EUROfusion

Technical challenges for reliable operation at JET and scenario preparations for DT

George Sips and JET contributors

JET

PPPL seminar
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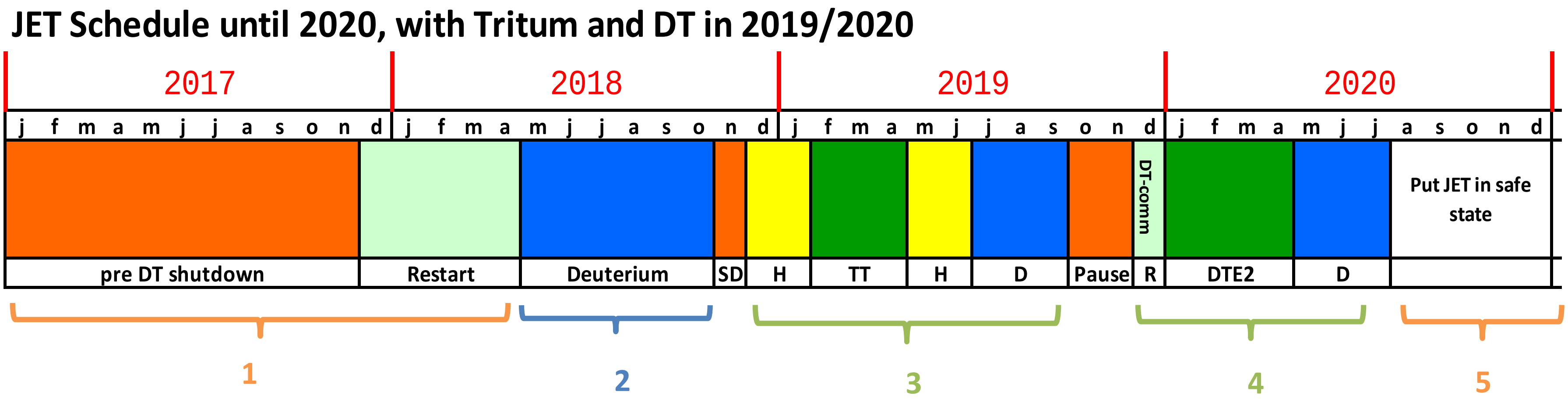
Introduction: JET Operation Schedule for 2018 - 2020



JET campaign sequence 2017-2020 (with DTE2 in 2019):

1. Pre-DT shutdown in 2017 followed by 4 month restart phase.
2. High power deuterium operation in 2018.
3. Isotope studies using hydrogen, tritium and deuterium in 2018-2019.
4. DTE2 phase followed by a final deuterium (clean-up & reference) phase.
5. Put JET in a safe state following the DTE2 (~6 months in 2020).

Short maintenance periods only during 2018-20 – no planned shutdowns.

Introduction: Pre-DT shutdown in 2016-17

Activities during the pre-DT shutdown:

- Removal of samples for ex-situ analysis, including the Mark II melt experiment (WPJET2) and the ITER mirror test
- Replacement of divertor tiles with degraded W coatings, planned on the basis of replacing “R” tiles with known sub-standard coatings
- Completion of DT diagnostic enhancements
- Install Tritium Injection Modules, Diagnostic Vacuum Crown and tritium compatible vacuum pumps
- Re-instate 3rd Super Grid transformer (fuses & cubicle were damaged)
- In-vessel repair of 27 high resolution magnetic coils, using the 2015 design.
- Install Shatter Pellet Injector
- Install a relayed view of visible/IR cameras
- Repairs and improvements to the NBI heating system

Part 1: Technical challenges for reliable operation at JET

Challenge:

- Can we operate JET at maximum power for two years?

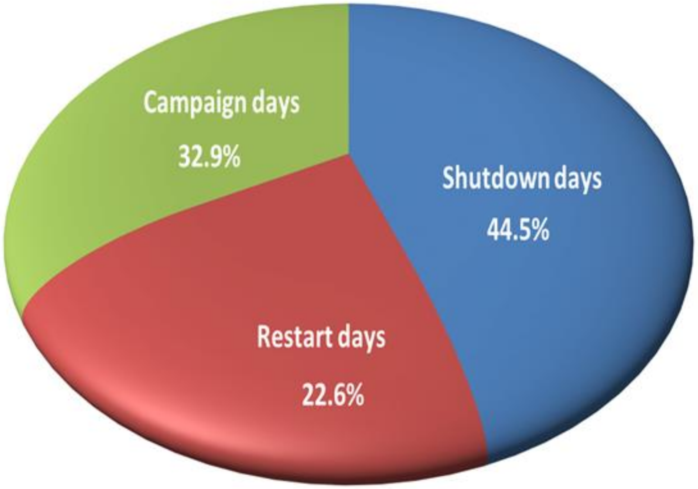
Historical archives:

- There are a large amount of data available since 1983, including DT operation in 1997.
- We have analysed the period 2000-2016 on JET operation for:
  - ✓ Every Shutdown, Restart and Campaign during this period
  - ✓ All delays logged by the Engineer-in-Charge in the Control Room (8599 entries). Validated by coordination meetings.
  - ✓ Detailed Logs of faults from essential sub-systems (CODAS, NBI, RF,…)
  - ✓ Performance logs for each JET pulse during this period (42505 entries)

Operation statistics 2000-2016

Campaigns, Shutdowns and Restarts for 2000-2016

- The dates of the Campaigns, Shutdowns and Restarts of JET have been logged.
- The number of weekdays have been computed.
- These have been compared to the plan as given each year by the JET Operation Implementation Document (JOID).

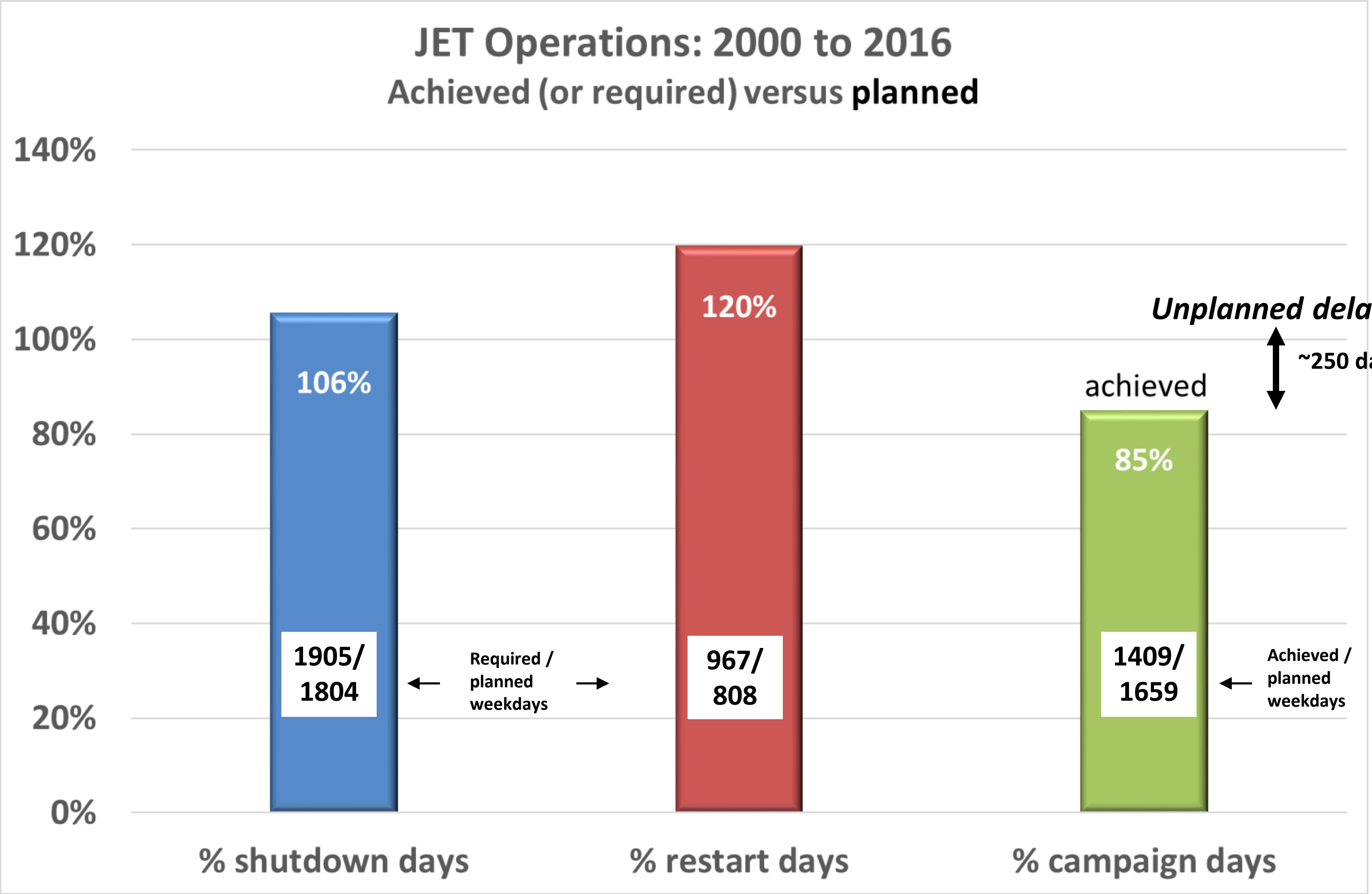


For the period 2000-2016: Achieved days

	weekdays	% of total time
Shutdown days	1905	44.5%
Restart days	967	22.6%
Campaign days	1409	32.9%
Total	4281	

On average
(83 campaign days a year)

