Progress on the ITER DMS design and integration

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Design and Performance of Shattered Pellet Injection Systems for JET and KSTAR Disruption Mitigation Research in Support of ITER

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Outline

- Introduction and ITER DMS Concept
- ITER DMS Overall Configuration
- ITER DMS Design Status
- ITER DMS Port Integration
- Progress on Engineering Studies and Design Specifications
- Conclusions

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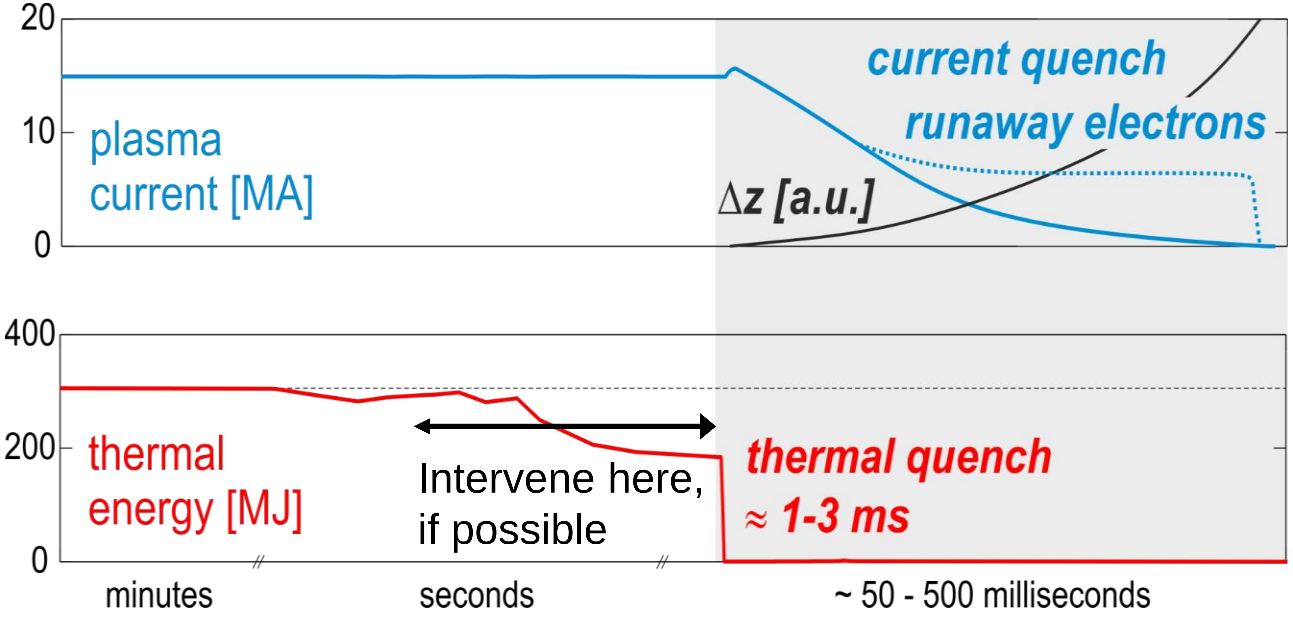
Mitigation of Disruptions in ITER

- Disruptions can cause large thermal and mechanical loads in absence of mitigation



Disruption Mitigation Concept

- Convert thermal and magnetic energy into radiation
- Runaway electron avoidance by increase of plasma density and resistivity

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ITER DMS Solution: Shattered Pellet Injection

- Conversion of plasma free energy (up to 800 MJ) into radiation with increased plasma density requires delivery of substantial mass to the plasma within a few milliseconds
  - Gas injection is slow with significant dispersion in the direction of mass flow
  - Solid projectile injection is fast but can go through plasma without the desired interaction and impact PFCs
  - Shattered Pellet Injection (SPI): speed and density of solid, but shattering before injection yields pieces absorbed in plasma

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ITER DMS Project Timeline

2018: Proposal to ITER Council of DMS design solution using Shattered Pellet Injection (SPI) in 3 equatorial ports and 3 upper ports

Phase I: Installation of captive components and completion of DMS final design by 2022

Phase II: Manufacturing, installation, and commissioning in time for PFPO-1 (end 2028)

