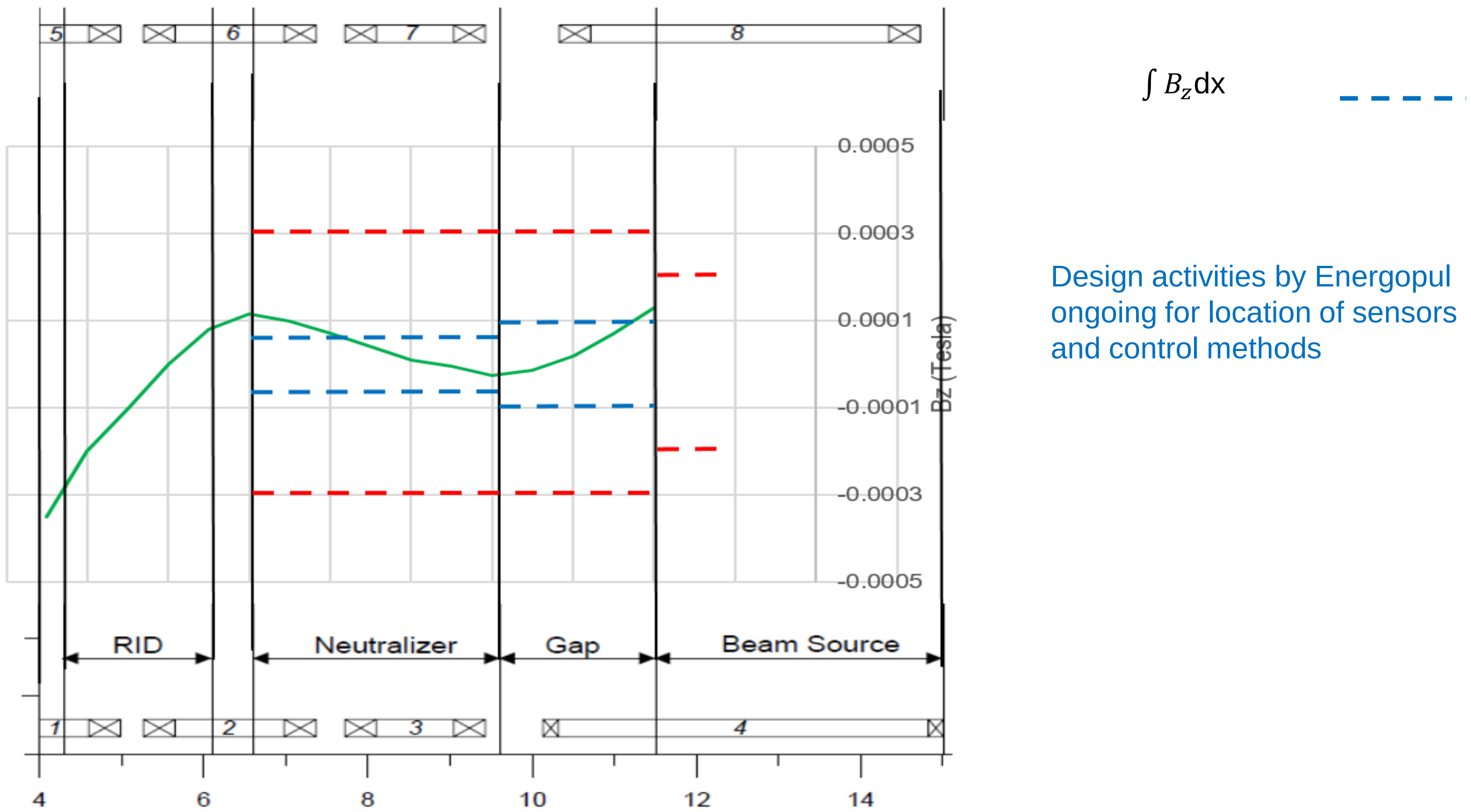
Neutraliser:

$|B_z| < 3 \times 10^{-4}$ T and $\int B_z dz < 2 \times 10^{-4}$ T.m

RID:

$|B_z| < 5 \times 10^{-3}$ T

Required B Field



Design activities by Energopul ongoing for location of sensors and control methods

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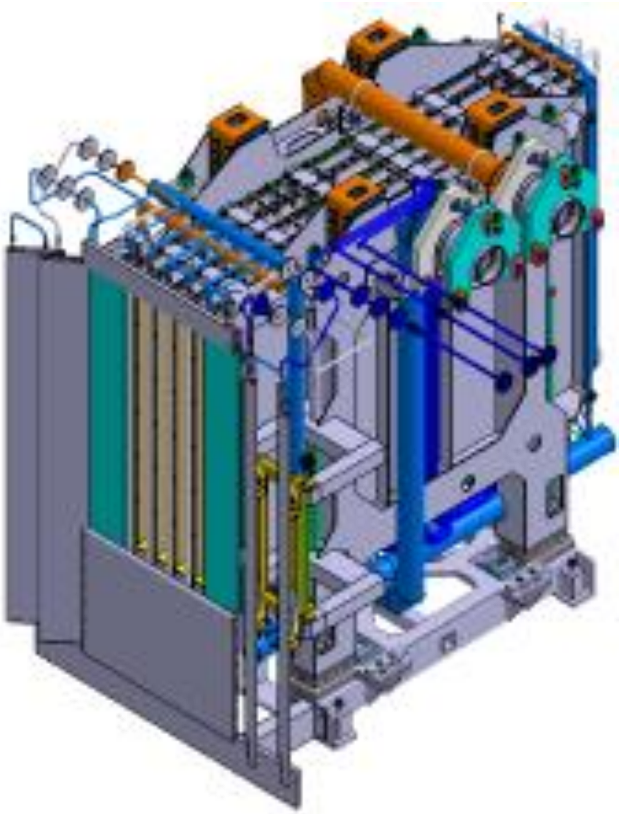
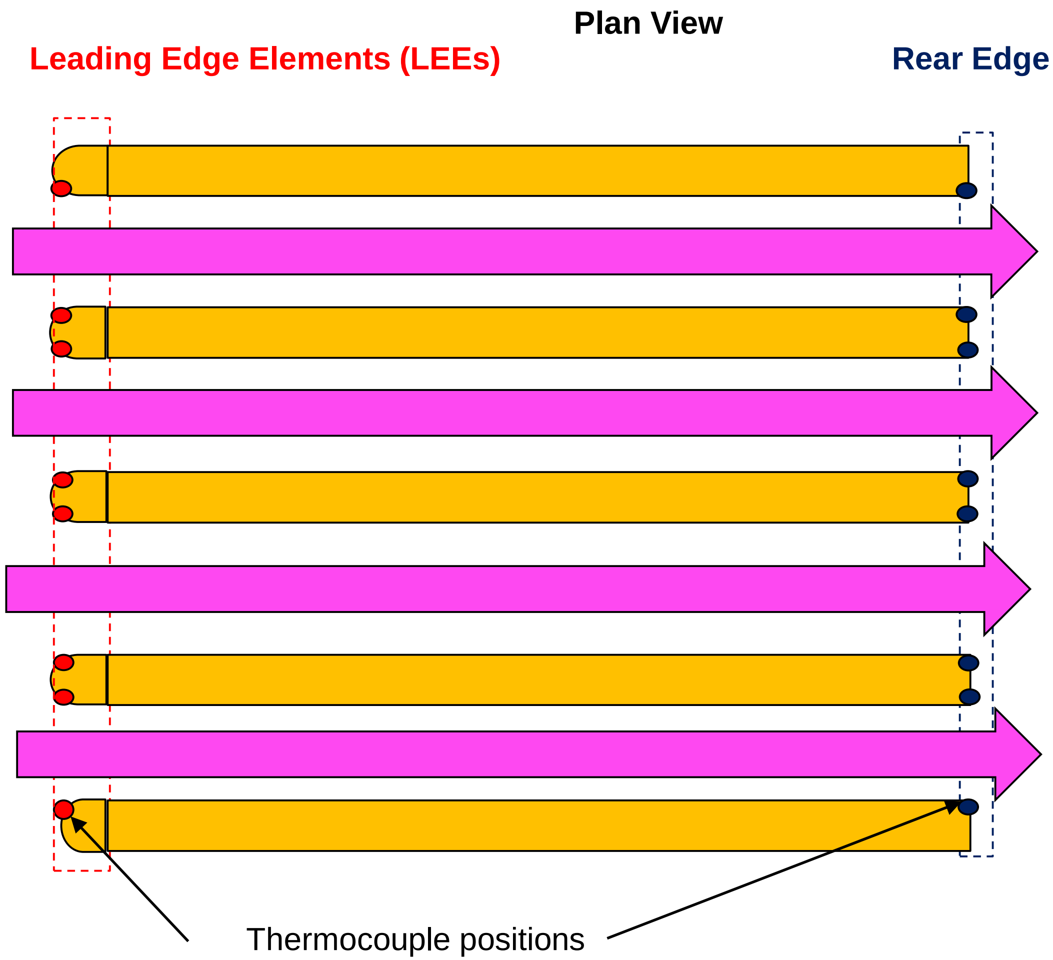
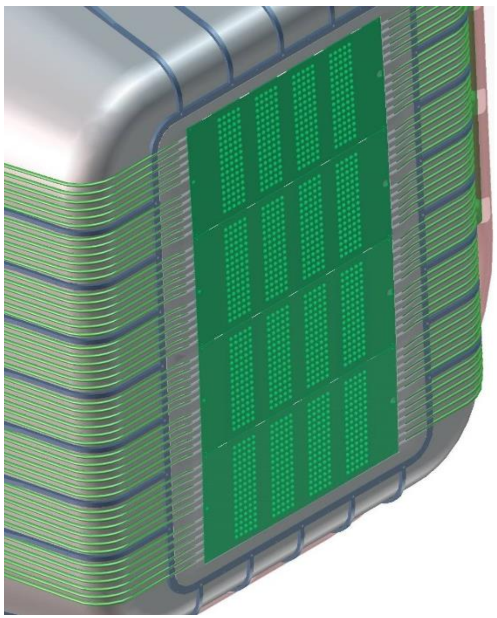
Neutraliser

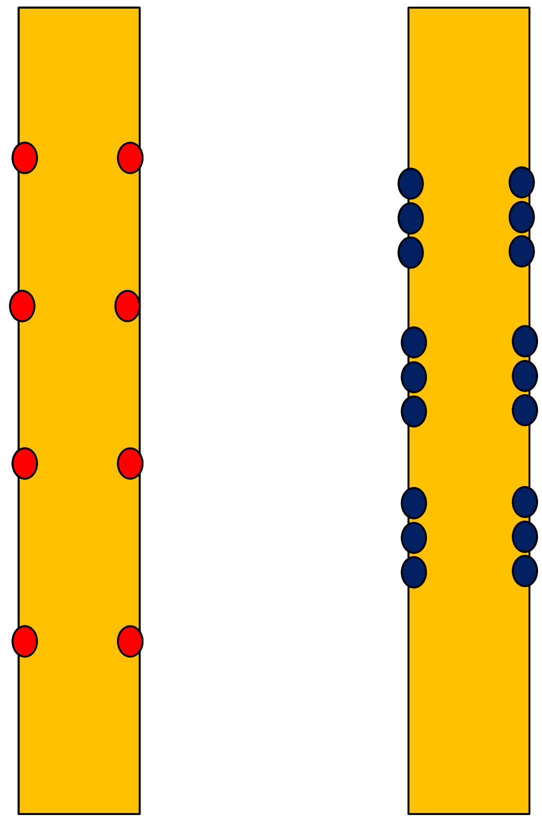




Neutraliser

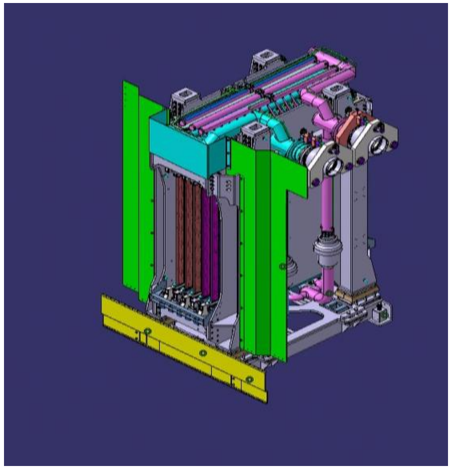
Leading Edge Elements (LEEs) **Rear Edge**

