ITER Project Status

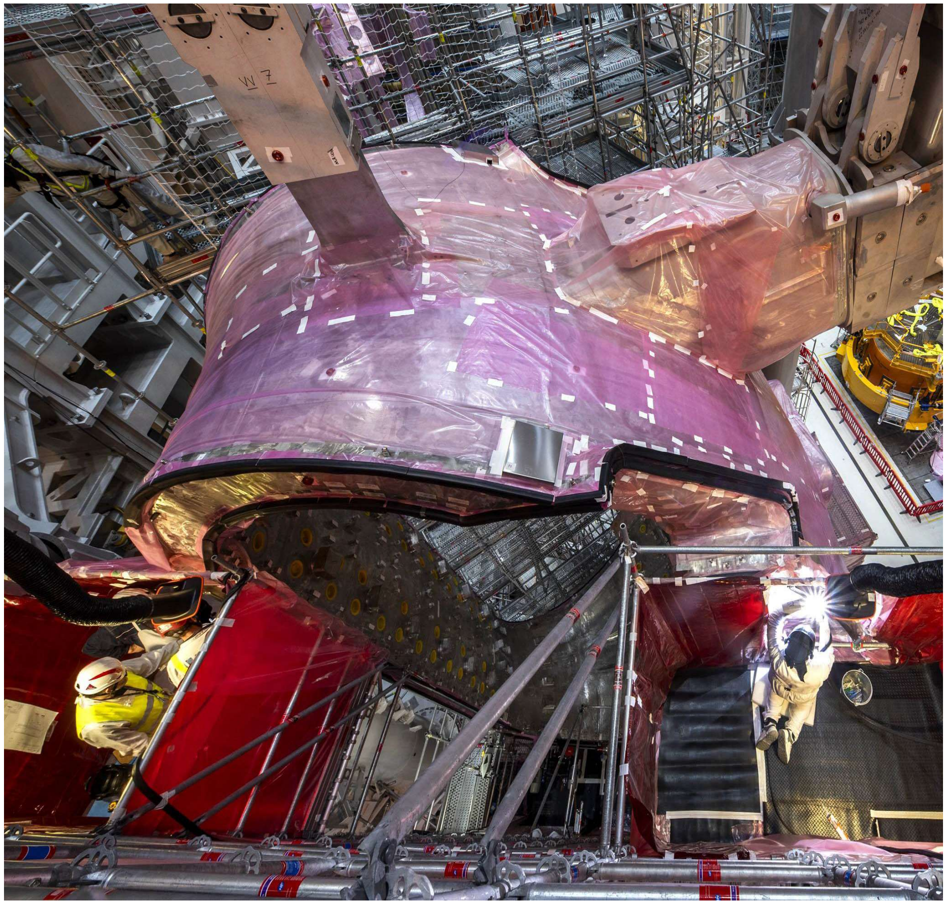
Alberto Loarte

On behalf of the ITER Organization, ITER Members' experts, ITER Scientist Fellows and Collaborators

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

Outline

- ITER Project Status and introduction to New Baseline
- New Baseline Research Plan
- Start of Research Operation
- 1st Deuterium-Tritium Phase
- Conclusions

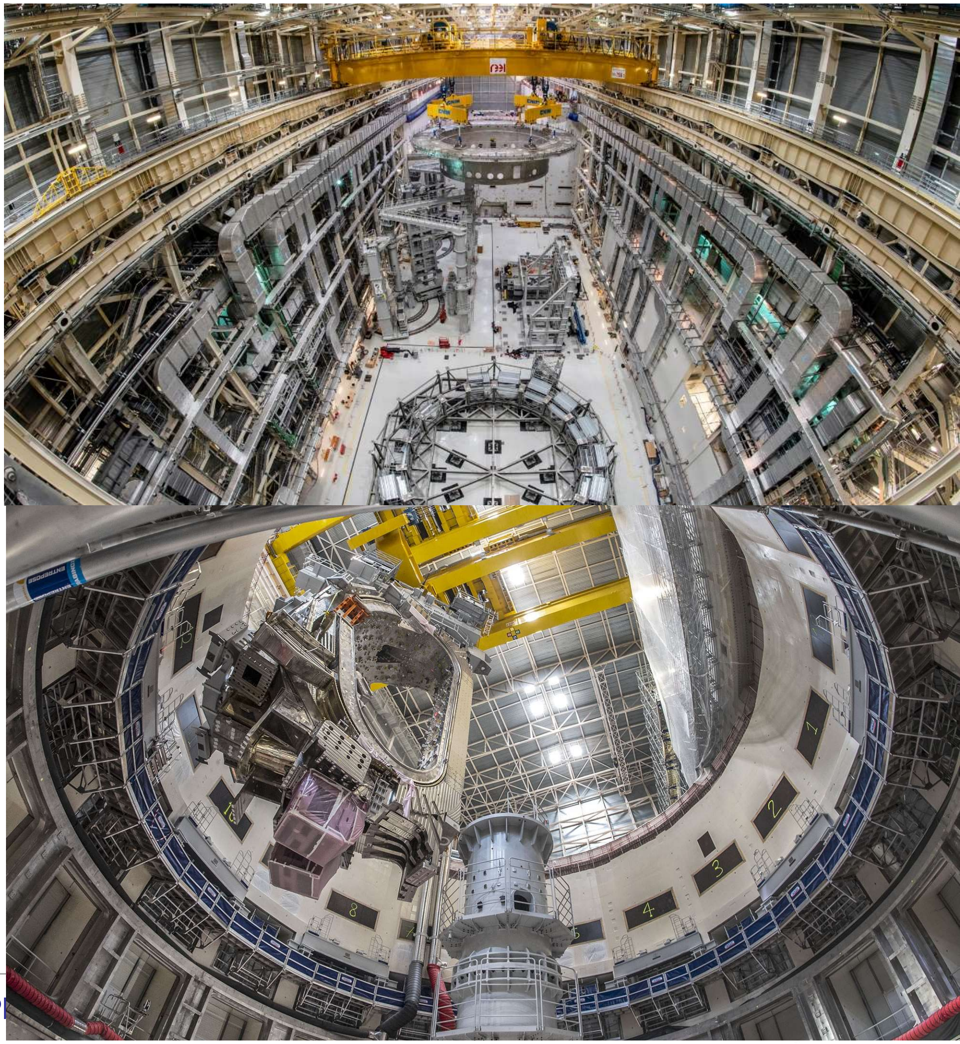


ITER project status and introduction to new baseline

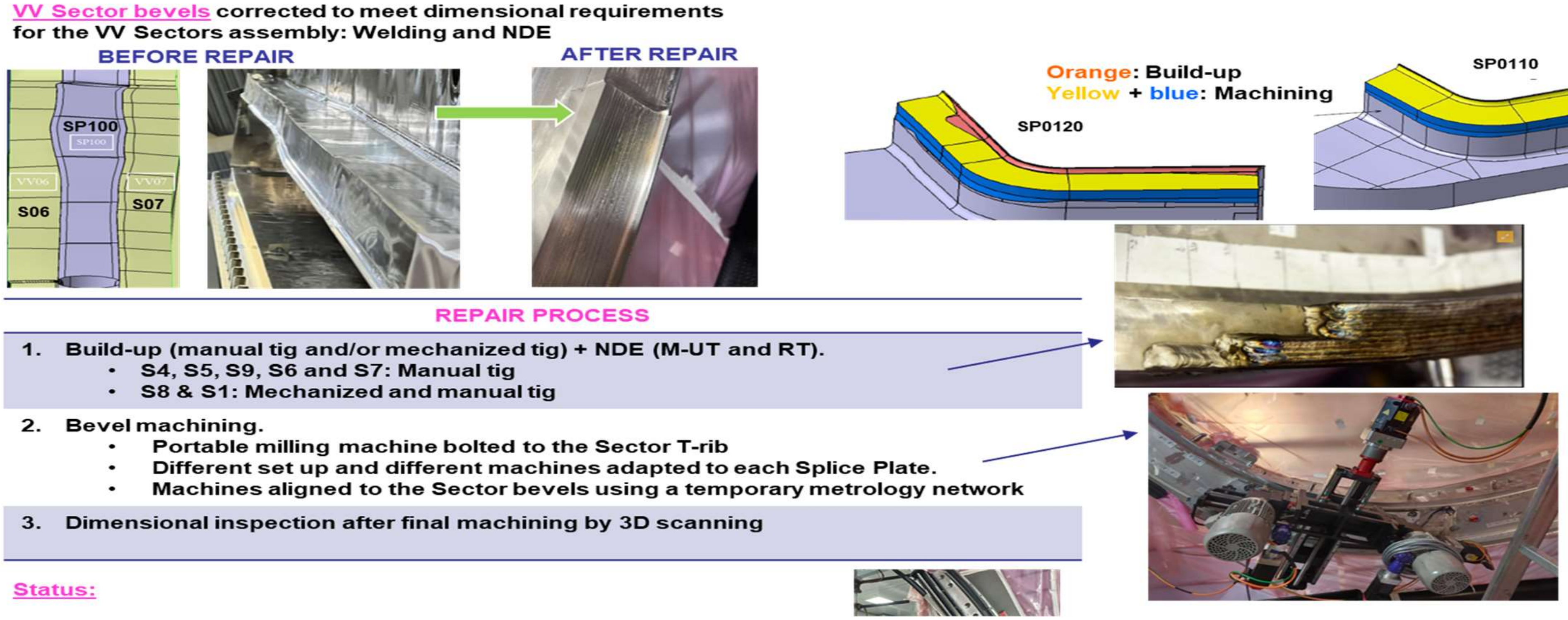
ITER Project Status

- ➢ **ITER machine assembly started in May 2020**
- ➢ **1st Machine Sector assembled & installed in May 2022**
- ➢ **Problems: Vacuum Vessel &Thermal Shield:**
    - **Repairs progressing well**
    - **Re-think of strategy → new baseline**

- ➢ **In the meantime, many ITER components completed**



VV Bevel repair



VV Sector bevels corrected to meet dimensional requirements for the VV Sectors assembly: Welding and NDE

BEFORE REPAIR

AFTER REPAIR

Orange: Build-up
Yellow + blue: Machining

REPAIR PROCESS

1. Build-up (manual tig and/or mechanized tig) + NDE (M-UT and RT).
    - S4, S5, S9, S6 and S7: Manual tig
    - S8 & S1: Mechanized and manual tig
2. Bevel machining.
    - Portable milling machine bolted to the Sector T-rib
    - Different set up and different machines adapted to each Splice Plate.
    - Machines aligned to the Sector bevels using a temporary metrology network
3. Dimensional inspection after final machining by 3D scanning

Status:

- **Sector 7 and 5 repair completed**
- **Restart of sector assembly in October 2024**

Magnet Status

3rd module stacking in B13, Aug. 24

Central Solenoid (USDA)

- *4 modules delivered, 3 (1 spare) at manufacturing stage*
- *3 modules stacked in pre-assembly building*

PF2 completion in B55, May 24

6 Poloidal field Coils (F4E-CNDA-RFDA)

- *6 & 5 in temporary position in PIT*
- *1 to 4 in storage*

CTB Shipment

Feeder components (CNDA)
81 % completed

18 Correction Coils (CNDA)
12 coils delivered.

First SCC prepared for cold test, April 24

19 Toroidal Field Coils (F4E-JADA)

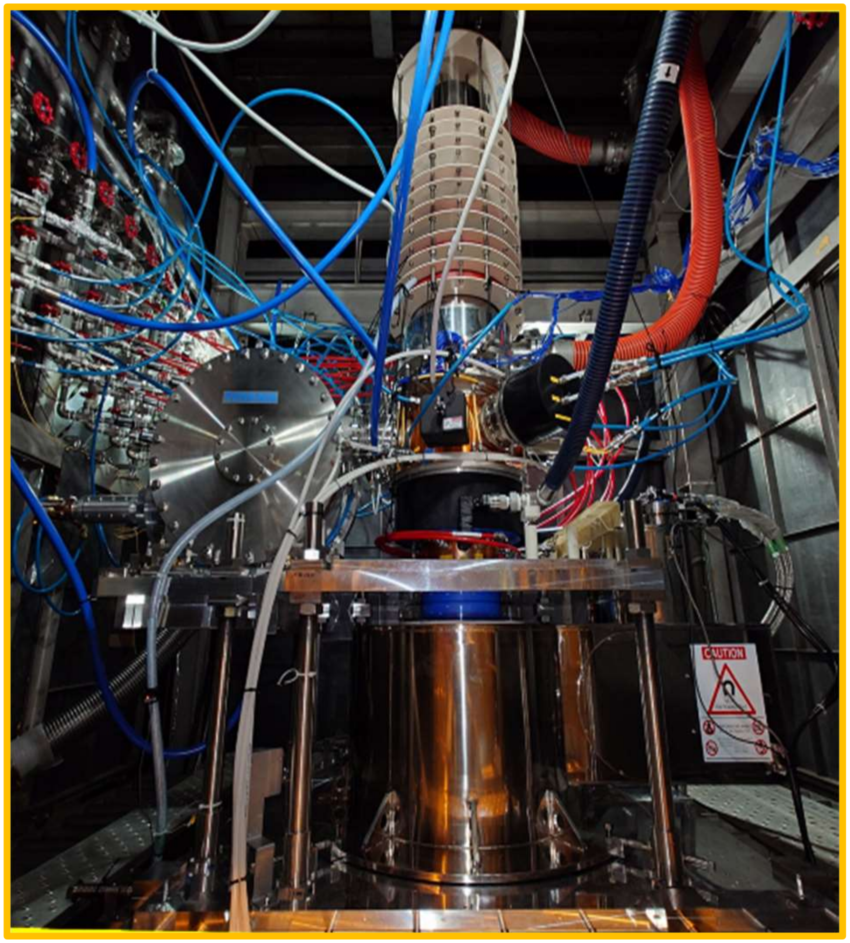
- *6 & 5 in temporary position in PIT*
- *1 to 4 in storage*

