The ITER Disruption Mitigation Strategy

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ITER Organization

Disclaimer:

ITER is the Nuclear Facility INB no. 174. This presentation explores physics processes during the plasma operation of the tokamak when disruptions take place; nevertheless the nuclear operator is not constrained by the results presented here. The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

Outline

- Design of the Disruption Mitigation System
- Mitigation Requirements
- DMS Task Force Activities

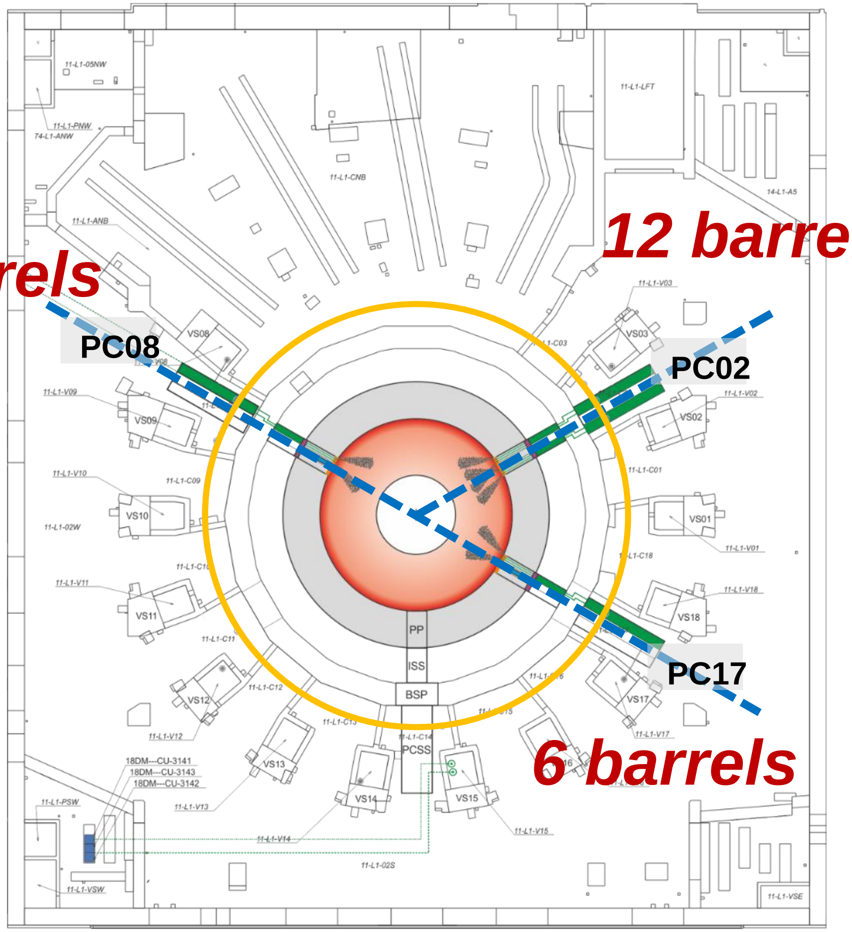
DMS port plug allocation

EP Shattered Pellet Injectors for a total of 24 pellets

Main injectors to mitigate the thermal & current quench and RE impact

Hydrogen, Neon, (Argon)
D = 28.5 mm / L = 57 mm
~10^{24} atoms / pellet

Equatorial ports



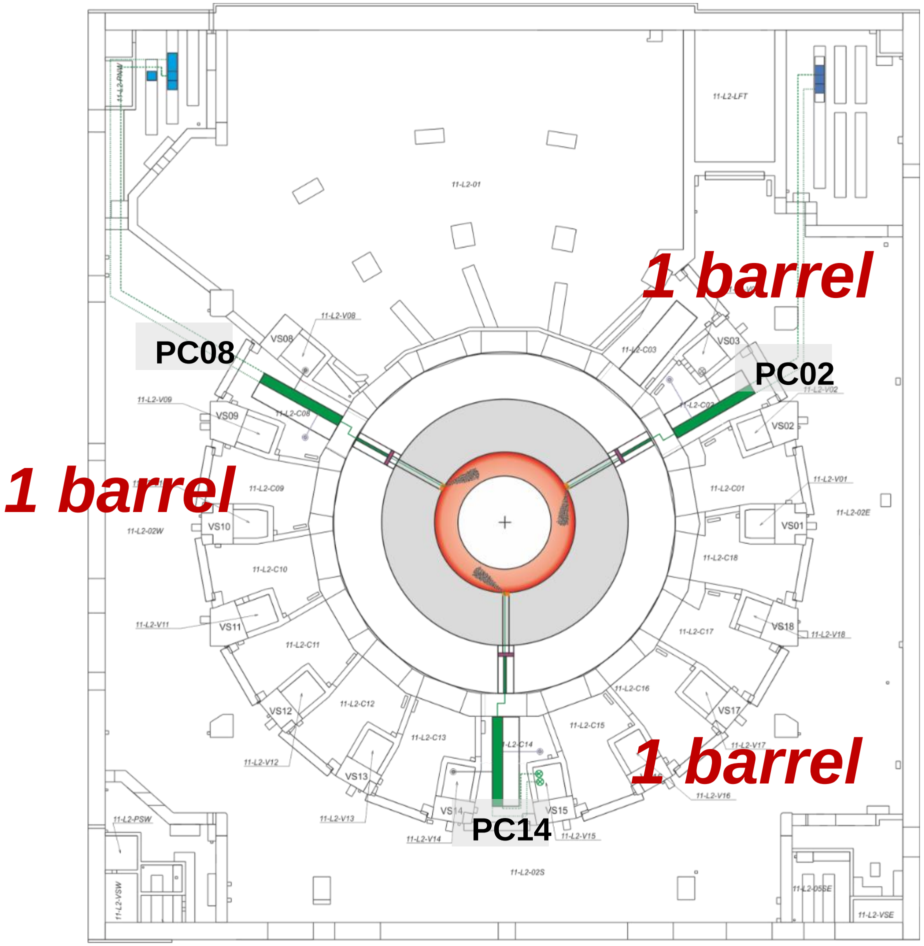
DMS port plug allocation

Upper ports equipped 3 x 1 SPI

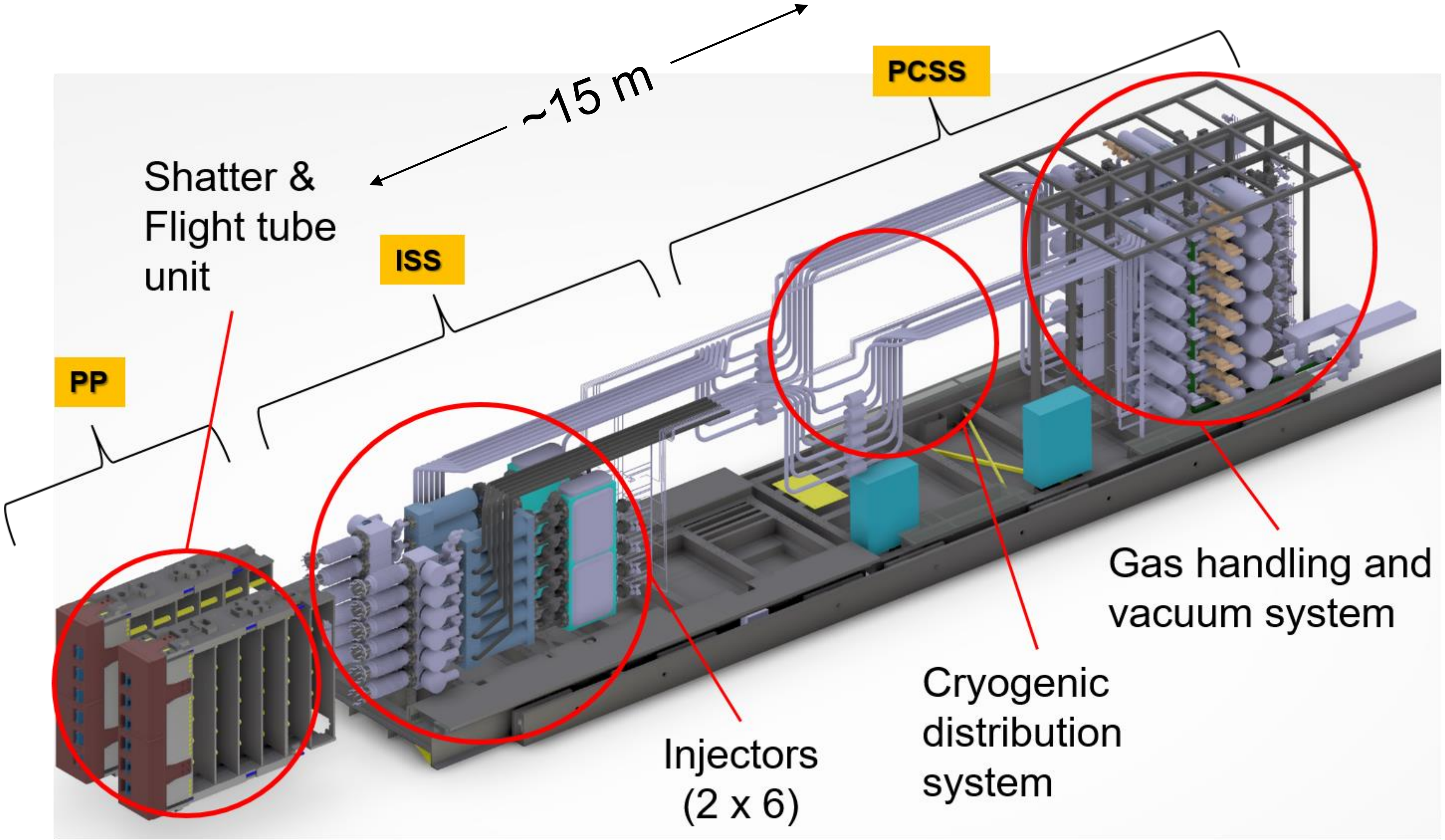
Injectors dedicated to late injection after the thermal quench