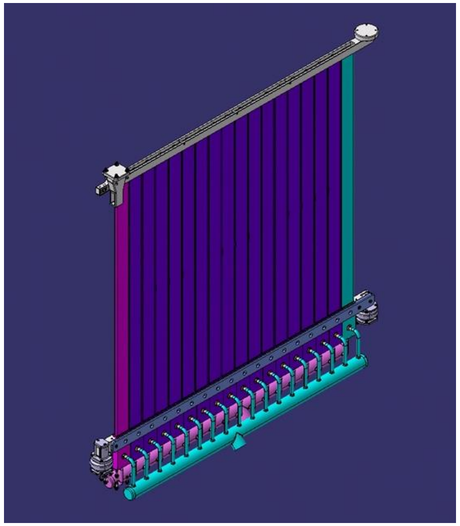


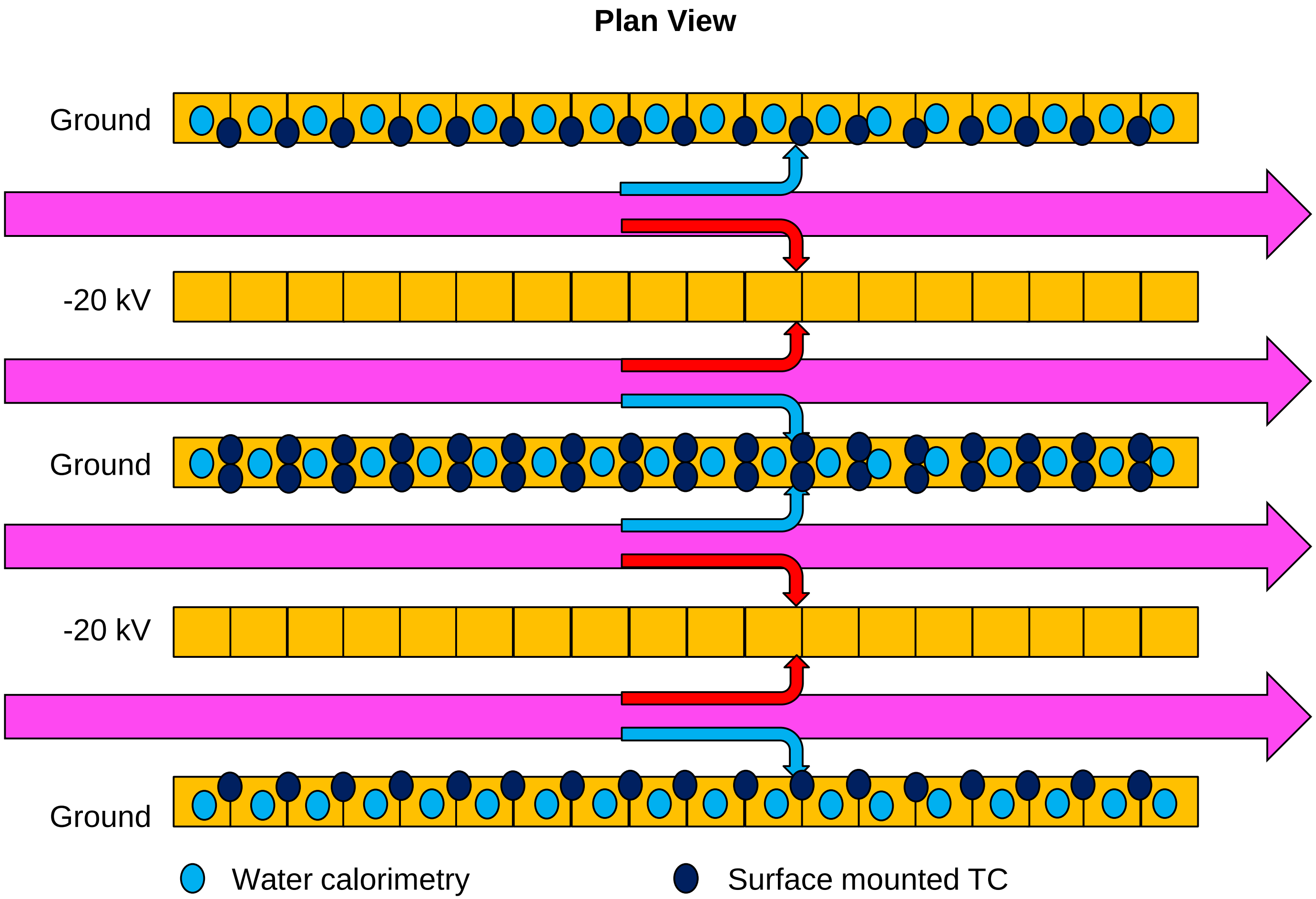


Accelerator made up of 4 horizontal segments –
4 groups of 16x5 apertures per segment
1280 apertures in total.

Electrostatic Residual Ion Dump







HV Voltage will sweep ±5kV to spread power load

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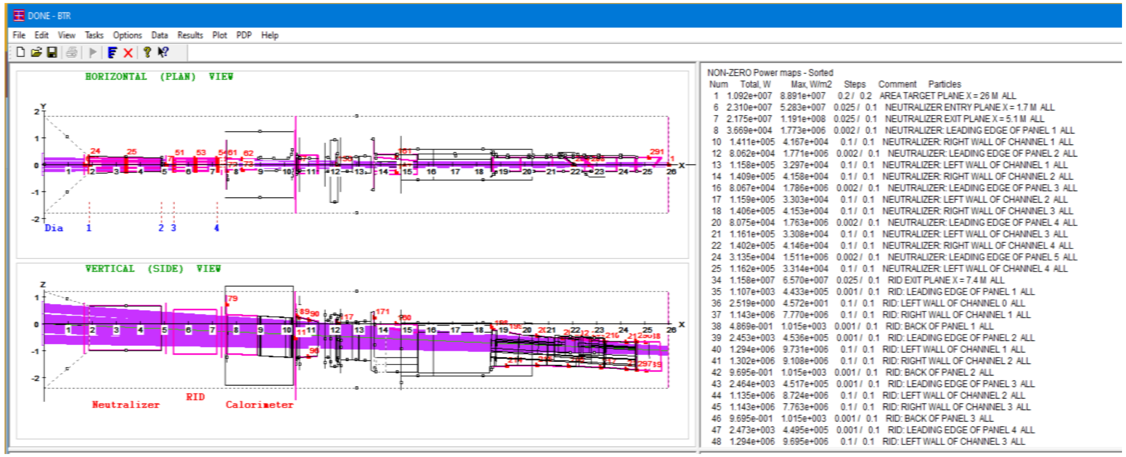
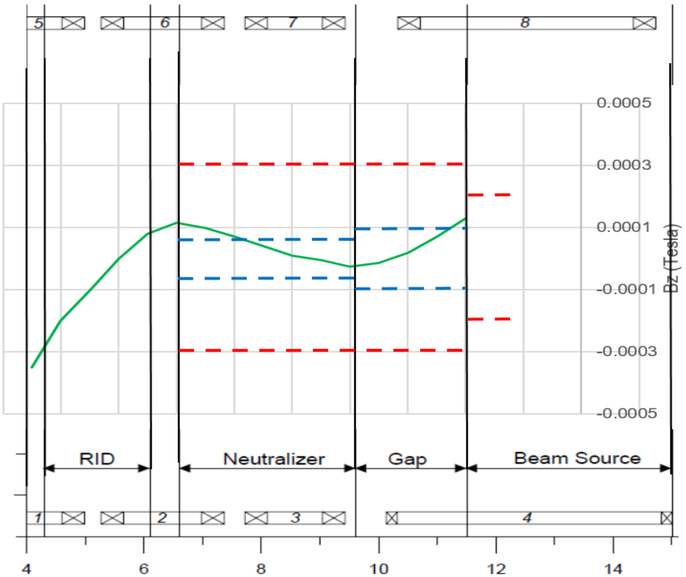
BTR Simulations

Beam Tracing and Re-ionization - ray tracing code



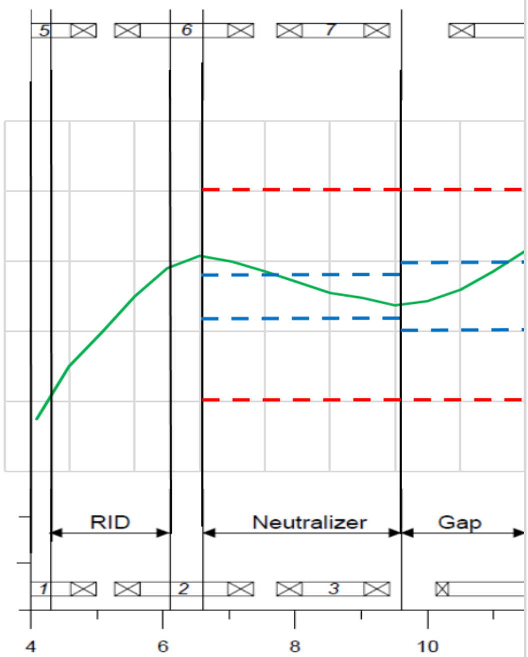
Assumptions for BTR runs:

- Effect of field before GG is ignored.
- Field in a region between coils is set to be uniform
- Fields used go from the limit in that region, up to the expected value if only the PMS is present.
- Halo fraction of 15%, with 30 mrad divergence
- Core Divergences of 3, 5 and 7 mrads were used.

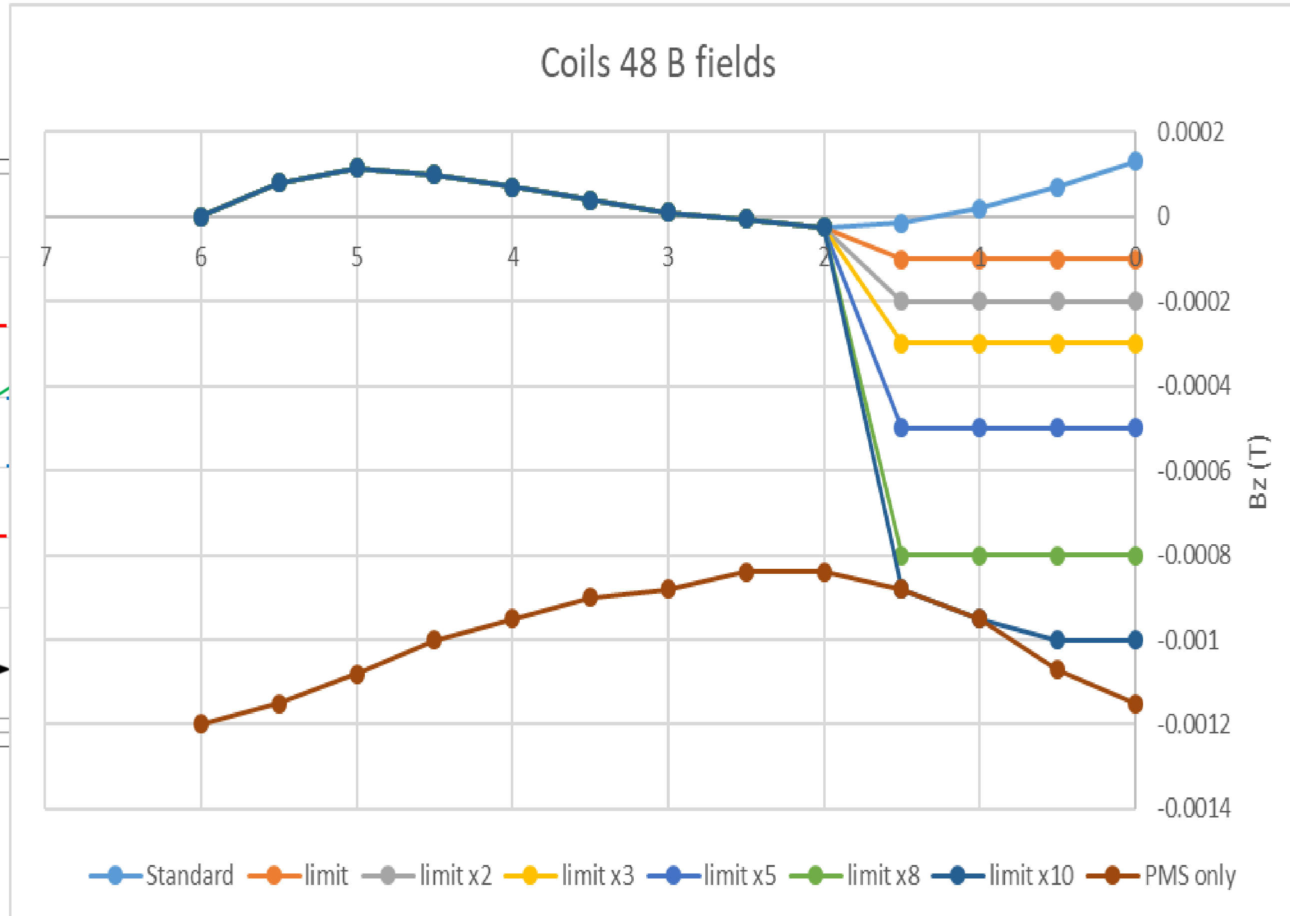


Since commissioning phase being considered, lower voltages used (500-700kV, H_2 only).
Horizontal misalignment is set to zero for most runs, but was added for some later runs