DMS Project Phase-I Tasks

- Design and install infrastructure for necessary services (gas, vacuum, cryogenic)
- Completion of DMS Design including Design Specification and Engineering Studies
- Integration of DMS in ITER Ports

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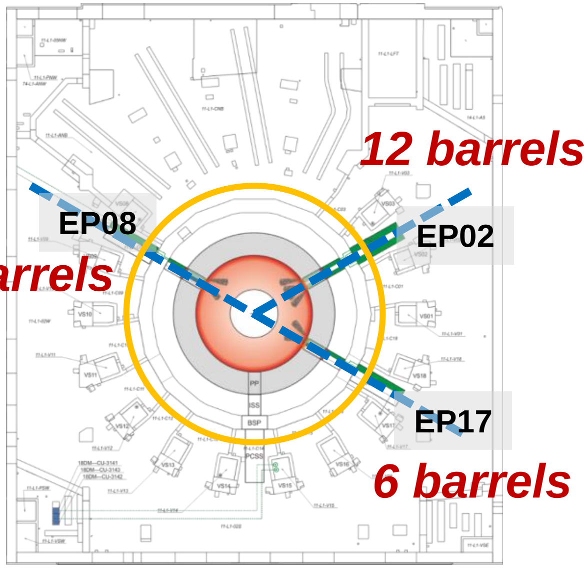
ITER DMS configuration

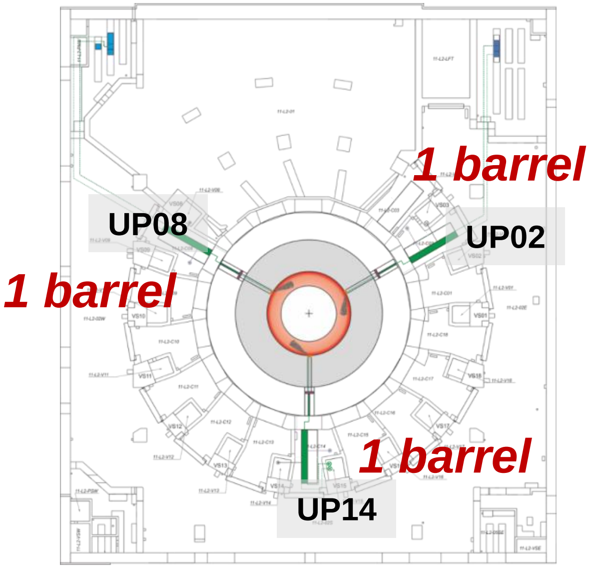
Equatorial Ports (24 Injectors)

- Main injectors to mitigate the thermal and current quench and runaway electron impact
- Pellets with H and H/Ne mixtures
- d = 28.5 mm, L = 57 mm (~10^{24} atoms)



Upper Ports (3 Injectors)

- Post-thermal quench injection
- Aiming at 100% reliability of electromagnetic load mitigation
- Strong shattering for maximum assimilation in cold post-TQ plasma



