Disruption Thermal Load Mitigation With JET SPI

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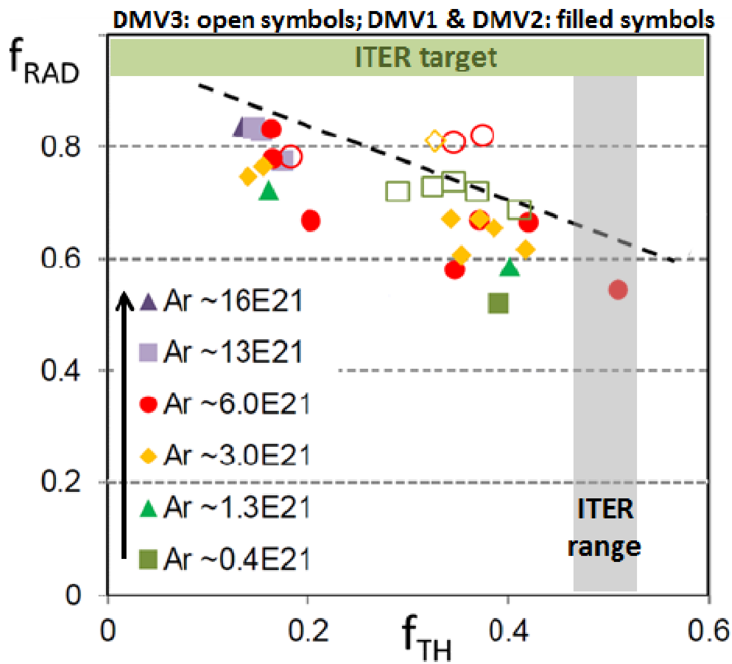
Motivation

- Disruption mitigation remains a critical, unresolved challenge for ITER
- Mitigation target is 90% of stored thermal energy (W_{th})
  - Need to validate SPI as viable ITER DMS
- Decreasing f_{rad} with increasing f_{th} observed on JET with MGI
  - This trend was not reproduced on AUG (Sheikh Nuc. Fusion 2020)
- Explored with JET SPI in this work



E. Joffrin 2016 IAEA FEC conference

$$f_{rad} = \frac{W_{rad}}{W_{mag} + W_{th} - W_{coupled}}$$

$$f_{th} = \frac{W_{th}}{W_{mag} + W_{th} - W_{coupled}}$$

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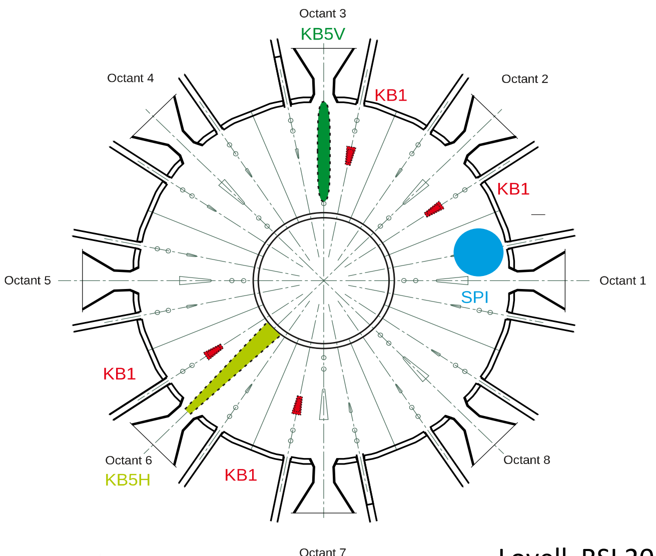
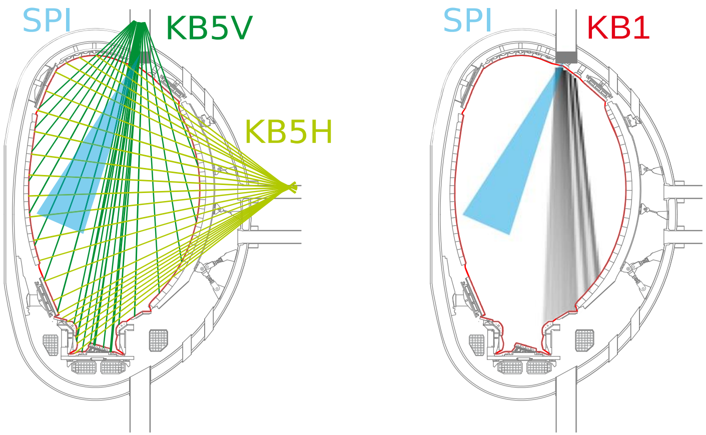
Diagnostics Overview