B fields

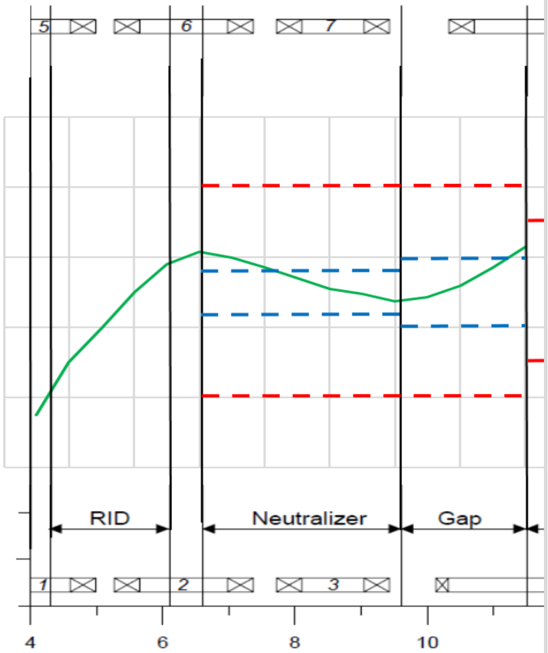


5
6
7
RID
Neutralizer
Gap
1
2
3
4
6
8
10

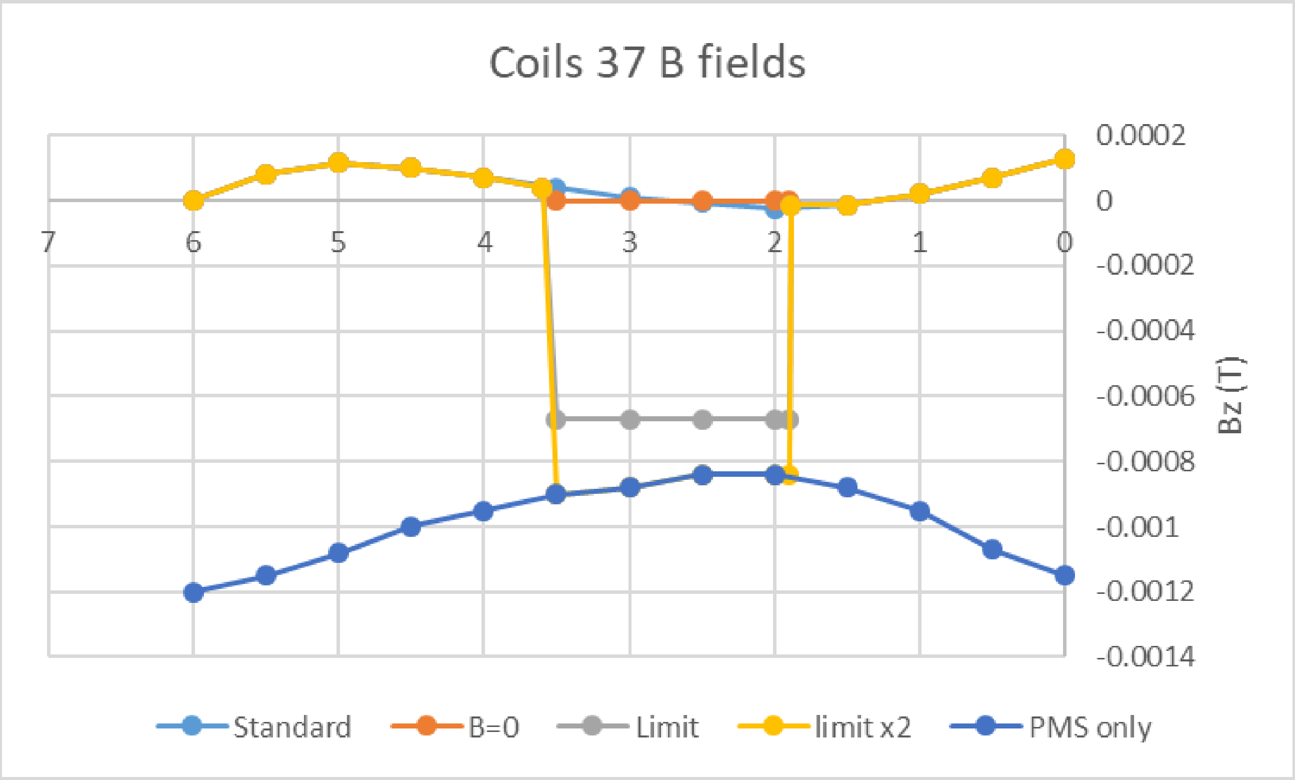


Coils 48 B fields
0.0002
0
-0.0002
-0.0004
-0.0006
-0.0008
-0.001
-0.0012
-0.0014
7
6
5
4
3
2
1
0
Bz (T)
Standard
limit
limit x2
limit x3
limit x5
limit x8
limit x10
PMS only

B fields (2)

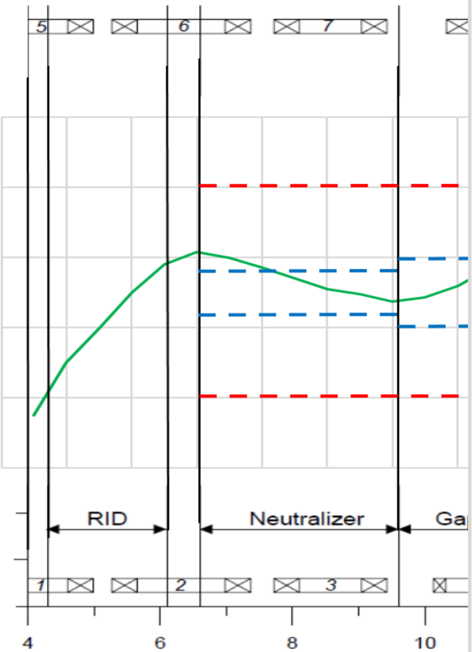


5
6
7
1
2
3
RID
Neutralizer
Gap
4
6
8
10

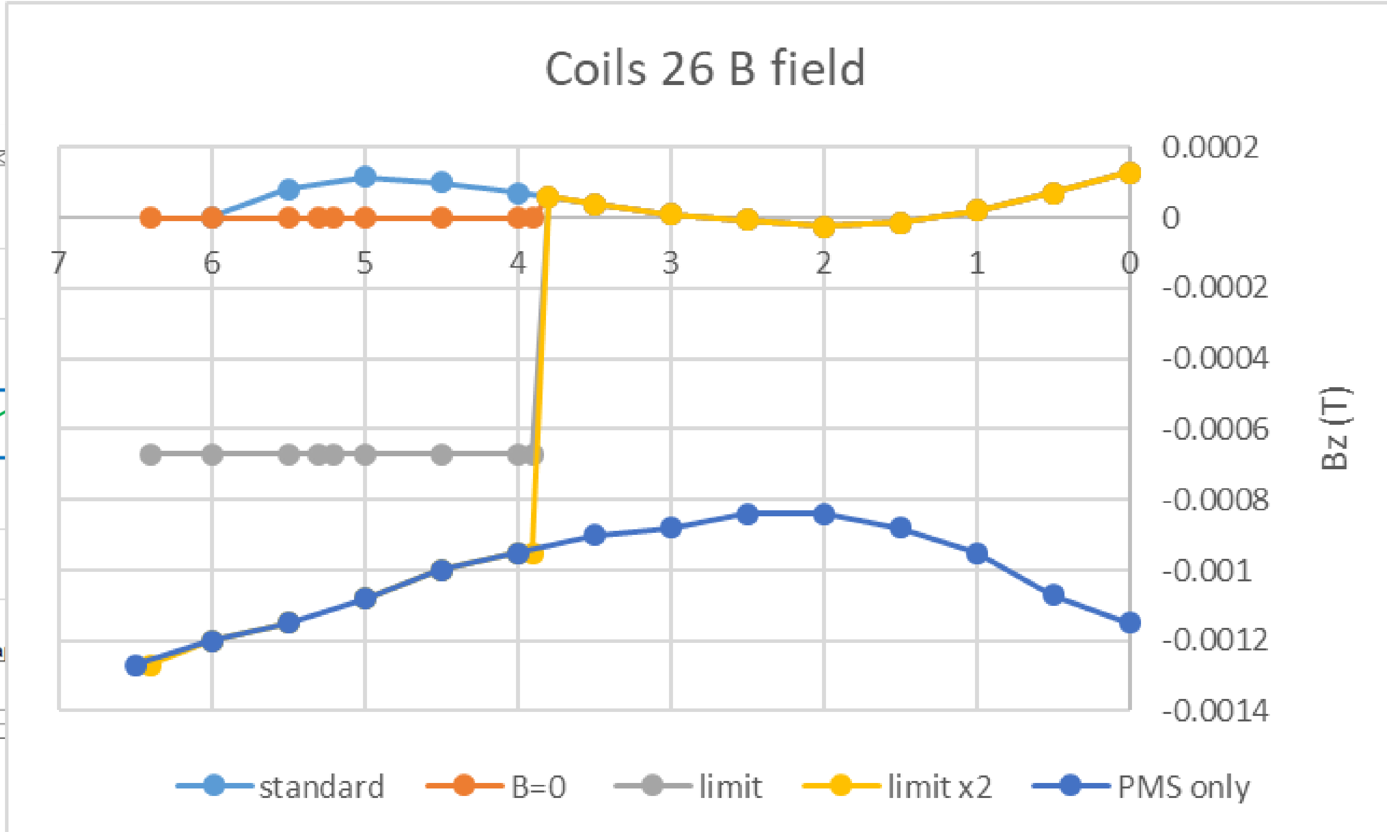


Coils 37 B fields
0.0002
0
-0.0002
-0.0004
-0.0006
-0.0008
-0.001
-0.0012
-0.0014
Bz (T)
7
6
5
4
3
2
1
0
Standard
B=0
Limit
limit x2
PMS only

B fields (3)



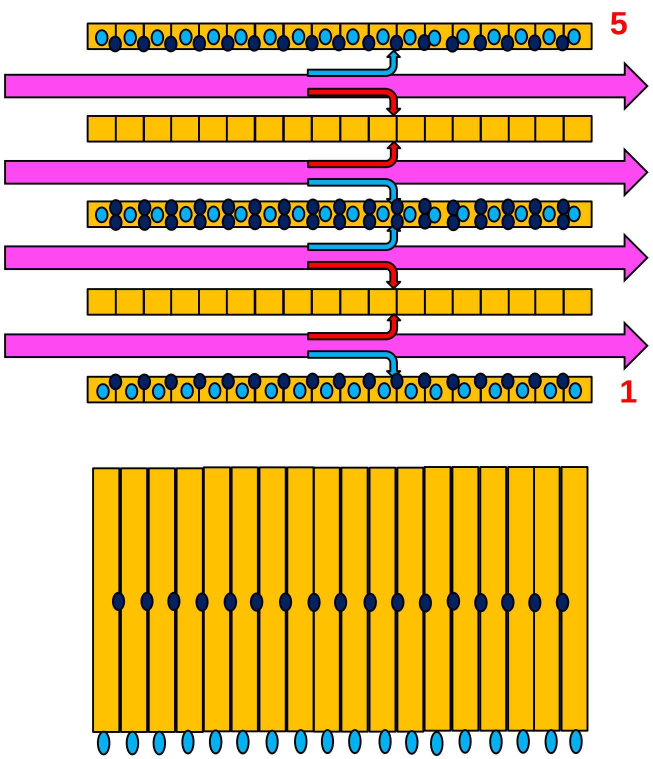
5
6
7
RID
Neutralizer
1
2
3
4
6
8
10

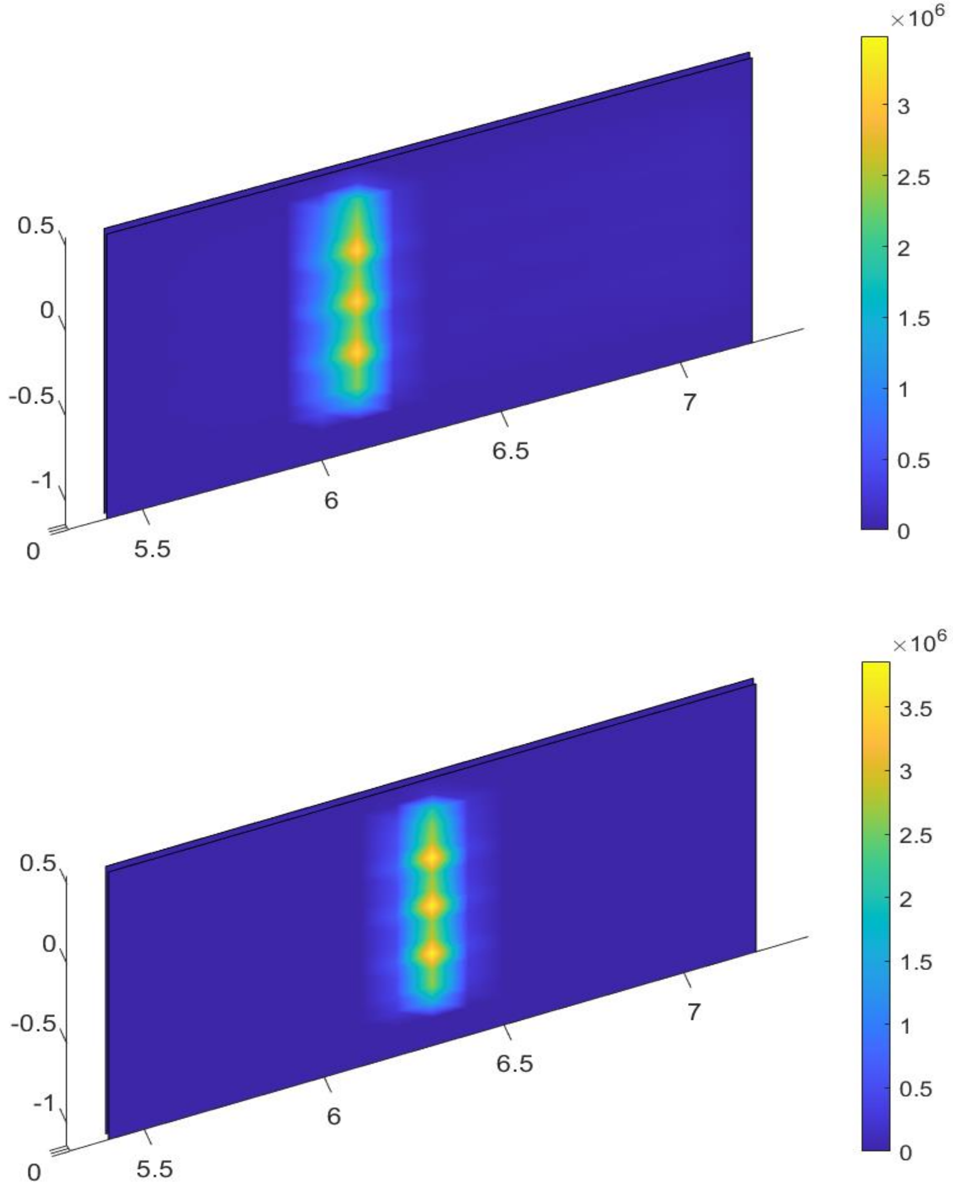


Coils 26 B field
0.0002
0
-0.0002
-0.0004
-0.0006
-0.0008
-0.001
-0.0012
-0.0014
Bz (T)
7
6
5
4
3
2
1
0
standard
B=0
limit
limit x2
PMS only