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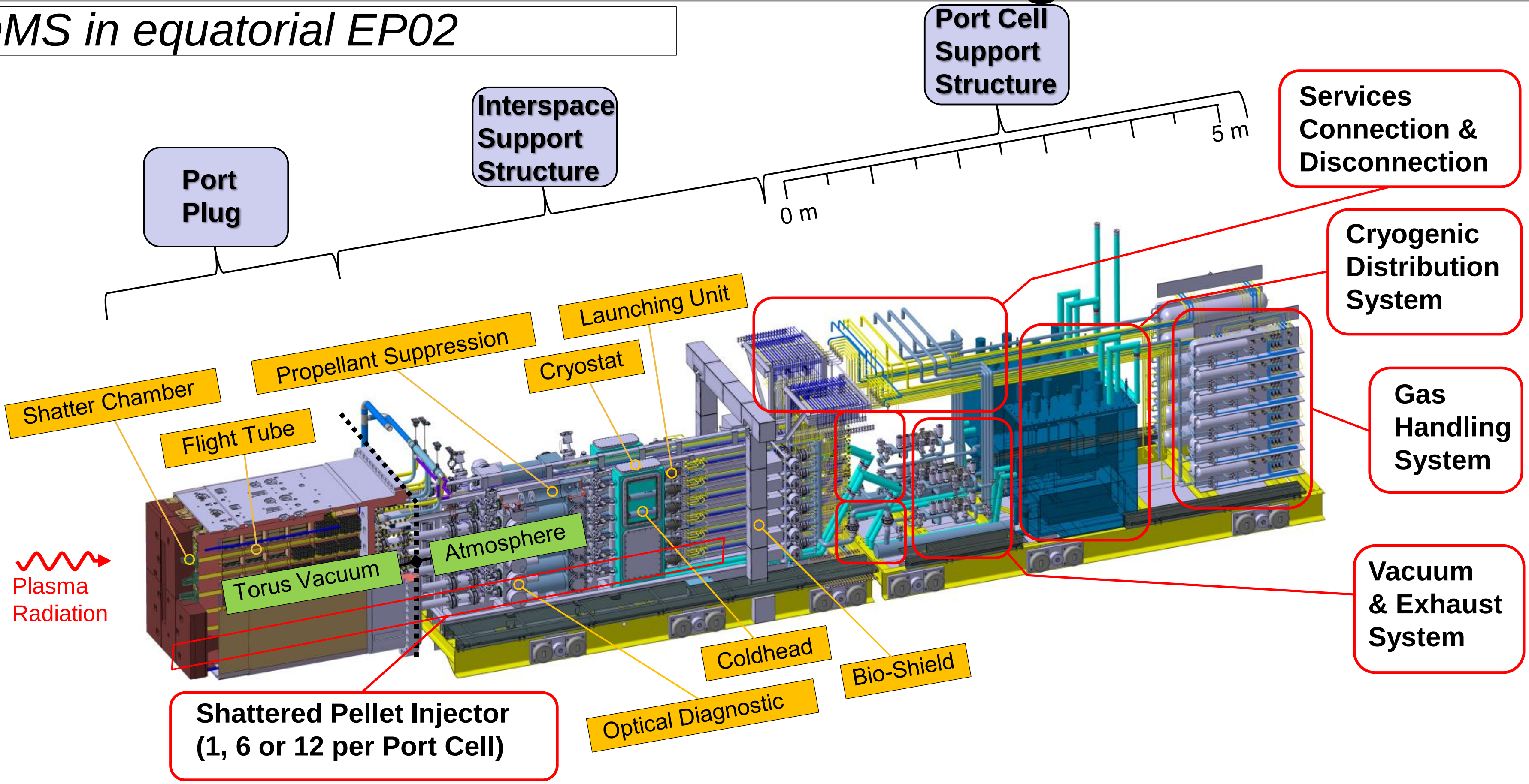
Overall DMS Design

DMS in equatorial EP02



- Port Plug houses flight tube and shatter chamber
- Interspace houses pellet formation, launch and diagnostic hardware
- Port Cell houses services

DMS Design Challenges

❑ Technological design challenges

- ➢ Robust and reproducible pellet generation and acceleration process
- ➢ Monitoring of pellet integrity and its trajectory with minimum interaction between the pellet and the flight tube
- ➢ Optimised shard distribution

❑ Mechanical implementation challenges

- ➢ Integration of complex SPI systems into an environment with advanced design maturity
- ➢ Integration of required services in limited space
- ➢ Design enabling maintenance in congested, activated, and potentially contaminated environment