Last TFC on the way to IO, Dec. 23

Other Systems

Cryopump panels

Gyrotons



New Baseline Rationale

- ❑ Robust achievement of Projects' goals, in view of past challenges (delays due to the Covid-19 pandemic, technical challenges in completing first-of-a-kind components and in nuclear licencing)

- ❑ Realistic & reliable assembly - commissioning – operation

- ❑ Achievement of earliest start of ITER Nuclear phase (D-D) & minimize technical risks (SRO)

- ❑ Stepwise Safety Demonstration (DT-1 & DT-2)
  - ❑ DT-1 focuses on the achievement of specific Project goal(s) → Q = 10, 300-500s
  - ❑ Limited neutron fluence (1/100 of present end-of-life) → ~ $3\ 10^{25}$ neutrons
  - ❑ DT-1 design requirements should not preclude possible future upgrades for DT-2
  - ❑ DT-2 → Full achievement of Project goal(s): safety demonstration based on DT-1

Key Elements of the New Baseline - I

Change of first wall material Be → W

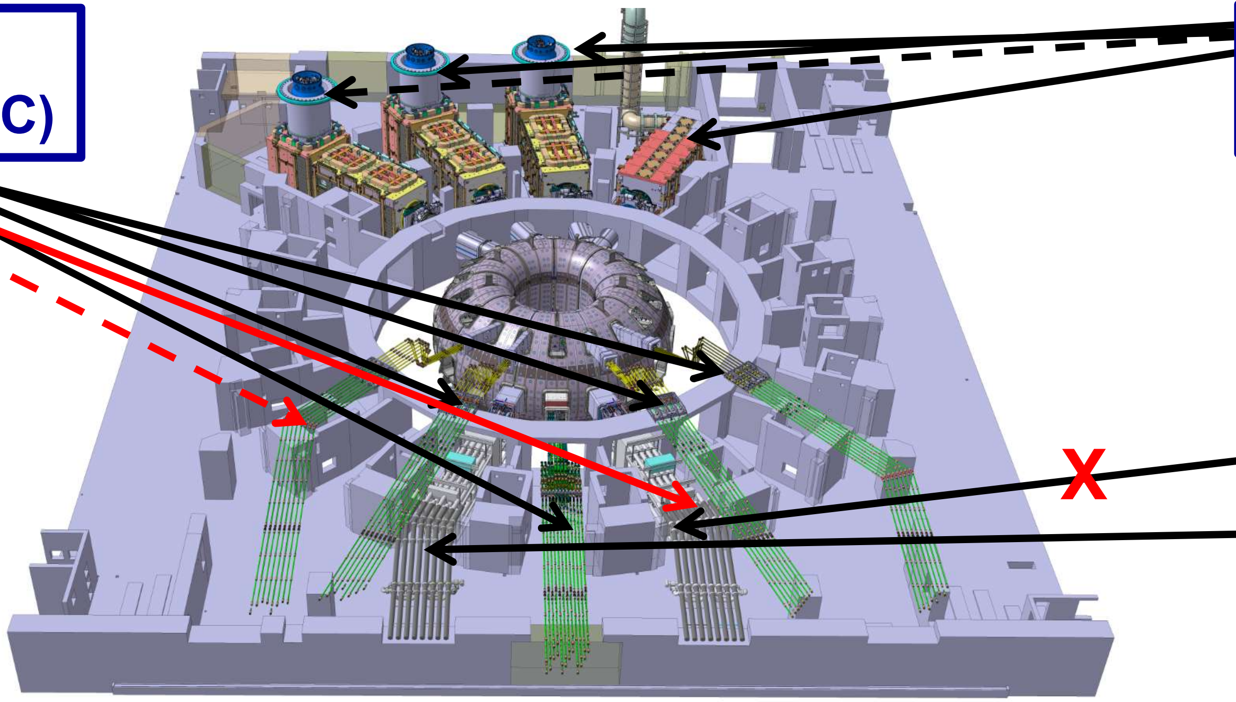
Reactor relevant material more resilient to transients (higher T_{melt})
Major benefit in assembly complexity and avoid costly later wall changeout but higher risk of plasma contamination and no oxygen getter

- ☐ Several issues with Be as PFC in ITER (R. A. Pitts, PSI 2024)
  - ➢ Erosion lifetime → Replacement of first wall panels within DT required
  - ➢ Tritium retention in co-deposits
  - ➢ Low melting point → Lower margin in I_p before potential "gap bridging" on FW panels (disruption current quench)
- ☐ Physics basis for tokamak operation with W walls is much stronger than it was at start of ITER construction
- ☐ Boron gettering routinely applied to lower oxygen levels

Key Elements of the New Baseline - II

Increase in H&CD installed power and change of power mix

Higher flexibility for experimental programme, reduction of risks and achievement of Q = 10 with low neutron fluence



Electron Cyclotron (EC)

170 GHz
20 MW (+20)
40 MW
+
20 MW (+7)

Neutral beam injection (NBI)

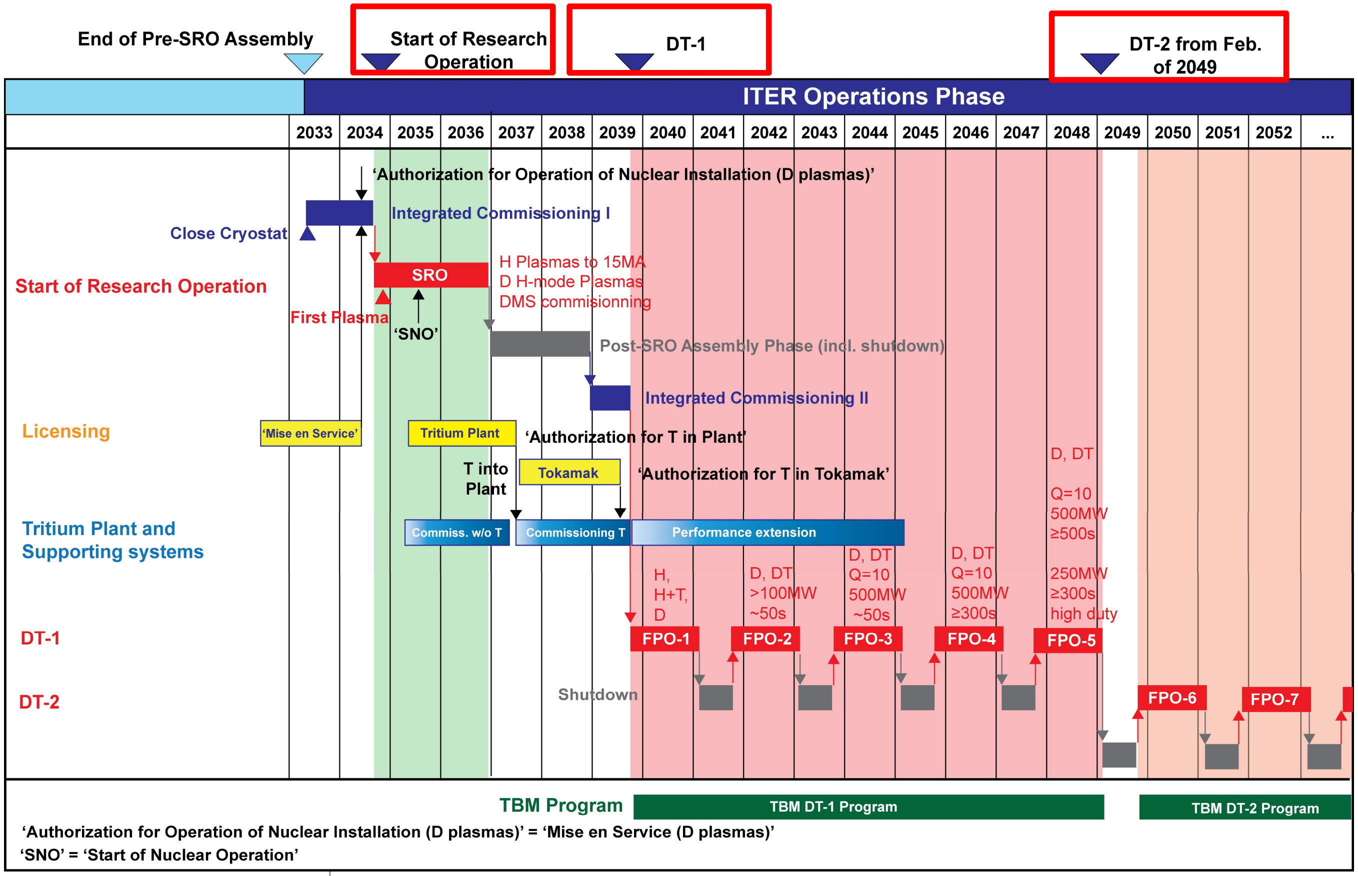
870 keV H^0
1 MeV D^0
33 MW (+16.5)

Ion Cyclotron (IC)

40-55 MHz
20 MW (+20)
10 MW (+10)

Updated ITER Research Plan (proposal to ITER Council)

Machine configuration and research plan to gradually retire risks and provide robust path to objectives with intermediate milestones



End of Pre-SRO Assembly

Start of Research Operation

DT-1

DT-2 from Feb. of 2049

ITER Operations Phase

2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | ...

‘Authorization for Operation of Nuclear Installation (D plasmas)’

Close Cryostat

Integrated Commissioning I

Start of Research Operation

SRO

First Plasma

‘SNO’

H Plasmas to 15MA
D H-mode Plasmas
DMS commisionning

Post-SRO Assembly Phase (incl. shutdown)

Integrated Commissioning II

Licensing

‘Mise en Service’

Tritium Plant

‘Authorization for T in Plant’

T into Plant

Tokamak

‘Authorization for T in Tokamak’

Tritium Plant and Supporting systems

Commiss. w/o T

Commissioning T

Performance extension

DT-1

H, H+T, D

FPO-1

D, DT >100MW ~50s

FPO-2

D, DT Q=10 500MW ~50s

FPO-3

D, DT Q=10 500MW ≥300s

FPO-4

D, DT Q=10 500MW ≥500s 250MW ≥300s high duty

FPO-5

DT-2

Shutdown

FPO-6

FPO-7

TBM Program

TBM DT-1 Program

TBM DT-2 Program

‘Authorization for Operation of Nuclear Installation (D plasmas)’ = ‘Mise en Service (D plasmas)’

‘SNO’ = ‘Start of Nuclear Operation’

Objectives and Research Plan for Start of Research Operation

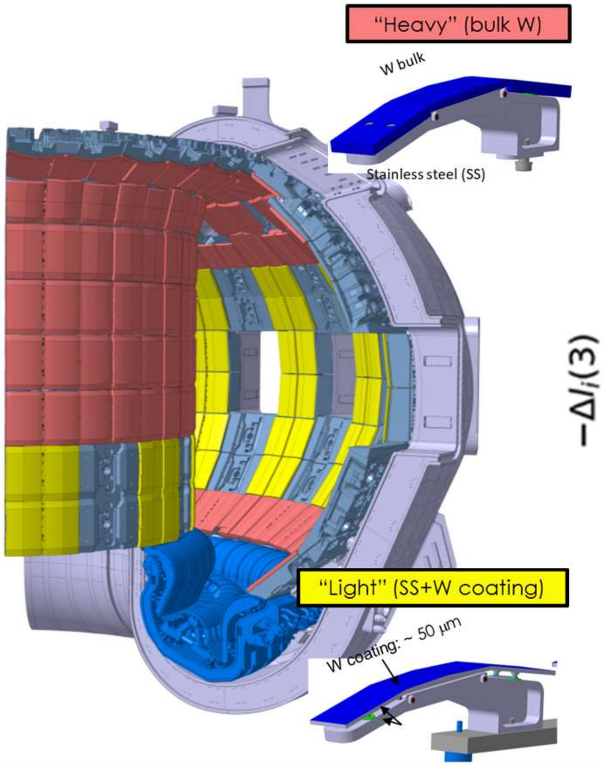
Objectives for SRO

(Start of Research Operation = Start of Research Operation Programme)