Contents

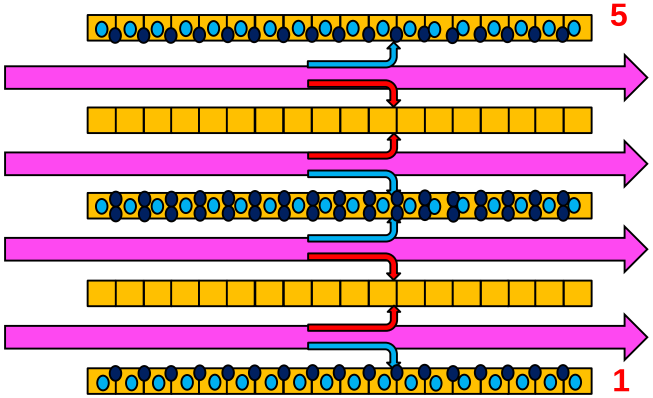
RID Calorimetry response for coils 26



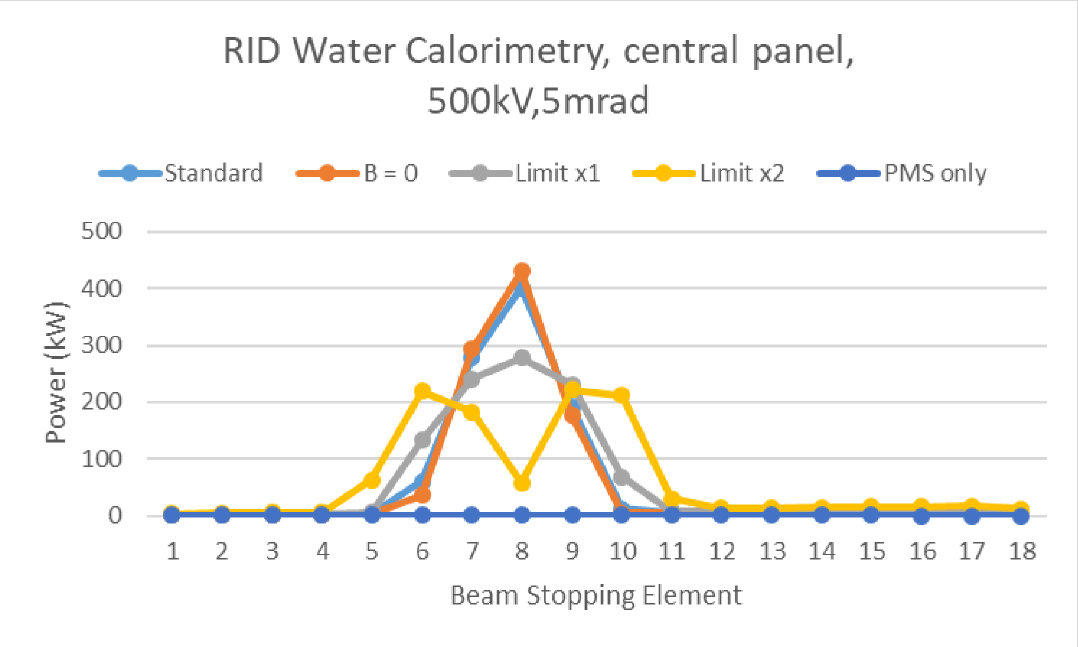


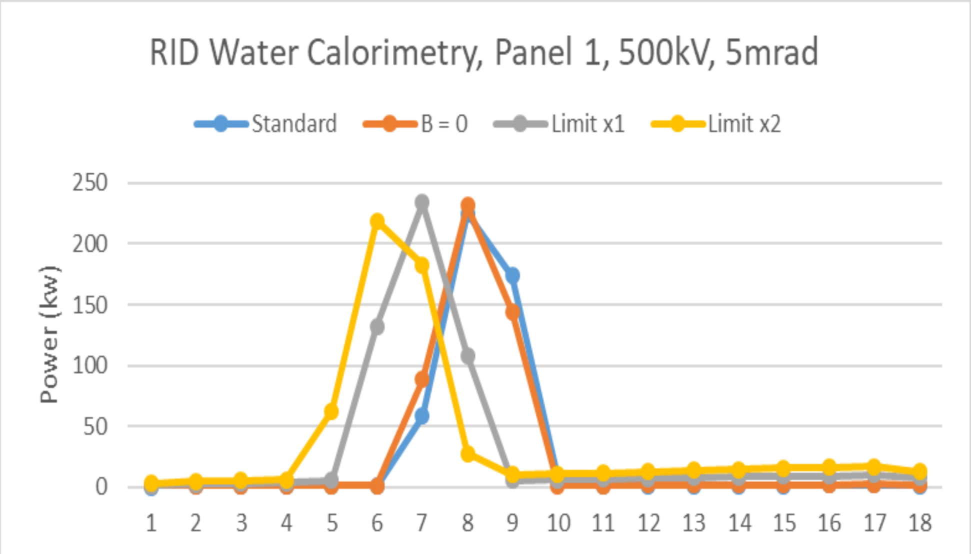
2D power maps used to find total power in each RID element, or power density at a surface thermocouple

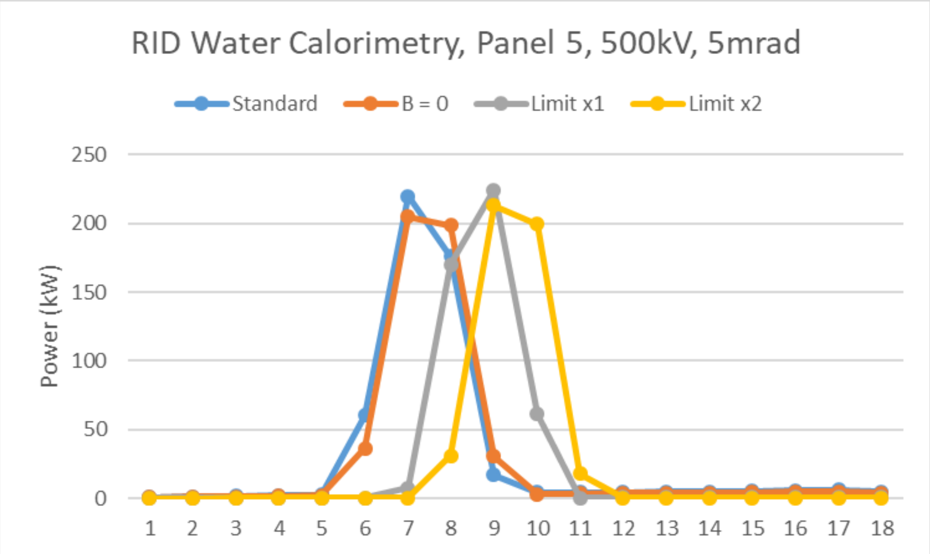
RID Calorimetry response for coils 26



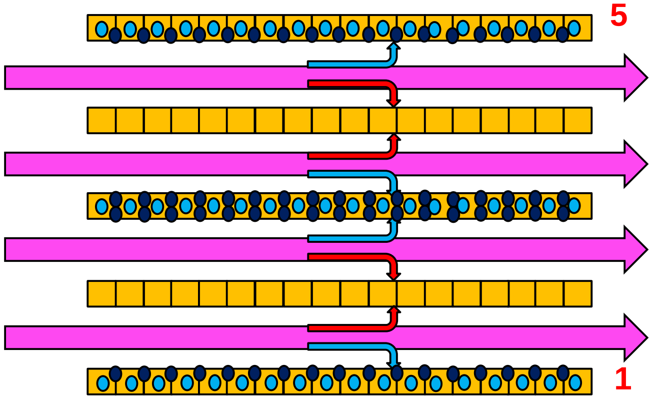
Divergence between loads on either side is expected, since same charge of ions moving in opposite directions.



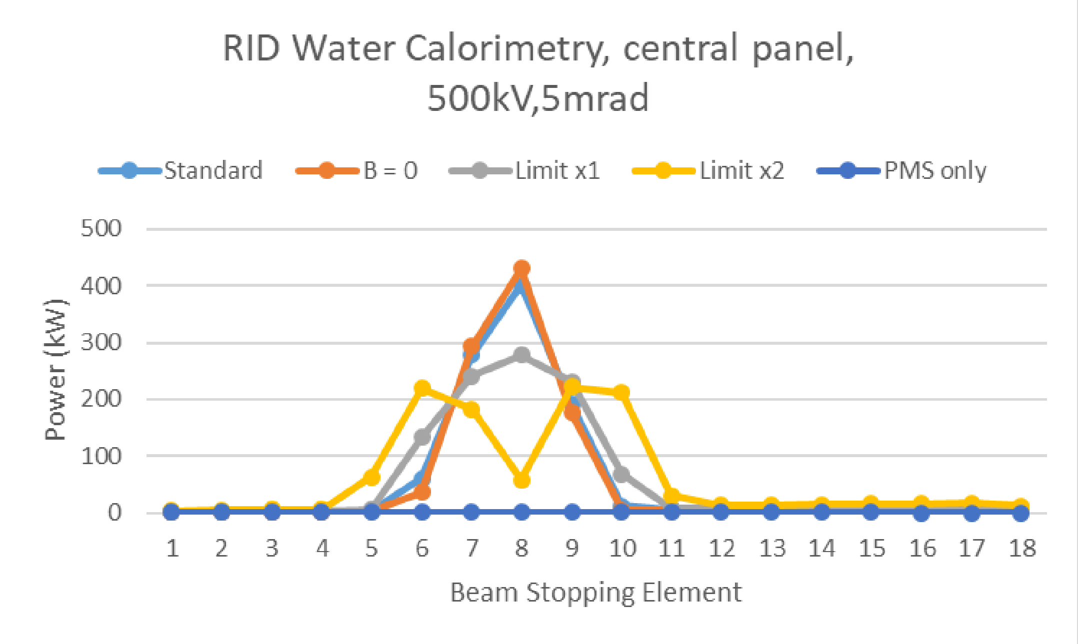


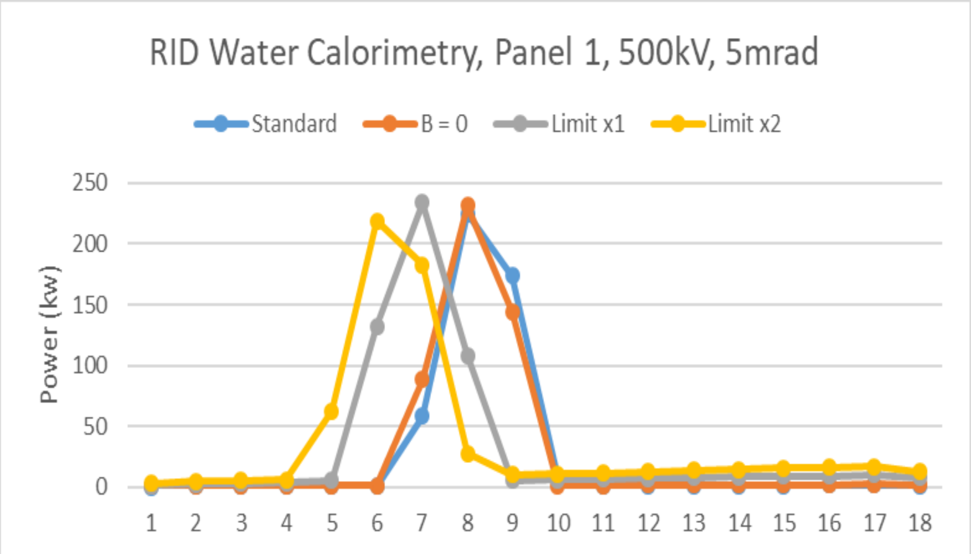


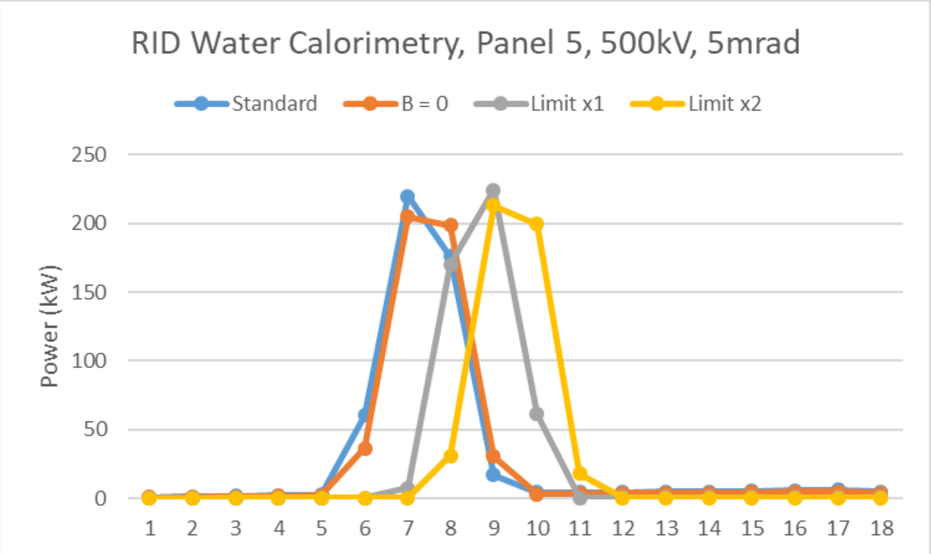
RID Calorimetry response for coils 26



On Central panel, 5MW gives ΔT ~40 ºC.
Side panels see ΔT ~20 ºC for 1.5MW.
Temperature rises will be small