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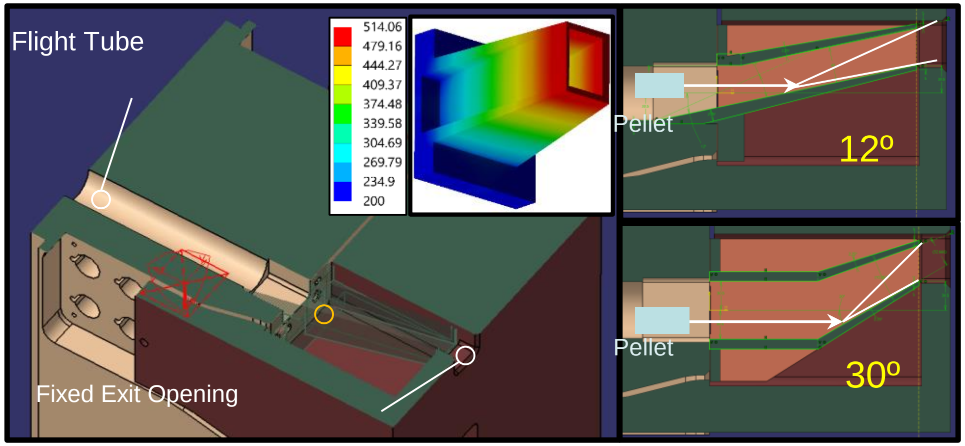
DMS Component Design Details

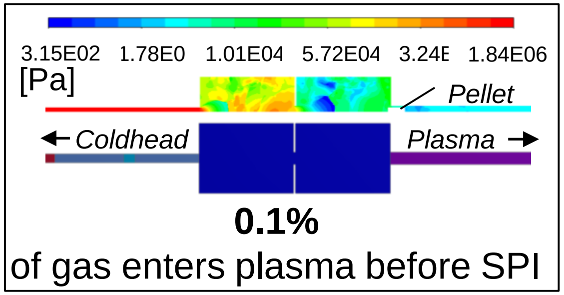
❑ Shatter Chamber

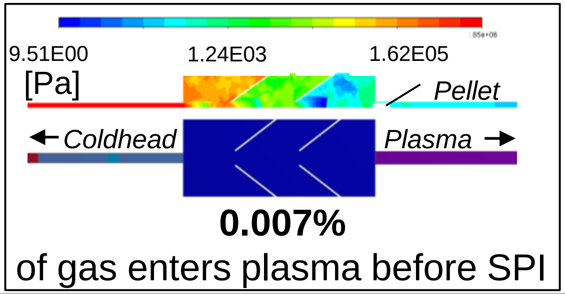
- ➢ Subject to plasma radiation and neutron heating → high temperatures (up to 600º C)
- ➢ Optimum shatter angles still not fixed → flexible design to accommodate range without modification of interfaces



❑ Propellant suppression system

- ➢ SPI propellant should not reach plasma before SPI shards (decreased mitigation efficiency)
- ➢ Propellant gas recovery system cannot be implemented in ITER due to space restrictions
- ➢ Propellant suppression system design being optimized to minimize the amount of gas entering the plasma before SPI shards





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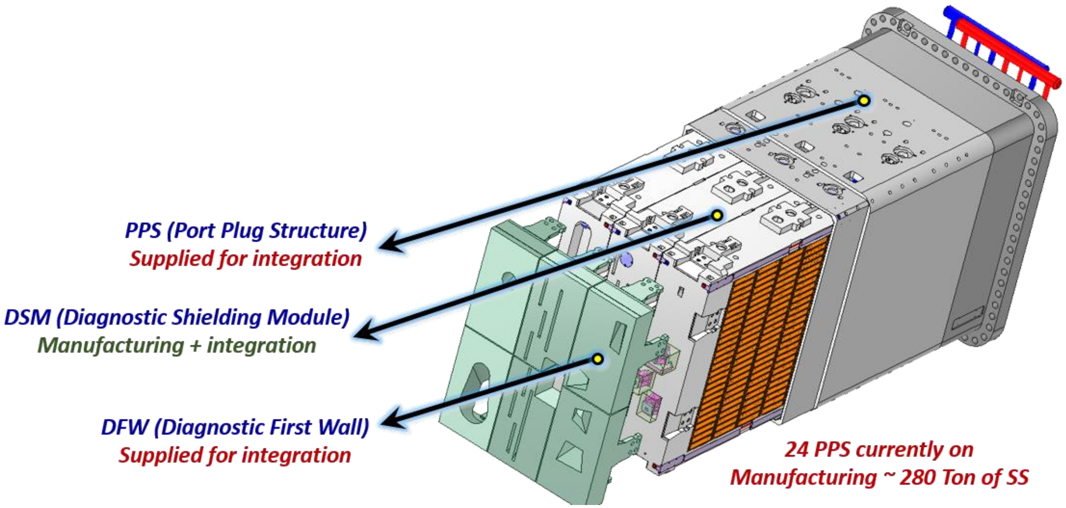
Overall DMS Port Integration