JET Operations 2000-2016



JET Restart phases 2000-2016

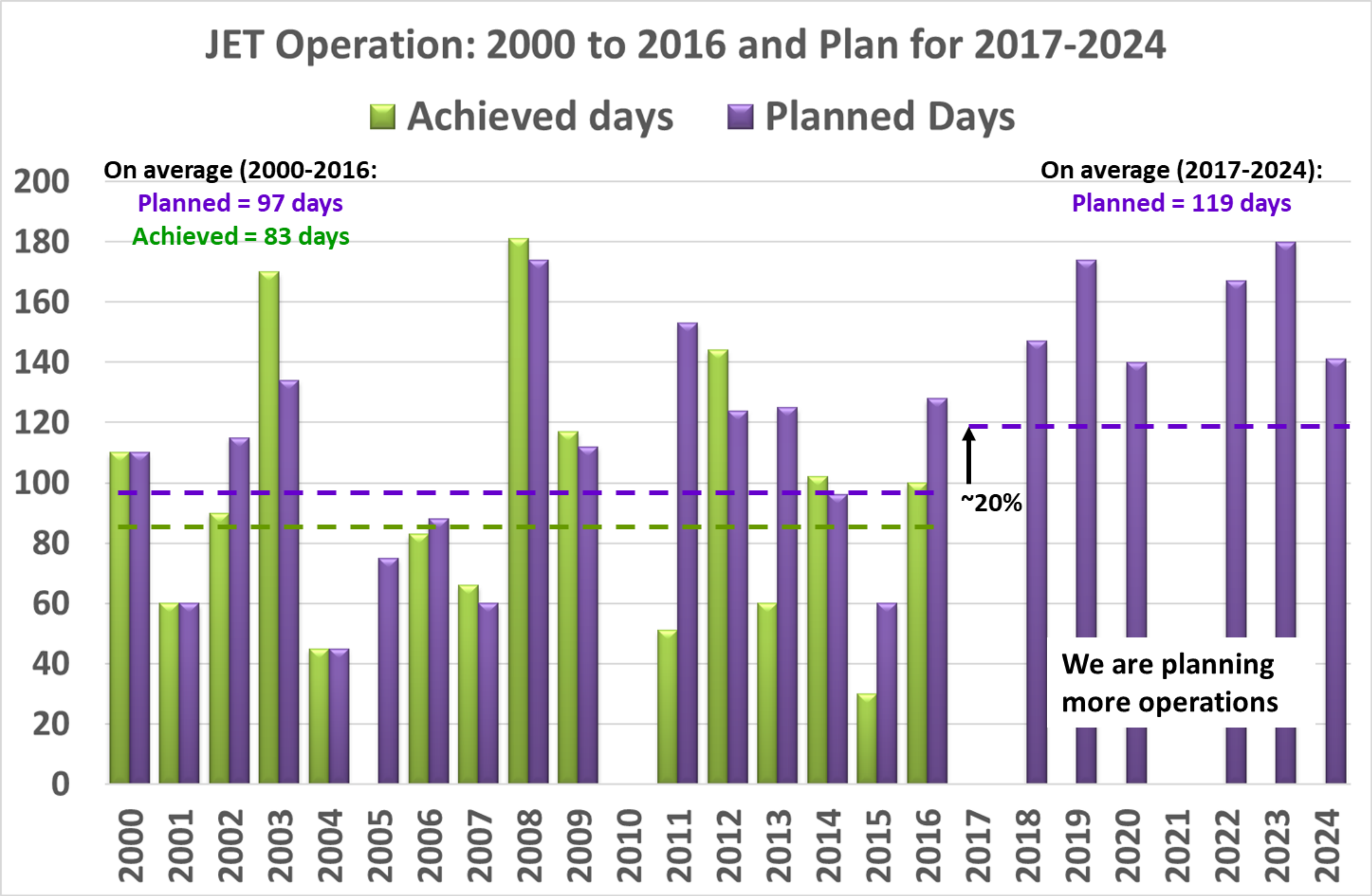
After main shutdowns, a Restart phase is required to commission systems and restart plasma operation.

- A Restart phase at JET requires significant time; 20-22 weeks on average

Shutdown period	Shutdown days	Restart days
2001 – 2002	228	**105**
2004 – 2005	206	**123**
2010 - 2011 (ITER-like Wall)	348	**104**
2014 - 2015	226	**115**
2016 – 2017 (pre DT)	303	**100 (planned)**

- The Operator needs to meet "Restart targets" for each restart phase;
  - ✓ a set of technical targets required for experimental campaigns
- **After short interventions** (maintenance) typically 2-4 weeks of restart is used to commission systems or re-establish plasma-operation

Future JET Operations 2017-2020 and beyond



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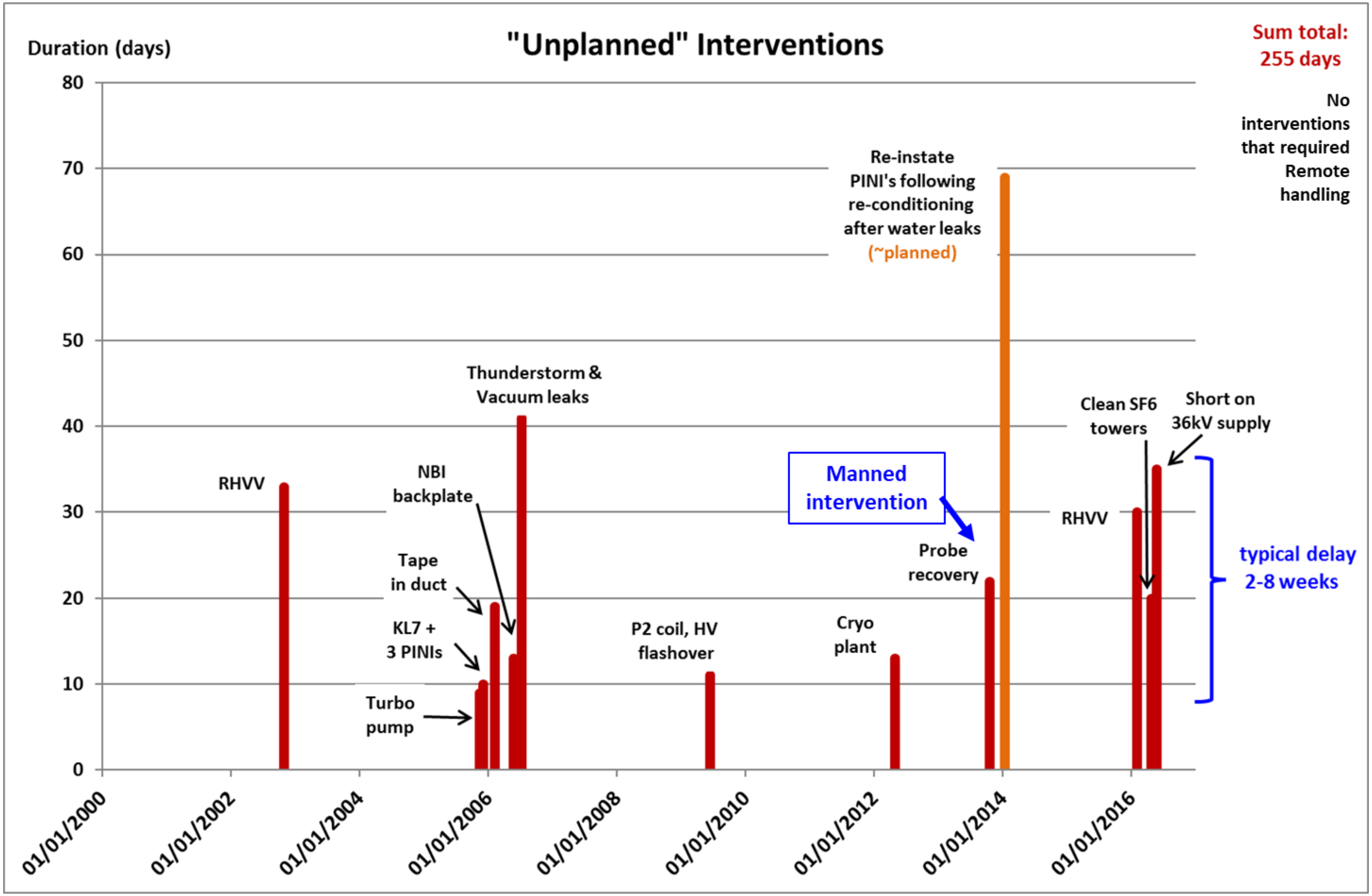
Unplanned interventions: 2000-2016



Delays during Operations: 2000-2016

Delays during JET Operations: 2000-2016

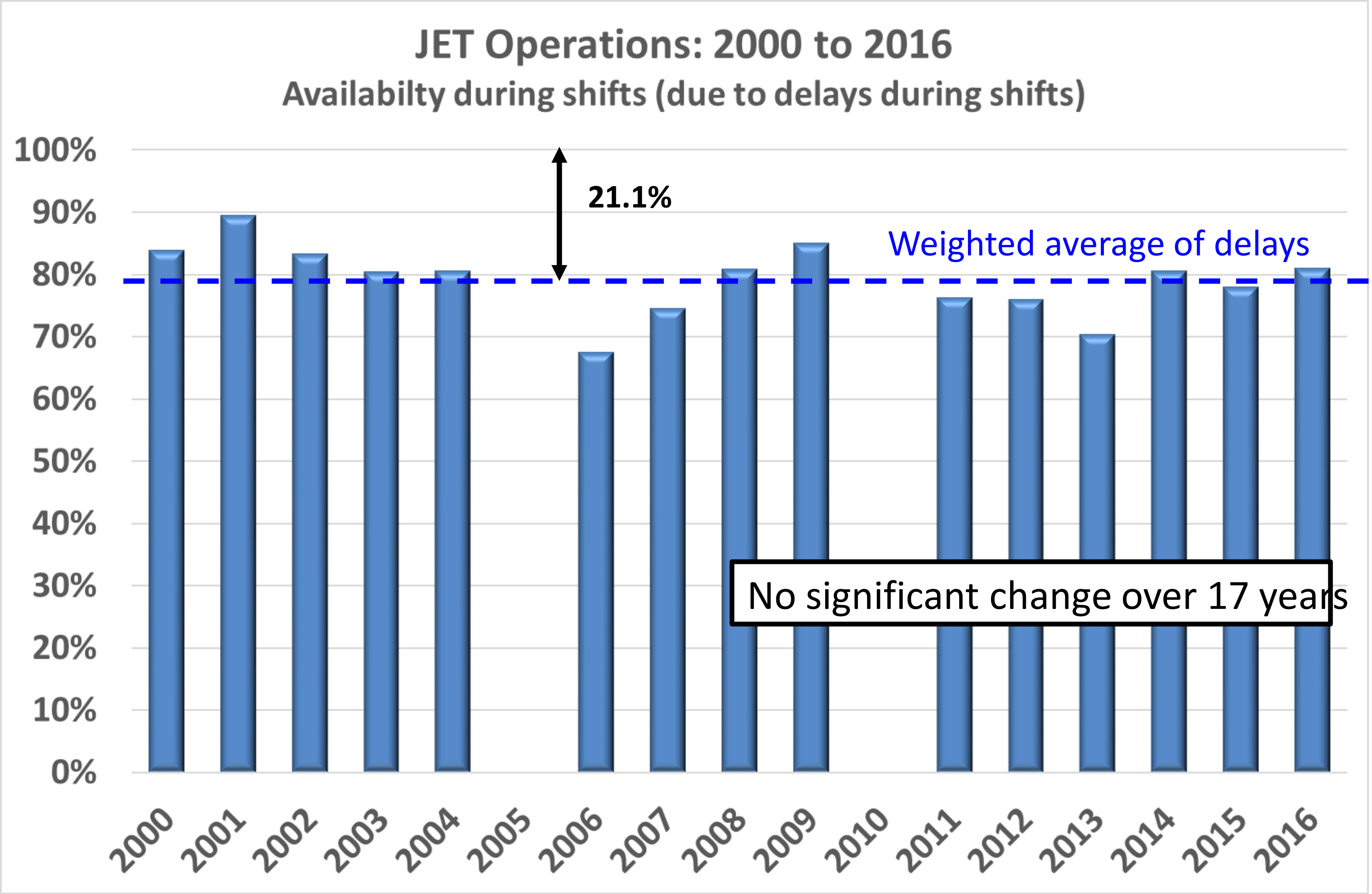
Over the period 2000-2016, we have 8599 entries providing details for machine delays during JET Operations. These records provide a wealth of data.