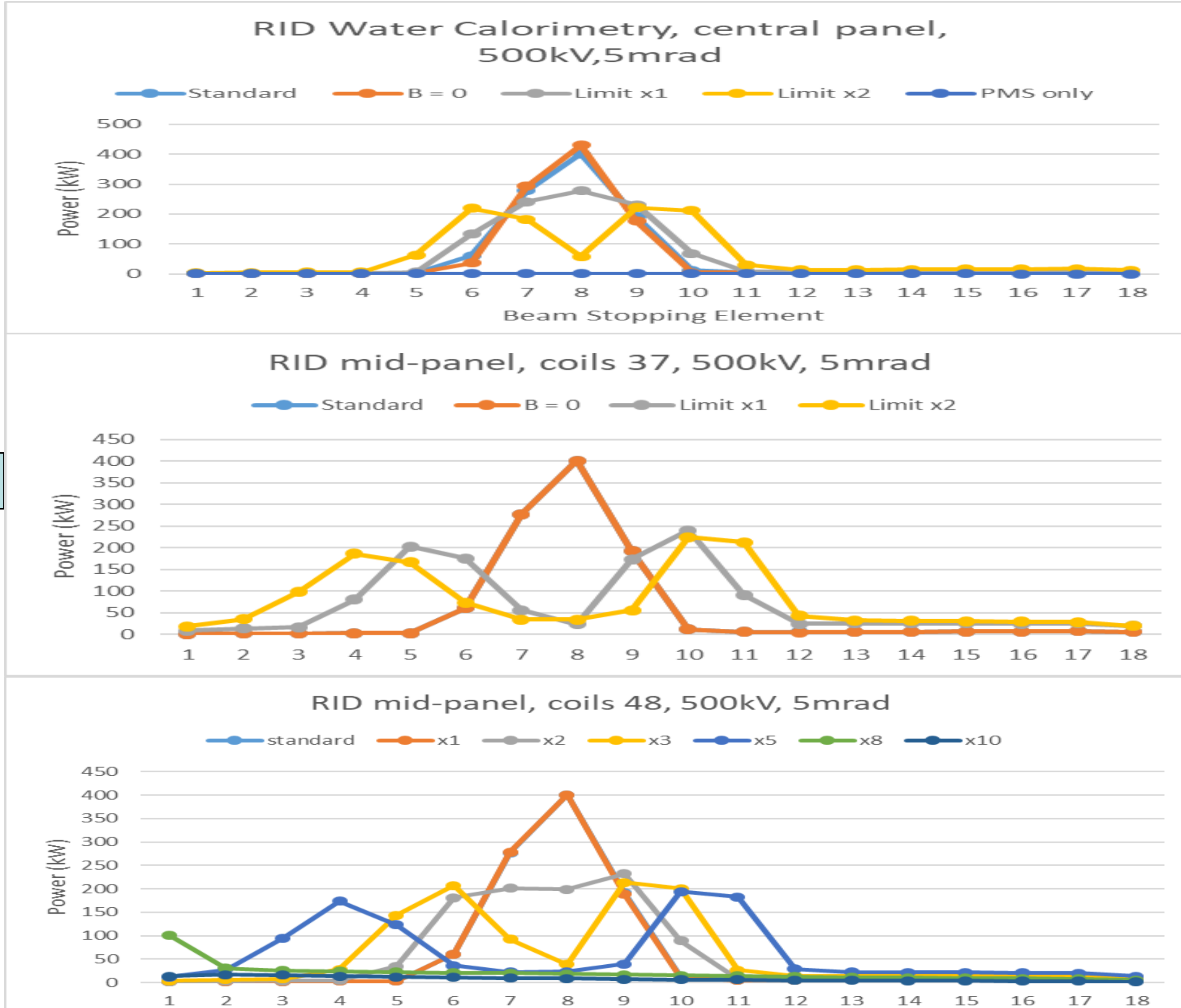






Effect of different coil pairs

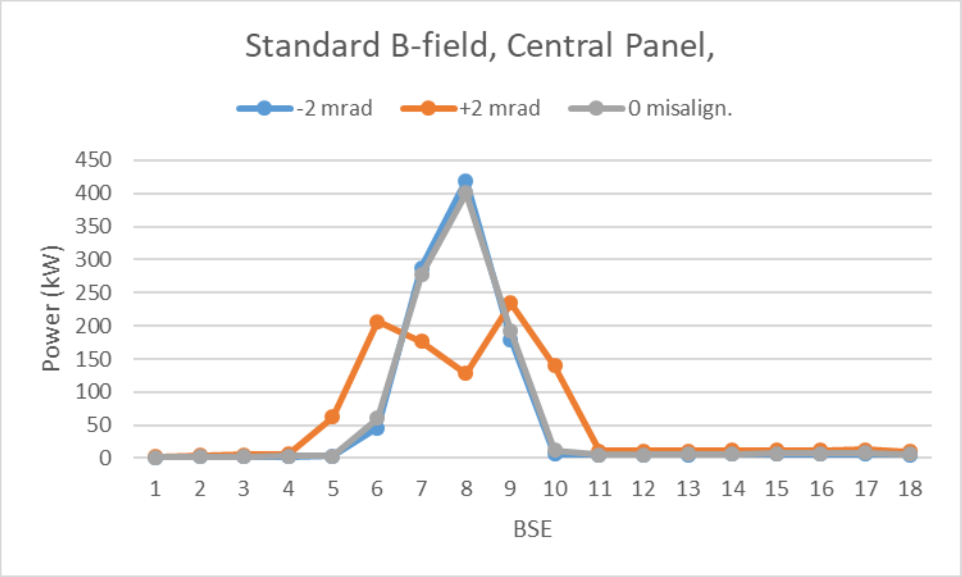
Panel 1



Panel 5

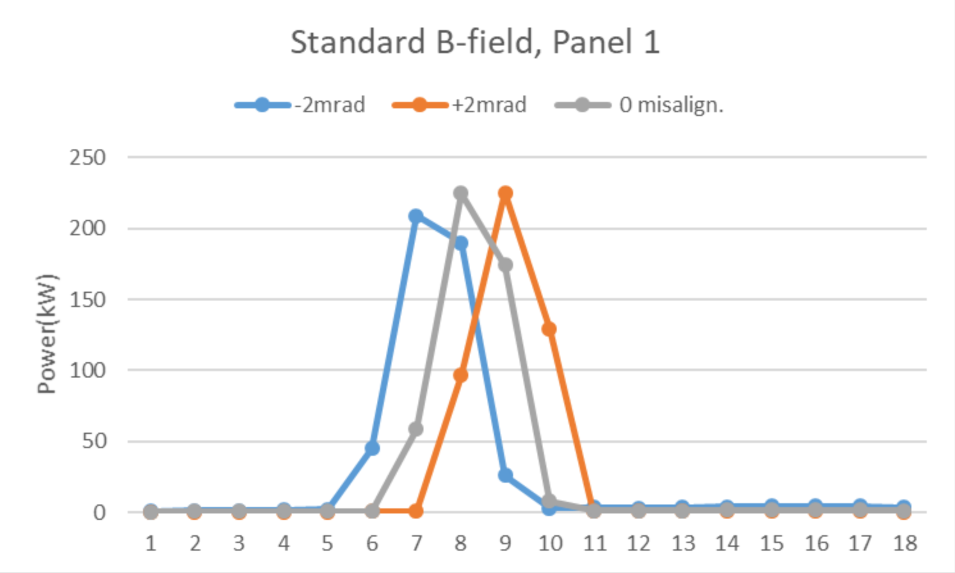
Misalignment Effect

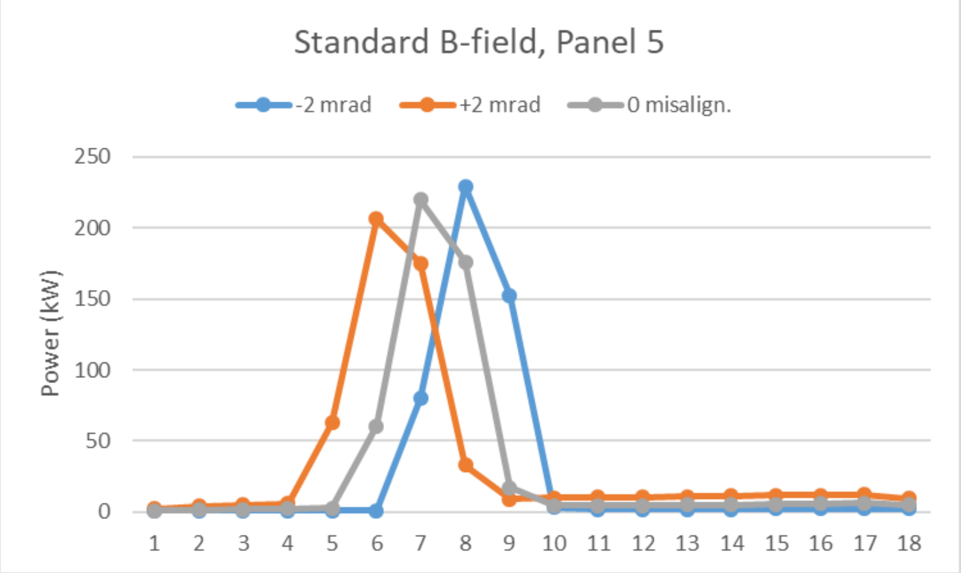
Standard field,
5 mrad divergence



Panel 1

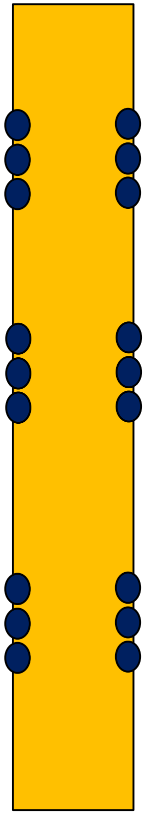
Panel 5

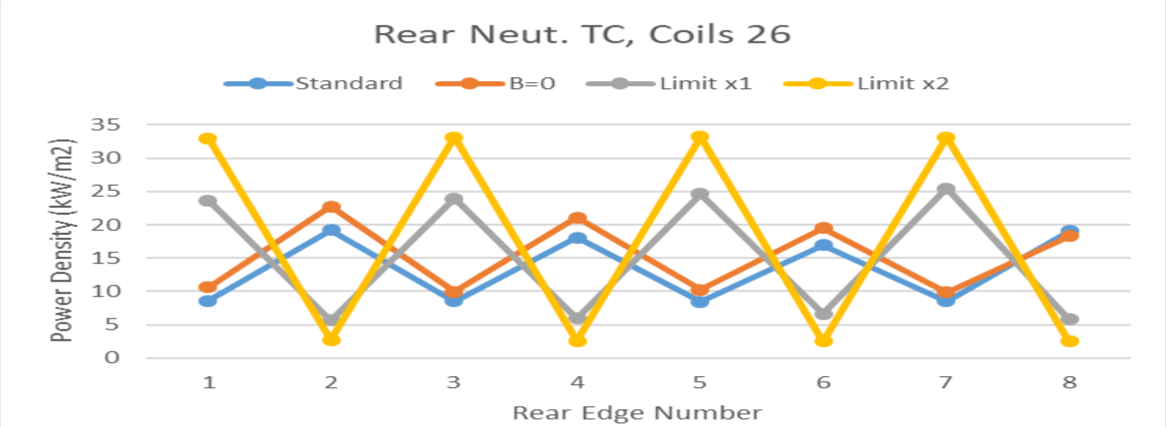


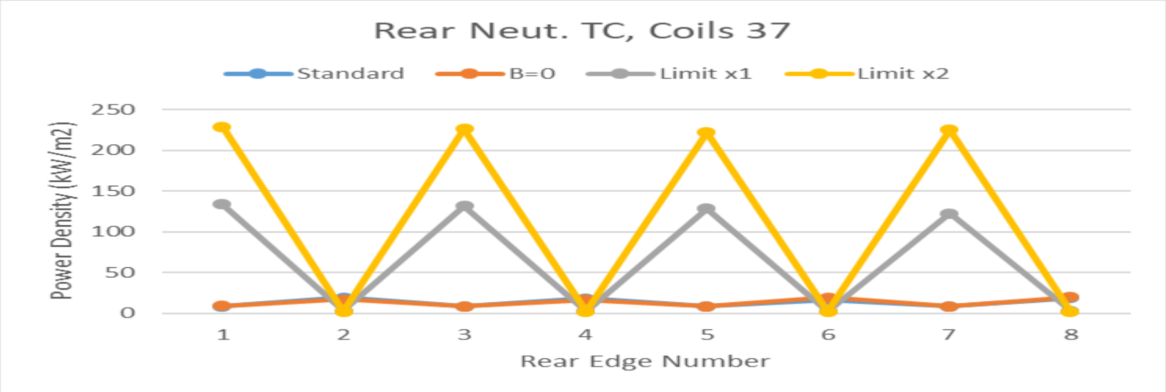


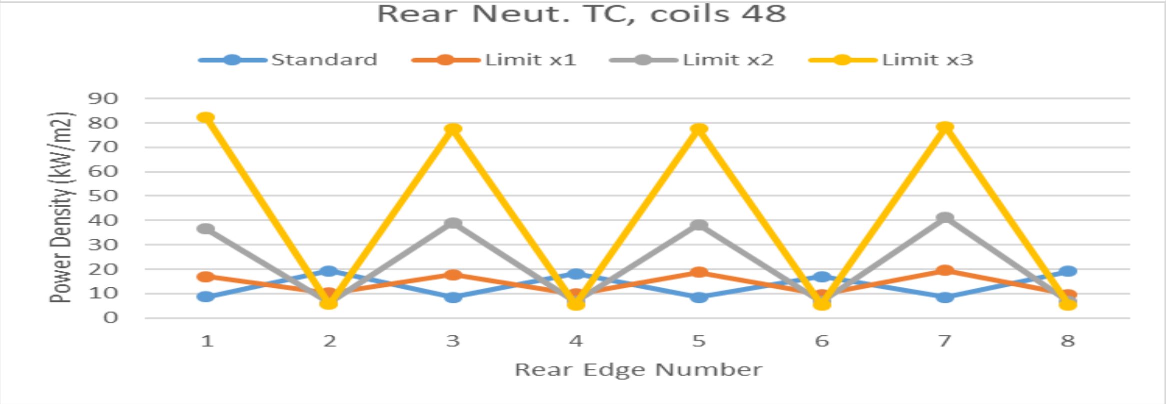