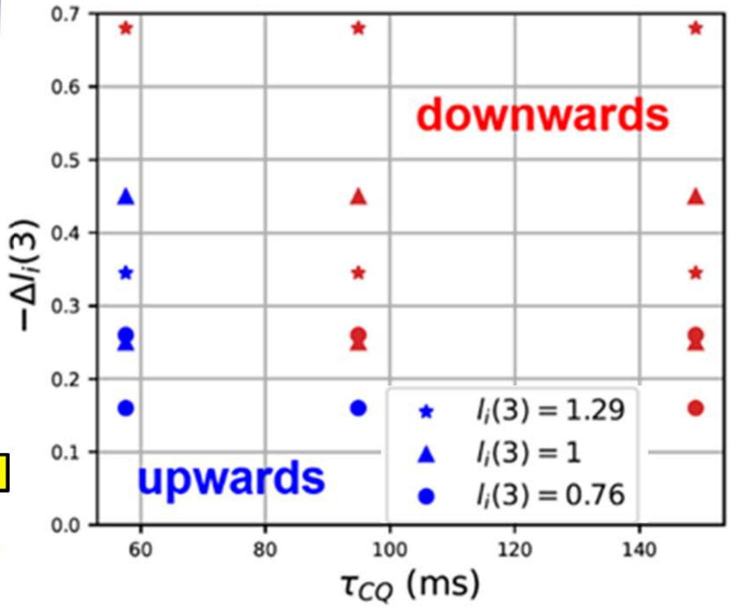
- **Demonstration of capability to operate plasma scenarios up to 15 MA/5.3 T → Full Magnetic Energy operation**
- **Exploration of the H-mode operational space up to 7.5 MA/2.65 T in deuterium plasmas**
- **Commissioning of H&CD (ECH and ICH) systems up to nominal power levels ~ 50s**
- **Identification and optimization of error field correction due to machine assembly and intrinsic non-toroidally symmetric features of ITER's design**
- **Characterization of disruption loads (~ 15 MA/5.3 T) → in-vessel component verification**
- **Demonstration of effective disruption mitigation up to 15 MA/5.3 T**
- **Demonstration of required divertor and first-wall protection and core impurity control methods necessary for high-performance H-mode scenarios in DT-1**

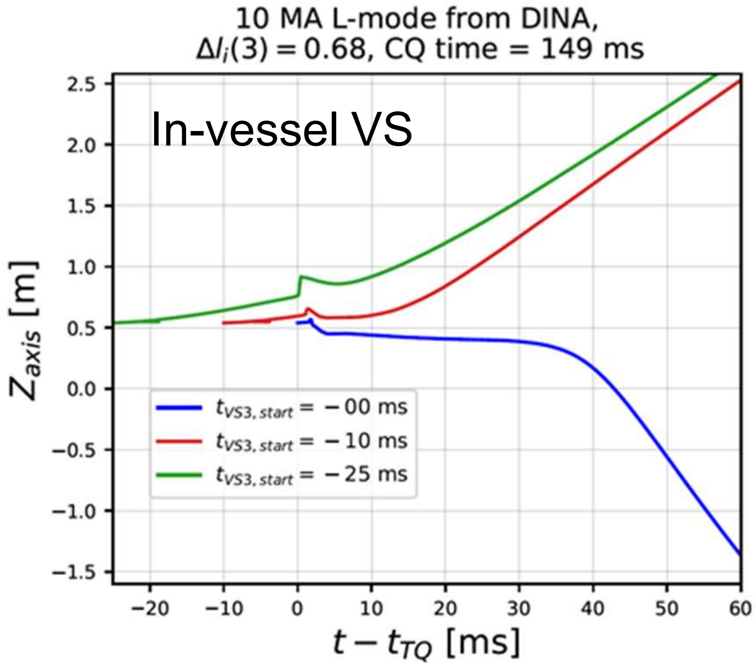
Inertially cooled wall for start of operation (not for DT)

Commissioning of control, protection and disruption mitigation system with lower risks



J. Artola - JOREK

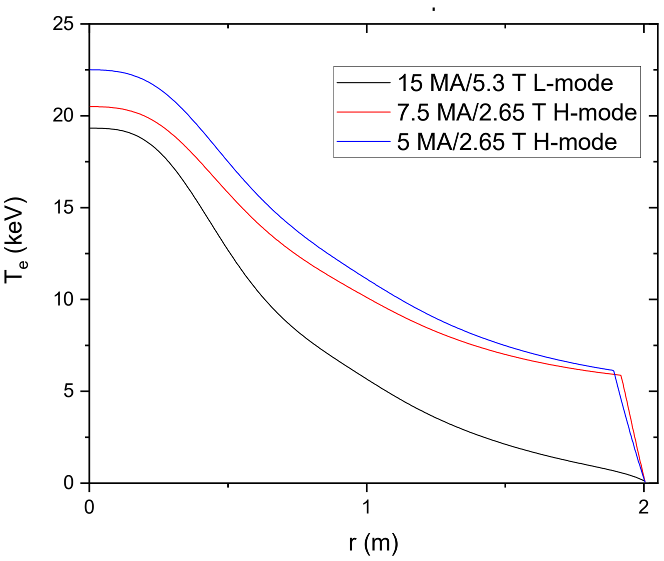


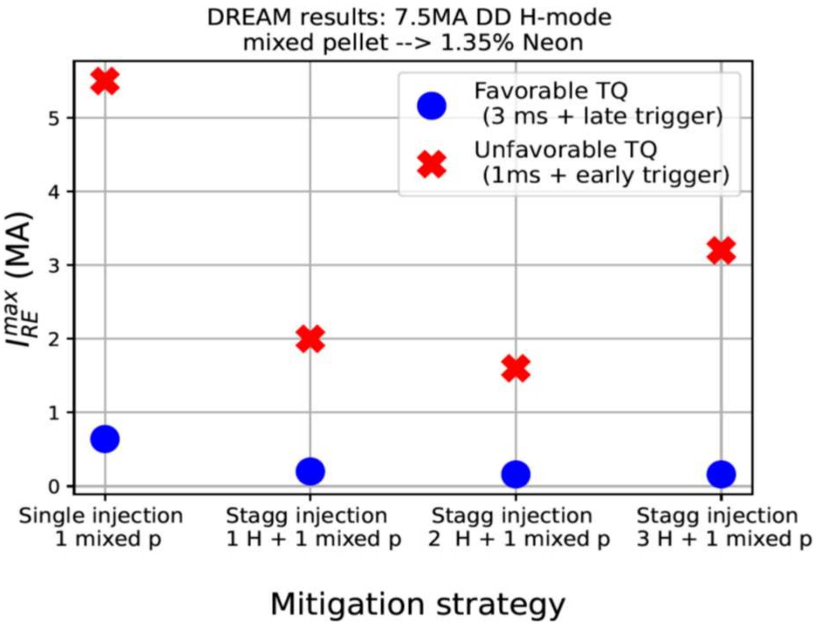


Disruption Risk Mitigation/Retirement in SRO

❑ **Effective risk mitigation by DMS commissioning with inertially cooled W PFCs requires approaching <u>as far as possible</u> DT conditions → many <u>but not all</u> risks retired in SRO**

Disruption Phase	CQ	TQ	RE Hot tail	RE β decay (T)	RE Compton e^-
DT	15 MA	350 MJ	10-20 keV	Y	Y
SRO	15 MA	60 MJ	10-20 keV	N	N

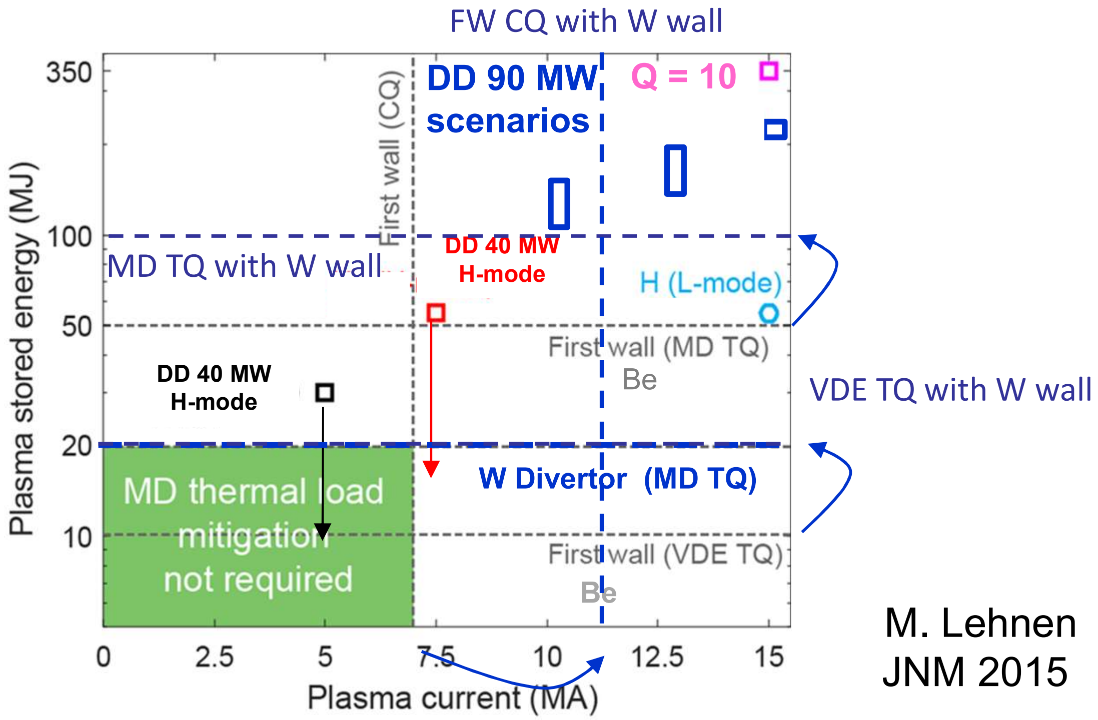




I. Pustzai
EPS 2023

Optimization of disruption mitigation strategy with W wall ?

- **W wall provides a wider operation range without melting during disruptions**



M. Lehnen
JNM 2015

- **Need for E_{rad} ~ 100% W_{plasma} with high symmetry for effective mitigation can be relaxed → better options for simultaneous mitigation of TQ, CQ and RE ?**

Objectives and Research Plan for 1st Deuterium Tritium Phase

Objectives for DT-1

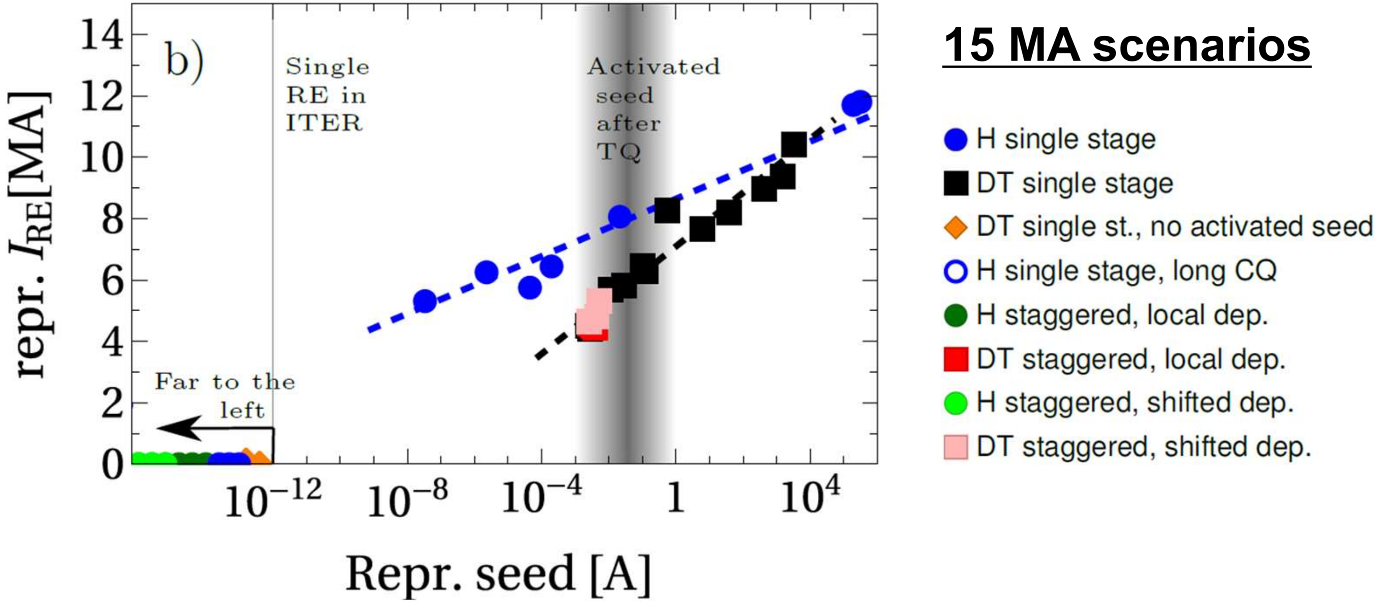
- Reproducible operation with fusion power of 500 MW $Q \geq 10$, $t_{burn} \geq 300s$
- Demonstration of high duty operation with fusion power of 250 MW $t_{burn} \geq 300s$
- Qualification of tokamak components/systems in $Q \geq 10$ operation, including assessment of neutron effects and nuclear heating (diagnostic and superconducting coils)
- Characterization of burning plasmas physics and associated control and load mitigation challenges in nominal $Q \geq 10$ operation
- Demonstration of in-vessel tritium management, measurement of dust production rates, etc., in nominal $Q \geq 10$ operation
- Operation of TBMs with $Q \geq 10$ and in high-duty operation with $P_{fusion} = 250$ MW

Start of DT-1 H + H+T phase

- ➢ **In DT-1 machine configuration will be near final (inc. water cooled wall) → important to retire disruption risks asap**
- ➢ **Operation starts in H and moves to H+T to retire T-β seed RE risk**
- ➢ **ITER SPI simulations with DREAM (1D) predict avalanche gain**

$$\log_{10}\left(\frac{I_{\mathrm{RE}}}{I_{\mathrm{seed}}}\right) = \boldsymbol{\alpha}_{av} I_p$$

$$\boxed{\boldsymbol{\alpha}_{av} \in [\mathbf{0.7}, \mathbf{1.4}]\ \mathbf{MA}^{-1}}$$