- The entries are grouped by main systems, such as Pulsed Power Supplies, Heating Systems, CODAS, Diagnostics, …
- Each of the main groups has sub-categories:
    - For example Pulsed Power Supplies is sub-divided into OH-circuit, toroidal field-circuit, generators, power supplies for additional heating, etc.
- The data have been analysed during CAMPAIGN shifts only:
    - A total of 2748 Campaign shifts have been analysed, with 6006 entries

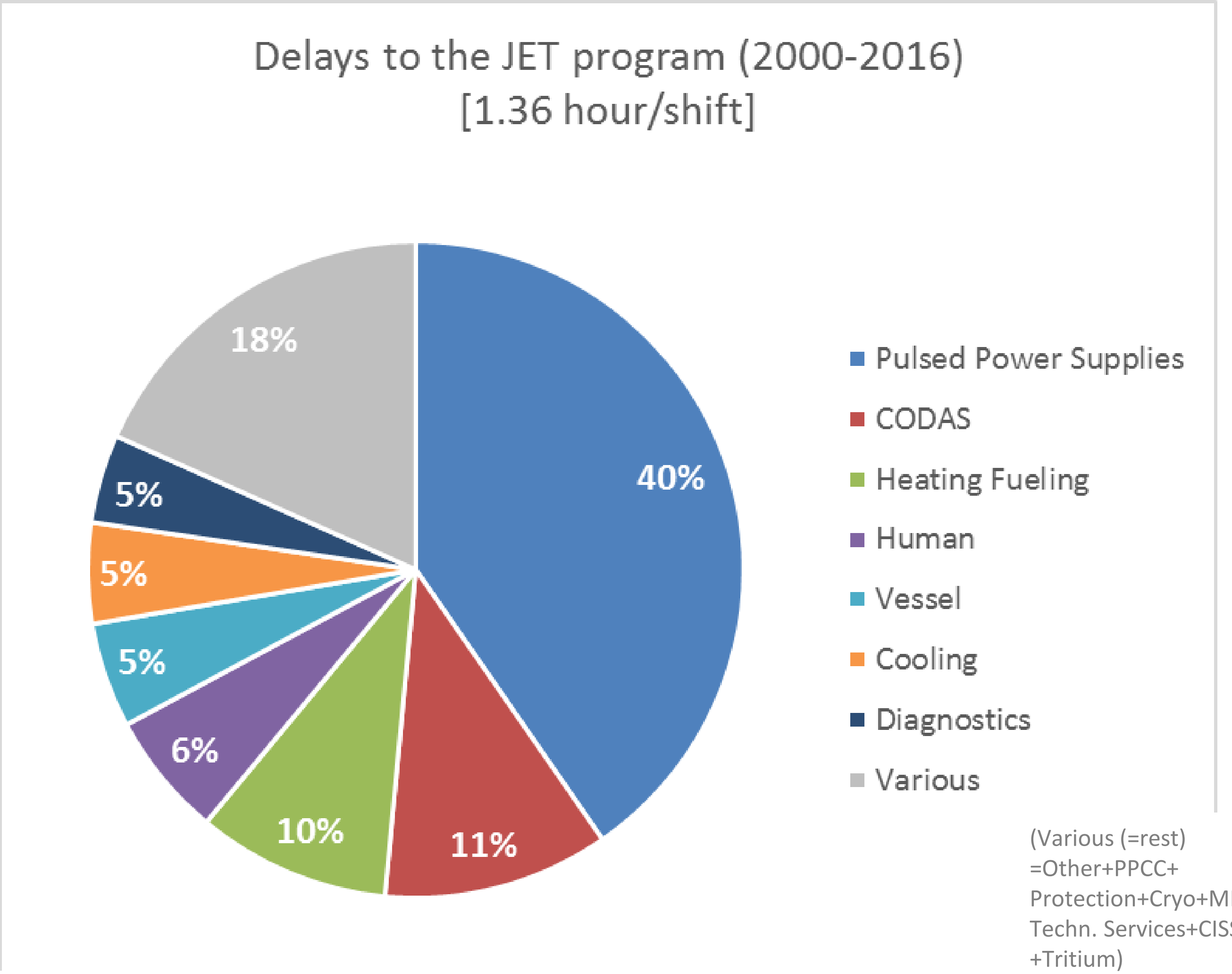
Please note:

- Campaign planning typically has 20% contingency to complete experiments.

Availability during Campaigns days: 2000-2016



Delays during Campaign shifts: 2000-2016



Conclusion:
Pulsed Power Supplies dominate delays

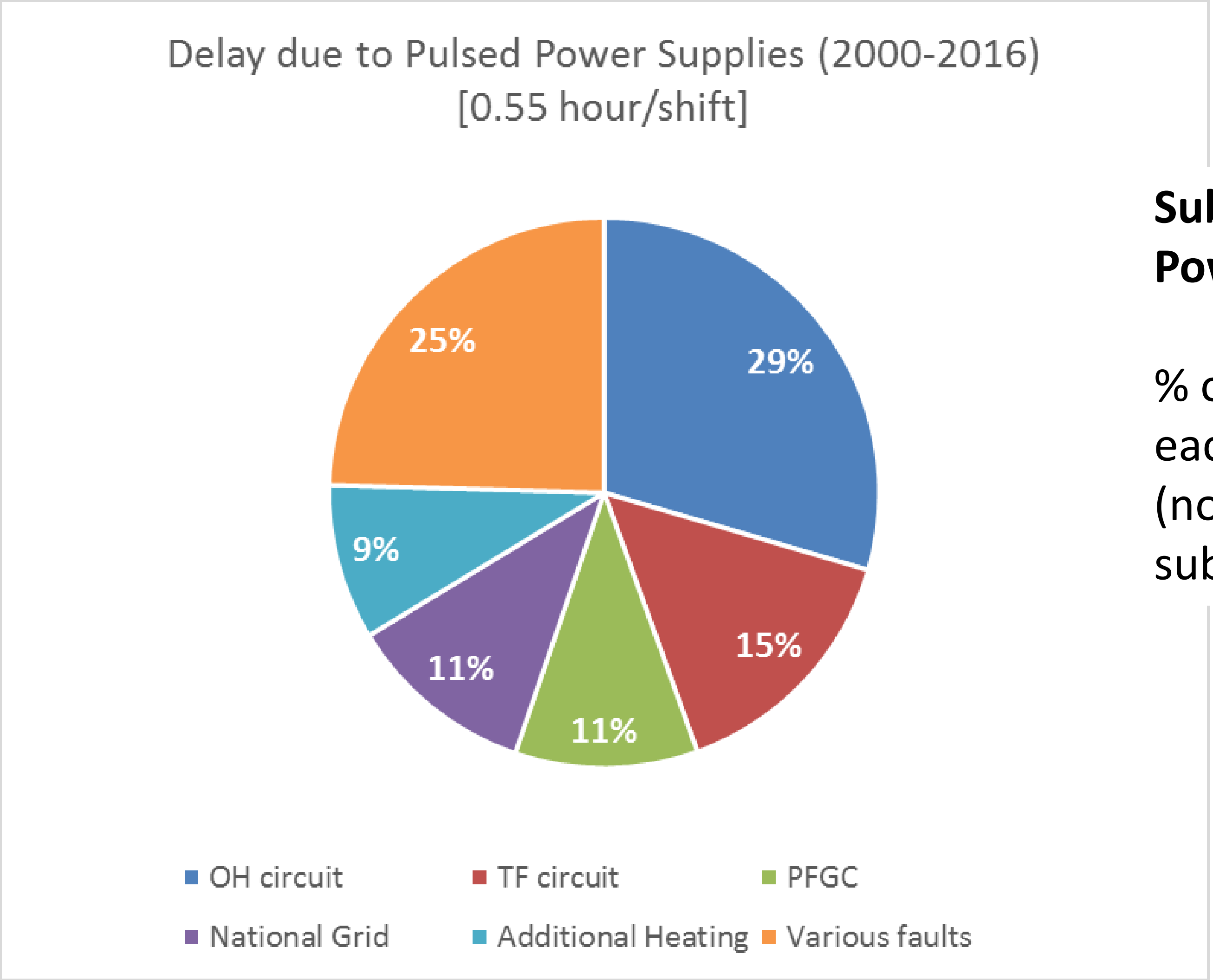
(Various (=rest) =Other+PPCC+ Protection+Cryo+MIPS+ Techn. Services+CISS +Tritium)