NED Rear TCs

Rear Edge



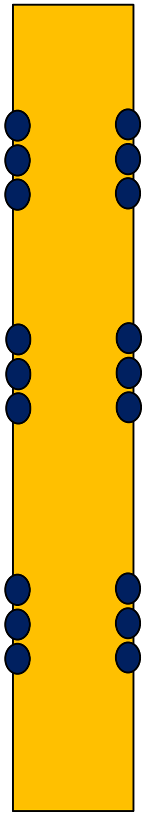


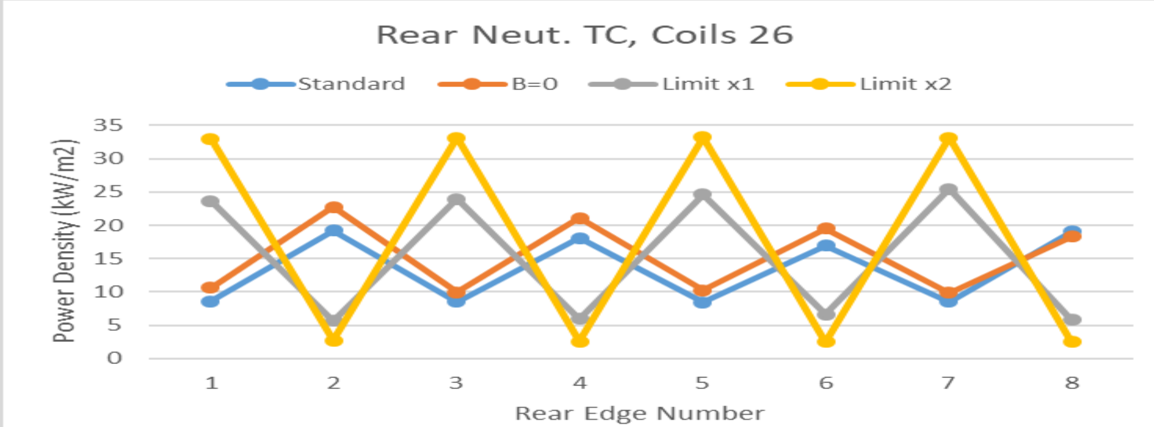


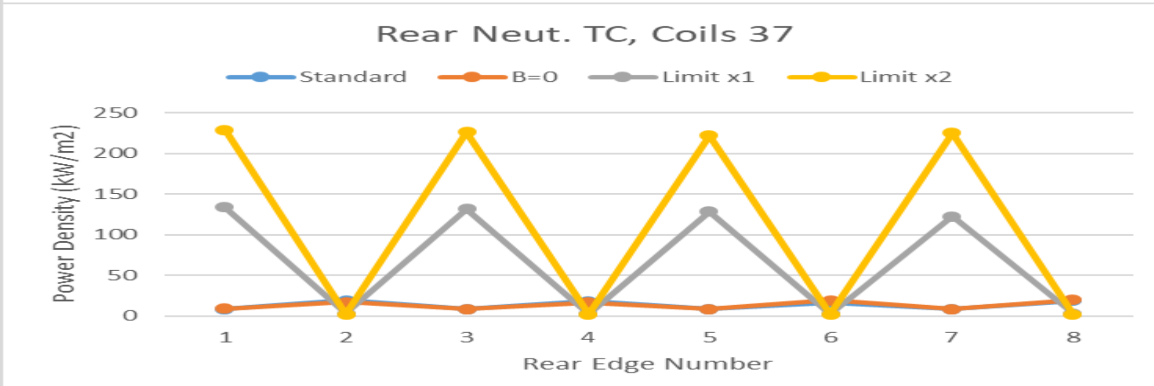


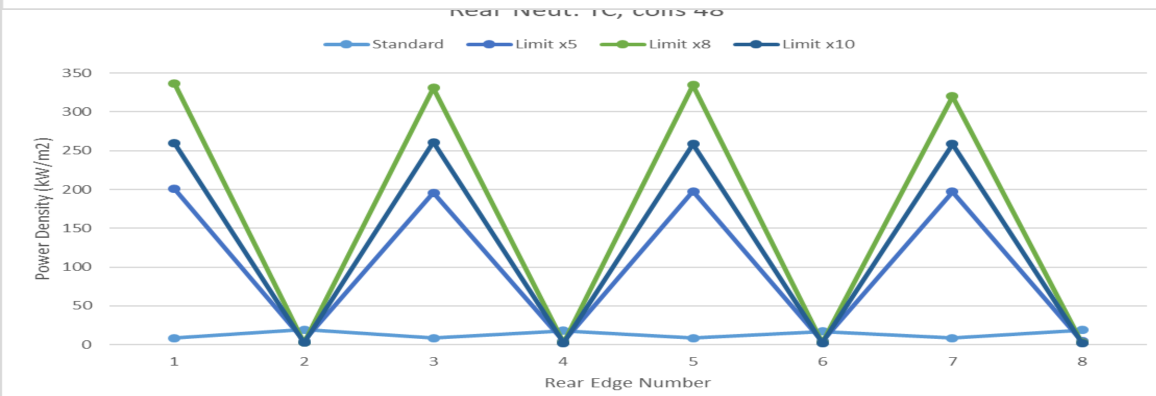
NED Rear TCs

Rear Edge





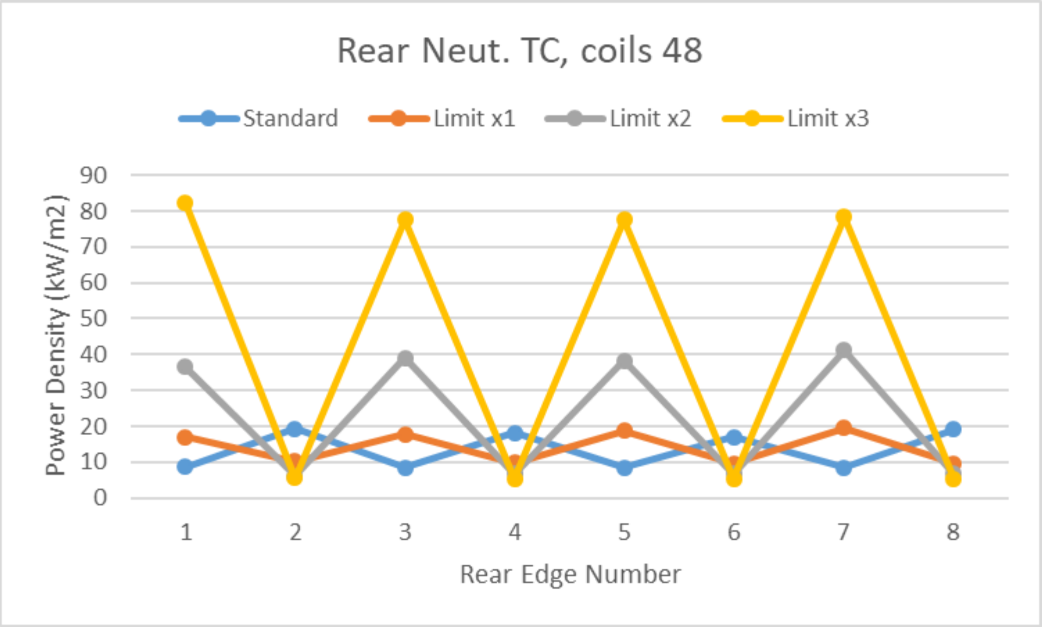


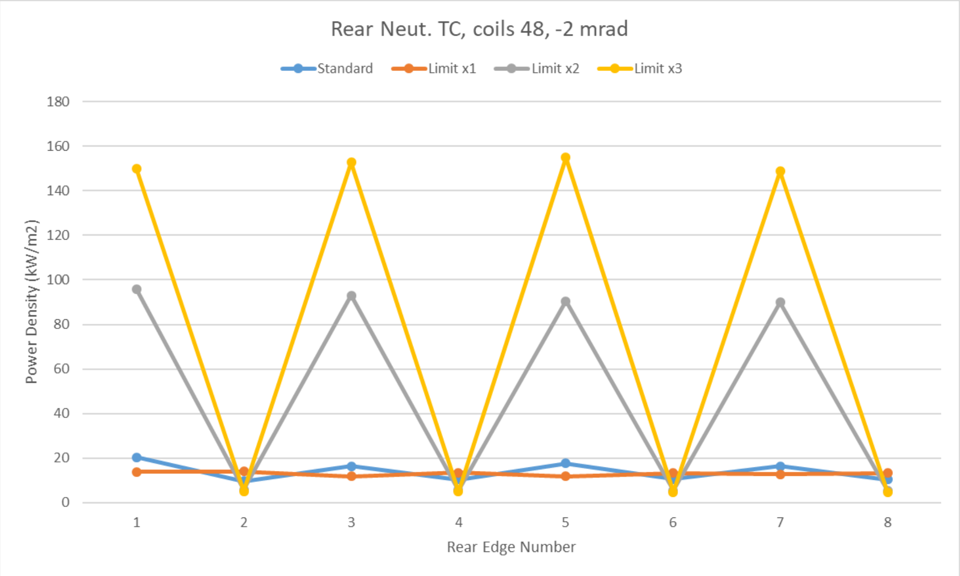


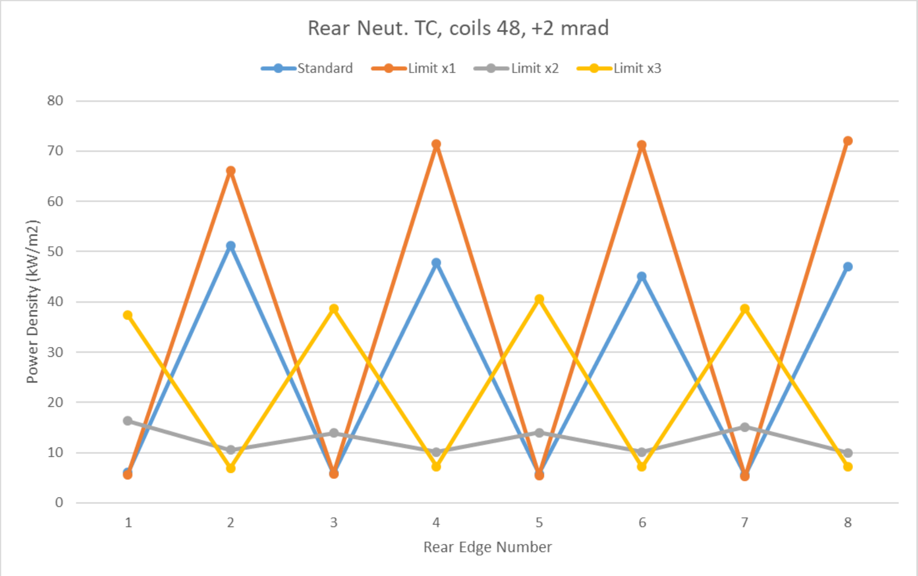
B-field effect and alignment effect

Designed Maximum Power Density = 540 kW/m2

This would be a 60-70 °C rise