- Radiated energy measured with bolometers
  - Weighted integration method applied due to high asymmetries
- Infrared cameras and density measurements unusable during mitigated disruptions

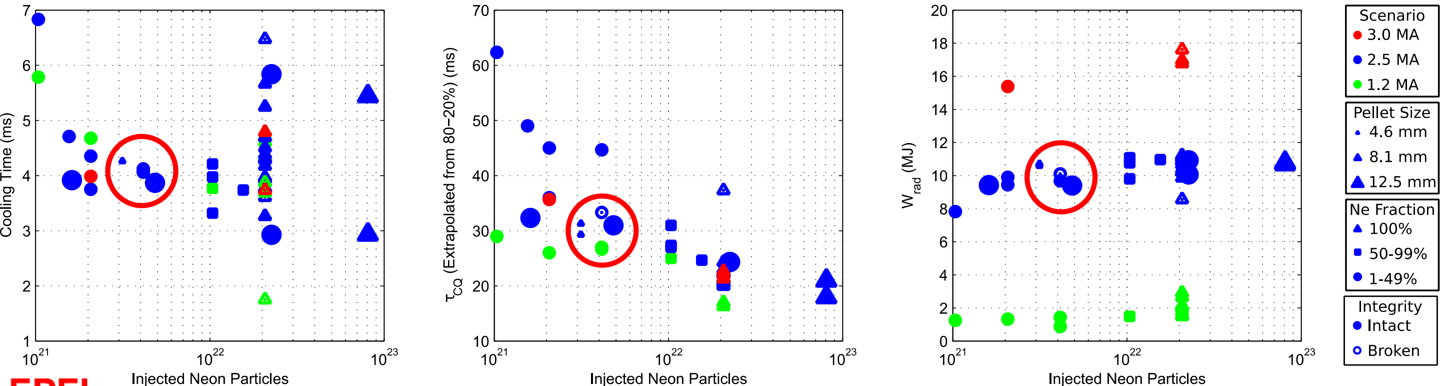




Lovell, RSI 2021

Single Pellet Injection Results

- Neon content varied in single pellet injections
  - Current quench (CQ) duration and cooling time vary with neon particles injected
  - Radiated energy (W_{rad}) saturates when total W_{th} is radiated (1e22+ inj. neon particles)
  - Increased deuterium quantity at fixed Ne content doesn't impact mitigation efficiency
    - Three pellet sizes with fixed neon content in red circles



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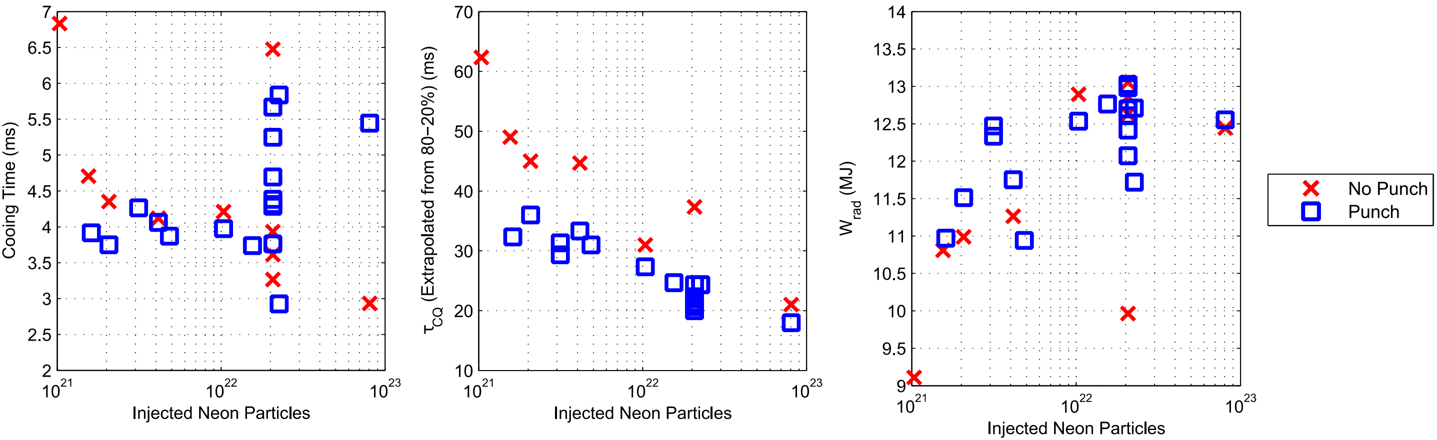
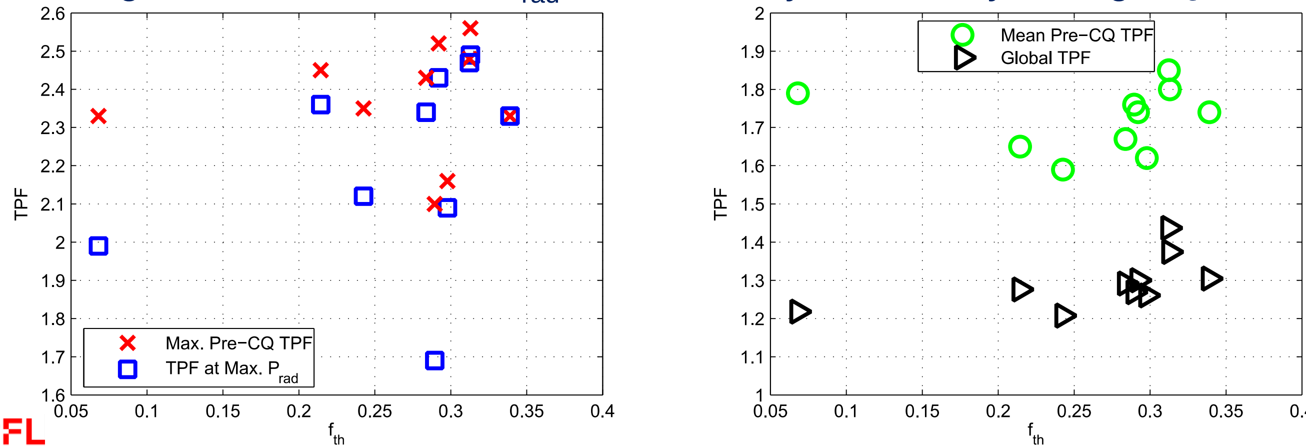
Influence of Mechanical Punch