Over 17 years, the average delay during Campaign shifts is 1.36 hour/shift*

**: 2 shifts per day of 7.5 hours each*

Delays for Pulsed Power Supplies

Delays during Campaigns 2000-2016

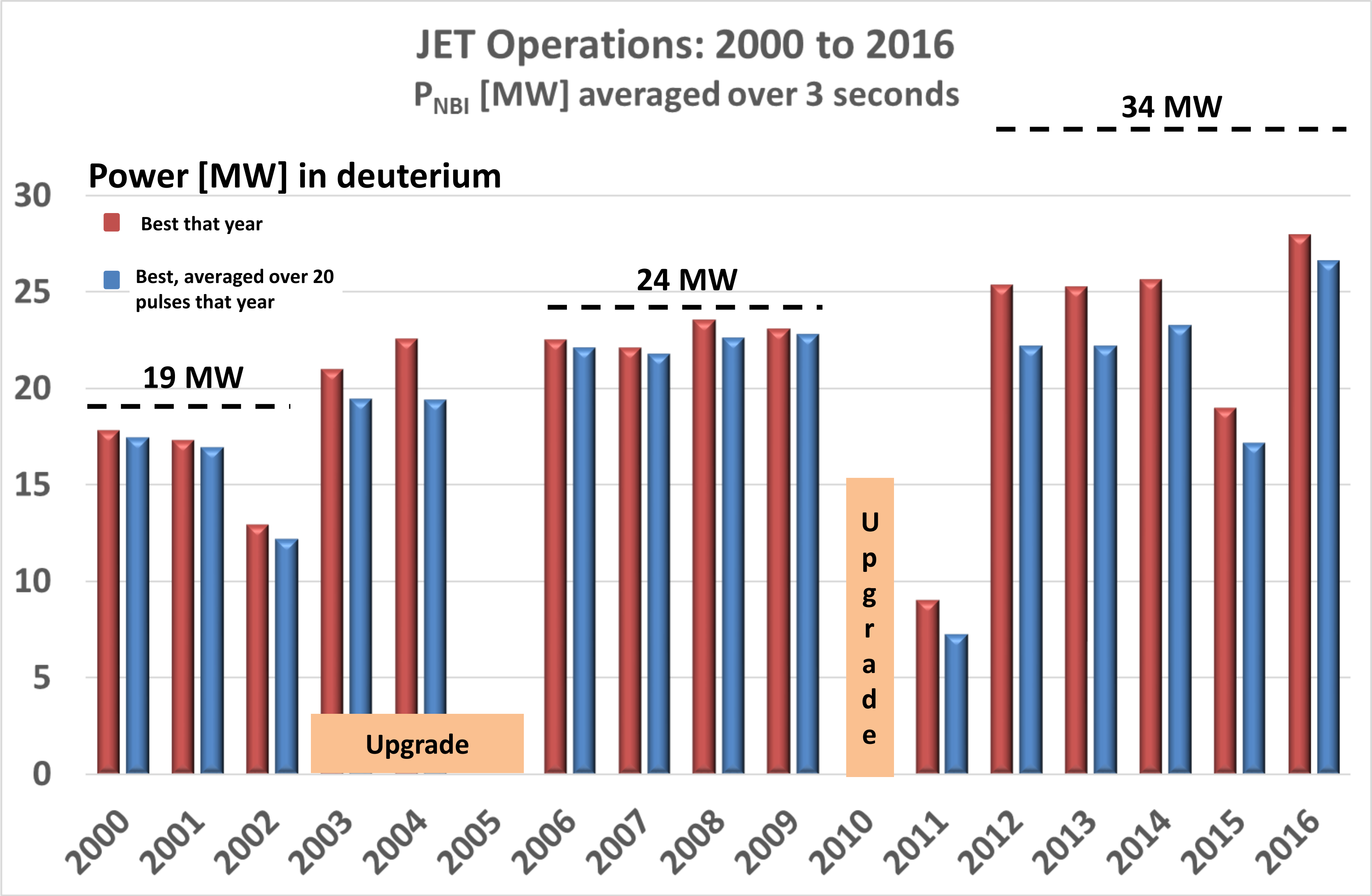


Sub-groups of Pulsed Power Supplies

% of delay caused by each sub-group (note: Various are 17 sub-groups)

→ OH circuit switches refurbished in 2017

Neutral beam system performance



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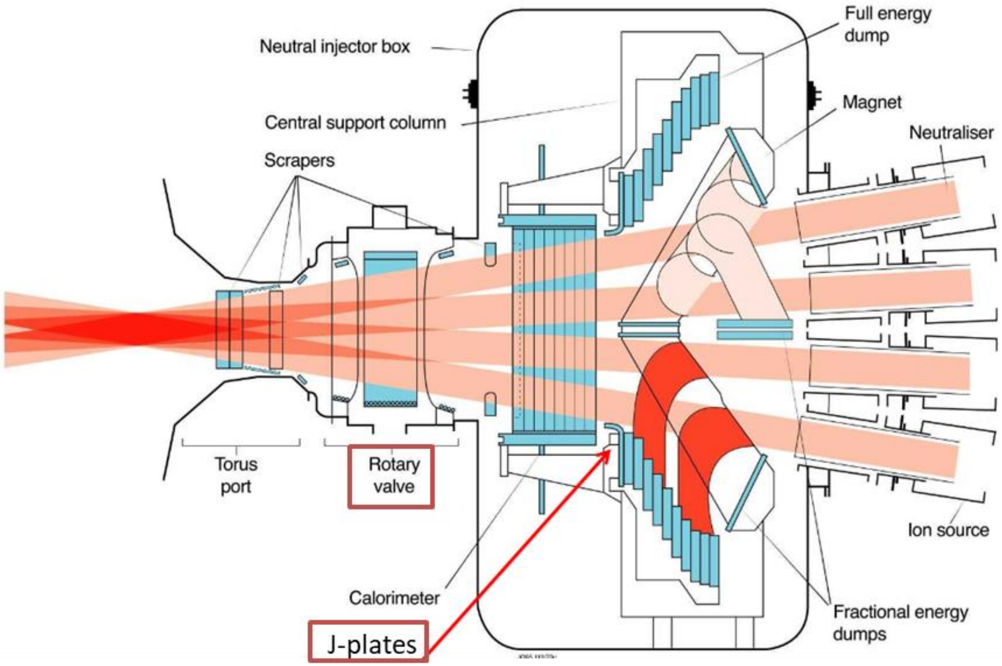
Neutral beam refurbishments - I



1. New J-plates (dumps for molecular beam ions) installed with updated design.
2. Calorimeter door aligned.
3. Octant 8 rotary valve repaired. Both rotary valves with improved open/closing mechanisms

Furthermore..:

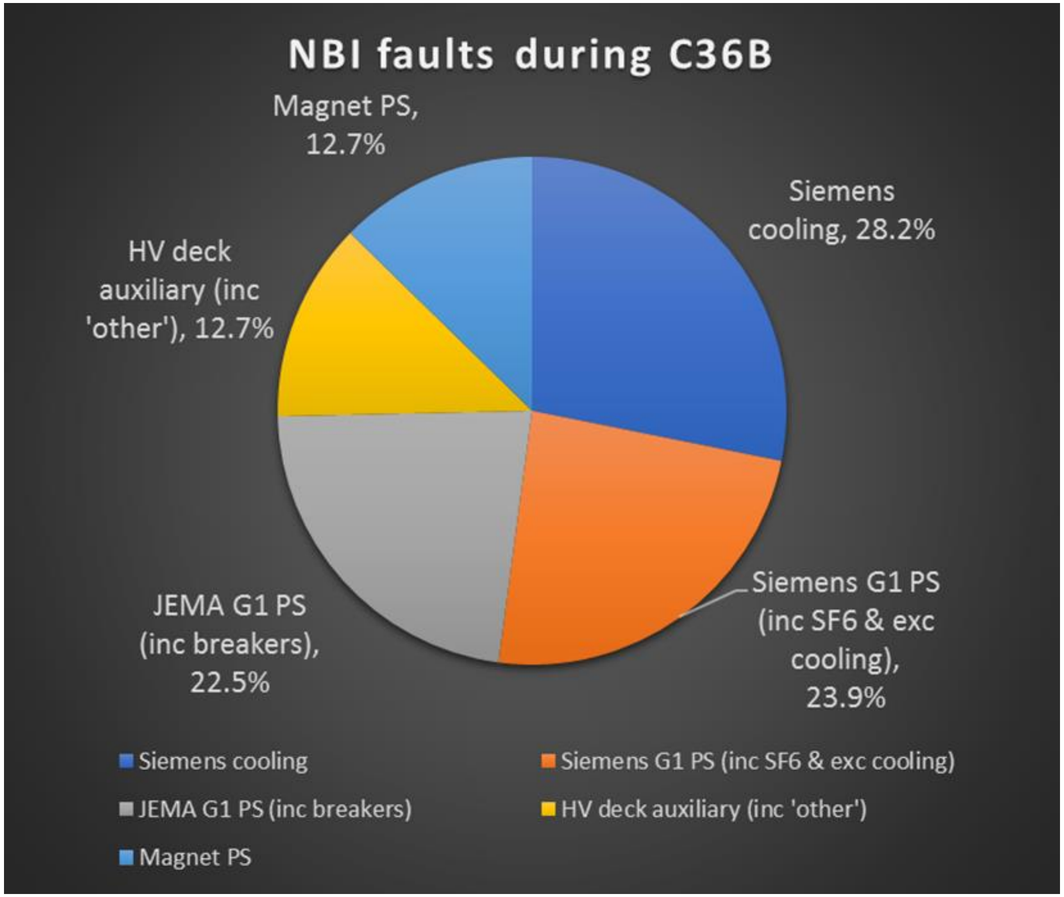
- Replacement of the cooling hoses in the SF6 tower.
- 4 PINIs reconditioned to high voltage in the neutral beam test bed.
- Full replacement of SF6 with "NOVEC®" → higher voltage stand-off

Neutral beam refurbishments - II

Continuous work over this period to improve power & performance of beams.

1. Major problems from 2013-16 have been resolved before or during shutdown.
2. Faults shown from 2016 have also largely been resolved.

Issues with power supplies during operation



Additional heating targets

Neutral beam system (NBI):

Parameter	Gas species		
	H_2	D_2	T_2
Maximum beam voltage (kV)	75	125	118
Maximum power per PINI (MW)	0.75	2.16	2.2
Maximum total power (MW)	**12.0**	**34.6**	**35.2**

Additional NB targets:

- Maintain high beam source availability of > 90%
- Obtain high average NB-power availability

Ion Cyclotron Resonance Heating (ICRH):

System	Power in H-mode		
	33 MHz	**42 MHz**	**51 MHz**
Four A2 Antennas (MW)	4-6	6-7	4-6
Re-instated: ITER-like Antenna (MW)	1-1.5	~ 1.5	1
Maximum ICRH power (MW)*	**7**	**7-8**	**7**

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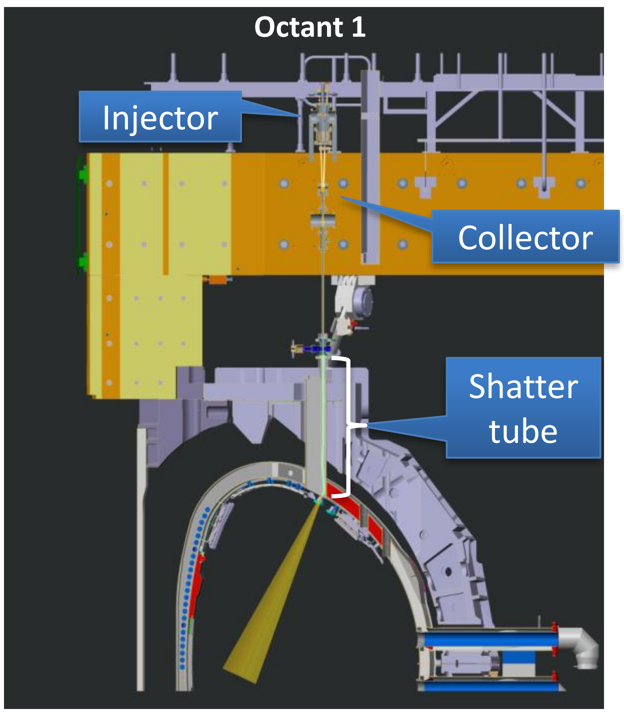
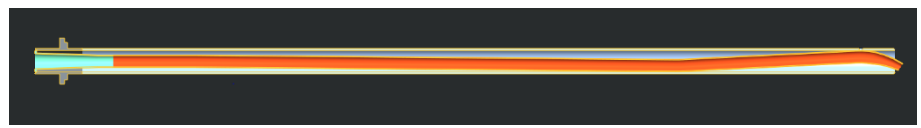
New for 2018: Shattered Pellet Injector (SPI)

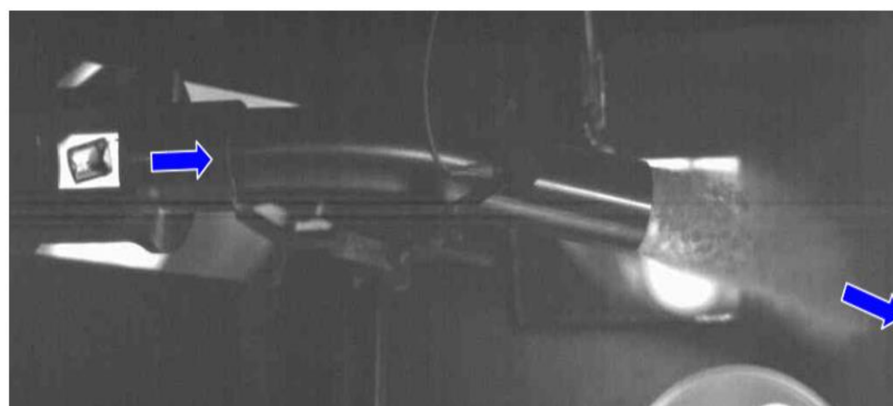
3-barrel concept with H2/D2/Ar/Ne pellets shattered by an inclined plate to mitigate disruptions and runaway electrons. Replaces the DMV1 disruption mitigation valve.