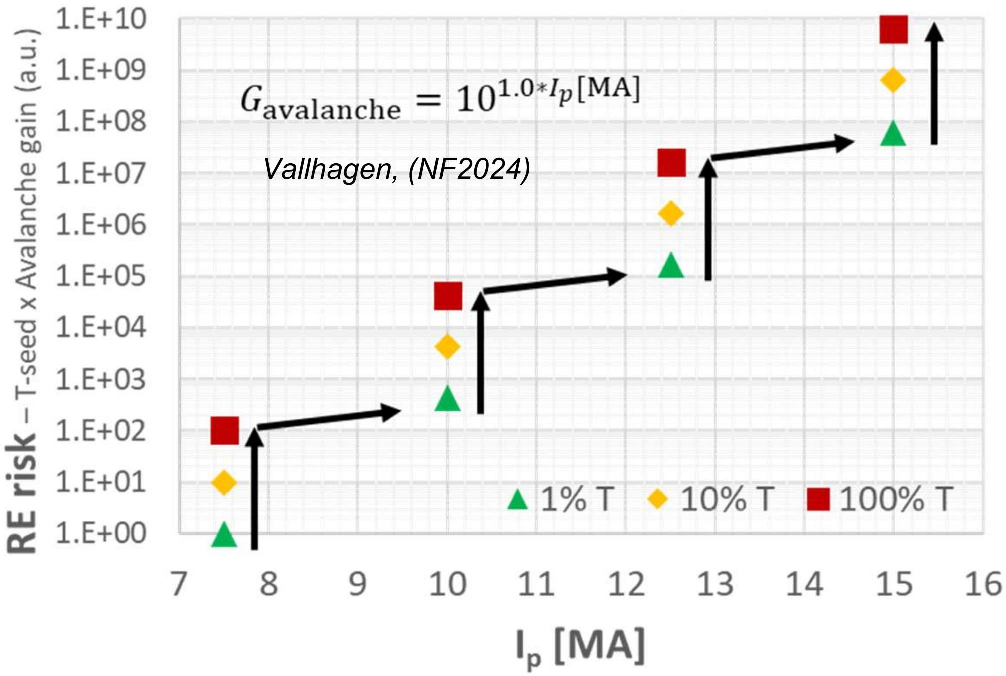


[Vallhagen, *NF*, 2024]

- ➢ **7.5 MA T-plasmas should not lead to large I_{RE} (< 100 kA)**

Disruption Risk Mitigation/Retirement in DT-1

- Mitigation demonstrated to 15 MA/5. 3T in SRO (incl. hot tail at 20 keV)
- T-beta decay and e-Compton effects assessed gradually and asap in DT-1 → T in H (FPO-1) and gradual build-up of P_{fusion} (FPO-2+FPO-3)



Strategy (H + T)

- Start from conditions with low RE risk

  7.5 MA T-plasmas → I_{RE} (< 100 kA)

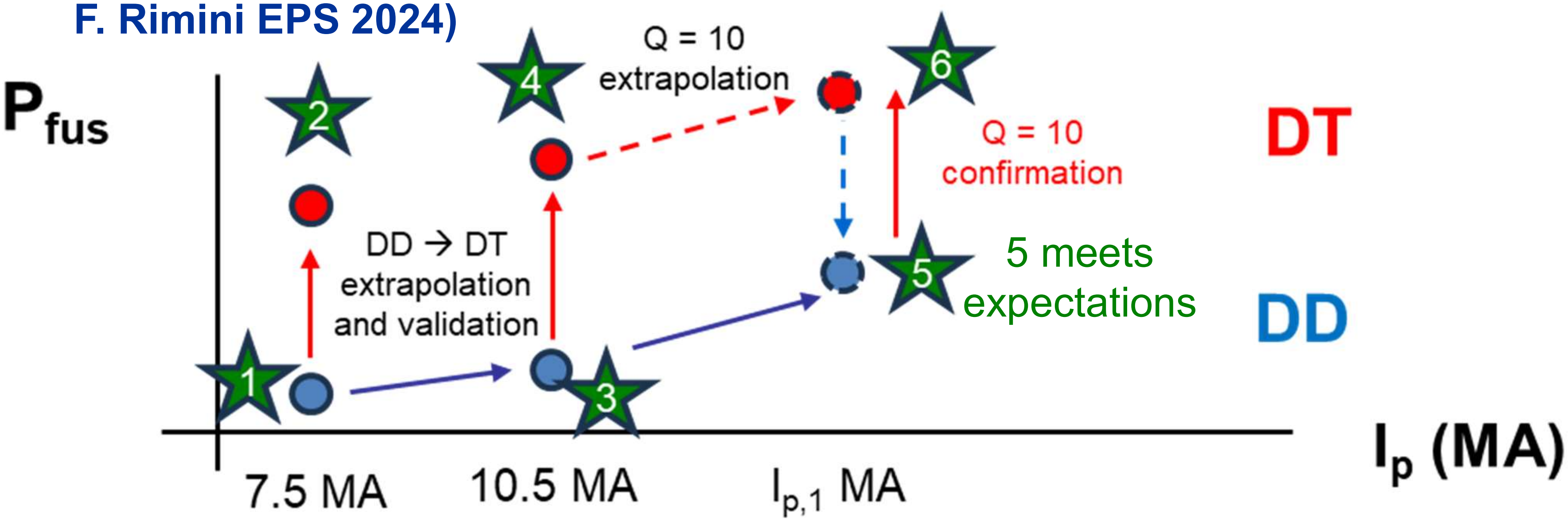
- Demonstrate disruption + RE mitigation or avoidance at given %T and I_p
- Increase %T and I_p to ensure overlap of

  $RE_{T\text{-}seed} \times G_{avalanche}$

  In successive steps

Strategy to increase W_{plasma} and P_{fusion} interleaving DD and DT

- **Minimize use of neutron fluence to develop 50-50 DT H-mode by interleaving D and D + T (< 50%) → gradual build-up of disruption-related T-effects**
- **Validate plasma models/demonstrate mitigation at lower I_p, %T ←→ predict next step and repeat**
  - **Strategy used successfully in JET DTE-2 (J. Garcia NF 2023, C.F. Maggi NF 2024, F. Rimini EPS 2024)**



Conclusions

- **Repair of Vacuum Vessel Sector and Thermal Shields is proceeding well → re-start of sector assembly to start in the next ~ month**
- **New baseline provides robust way to achievement of ITER' goals including:**
  - **Realistic & reliable assembly - commissioning – operation**
  - **Stepwise Safety Demonstration (DT-1 & DT-2)**
- **ITER Research Plan has been developed jointly with Members' experts**
  - **Self-consistent goals, machine configuration and operational strategies for risk mitigation/retirement, especially disruptions and their mitigation**
  - **Based on state of the art experimental/modelling/theorical plasma physics**
- **Details of Research Plan will change as R&D on open issues advances**
- **Validation of models and tools to predict ITER plasma behaviour and planning of experiments in essential for efficient implementation of Research Plan**

Support by Members' fusion researchers is essential for ITER's success

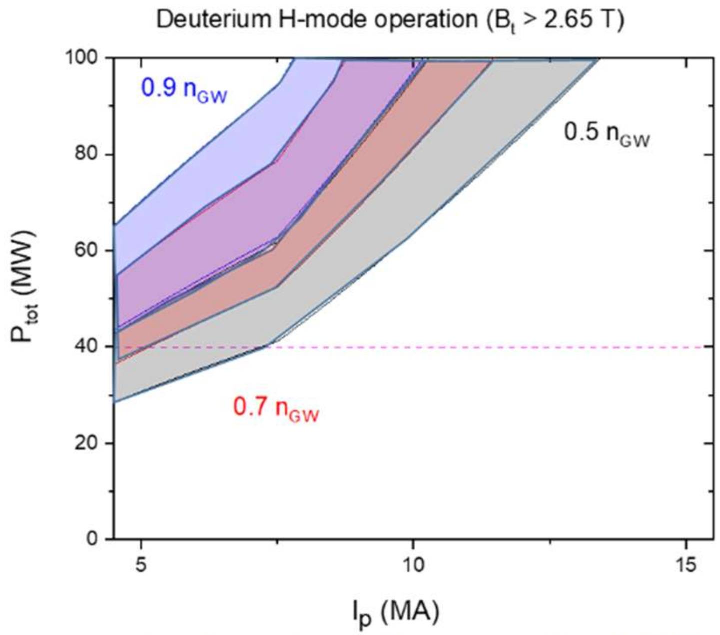
Thank you for your attention !

china eu india japan korea russia usa

Additional Material

Key Elements of the New Baseline - III

Increase in H&CD installed power and change of power mix



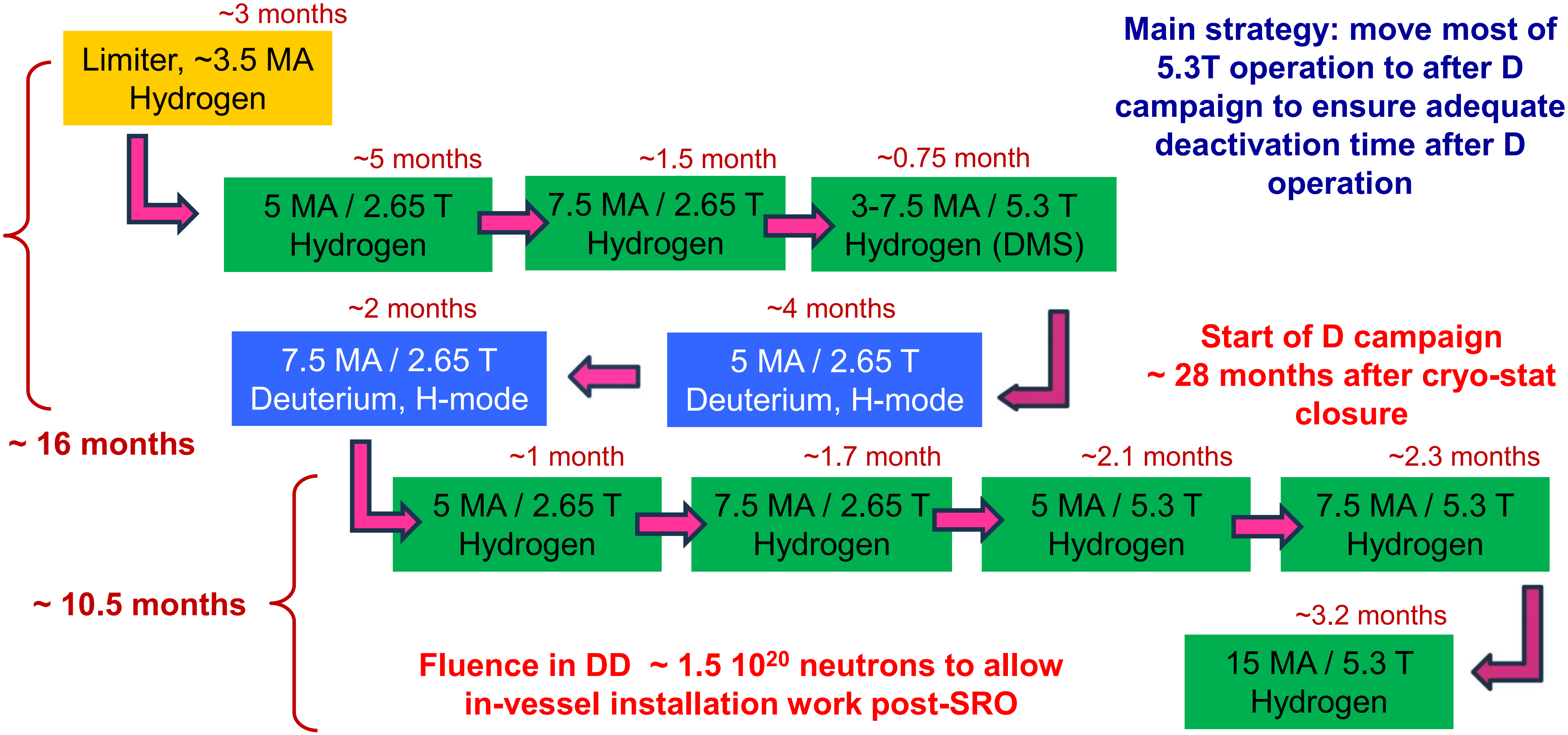
H-mode operational space

$$0.25 \leq P_{rad}^{core}/P_{tot} \leq 0.5$$

$$P_{sep} \geq 1.5\ P_{LH}$$

- ☐ Larger P_{input}/P_{LH} margin for development of DD (and later DT) H-mode plasmas → Robust scenarios for low fluence development of Q = 10
- ☐ PFCs can be tested to ~ Q = 10 edge power flux levels before DT
- ☐ Mix optimized to minimize W-wall risks (ICH W production minimized by antenna design)

Overall Plan for SRO (incl. FP demonstration)



~3 months

Limiter, ~3.5 MA
Hydrogen

~5 months

5 MA / 2.65 T
Hydrogen

~1.5 month

7.5 MA / 2.65 T
Hydrogen

~0.75 month

3-7.5 MA / 5.3 T
Hydrogen (DMS)