Hydrogen, Neon
size TBD
strong shattering

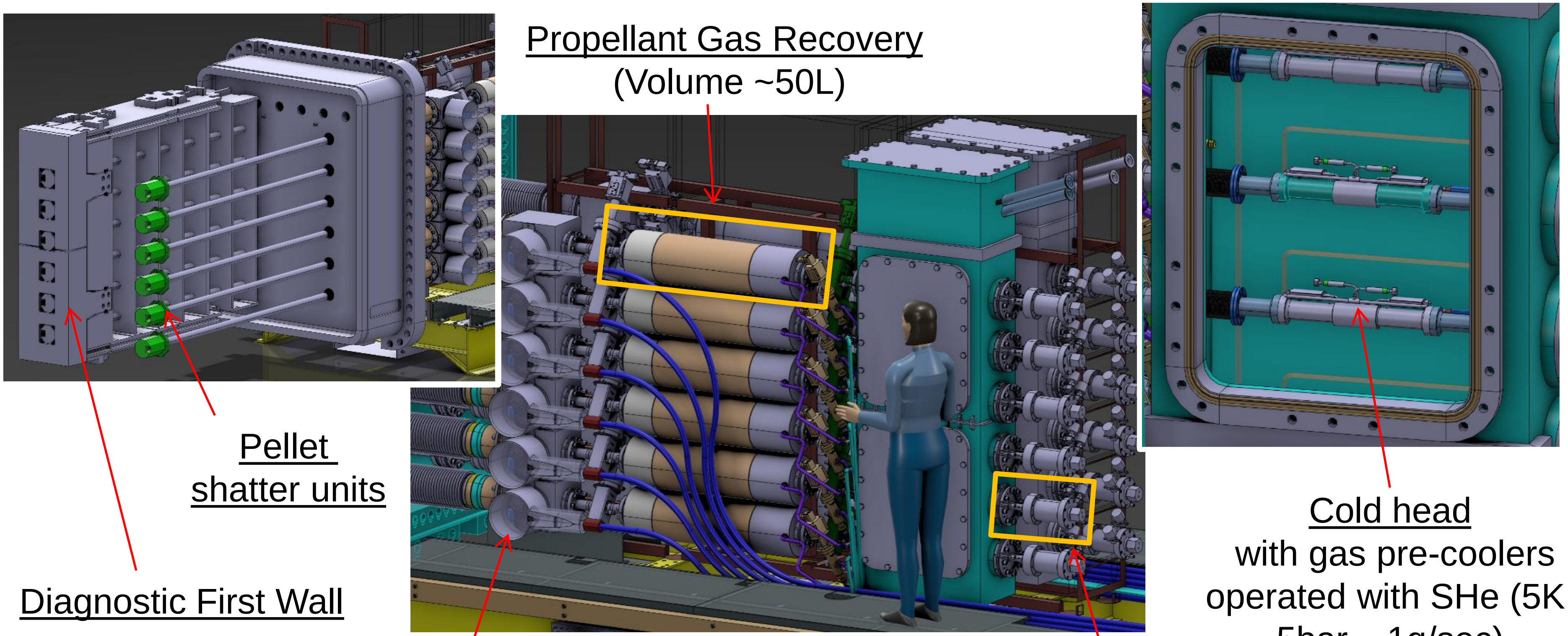
Upper ports



ITER DMS Configuration



Preliminary design of DMS components



Propellant Gas Recovery (Volume ~50L)