The SPI system is not tritium compatible



Cut away model of the JET shatter tube



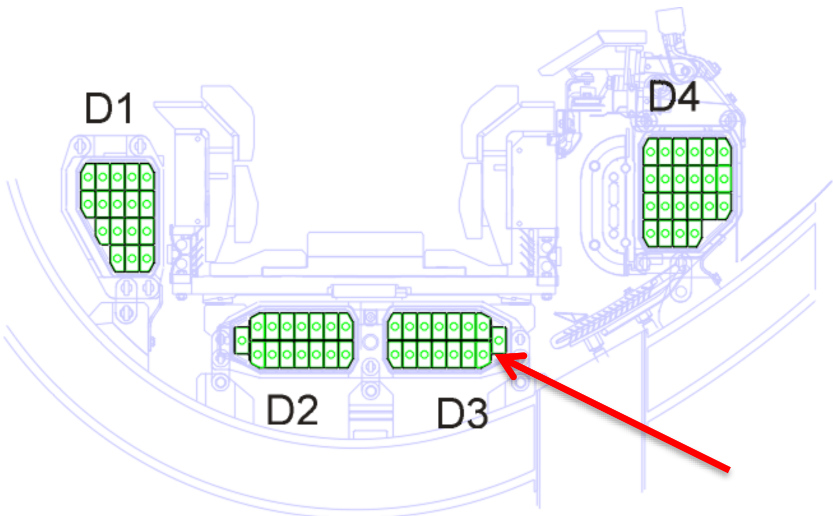


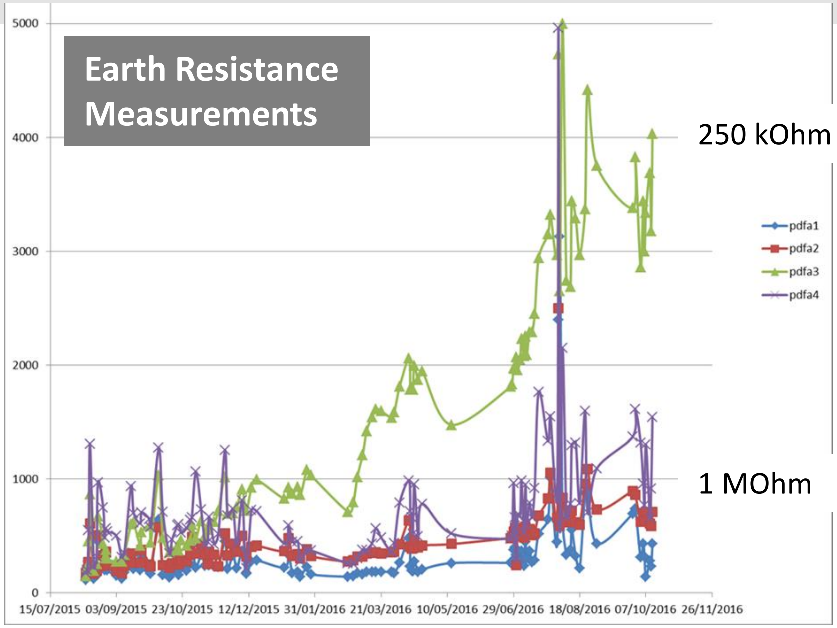
Additional concerns – D3 earth leakage fault

Issue

An earth leakage fault identified on D3

Progressively worsened since late 2015 where resistance originally several MΩ, to a resistance around 250kΩ





Risk
The main concern is that the fault could develop into a turn-to-turn fault, as this will affect the output of the coil (i.e. field)

Assessment

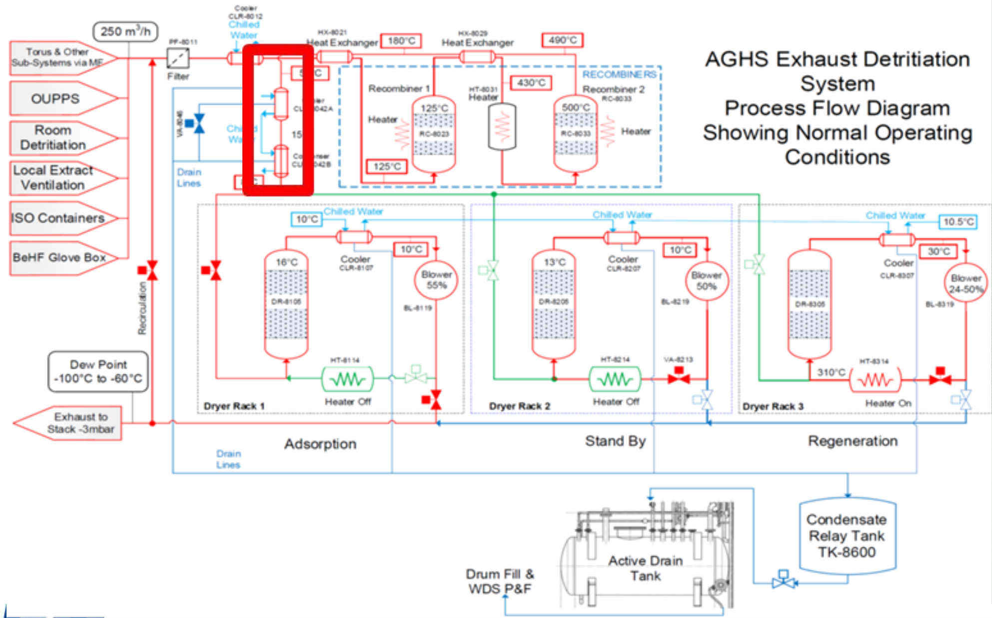
- The location of the fault has been determined.
- Simulations suggest any turn-to-turn fault would be detectable when still high enough resistance to have negligible effect.
- In event of D3 failure and removal from service, plasma operations would be achievable via modified configurations.
- To date, no clear indication of similar fault on any other divertor coil, but evaluation continuing.

Additional concerns – Exhaust Detritiation System

The Active Gas Handling System at JET has an Exhaust Detritiation System (EDS), processing exhaust gas from JET during operation and shutdowns (ventilation).

In summer 2017 it was found the system had "ingested" 2-5 kg of halogens from repair work to JET cooling loops of the toroidal field – then the dryers, recombiners and heat exchangers of EDS then produced highly corrosive acids that have affected many essential parts of the EDS system.

→ Full repair ~ 1 year, until operation with tritium is allowed (early 2019)



JET operation beyond 2020 ?

- In parallel to the discussion with ITER, an alternative vision for the use of JET beyond 2020 is being developed, based, so far, on the following boundary conditions:
  - Completion of significant DT operation by 2024;
  - Some DT and TT pre-2020;
  - No major enhancements;
  - Focus on issues where JET provides unique added value;
  - Refurbishment as required for reliable operation;
  - Start of conceptual design from January 2018;
  - Decision to commit resources December 2018;

- A review at the end of 2017 concluded that:

  “ There is ‘no obvious sign’ that the JET facilities, as a whole, are reaching their ‘end of life’ “

Part 2: Scenario preparation for JET DT operation

DTE1 in 1997 achieved:

- 16MW transiently
- 4MW steady state (5s)

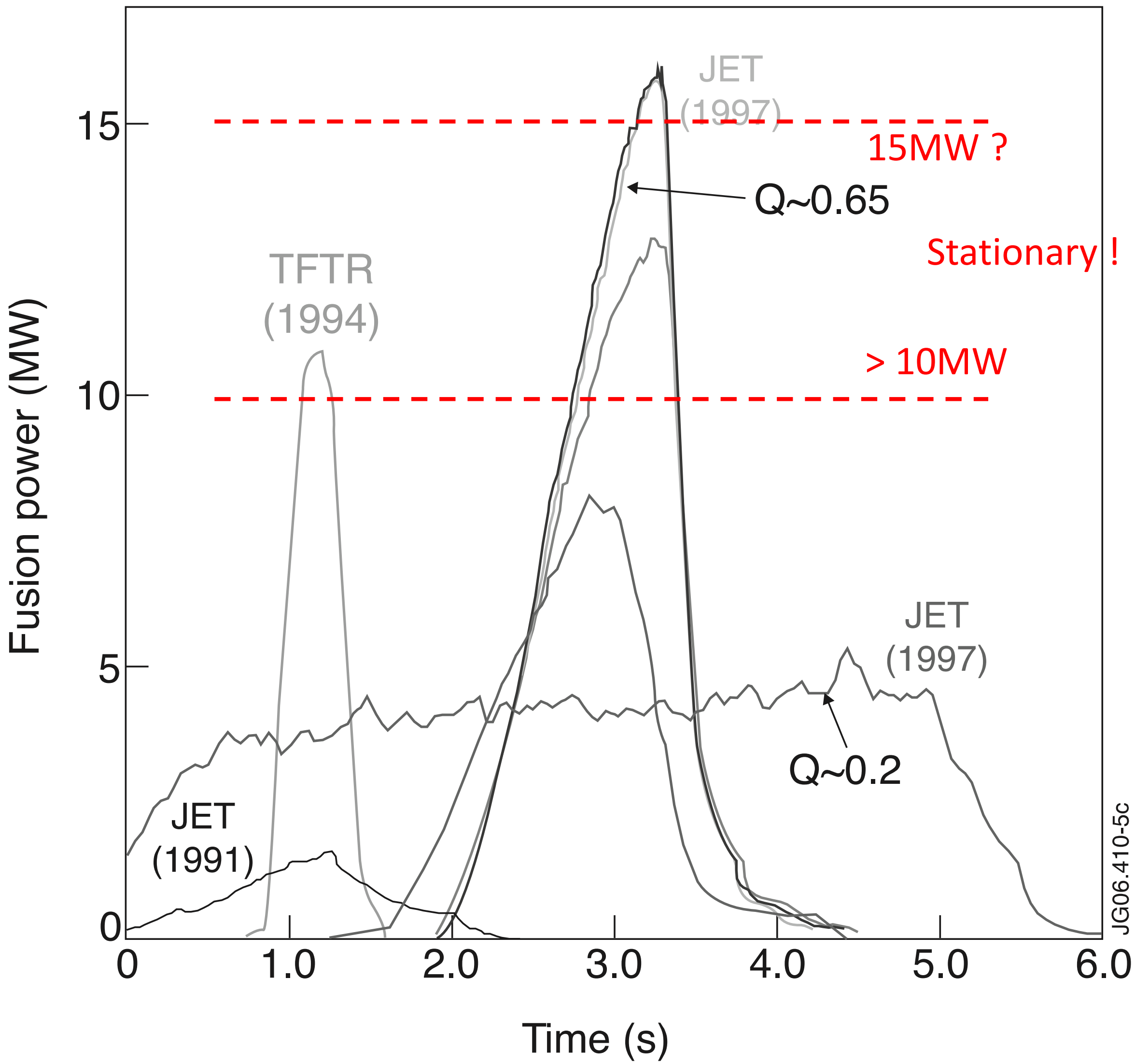
Aim for the next DT phase:

- 10-15 MW stationary for 5s
- With the Be/W wall at 40MW input power

Supported by other physics studies:

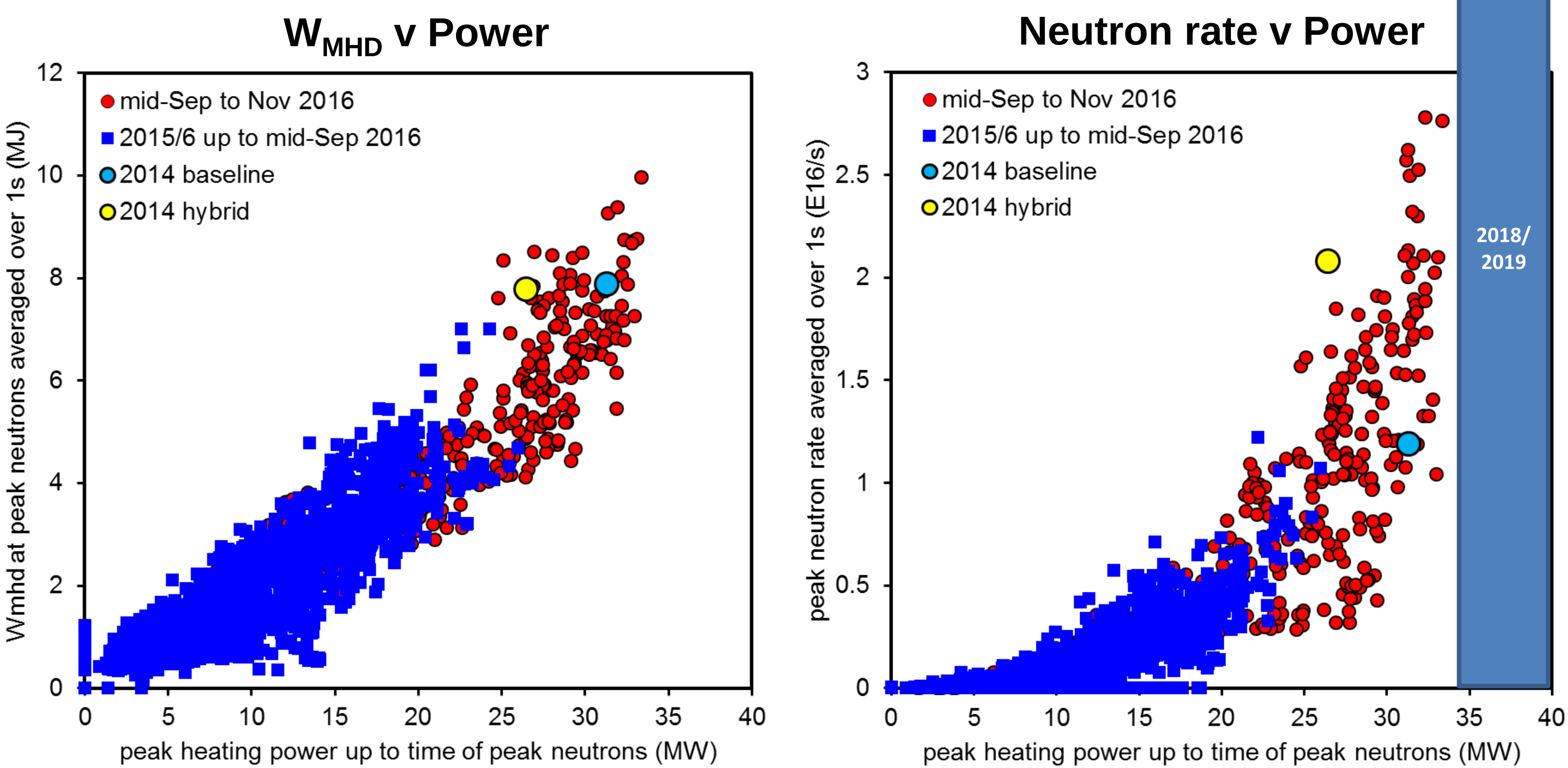
- Isotope effects (H, D, T)
- Fast particle studies (α's)
- RF heating scenarios in DT
- Others…

(PPPL seminar by M. Romanelli, December 2017)



High plasma performance in November 2016 (C36b)

- Plasma performance improved in C36b compared with C35-C36 due to availability of high power heating



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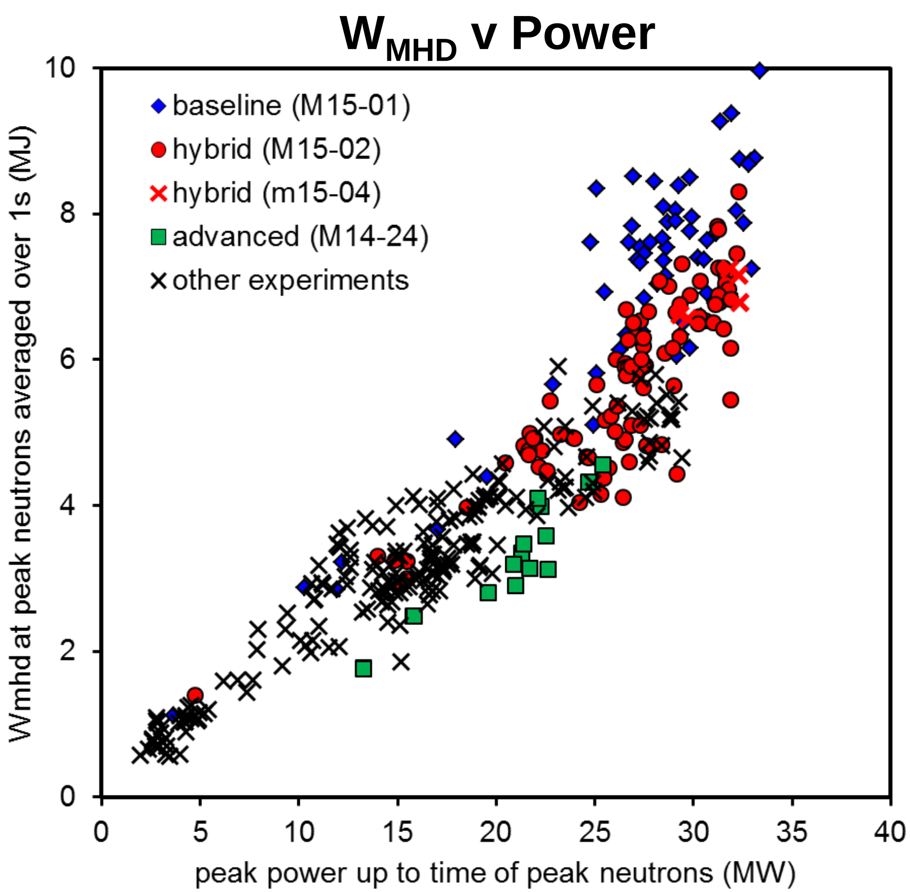
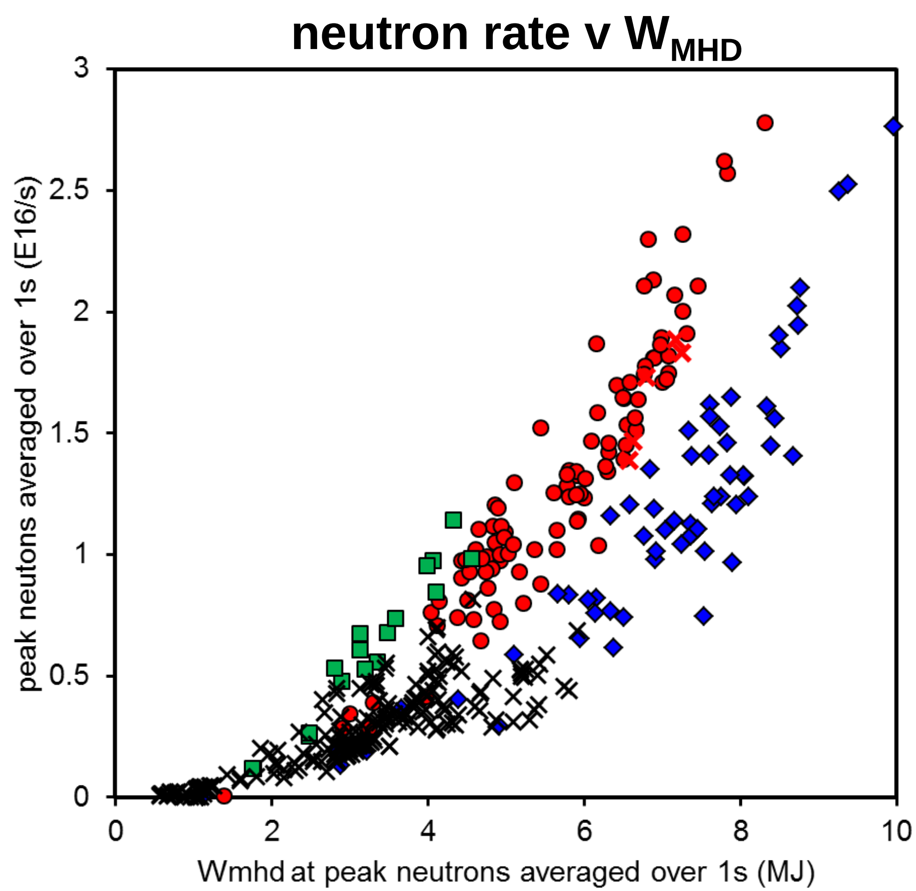
τ_E & P_{fusion}/W are scenario dependent