Main strategy: move most of 5.3T operation to after D campaign to ensure adequate deactivation time after D operation

~4 months

5 MA / 2.65 T
Deuterium, H-mode

~2 months

7.5 MA / 2.65 T
Deuterium, H-mode

~ 16 months

Start of D campaign ~ 28 months after cryo-stat closure

~1 month

5 MA / 2.65 T
Hydrogen

~1.7 month

7.5 MA / 2.65 T
Hydrogen

~2.1 months

5 MA / 5.3 T
Hydrogen

~2.3 months

7.5 MA / 5.3 T
Hydrogen

~3.2 months

15 MA / 5.3 T
Hydrogen

~ 10.5 months

Fluence in DD ~ 1.5 10^{20} neutrons to allow in-vessel installation work post-SRO

Overall Plan for DT-1 - I

Fluence in DT-1 limited to ~ 3 10^{25} neutrons (~ 1% of final DT-2 goal)

FPO-1

~ 11 months
Commissioning
15 MA/5.3 T
H, L-mode, 50 s

→

~ 1 month
15 MA/5.3T
H+T, 50 s

→

~ 4 months
3.75 - 7.5 MA/2.65T
D, H-mode 50 s

FPO-2

($P_{fus} \geq 100MW$)

~2 months
Commissioning
H&CD $t_{HCD} \geq 600$ s

~0.7 month
5.0-7.5 MA/5.3T
D, 50 s

→

~2.5 months
7.5 MA/5.3T
DT, 50 s

→

~2.5 months
10 MA/2.65T
D, 50 s

→

~ 8.3 months
10 MA/5.3T
DT, 50s

FPO-3

($P_{fus} = 500MW$)

~2 months
Commissioning
H&CD $t_{HCD} \geq 600$ s

→

~2.5-5 months
$I_{p1} – I_{p2}$/5.3T
D, 50 s

→

~ 8.5 months
I_{p2}/5.3T
DT, 50s

- **Q ≥ 10 P_{fusion} = 500 MW t_{burn} = 50 s**
- **First attempt to Q = 10 t_{burn} > 50 s**

Overall Plan for DT-1 - II

FPO-4

(P_{fus} = 500MW)

~2 months

Commissioning
H&CD $t_{HCD} \geq 600$ s

~3 months

I_{p2}/5.3T
D, 300s, 1st
scheme (active)

~ 1.5 months

I_{p2}/5.3T
DT, 300s, 1st
scheme (active)

~3 months

I_{p2}/5.3T
D, 300s, 2nd
scheme (passive)

~ 1.5 months

I_{p2}/5.3T
DT, 300s, 2nd
scheme (passive)

~3 months

I_{p2}/5.3T
D, 300s, 3rd
scheme (passive)

~ 1.5 months

I_{p2}/5.3T
DT, 300s, 3rd
scheme (passive)

- **First Q ≥ 10 P_{fusion} = 500 MW $t_{burn} \geq 300$s**

FPO-5

(P_{fus} = 500MW)

~2 months

Commissioning
H&CD $t_{HCD} \geq 1000$ s

~ 1 month

I_{p2}/5.3T
DT, 300s, Q ≥ 10
reproducible
operation

~ 2 months

I_{px}/5.3T
D, 300s, high duty
operation

~ few days

I_{px}/5.3T
DT, 300s, P_{fusion} =
250 MW, high duty

~ 1 month

I_{p2}/5.3T
DT, Q ≥ 10 tburn = 300-500 s

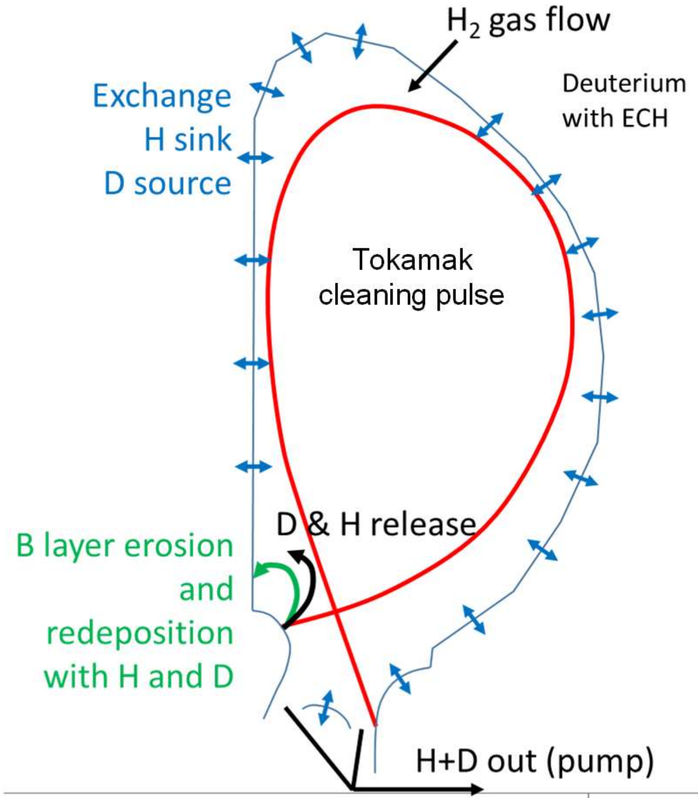
~ 10 months

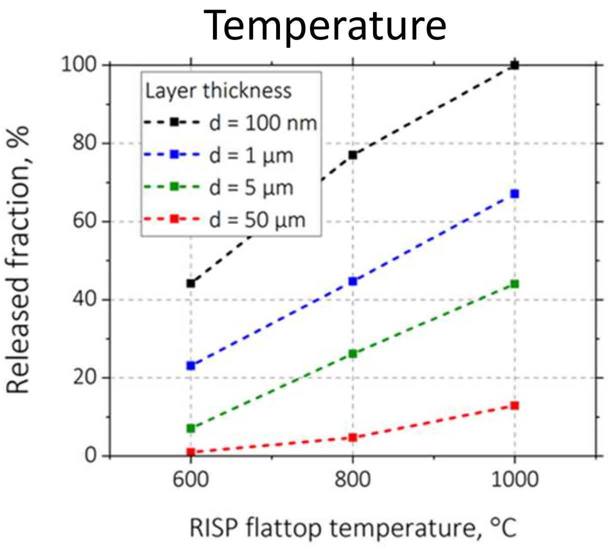
Time reserved to complete DT-1
objectives if difficulties arise

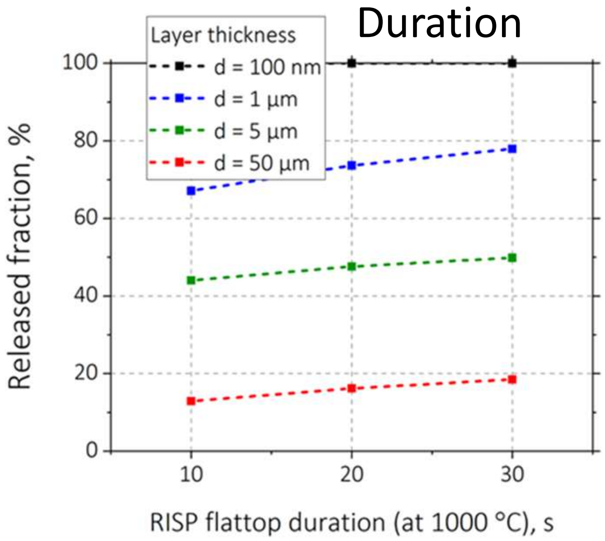
- **Reproducible Q ≥ 10 P_{fusion} = 500 MW $t_{burn} \geq 300$s**
- **High duty operation with P_{fusion} = 250 MW**

D retention and removal in SRO

- H → D → H measurement of retention (in B) and efficiency of removal strategy
- Removal ~ JET DTE -1 : Raised inner Strike Point + Ion Cyclotron Wall Conditioning





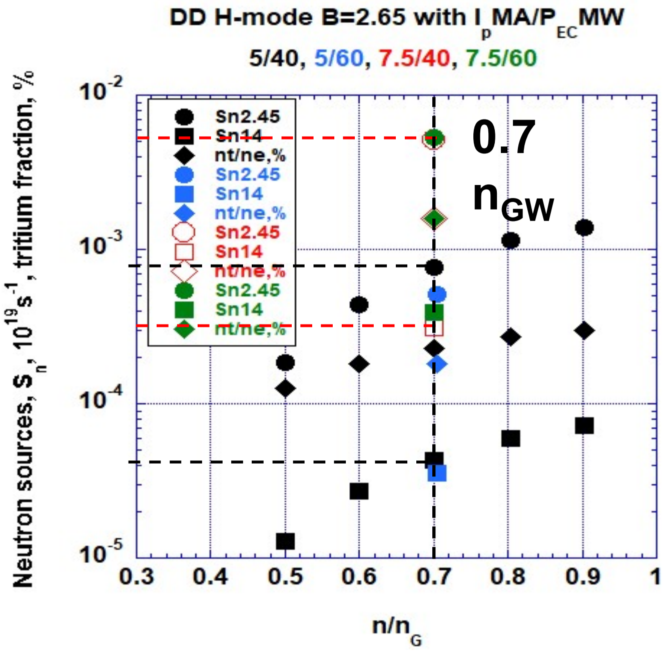


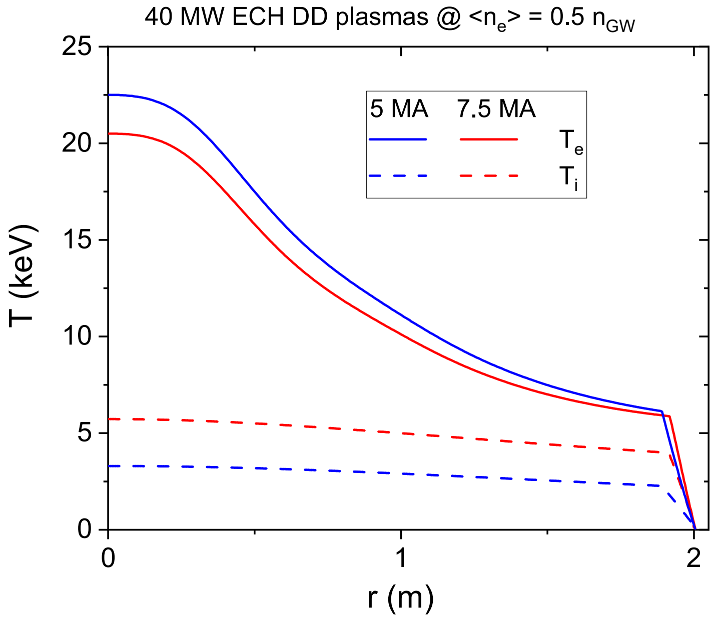
D. Matveev, ISFN

P_{ICWC} ≤ 2.5 MW coupled to plasma
Access to main chamber recessed areas by charge exchange neutrals

Neutron production in SRO D campaign

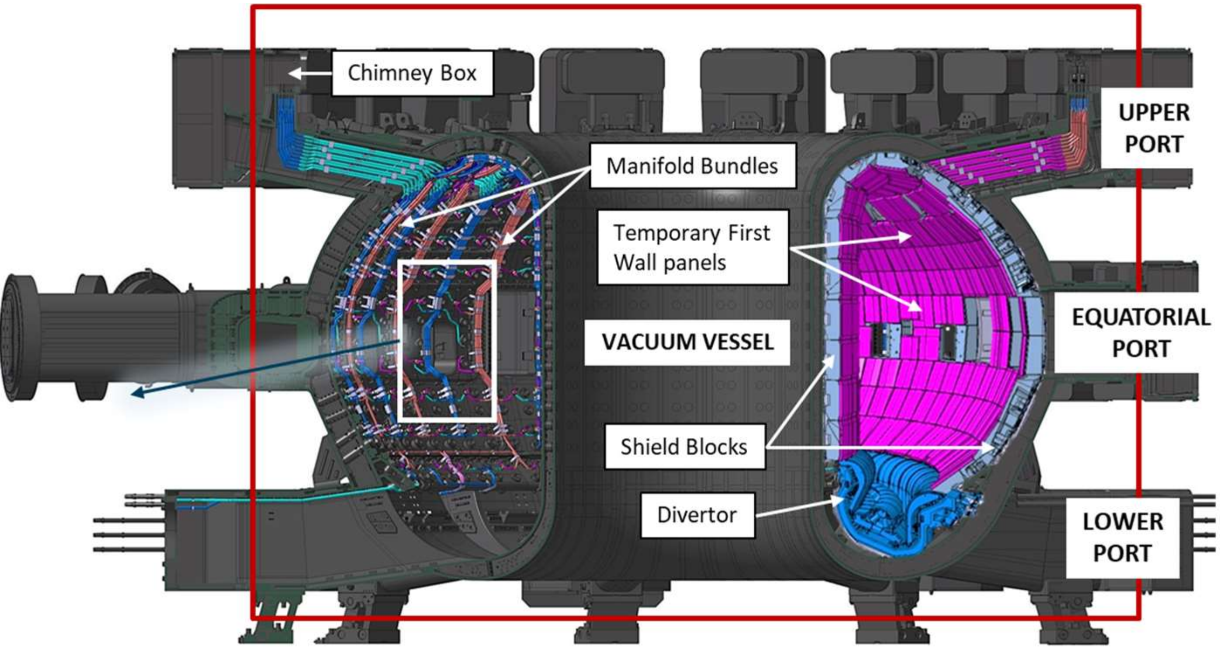
Total neutron budget to allow post-SRO water cooled in-vessel human access : 1.5 10^{20} n