Pellet shatter units

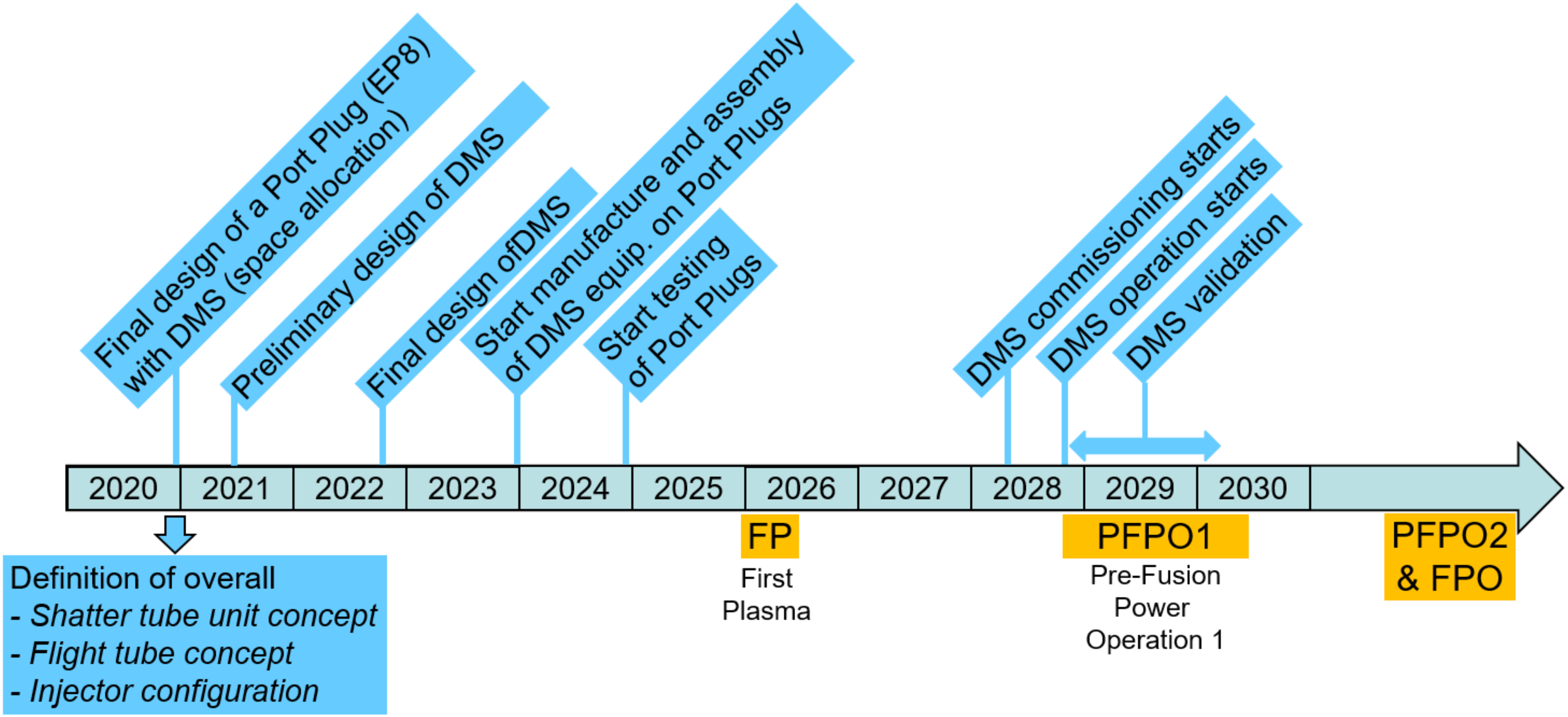
Diagnostic First Wall

Cold head with gas pre-coolers operated with SHe (5K, 5bar, ~1g/sec)

Optical pellet diagnostic for pellet monitoring

Pellet Launcher Unit: Possibly pneumatically operated with H_2 gas (up to 100bar) or electromagnetic driven punch system

Schedule for the design of the ITER DMS



Final design of a Port Plug (EP8) with DMS (space allocation)

Preliminary design of DMS

Final design ofDMS

Start manufacture and assembly of DMS equip. on Port Plugs

Start testing of Port Plugs

DMS commissioning starts

DMS operation starts

DMS validation

2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030

Definition of overall
- *Shatter tube unit concept*
- *Flight tube concept*
- *Injector configuration*

FP
First Plasma

PFPO1
Pre-Fusion Power Operation 1

PFPO2 & FPO

ITER DMS Present requirements for thermal load mitigation

Thermal energy conducted to the first wall and divertor below 20 MJ

► Assimilation of a maximum of 5×10^{22} Ne atoms

? Quantity from EM load limit

No scaling law and simulations not yet quantitative

! Experiments + 3D MHD modelling (validation / extrapolation) for energy and size scaling

Impact of massive H injection on radiation efficiency to be assessed (possibly needed for RE avoidance)

Identify ideal fragment size distribution and velocity for maximum assimilation

ITER DMS Present requirements for thermal load mitigation

Avoid runaway electron formation

▶ Assimilation of the order of 10^{24} H atoms

? Based on simplified 1D modelling

Recent simulations for DT RE sources: avoidance may not be compatible with EM load reduction, massive H injection may even facilitate RE formation

! Self-consistent models required for hot tail formation and magnetic reconnection

Coupling of RE codes to 3D MHD codes

Experiments and modelling on multiple injection efficiency

- $\Delta n_e \sim N_{injectors}$? Spatial distribution of Δn_e?
- Requirement for arrival time jitter to be identified (input for design)
- Identify ideal fragment size distribution and velocity for maximum assimilation

Exploration of staggered injection scheme:
multiple H injection (raise the density) followed by H/Ne injection before TQ (mitigation of thermal and EM loads)

Injection trains of H pellets after TQ to target on early runaways?