- Mechanical punch used to dislodge pellet reduces velocity
  - Leads to larger pellet fragments after shattering (GEBHART 2021)
- CQ duration reduced with punch -> higher impurity assimilation
  - Does not influence cooling time or radiated energy



Radiation Asymmetries

- Investigated with Emis3D (Sweeney, 2020 APS)
  - Toroidal peaking factor (TPF) = emission in SPI sector / toroidal mean
- Peak TPF up to 2.6, pre-CQ average of up to 1.9
  - ITER limit is 2.0
- Lower global TPF at low f_{th}
  - Higher fraction of total W_{rad} is radiated symmetrically during CQ at low f_{th}



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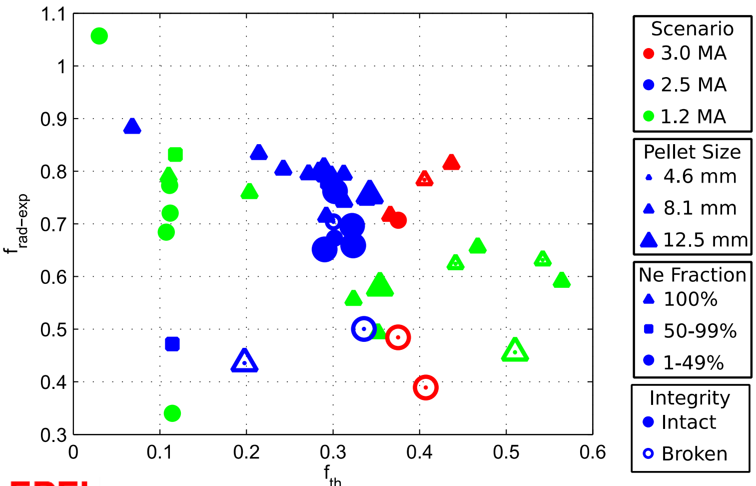
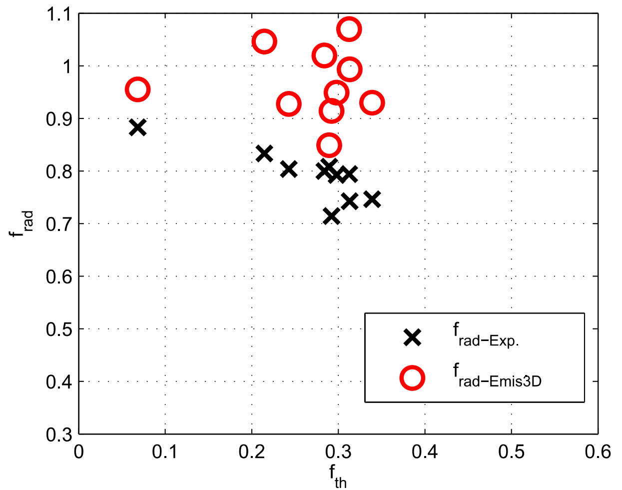
Energy Balance