- 'Baseline' achieves highest plasma stored energy, due to high current
- 'Hybrid' & 'AT' produce most fusion power per MJ of stored energy

➢ Different routes to goal of high fusion power

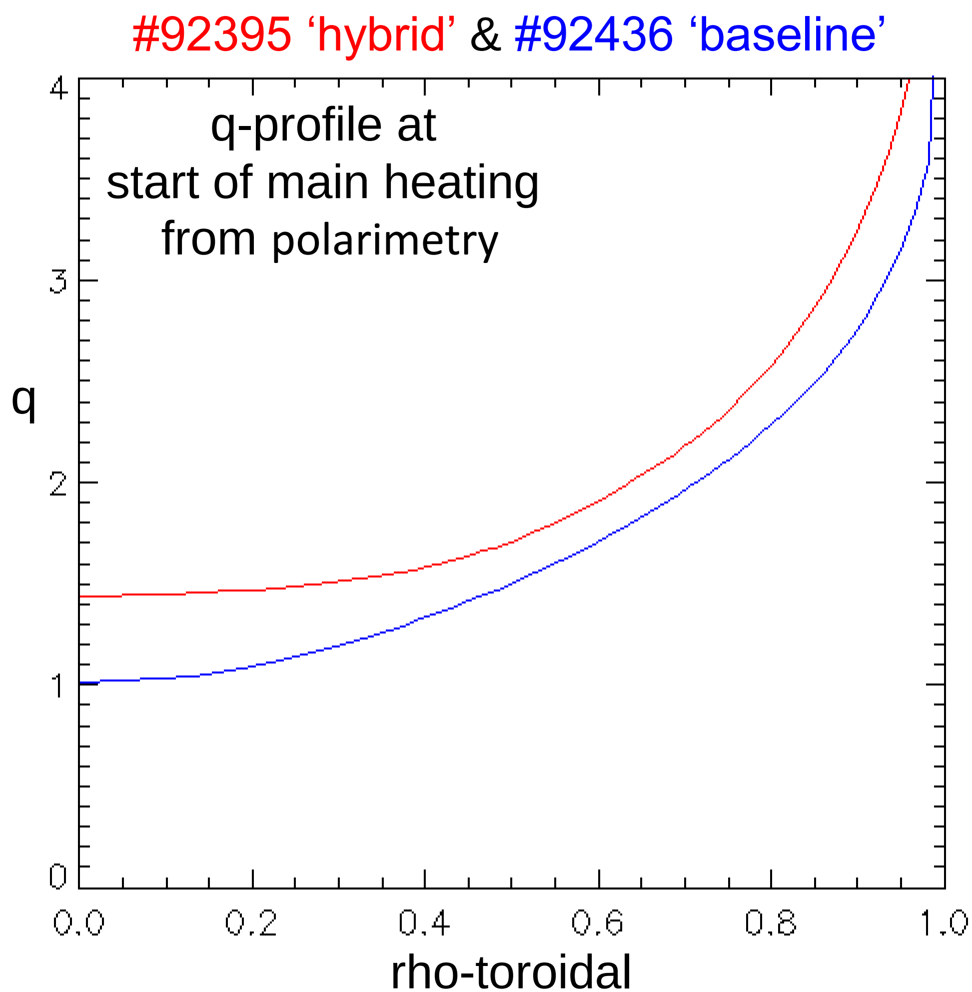




q(r) varies between scenarios

Characteristic of q-profile in record ILW fusion power pulses:

- 'Baseline': q_0 close to 1 at start of heating with sawteeth during high performance phase
- 'Hybrid': q_0 above 1 at start of main heating with no 1,1 activity for first couple of seconds of high performance phase



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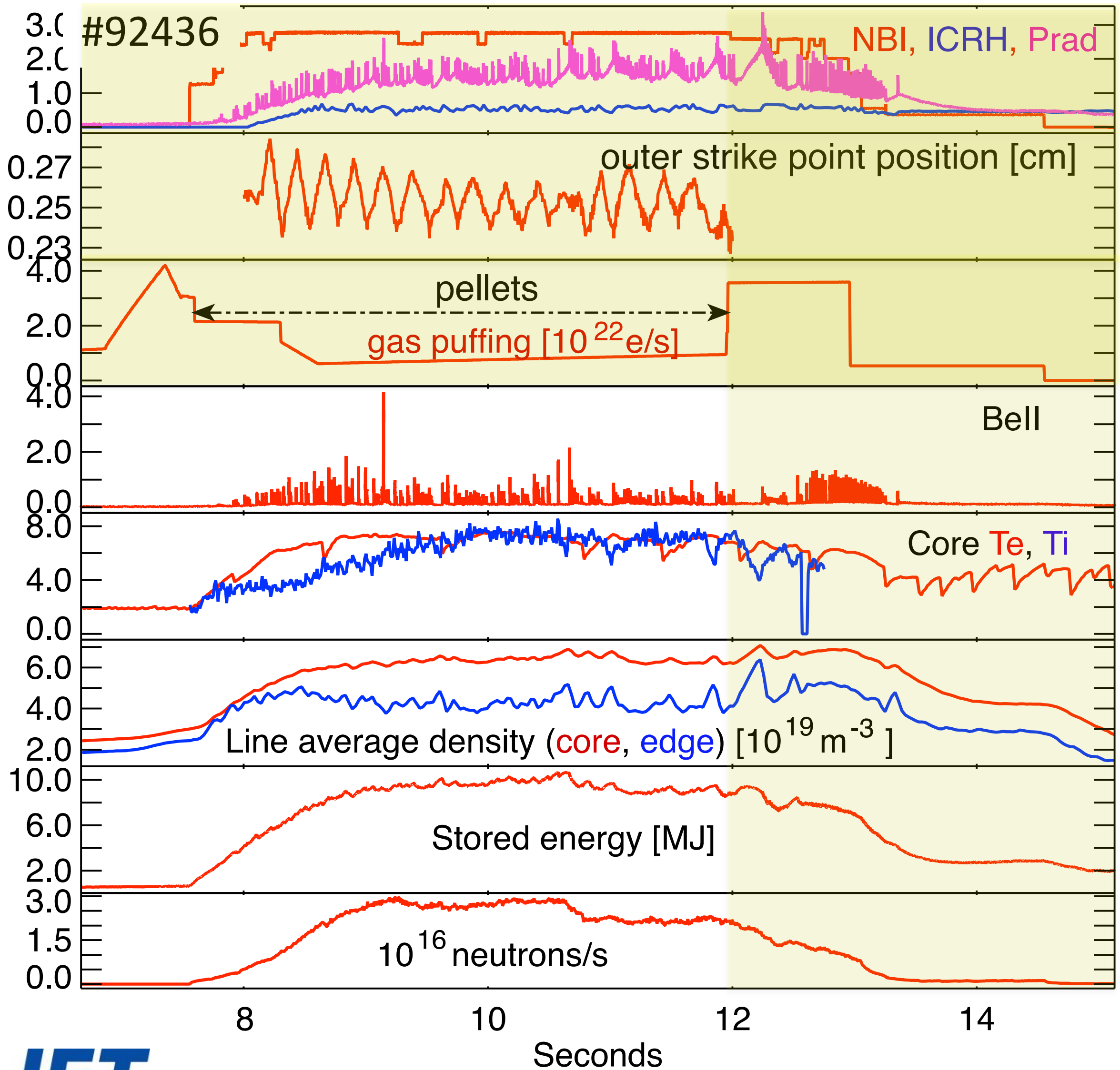
Baseline scenario: High Ip (3MA), q_{95}~3, H_{98} ~ 1

I. Nunes



- ICRH for W control
- Sweeping for heat load control
- Pellets for W control and to minimise gas puffing

- Scenario termination

Increase P_{add}, I_p, B_T

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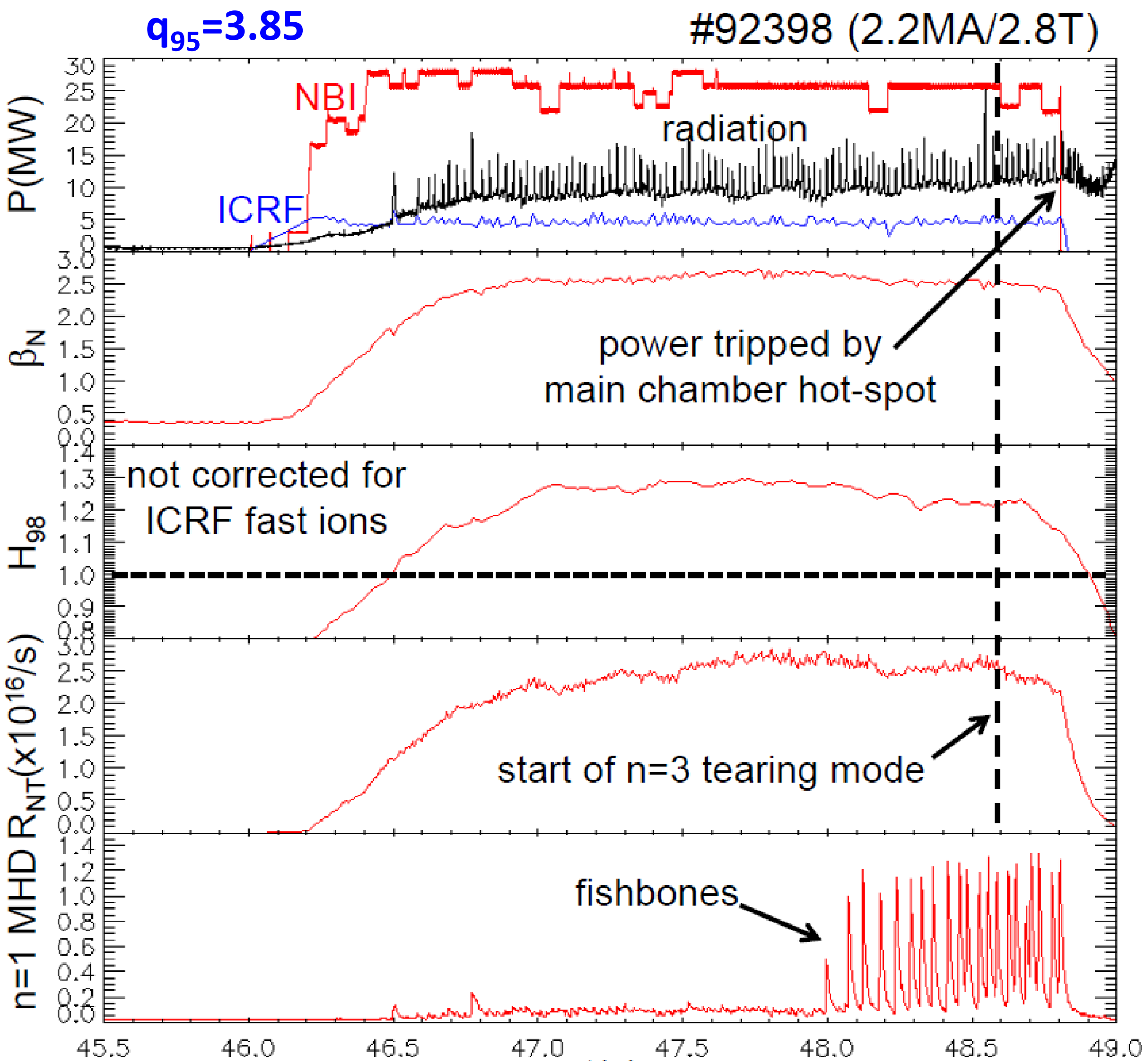
Hybrid scenario: higher β_N~2.5-3, elevated H_{98} ~ 1.2-1.4