- **@ 0.5 - 0.7 n_{GW} → Total fluence consumed in 375 – 1500 pulses of 50 s at 5 MA**
- **About 6 times more neutron produced at 7.5MA/2.65T (○+□) than at 5MA/2.65T (○+□)**
- **Planning and execution of experiments with high D neutron production needs to be effective to achieve scientific goals → good training for DT-1**

Machine and ancillaries’ configuration for SRO



Full Magnetic Diagnostics

Partial Neutron Diagnostics

Partial Composition Diagnostics

Partial Temp. & Density Diagnostics

Partial Machine Protection

55.A0 Magnetic diagnostic	
55.A1 Continuous External Rogowski	
55.A3/A4/A9 Outer Vessel Coils	
55.A5/A6 Steady State Sensors	
55.A7/AD/AE/AF/AH/AI Flux Loops	
55.A8 Fiber Optic Current Sensors	
55.AA/AB/AC/AG/AJ In vessel pickup coils	
55.AL Divertor Equilibrium Coils	
55.AM Divertor Shunts	
55.AN Rogowskis (Divertor)	
55.AO Toroidal Coils (Divertor)	
55.AP Rogowskis (Blanket)	
55.AQ Plasma Current Monitor	
55.B8 Neutron Activation System	
55.BC Divertor Neutron Flux Monitors	
55.BV In Vessel Neutron Calibration	
55.C1 Thomson Scattering (Core)	
55.C2Thomson Scattering (Edge)	
55.C5 Toroidal Interferometer/Polarimeter	(partial)
55.D1 Bolometry System	(partial)
55.E* Mirror cleaning test	
55.E2: H-alpha (+ visible spectroscopy)	
55.E3 Vacuum UltraViole Survey	
55.E4: Impurity Influx Monitor (Div. Vis/UV))	(partial)
55.E5 X-ray Crystal Spectrometer (core high-resolution)	
55.E6 Visible Spectroscopy Reference System	
55.E7 Radial X-Ray Camera	
55.ED X-Ray Crystal Spec Survey	
55.EE Hard X-ray	
55.EG Divertor VUV Spectroscopy	
55.EH Vacuum UltraViolet Edge	
55.F1 Electron Cyclotron Emission	
55.F2 Reflectometry LFS	
55.F9 Reflectometry HFS	
55.FA Density interferometer Polarimeter	(partial)
55.G1 IR Cameras, Vis/IR TV (Midplane)	(partial)
55.G2 Thermocouple Outer Target	
55.G3 Pressure Gauges	(partial)
55.G4 Residual Gas Analyzers	(partial)
55.G6 IR Thermography (divertor)	
55.G7 Langmuir Probes	
55.G9 Dust monitor	
55.GA IR Cameras, Vis/IR TV (Upper)	(partial)
55.GB In-vessel ECH detectors	
55.GC Tritium Monitor	
55.GD FW Samples	
55.GE Boundary Imaging System	
55.GF Toroidal Field Mapping *	
55.GT Tokamak Structural Monitoring system	

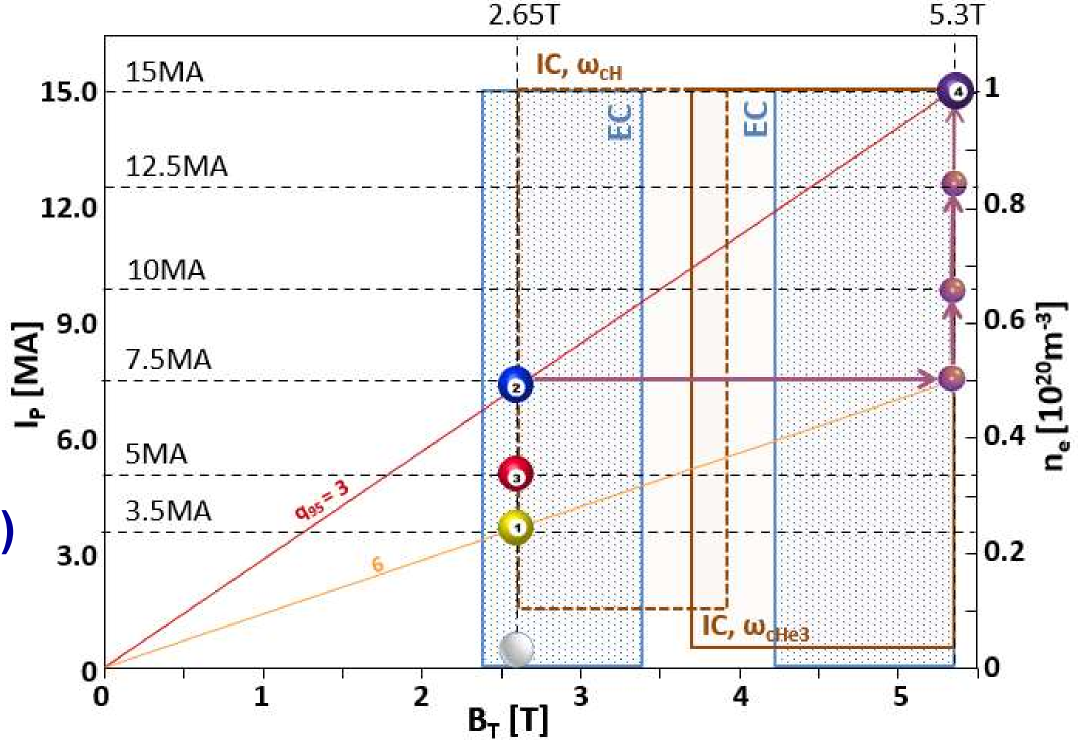
- **P_{ECH} = 40 MW (one equatorial and 3 upper launchers)**
- **P_{ICH} = 10 MW (ICH in W environment and ICWC)**
- **Disruption Mitigation System (DMS)**
- **4 pellet injectors for plasma fuelling and ELM control**
- **Complete set of in-vessel coils and PS for both VS and and ELM control coils**
- **Boronization system to deposit boron films with (partial set of) GDC anodes**

SRO - Scenario development path

Use of W wall favours B_t values that provide effective central heating → scenario development at 2.65 and 5.3 T

- **EC operation** (40 MW available):
  - 2.65T: X2 in L-mode, O2 in H-mode
  - 5.3T: O1 in flattop (with X1 in ramp-up)

- **IC operation** (10 MW available):
  - 2.65T:
    - in D: H minority at 42 MHz
    - in H: no efficient scheme
  - 5.3T:
    - in D or H: ^{3}He min. at 53 MHz (1-5%) → scheme to assess coupling, PWI, RF sources, etc.



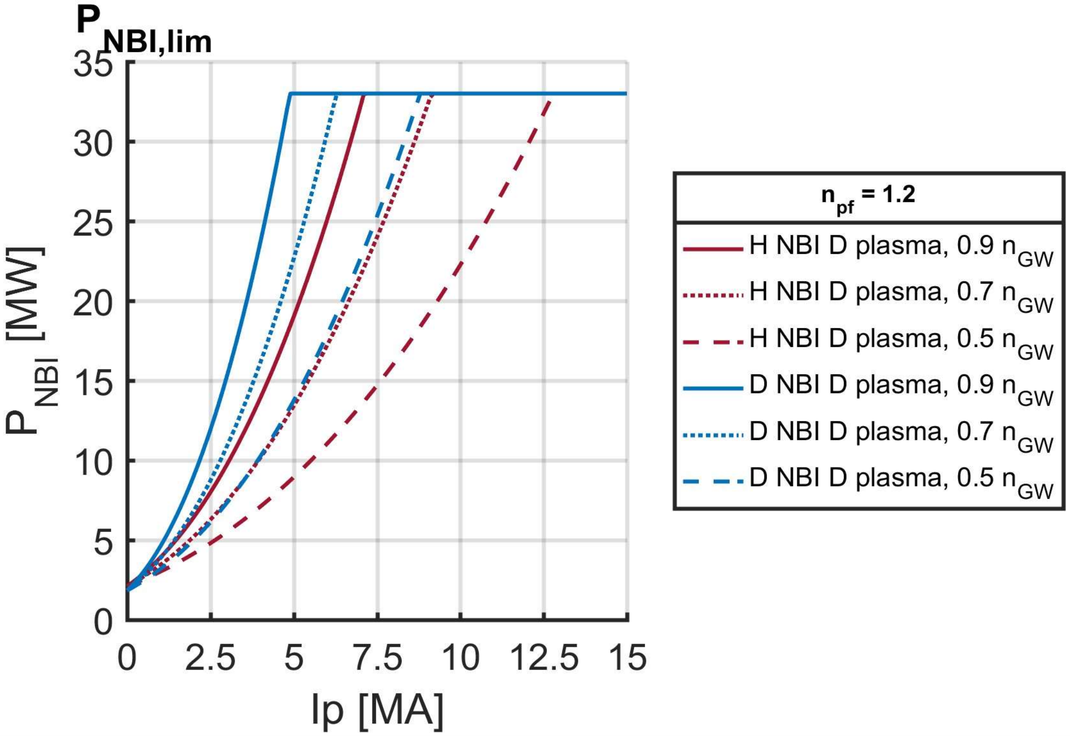
Strategy for DT-1 H-mode development to $Q \geq 10$ $t_{burn} \geq 300s$

- Develop H-mode operation in q_{95} = 3-6 range first at 2.65 T and then at 5.3 T to ensure central ECH heating (W risk minimization)
- Develop D H-mode scenarios, interleaved with DT, to minimize neutron fluence consumption
- Develop H-mode scenarios to ~ 50 s duration (burn or high $t_{HCD\text{-}max}$) first and then to 300s → earliest achievement of Q = 10 short pulse
- Re-tune disruption mitigation at every I_p step to account for increasing W_{plasma} and T-related effects
- Account for operational risks impacting PFC lifetime in development
- Include operational time (2 days/2 weeks) for T removal every 2 weeks of operation and maintain low T ~ (<1%) in D plasmas
- Maintain NBI in H in FPO-1 and consider NBI in D in FPO-2 or later if supported by NBTF R&D programme results → see P. Vincenzi I.352

H-mode operation in DD

- H-mode operation in D will be carried out with H-NBI in FPO-1 with 2.65 T
- NBI power will be limited by shine-through at low $I_p/\langle n_e \rangle$

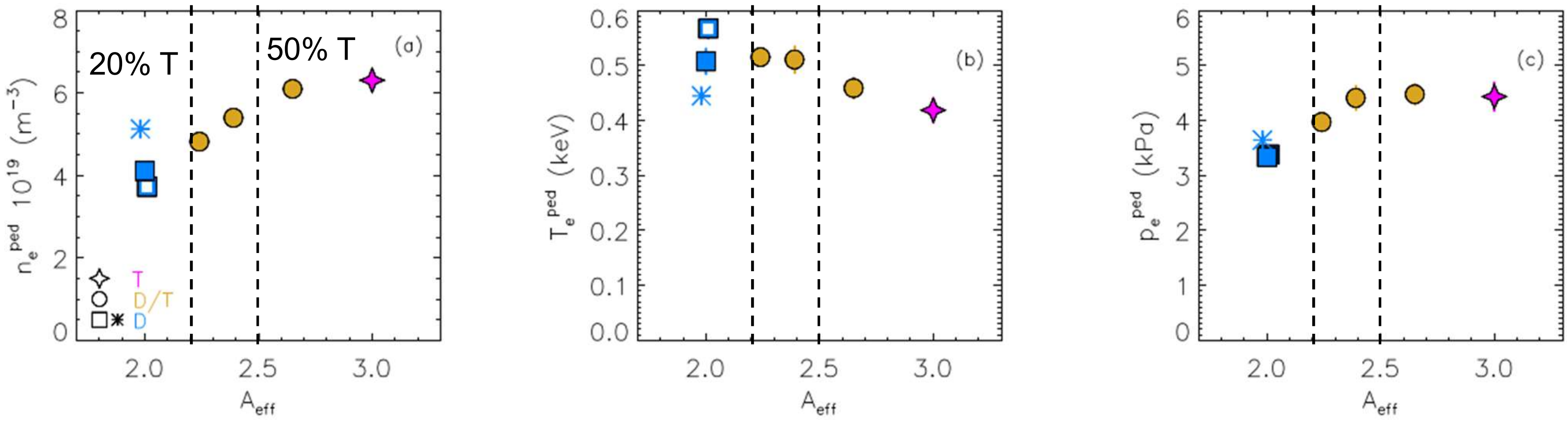
(P_{LH} ~ 13-32 MW and P_{ECH} = 60-67 MW, P_{ICH} = 10-20 MW)