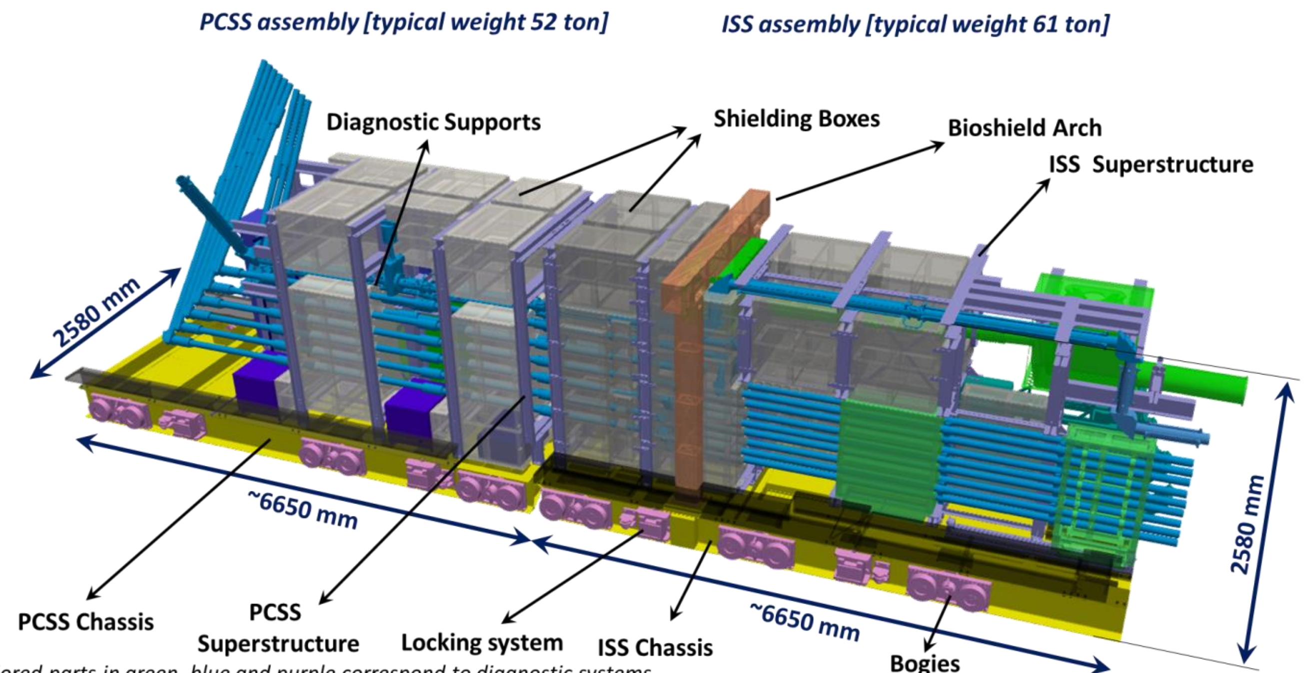


Integration in modular design ports (in-port)

- Standardization of components and interfaces allows faster adaptation of previous designs

Integration in modular design ports (ex-port)

- Common solutions allow efficient maintenance
- Integration follows other ports applying the same concept for faster development