- Decrease in f_{rad} at high f_{th} observed when asymmetries ignored
- Accounting for asymmetries removes negative trend
  - Constant f_{rad} maintained with 100% neon pellets in 2.5MA scenario
  - **Indicates SPI performance not reduced at high f_{th}**
  - Large scatter attributed to the under-constrained Emis3D analysis





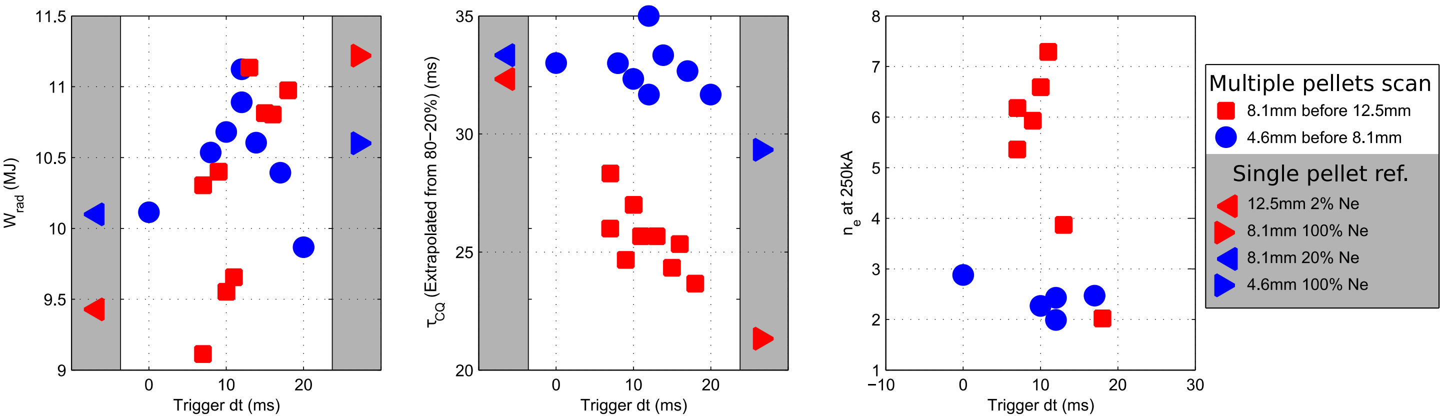
Multiple Pellets (Staggered Arrival)

- Two pellets launched from single injector
- Slower 8.1mm pellet fired first
- Scan limited by cooling time duration

	Composition			
	12.5mm pellet	**8.1mm pellet**	**4.6mm pellet**	**Total neon injected**
Larger pellets scan	2% Ne, 98% D	100% Ne		2.2×10^{22}
Smaller pellets scan		20% Ne, 80% D	100% Ne	7.3×10^{21}

Multiple Pellets (Staggered Arrival)

- Arrival delay influences radiated energy, CQ duration and density increase
  - Dataset bound by single pellet references
- Larger pellets scan indicates deuterium can be assimilated from a pellet arriving after an initial neon pellet
  - Increase in plasma density during CQ measured