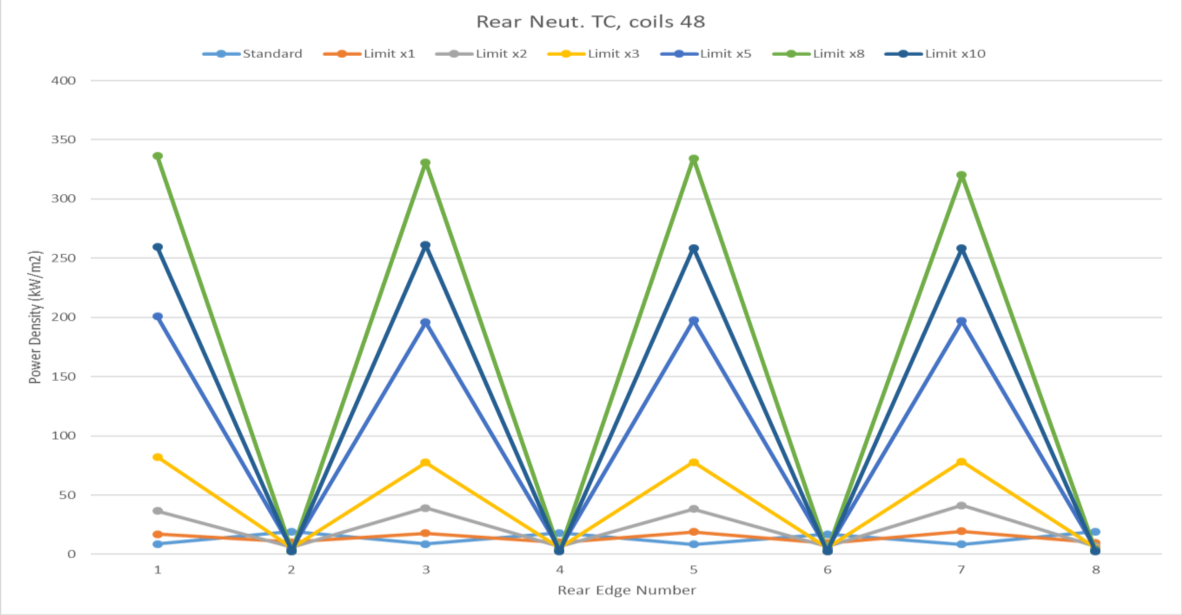


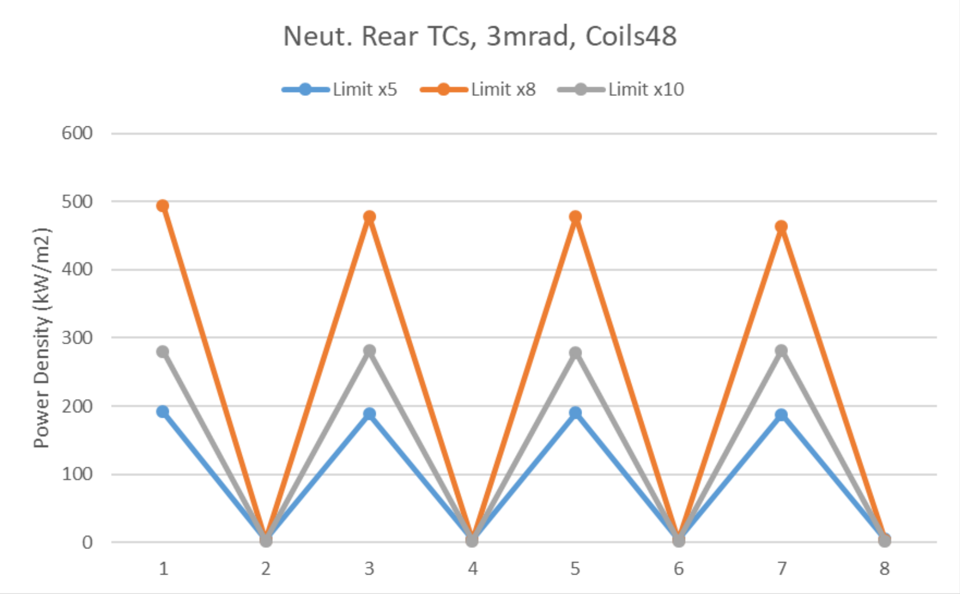


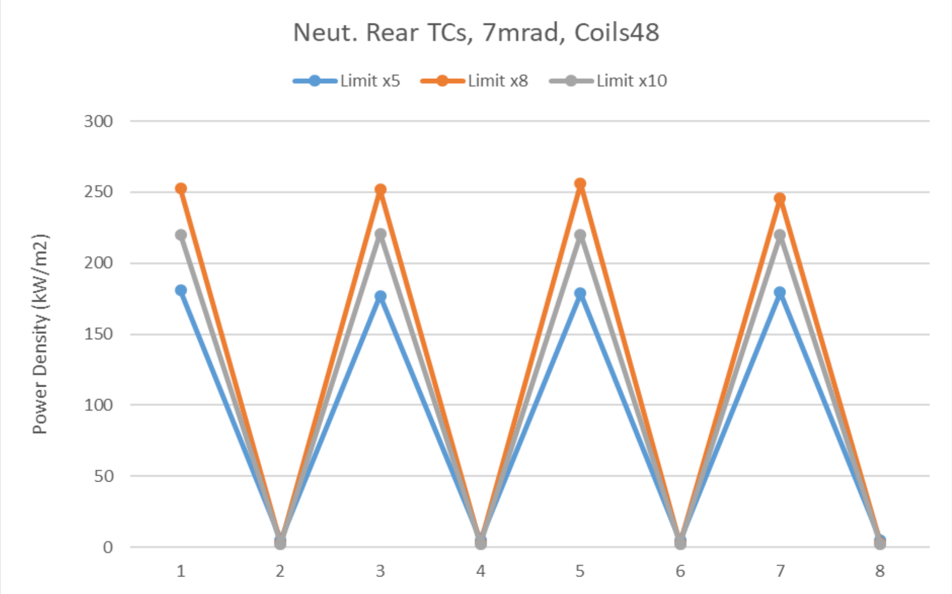
Neut. Rear Thermal Limit

Designed Maximum Power Density = 540 kW/m2

This would be a 60-70 °C rise



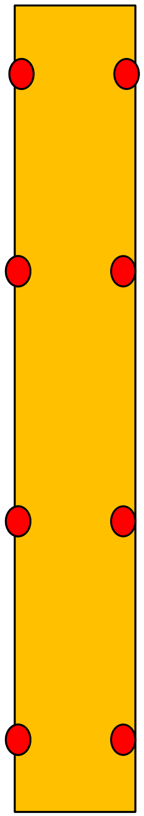


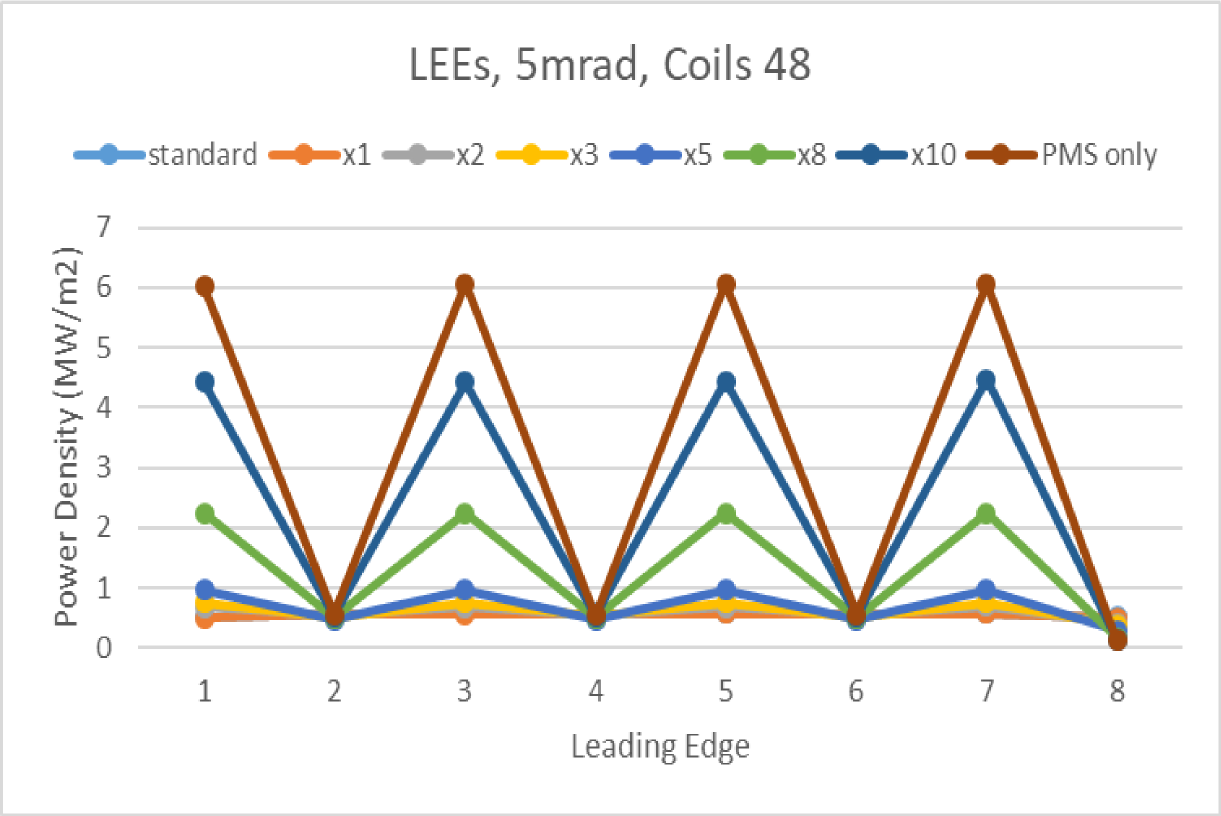


NED LEEs TCs

Leading Edge Elements (LEEs)

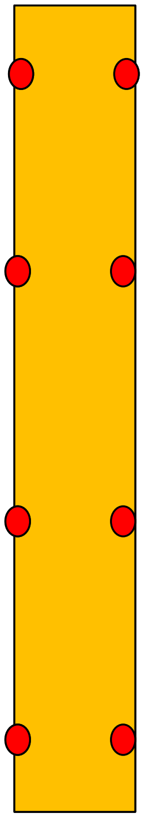
Designed Maximum
Power Density =
~10 MW/m2