ITER DMS Present requirements for thermal load mitigation

Avoid magnetic energy deposition on first wall (halo heat loads)

▶ Assimilation of 10^{22} Ne atoms

? Based on DINA simulations without H injection

! Simulations with H

Addressed in JET experiments

ITER DMS Present requirements for thermal load mitigation

Avoid first wall melting through localisation of radiation heat fluxes

▶ Radiation peaking < 4 during the TQ

? Peaking defined for design purposes of in-vessel systems and implies superficial melting at high energies;

Initial experimental assessment done in DIII-D for toroidal peaking with a single injector

Peak radiation heat flux inversely proportional to $N_{\text{injection locations}}$?

Initial JOREK modelling shows reduction by ~50% for dual injection (180°)

! Main focus of KSTAR dual SPI project

3D MHD modelling

ITER DMS Present requirements for RE impact mitigation

Dissipate energy of a fully formed RE beam through high-Z injection

▶ Assimilation of >> 10^{24} Ne atoms

? Based on DINA simulations (no full mitigation);

Multiple issues:

- RE scraping-off due to vertical displacement
- limited assimilation
- significant magnetic energy at time of final loss

! Integrated simulations including background plasma

3D MHD simulations of final loss and related magnetic energy conversion

Conclude if argon is still required for the ITER DMS (significant technical and operational simplification)

ITER DMS Present requirements for RE impact mitigation

Minimize RE impact through hydrogen injection

► Not quantified yet

? Experimental observations at JET and DIII-D with deuterium injection show benign termination, but are qualitative so far.

! Further experiments needed

Integrated simulations including the companion plasma

Simulations of the final loss with 3D MHD codes + RE fluid model.

ITER DMS Requirement for current quench control

Control the current quench rate to be $50 < t_{CQ} < 150$ ms

▶ Assimilation of 4×10^{21} to 5×10^{22} Ne atoms

? Based on DINA simulations without H injection with assumptions for the halo region

! Simulations with H (likely to reduce the required quantity of Ne)

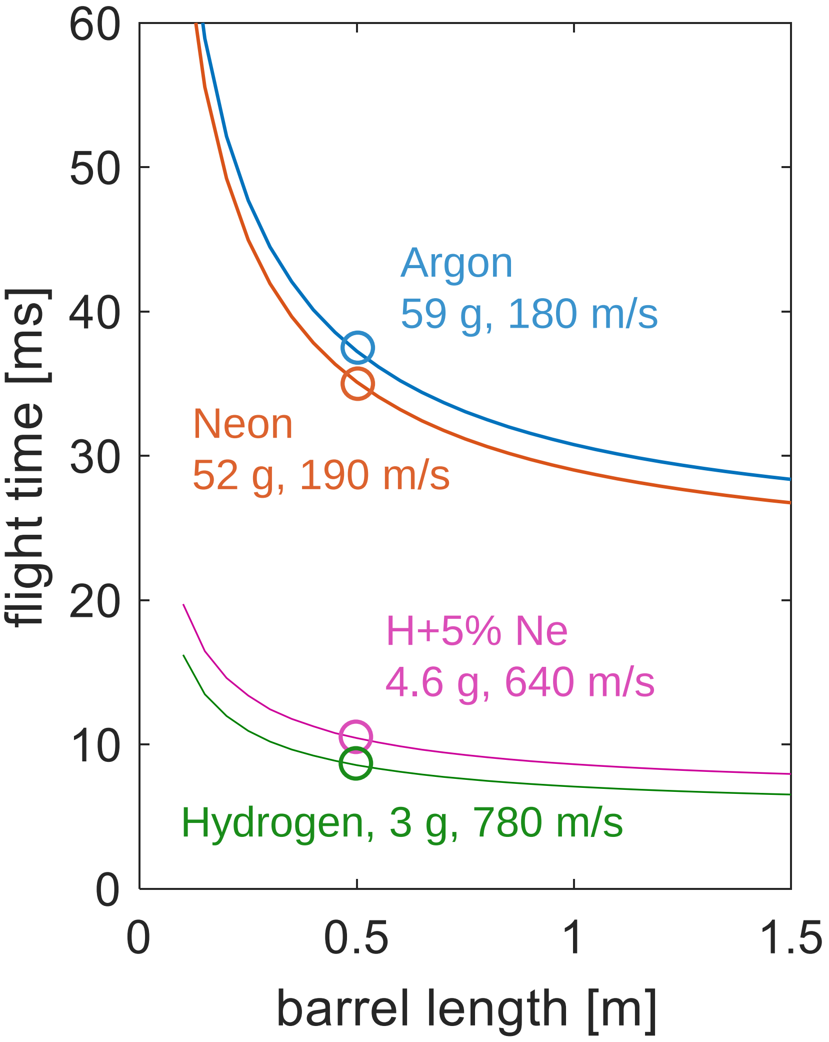
Validation through JET and DIII-D experiments, including simulations with e.g. KPRAD