- Initial q_0>1 allows high performance phase with no 1,1 MHD
- Compatible with β_N>2.5 & high H_{98} without prompt tearing mode
- To extend need to:
  - ➢ Increase initial q_0
  - ➢ Increase T_e to 'freeze' q

Increase P_{add}, B_T (I_p)



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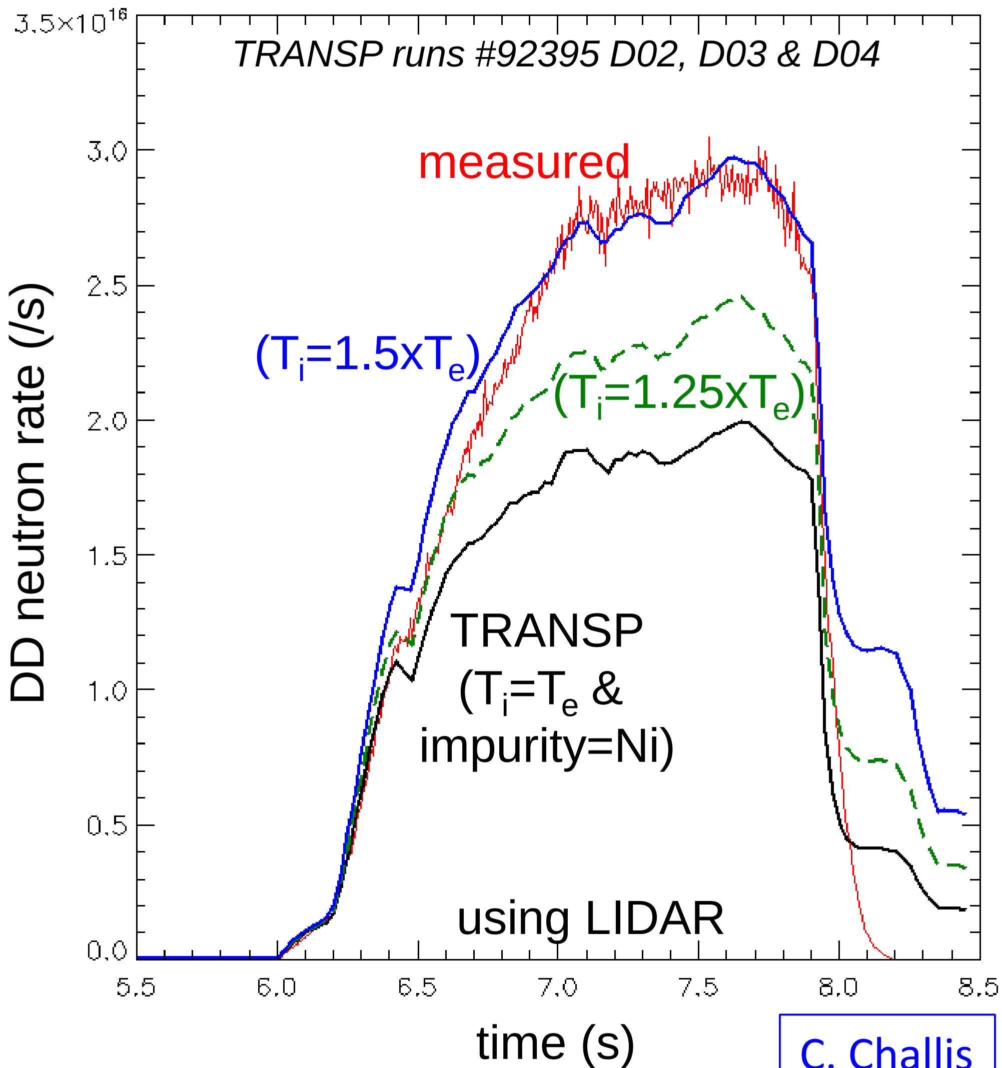
'Hybrid' plasma – D plasma

- TRANSP simulations consistent with measured neutron rate provided that:
  - Significant part of measured Z_{eff} (~1.8) assumed to be mid-Z metals rather than Be
  - $T_i > T_e$ as indicated by preliminary CX measurements
- No T_i or rotation profiles
- JETFUSE simulations sensitive to equilibrium at high β, awaiting improved reconstructions
- ICRF+NBI effect ~21% ±2% from TOFOR (not included in simulations)

#92395 (2.2MA/2.8T/31MW)



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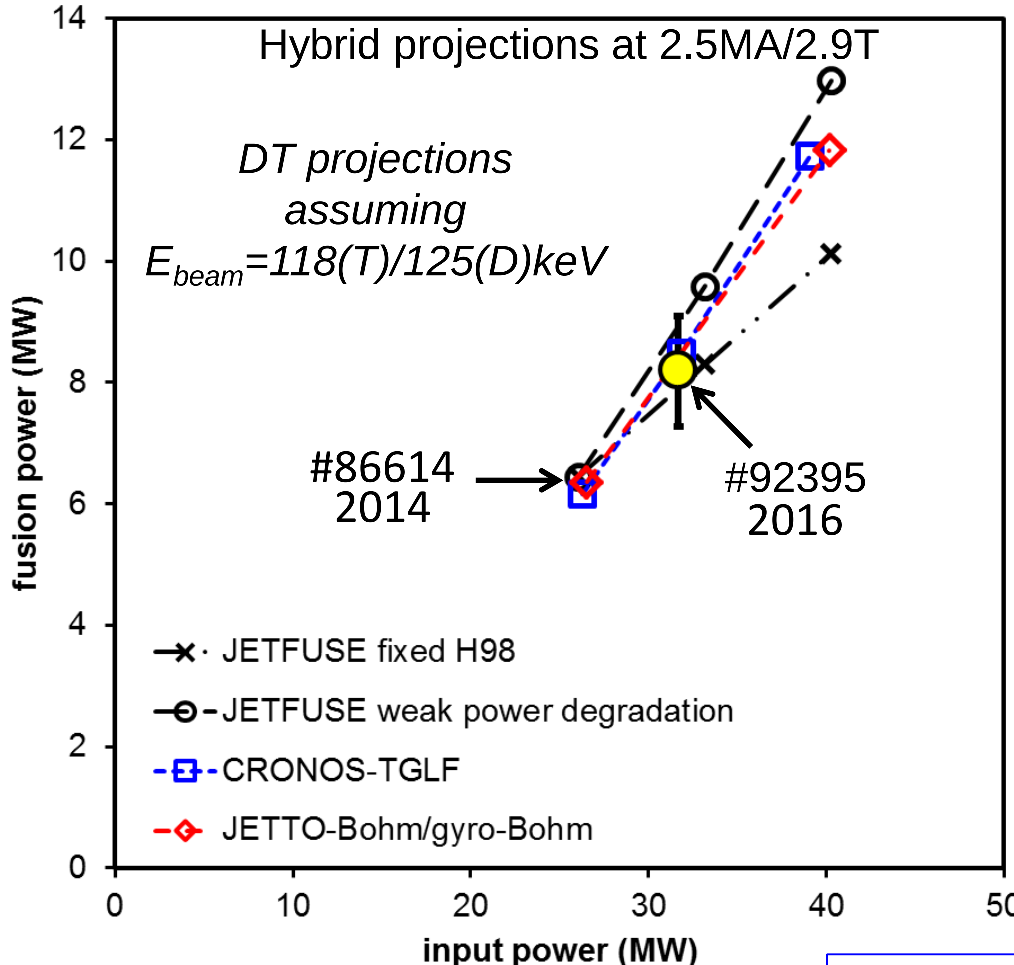
Progress v DT projection ('hybrid')

- Assumptions for original projection scan using JETFUSE:
  - Reference plasma #86614 (2.5MA/2.9T H_{98}~1.1)
  - Temperature & density profile shapes constant
  - $n/n_{Greenwald}$=constant
  - H_{98}=constant or $H_{98} \sim \beta^{0.48}$
  - I_P constant
  - B constant
  - $P_{NBI,max}$=34MW
  - E_{beam}=118/125keV
  - P_{RF}/P_{NBI}=constant
  - Predictive simulations consistent with fixed profile projection assuming weak power degradation
  - No credit for isotope scaling or α-particle effects

Similar projections for Baseline scenario



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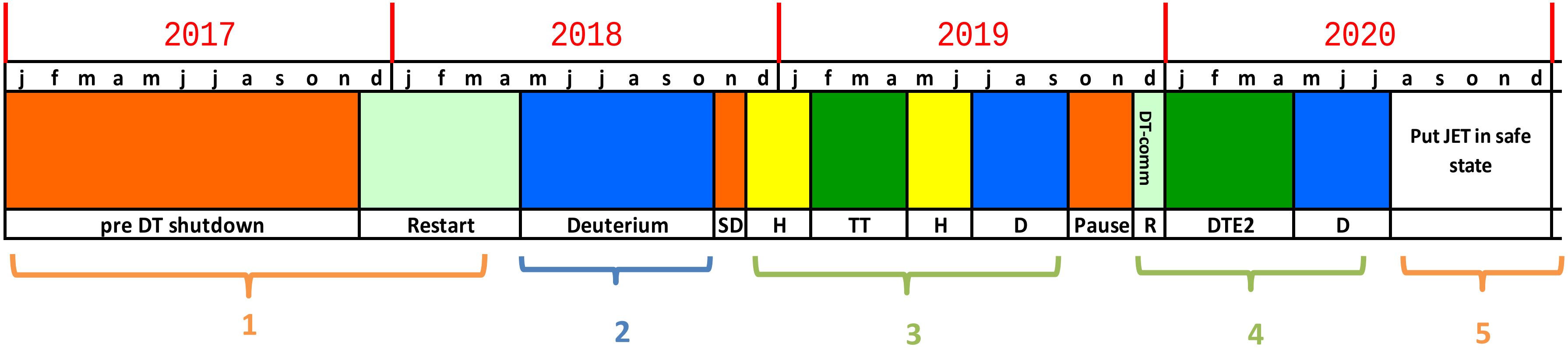
Conclusion: JET Operation Schedule for 2018 - 2020

JET Schedule until 2020, with Tritum and DT in 2019/2020



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