Strategy to interleave DD and DT – I

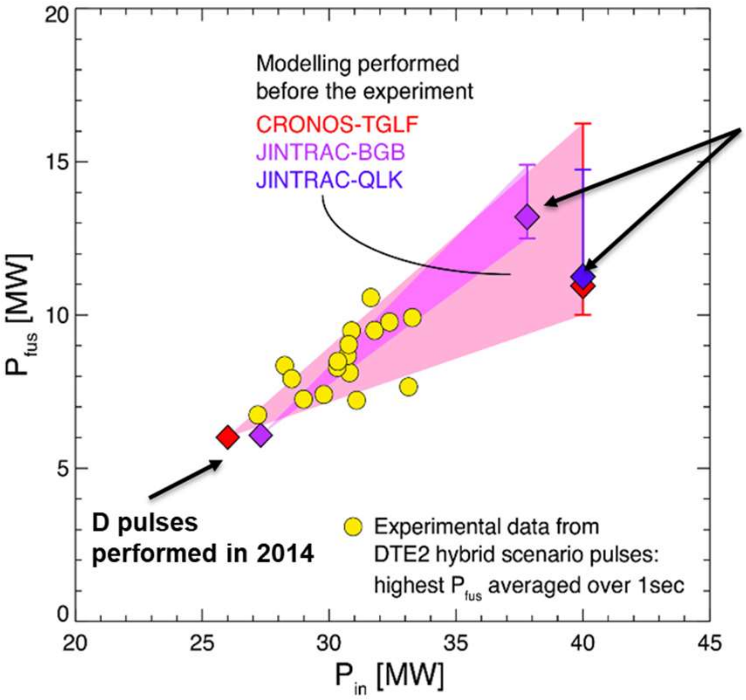
- ➢ **Minimize use of neutron fluence to develop 50-50 DT H-mode scenarios by D and D + T (< 50%) H-mode scenarios**
- **Use %T ≤ 20 as intermediate step between DD and 50-50 DT to understand/control T effects on pedestal (incl. entrance/exit to H-mode)**

JET - L. Frasinetti et al, Nucl. Fusion 63 (2023) 112009



Strategy to interleave DD and DT - II

- Use DD and DT H-modes to identify I_p level leading to Q = 10 before attempting Q = 10 in DT
- Requires experimental results and validated models (FPO-2)



D extrapolation (Eq. fusion power) and sensitivity to:

- **DT Isotope effects**
- **I_p**
- **Density**
- **Pedestal characteris.**

Main references

J Garcia et al 2017 Plasma Phys. Control. Fusion 59 014023

J. Garcia *et al* 2019 *Nucl. Fusion* **59** 086047

S. Saarelma et al, Phys. Plasmas 26, 072501 (2019)

L. Garzotti *et al* 2019 *Nucl. Fusion* **59** 076037

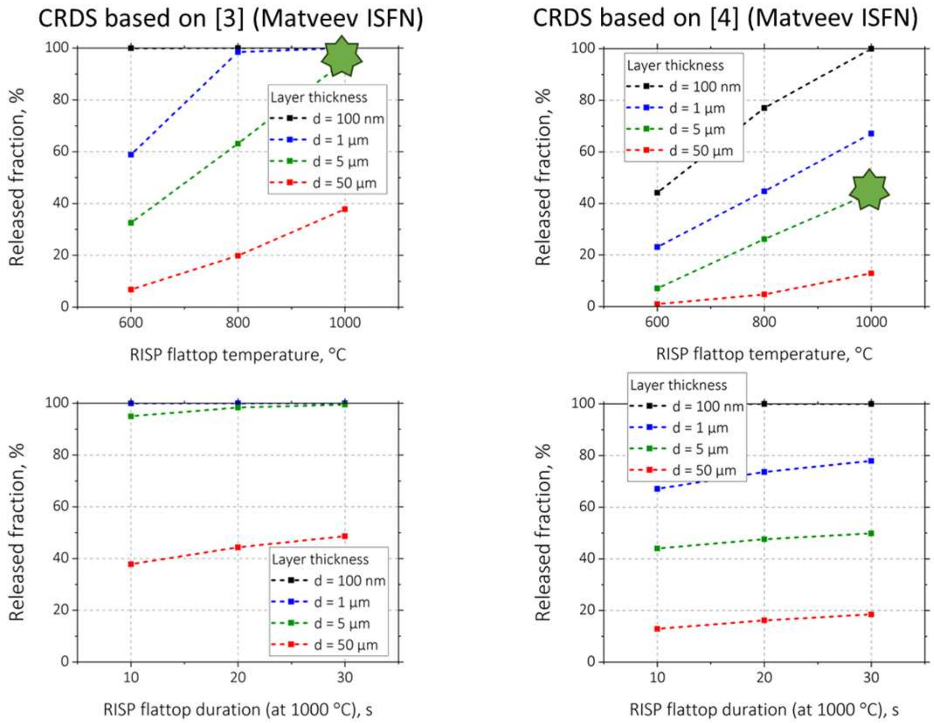
L. Garzotti et al, submitted to NF, 2024

Overview

J. Garcia *et al* 2023 *Nucl. Fusion* **63** 112003

T removal strategy

- Combination of RISP operation and ICWC expected to remove efficiently T for thin boronized deposited layers (~μm) at divertor and wall (~ 10's nm)



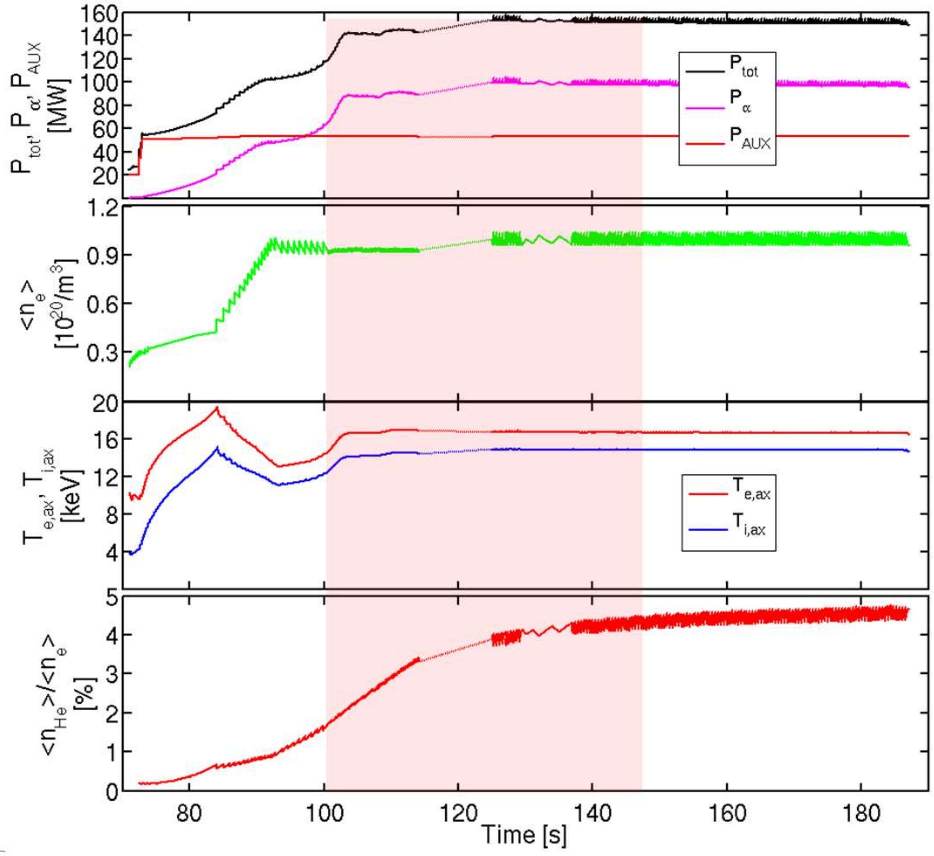
- RISP to be performed before thick B layers build-up at divertor
- ICWC cycle (20-30 mins) effectively depletes T re-implanted in near surface layers before/after RISP

→ ~ 15% of time allocated every two weeks of DT operation

Basis for ~ 50 s H-mode burn duration in Q = 10 scenario

- **Achievement of stationary plasma parameters (incl. n_{He}) except j(r)**

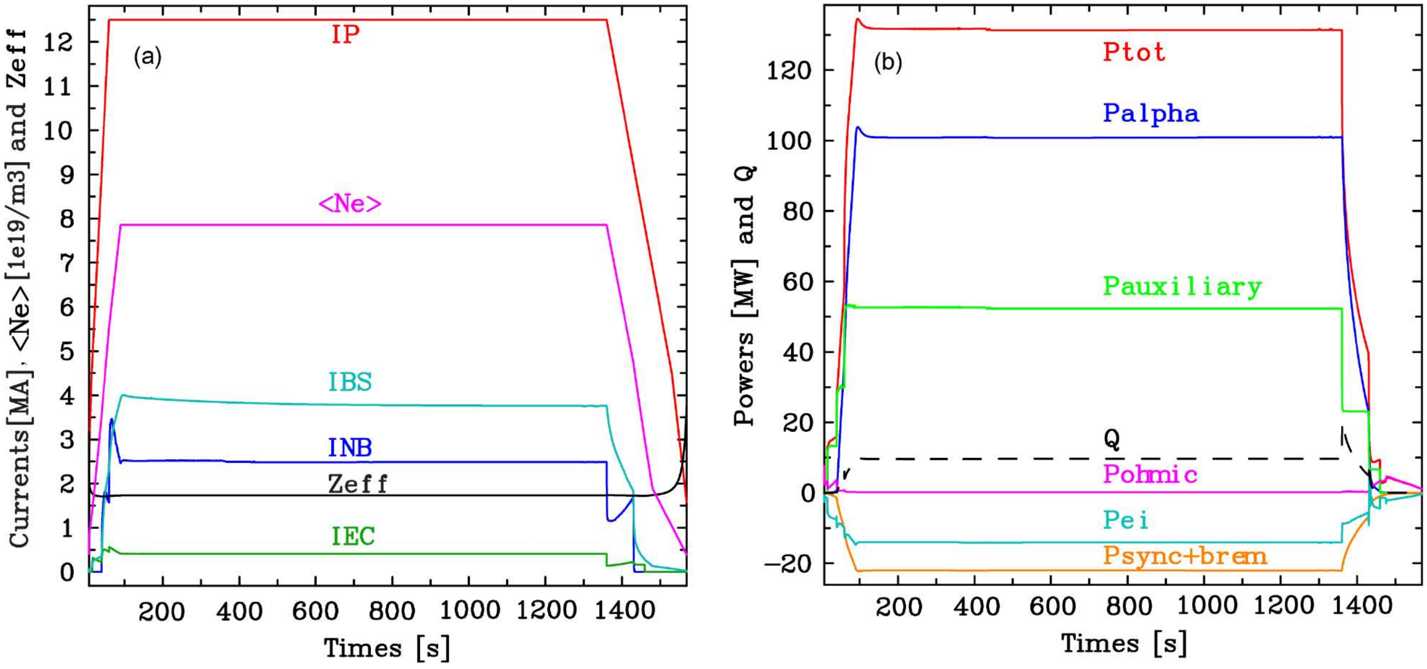
F. Köchl
NF 2020



High heating H&CD duration ~ 100 s

FPO-2 Outcome for FPO-3 (back-up)

- **$I_{p,1} \geq 12.5$ MA expected**
- **$I_{p,2}$ up to 15 MA may be required**



At EOF ($t = 1359$ s)	NB33/ EC20 (ref.)	EC40/IC20
W_{th} (MJ)	361.3	379.7
H_{98}	1.261	1.283
β_N	2.516	2.545
$l_i(3)$	0.745	0.722
$q(0)$	0.982	0.972
q_{min}	0.971	0.971
I_{BS} (MA)	3.76	3.95
I_{NB} (MA)	2.49	—
I_{EC}/I_{LH} (MA)	0.41/—	0.82/—
P_α (MW)	100.9	108.4
P_{loss} (MW)	131.4	145.8
P_{aux} (MW)	52.30	59.99
Q	9.64	8.93
$T_e(0)$ (keV)	28.71	30.31
$T_i(0)$ (keV)	29.31	30.38
$T_{e,ped}$ (keV)	3.56	3.70
Flux (Wb)	−90.22	−96.35

S.H Kim NF 2016

FPO – 1 H+T phase

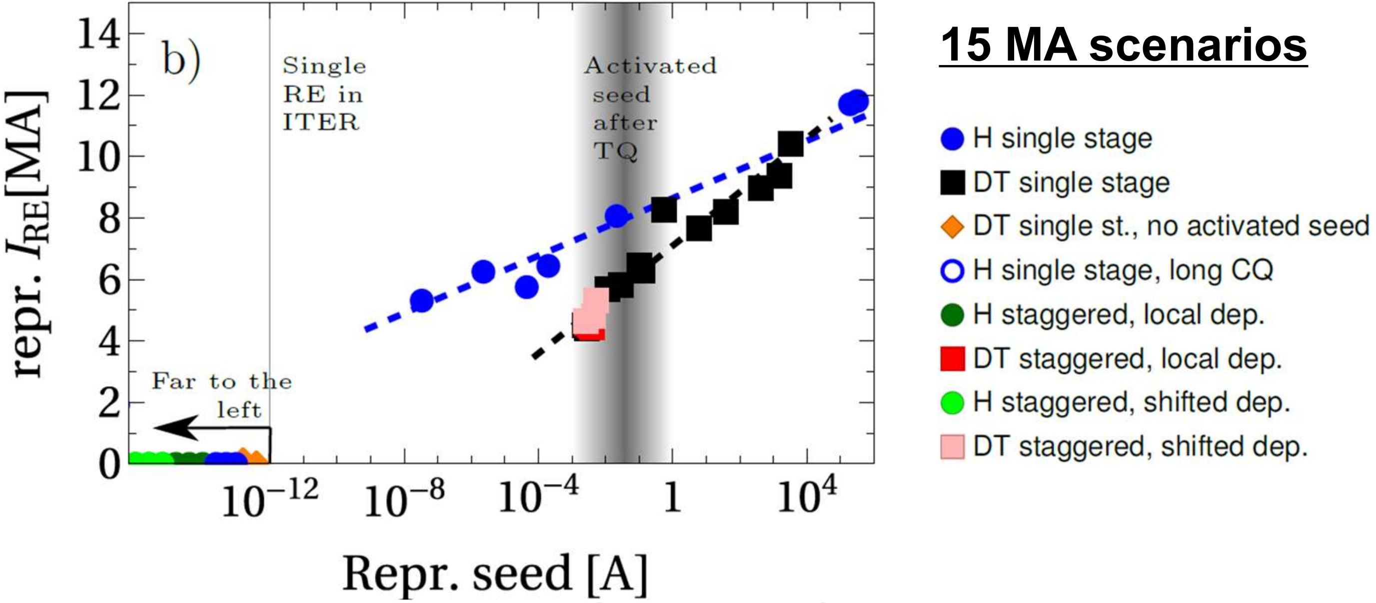
Objective 1: Retire risk of RE formation during mitigation due to RE seeds