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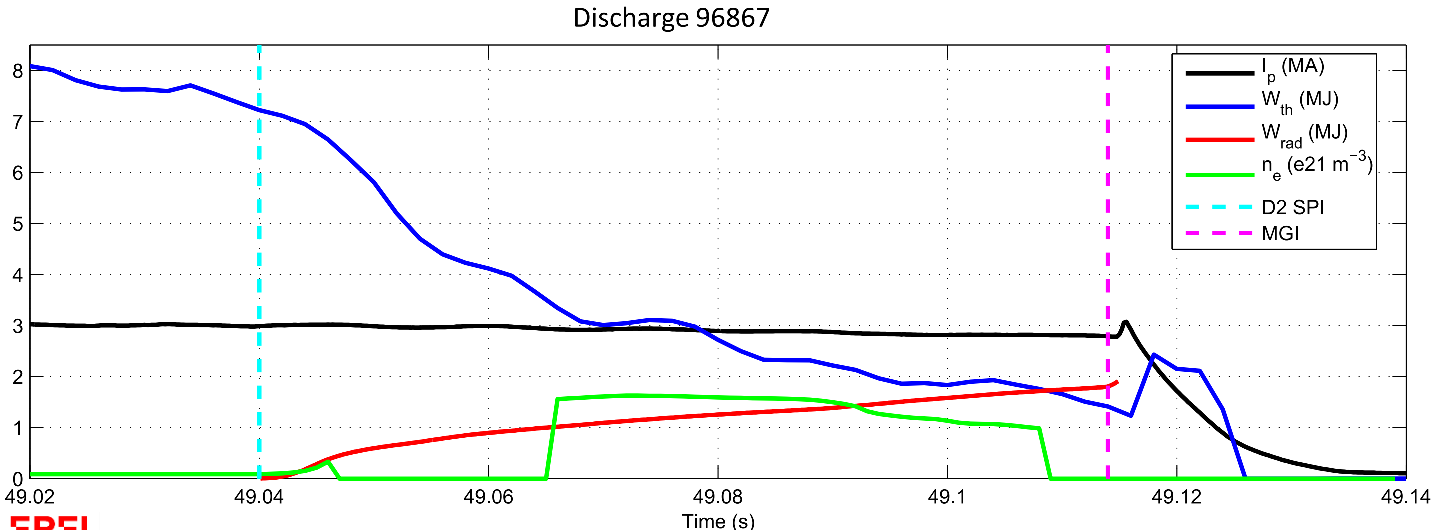
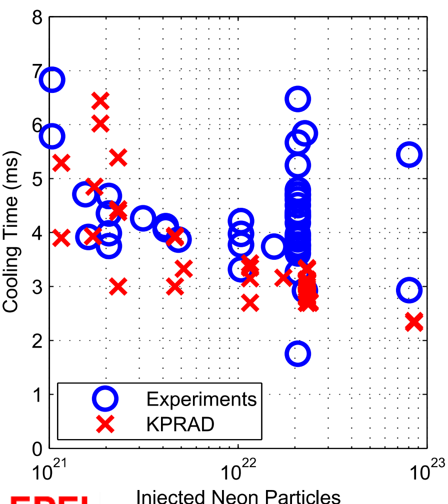
Pure Deuterium Pellets

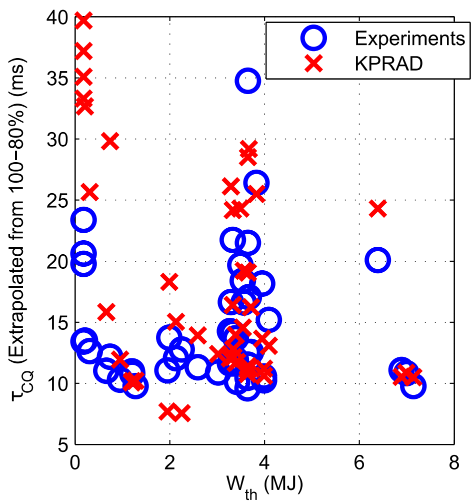
- Long cooling times of up to 75ms possible
- Gradual decrease in W_{th} of up to 80% (2MJ through radiation)
- Cooling time appears to be limited by n=1 instability growth (Shiraki, this conf.)

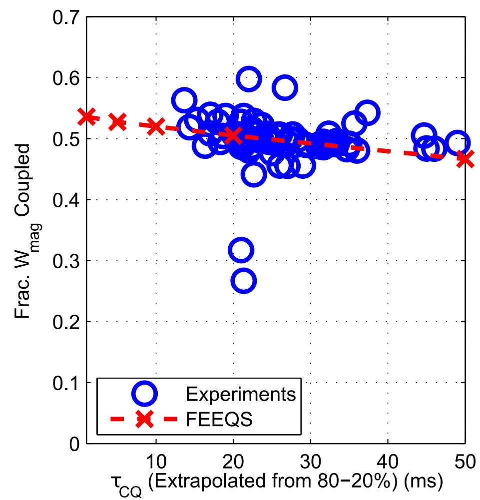


Modelling Comparisons

- FEEQS simulations show good agreement for coupled magnetic energy estimates
- KPRAD captures cooling time and CQ duration at high W_{th}
  - Poor agreement for CQ duration at low W_{th} due to strong influence of sputtering, background impurities etc not accounted for by KPRAD







Conclusions

- CQ duration and cooling time vary with neon particles injected
  - Saturation of radiated energy indicates total W_{th} radiated if 1e22+ neon particles injected
  - Slower pellets (punched) have higher impurity assimilation
- **Mitigation performance maintained at high f_{th} if asymmetries considered**
  - Large uncertainties remain due to limited diagnostics
- Multiple pellet injection can be used to tailor mitigation
  - Deuterium pellets trailing neon pellets can still be assimilated
- Pure D pellets produce long cooling times with gradual reduction in W_{th}
- KPRAD modelling successfully reproduces SPI shutdowns at high W_{th}

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