ITER DMS Reaction time

Overall reaction time includes:

- *Delay from trigger decision to trigger arrival at the PS*
- *Valve opening and gas release*
- *Pellet acceleration + flight time*

Flight time estimate based on adiabatic expansion



Pellet release pressure ~4 MPa
Barrel length: 0.5 m
Flight tube length (equatorial port): 6.3 m
H propellant

ITER DMS Task Force

Objective

Physics and engineering studies to validate the design of the ITER DMS and to optimise the technology

Theory & Modelling (led by E. Nardon and A. Matsuyama)

Providing an umbrella to coordinate information exchange in the field

Support to fill gaps and to perform ITER specific simulations

Two main groups: runaway electrons / 3D MHD modelling with regular meetings

Experiments (led by N. Eidietis)

Motivating and providing support for SPI experiments and appropriate diagnostics equipment

Presently two central projects: KSTAR and ASDEX

Technology (led by U. Kruezi and N. Balshaw)

Providing design justification and validation for the ITER DMS

Projects: Optical Pellet Diagnostic, Pellet Launching Unit, Fundamental Studies,
Support Lab (component testing, e.g. shattering unit)

ITER DMS Task Force – KSTAR SPI Experiments

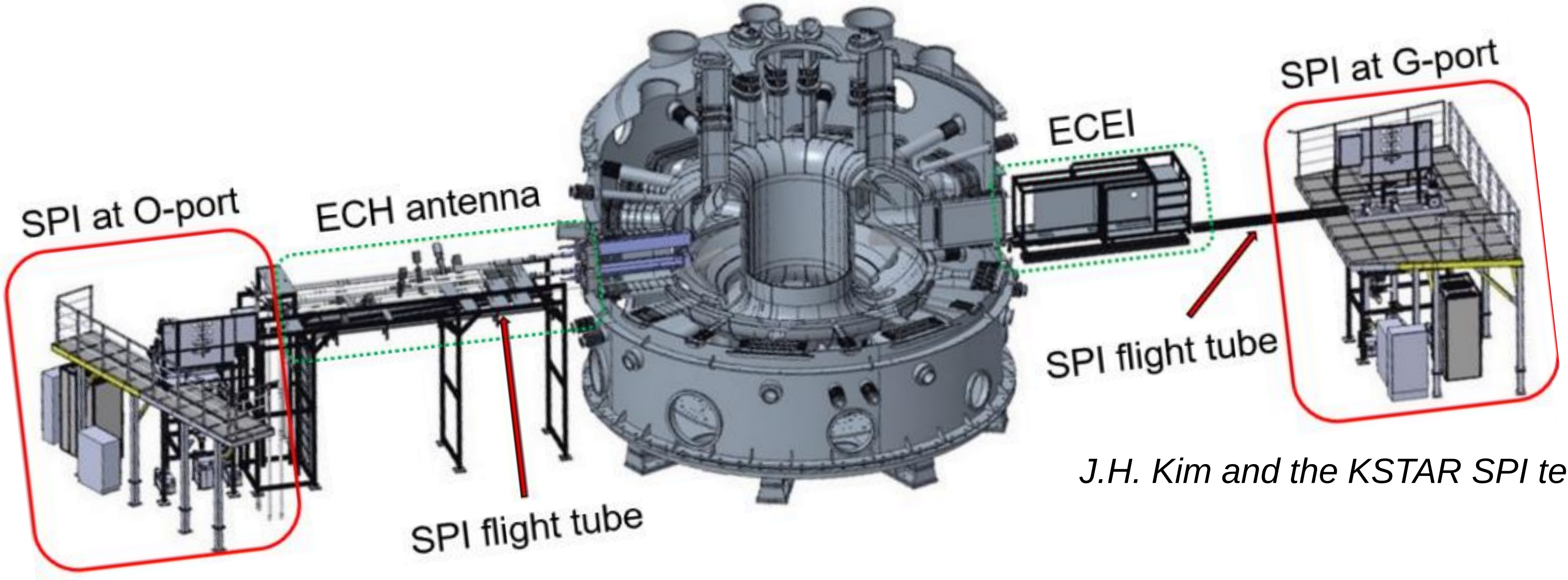
Assess the radiation distribution and density rise with multiple injection