- **ITER SPI simulations with DREAM (1D) predict avalanche gain**

[Vallhagen, *NF*, 2024]

$$\log_{10}\left(\frac{I_{\mathrm{RE}}}{I_{\mathrm{seed}}}\right) = \boldsymbol{\alpha_{av}} I_p$$

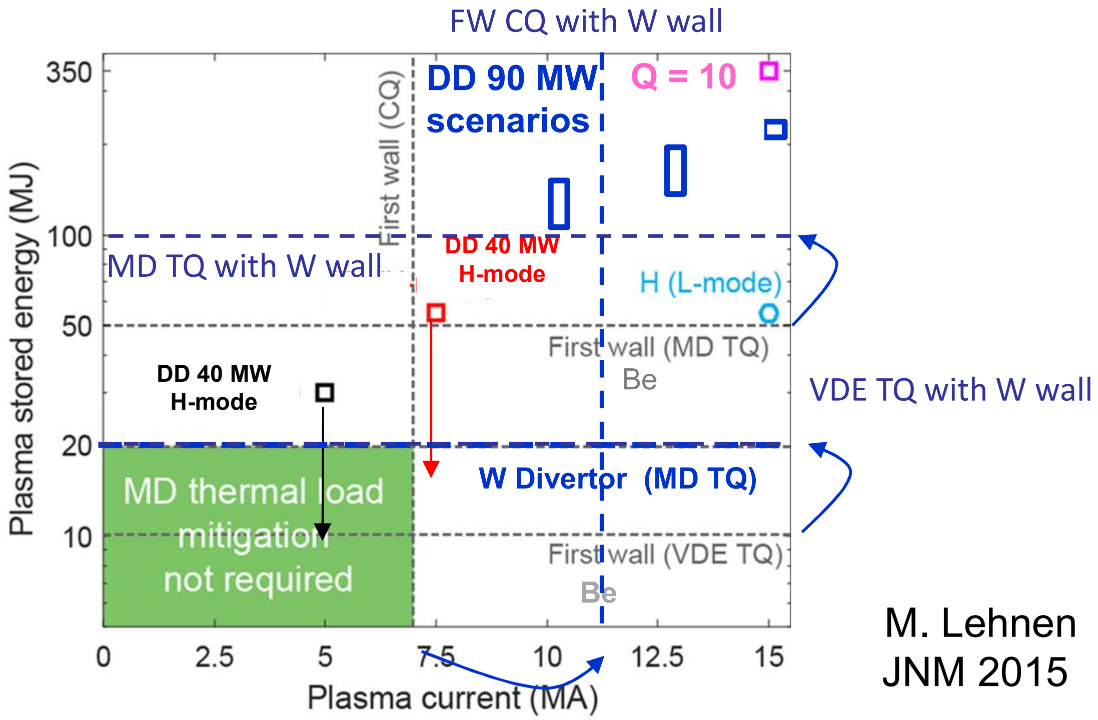
$$\boxed{\boldsymbol{\alpha_{av}} \in [\mathbf{0.7}, \mathbf{1.4}]\ \mathbf{MA^{-1}}}$$



- **7.5 MA T-plasmas should not lead to large I_{RE} (< 100 kA)**
  (mitigation without T already established in L-mode up to 15 MA in SRO and FPO-1)

Optimization of disruption mitigation strategy with W wall

- **W wall provides a wider operation range without melting during disruptions**

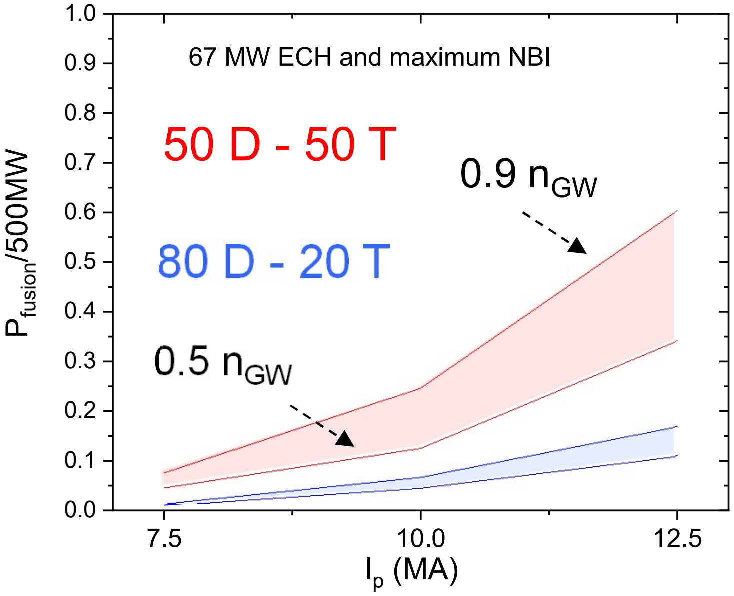


M. Lehnen
JNM 2015

- **Need for E_{rad} ~ 100% W_{plasma} with high symmetry for effective mitigation can be relaxed → better options for simultaneous mitigation of TQ, CQ and RE ?**

Neutron fluence consumption

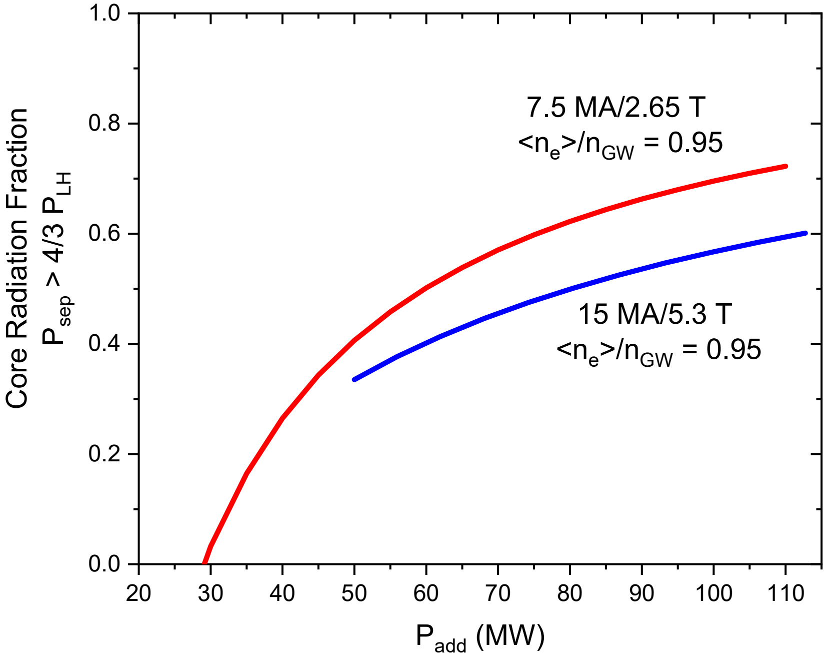
- DT-1 fluence = 3.5 10^{25} DT neutrons
- Fluence Q = 10 P_{fusion} = 500 MW 300s burn pulse ~ 6 10^{22} neutrons → 580 pulses (3.5 10^{25} DT neutrons = 660 x 300 s at P_{fusion} = 500 MW)
- Essential to perform programme without wastage of neutrons

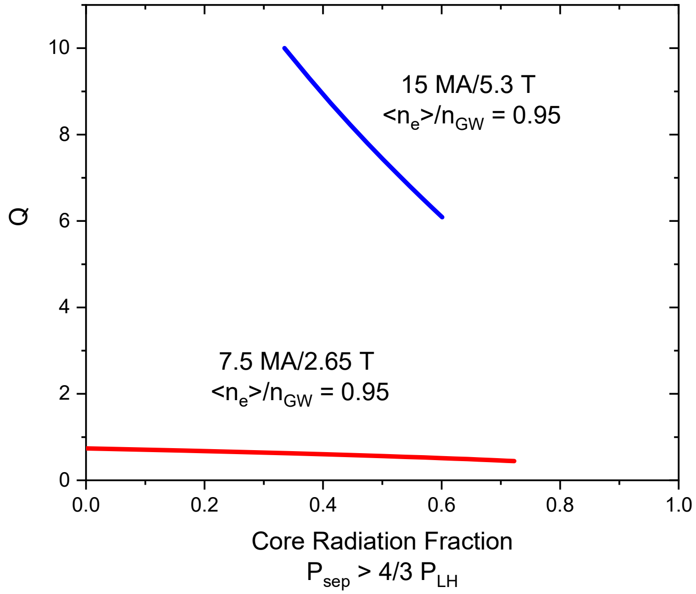


H_{98} = 1

DT-2 DEMO scenario studies - I

- **Heat exhaust studies (core+divertor exhaust) with high P_{aux}**
- **Core radiated powers of ~ 50% cand be demonstrated with Q ≥ 5 and same divertor power flow as Q = 10 → DEMO core + divertor exhaust solution**

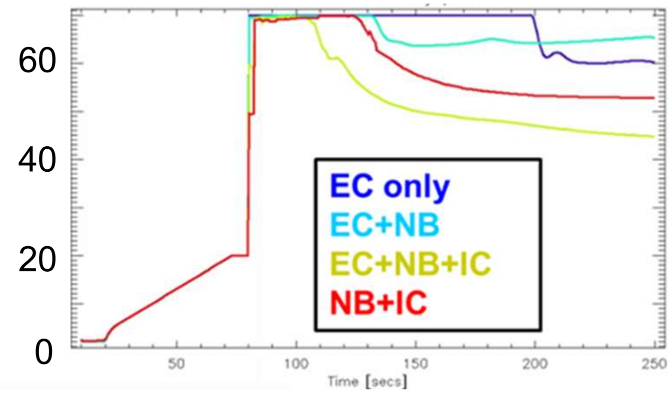




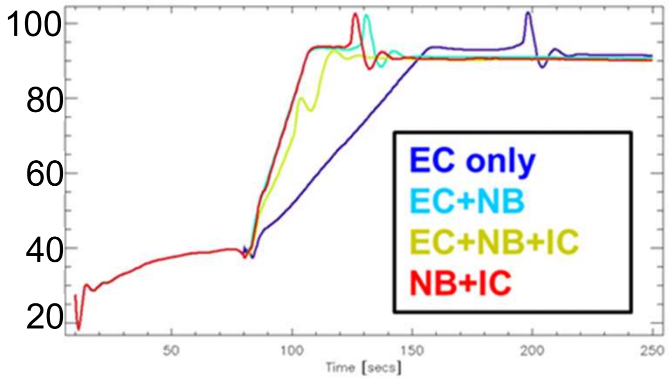
DT-2 DEMO scenario studies - II

- **H & CD studies to determine optimum H&CD for DEMO (e.g. to confirm ECH as sufficient) with Q ~ 10**

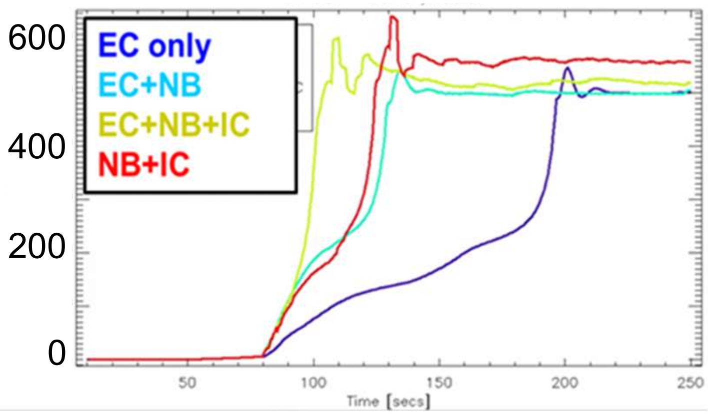
P_{aux} (MW)



n_e/n_{GW} (%)



P_{fus} (MW)



DT-2 DEMO scenario studies - III

- **DEMO-relevant plasma operation → auxiliary systems constrained to limitations coming from DEMO scope and operational capabilities**

  - **Heating and Current Drive schemes**
  - **Diagnostics**
  - **Control algorithms**
  - **Fuelling (e.g. T plant operating in direct recycling mode)**
  - **Etc.**