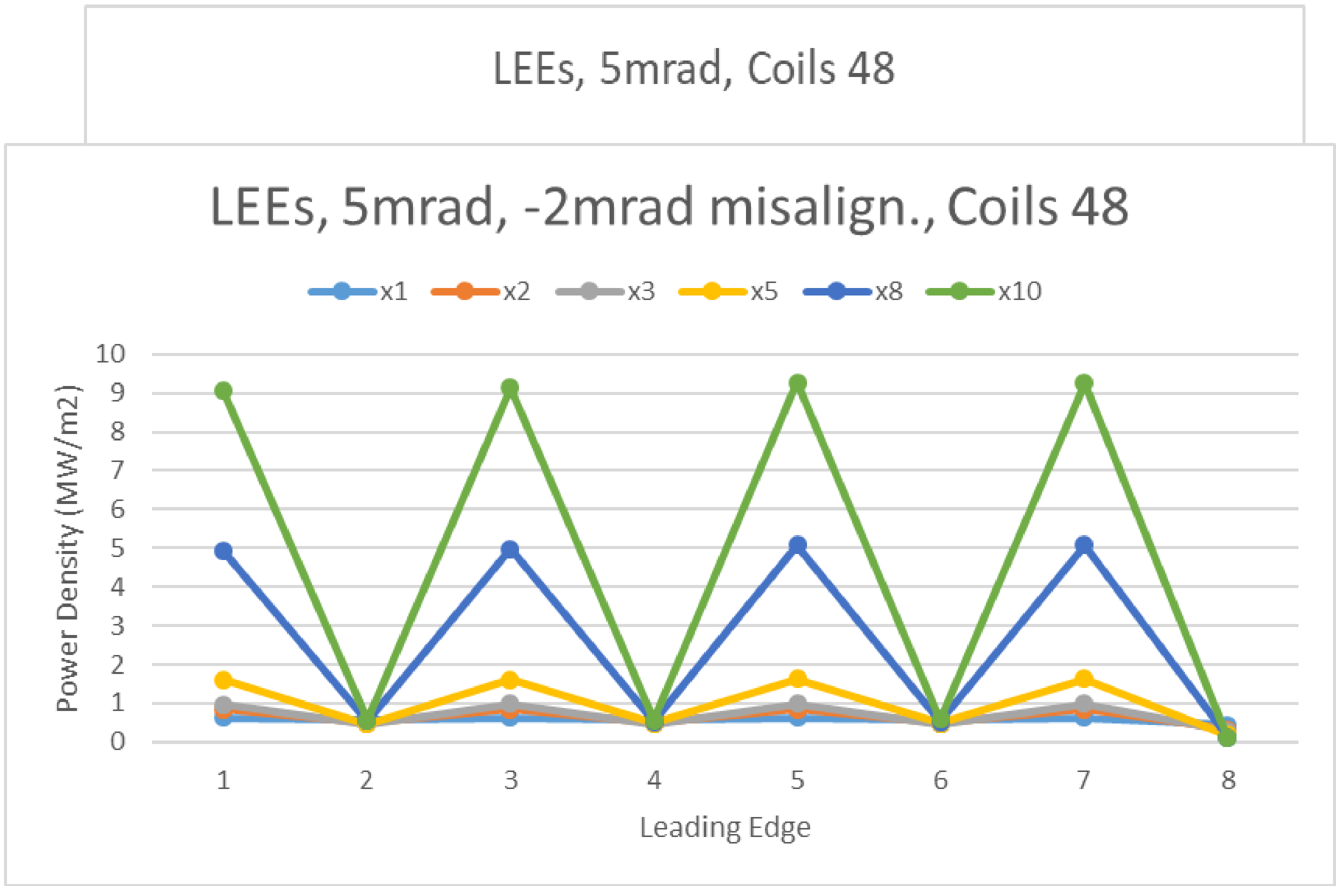


NED LEEs TCs

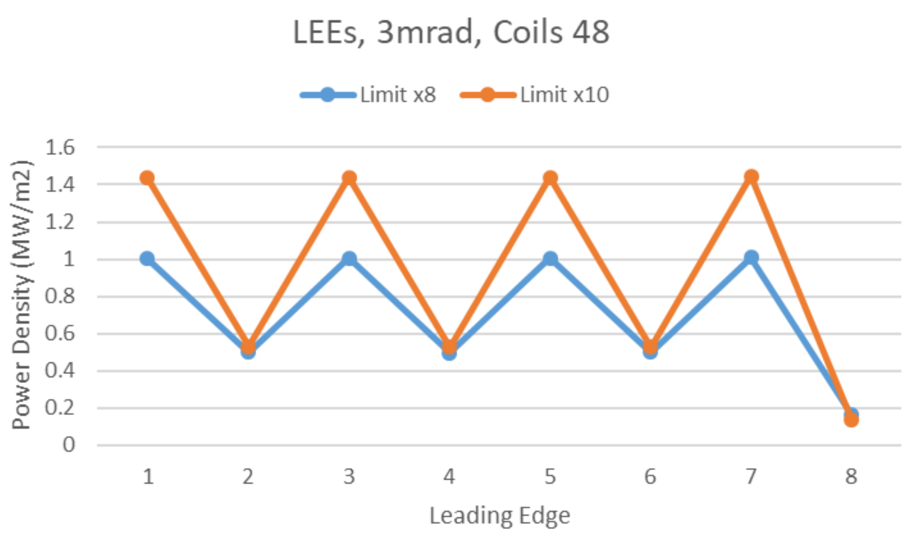
Leading Edge Elements (LEEs)

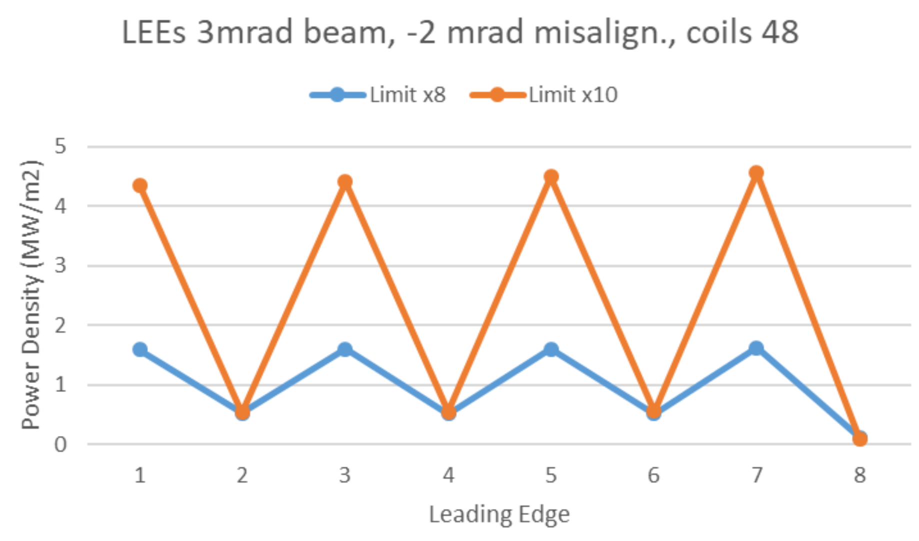


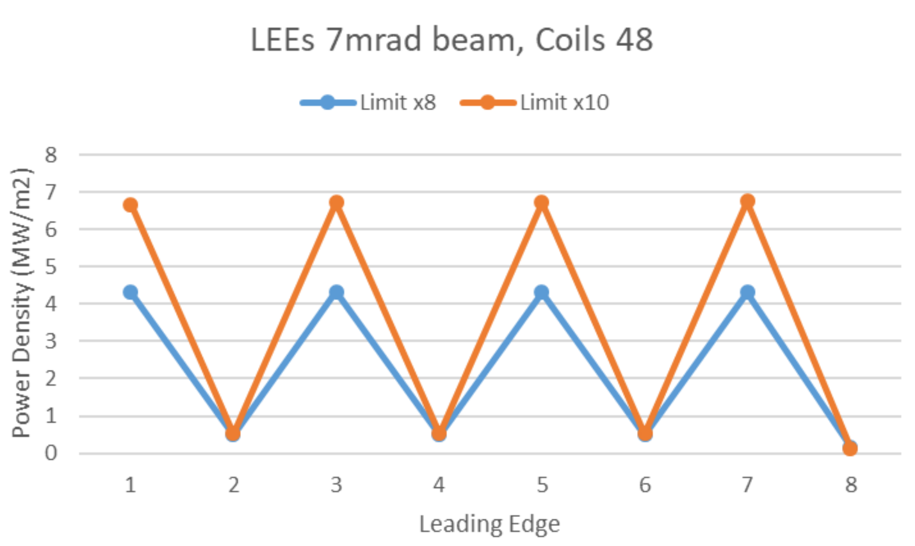
Designed Maximum
Power Density =
~10 MW/m2

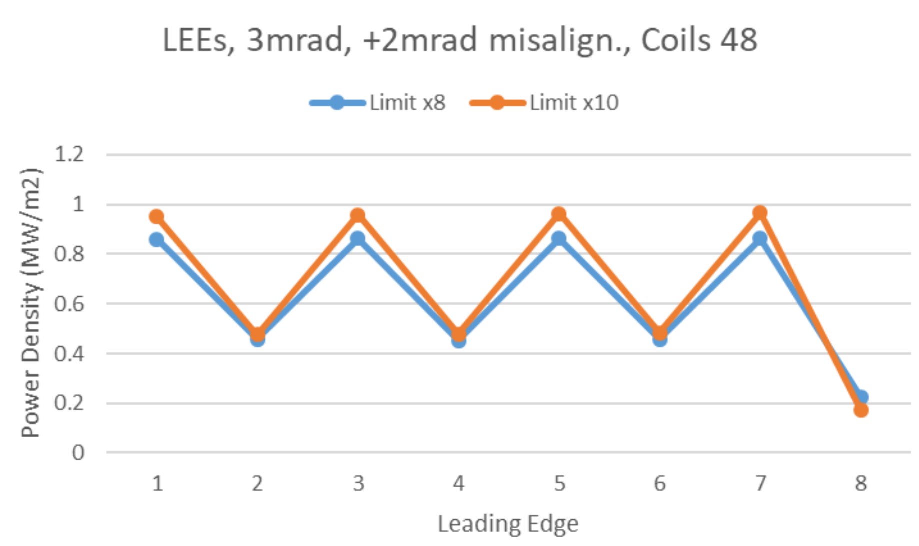


NED LEEs TCs Coils 48









The 3 mrad cases shouldn't cause problems on the LEE, but the 7 mrad will approach the limit, especially if negatively misaligned

Summary

- The addition of the ITER magnetic field and the ACCCs adds another factor into understanding the measurements compared to those to be performed on MITICA.

- Neutraliser Rear and LEE thermocouples can give information on the divergence, separate to the ACCC operation, although if there is also misalignment, this could cause excessive power loads at 500 kV. This does mean that analysis could be performed at even lower voltages, which is advantageous.

- In the -2mrad direction, the misalignment makes any failure of the ACCC much worse.

Summary (2)

- Shift of peak locations on RID central panel can show quality of ACCC operation, however at <500kV, the water calorimetry may see little to no rise in temperature. Surface thermocouples should still be of use.

- This shift could also be seen due to horizontal misalignment. However, once misalignment is determined, this could provide a good method for monitoring the ACCC.

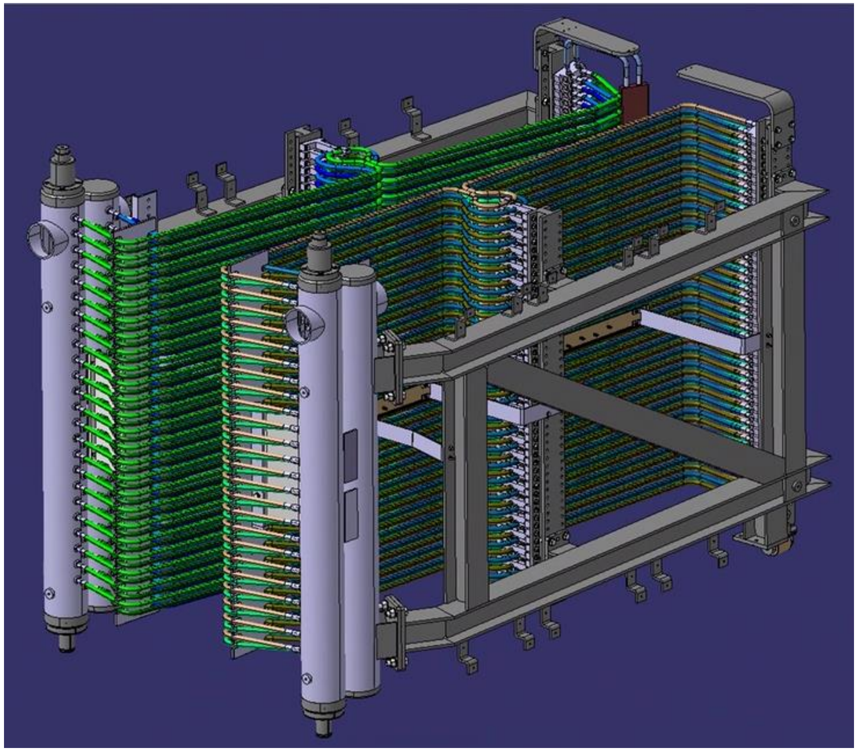
- Once the voltage oscillation begins on the RID, the water calorimetry can not be used for this.

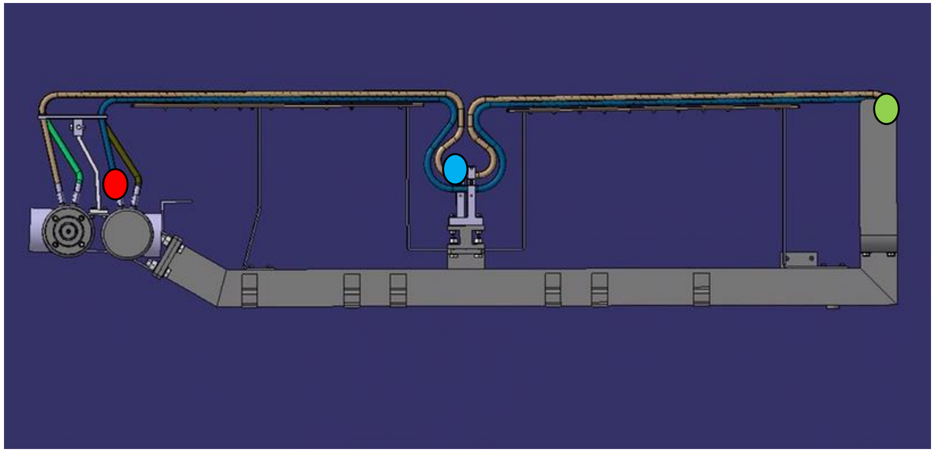
Summary (3)

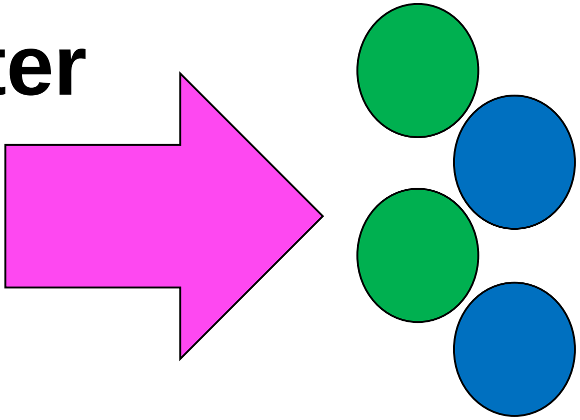
- Due to the effect of divergence and misalignment, the operation of the ACCC cannot be distinguished on the Neutraliser thermocouples from just one set of data. However, since at low voltage, the possibility to vary the current in coil pairs during several pulses (or even a longer pulse), may allow the ACCC effect to be seen and separated from the misalignment and divergence.

Modelling of the expected temperature rises seen by the surface thermocouples on the RID will also provide useful information on the level of power required in order to see the heating effect.
Also, modelling of the maximum Beam Energy that can be used without RID voltage oscillations would be needed so as to not affect the fatigue life of the RID.

Calorimeter







48 Swirl Tube element pairs: Temperature measurement on each outlet.

Middle 28 pairs: Temperature measurement at halfway point

Middle 28 pairs: Temperature measurement halfway along outlet tube

Divergence effects on RID