2 injectors 180° apart

2 x 2 pellets of 7 mm + 2 pellets 4.5 mm

Bolometer and interferometer upgrades

See J.-H. Kim, MIT(SPI)-116



J.H. Kim and the KSTAR SPI team

5 run days planned for Oct/Nov 2020

ITER DMS Task Force – ASDEX SPI Experiments

Assess optimum fragment size and velocity for maximum penetration and assimilation

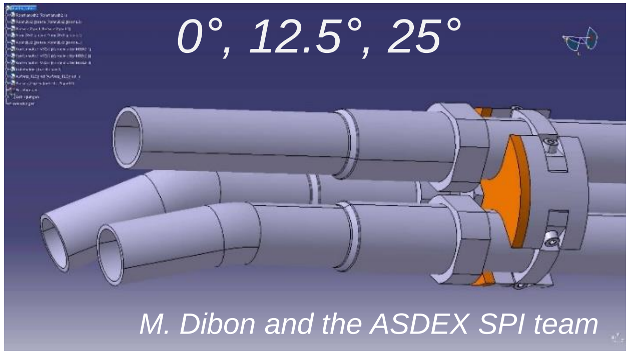
3 injectors with individual flight tubes

Pellet sizes 1, 4 or 8 mm

3 cameras to observe ablation

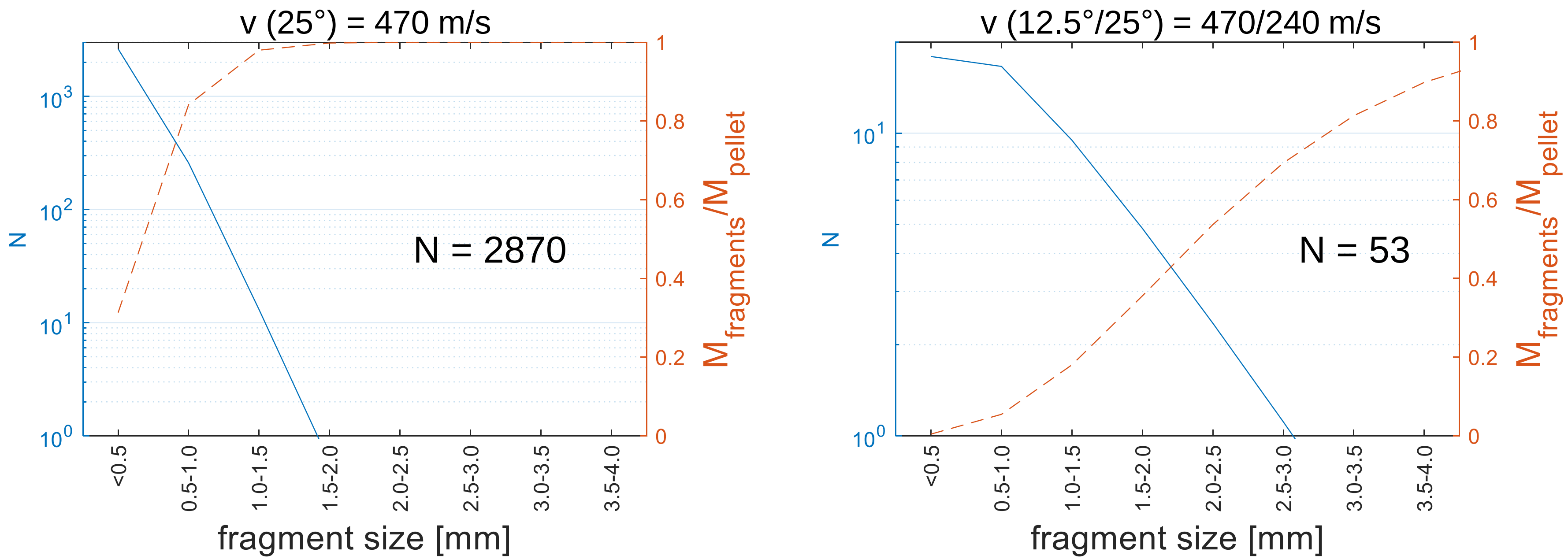
Bolometer/Diode upgrades

See G. Papp, MIT(SPI)-135


0°, 12.5°, 25°

M. Dibon and the ASDEX SPI team

Approximate range of distributions for a 4 mm D_2 pellet


v (25°) = 470 m/s

v (12.5°/25°) = 470/240 m/s

Statistical model calibrated with ORNL lab data [T.E. Gebhart+, IEEE2020]

ITER DMS Task Force – Technology Development

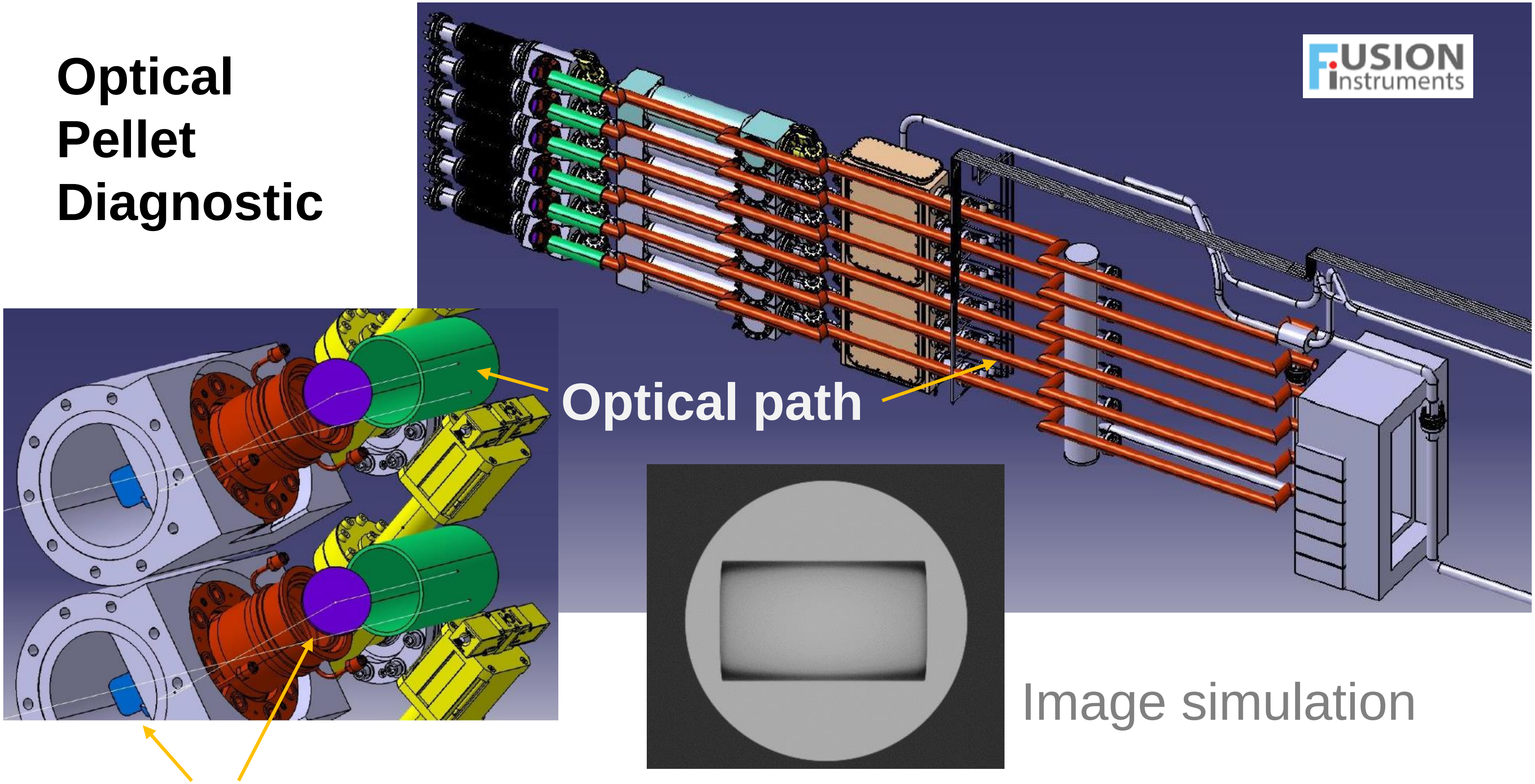
The system must be robust with respect to availability, pellet arrival time and fragment size distribution

- Pellet Launching Unit development (punch and fast valve)
- Pellet forming, release and shattering studies
- Pellet Diagnostic

All to be scaled to 28.5 mm x 57 mm pellets

ITER DMS Task Force – Technology Development

Optical Pellet Diagnostic



Optical path

Image simulation

Mirrors

- Pellet integrity, velocity, and orientation
- Pellet flight path alignment

Summary

ITER's **Disruption Mitigation System** has significant injection capabilities.

The focus in the next two years must be on how to use these to achieve the mitigation targets.

→ Refinement of the requirements

Identifying deficiencies of the mitigation scheme has to lead to exploration of *alternative schemes* → beyond the next 2-3 years

DMS TF material e.g. from meetings can be found here (ITER account required)