*Colored parts in green, blue and purple correspond to diagnostic systems

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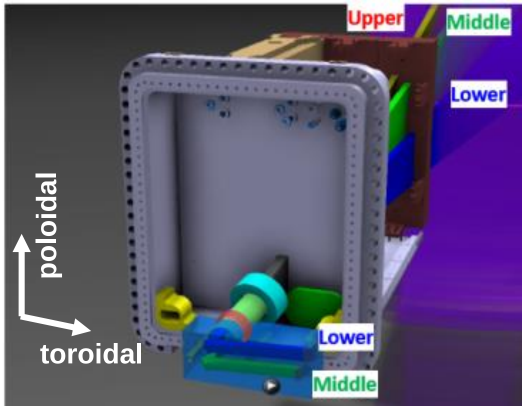
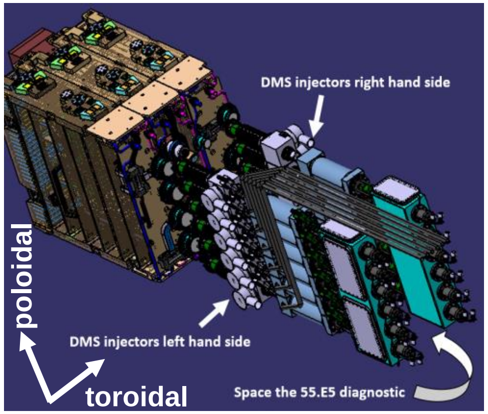
Diagnostic Integration: X-Ray Spectrometer

Original 55.E5 X-Ray Spectrometer:

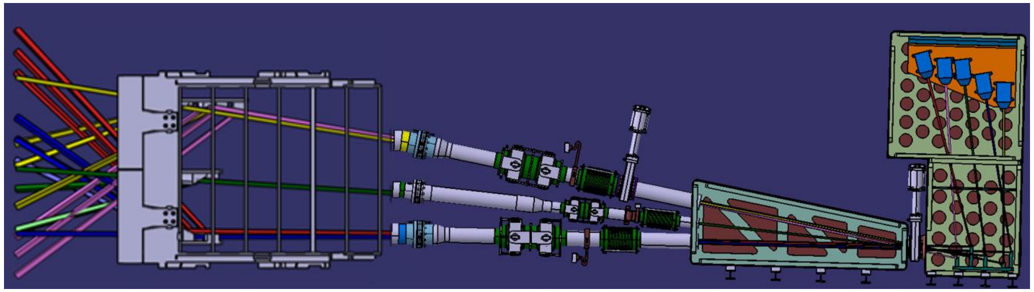
- Poloidal spatial coverage and toroidal spectral dispersion





Introduction of Highly Oriented Pyrolytic Graphite (HOPG) reflectors:

- Discrete lines of sight, rather than imaging, and spectral dispersion in vertical direction
- (+) Dispersion crystals and detectors can be placed behind bioshield
- (-) Limits bandwidth and signal throughput



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DMS Engineering Studies and Design Specification

Engineering studies are necessary to develop SPI technology and adapt to the ITER requirements

- To bring the technology to the level needed for investment protection in ITER
- To prototype and improve components that can be used in the ITER environment

Design Specifications are refined or determined through experiments and modelling

- Operational requirements
- Optimization of pellet mass and mixture
- Optimization of shattering

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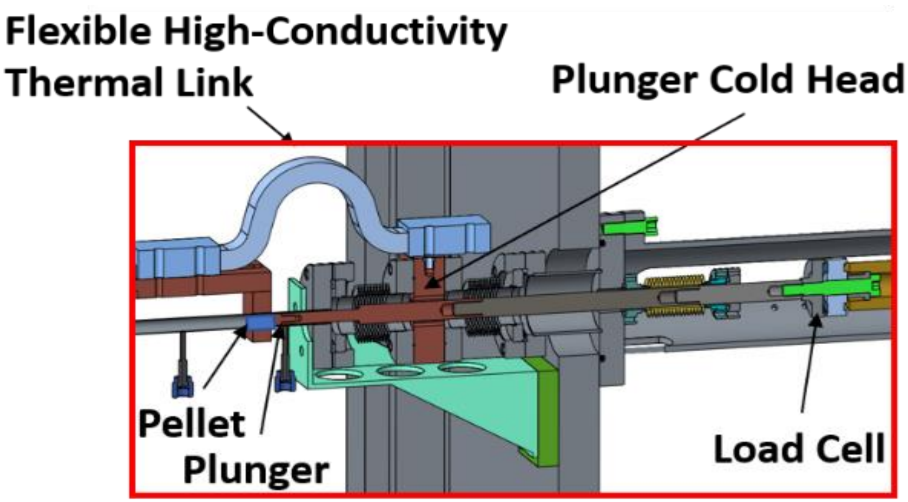
DMS Engineering Studies - I

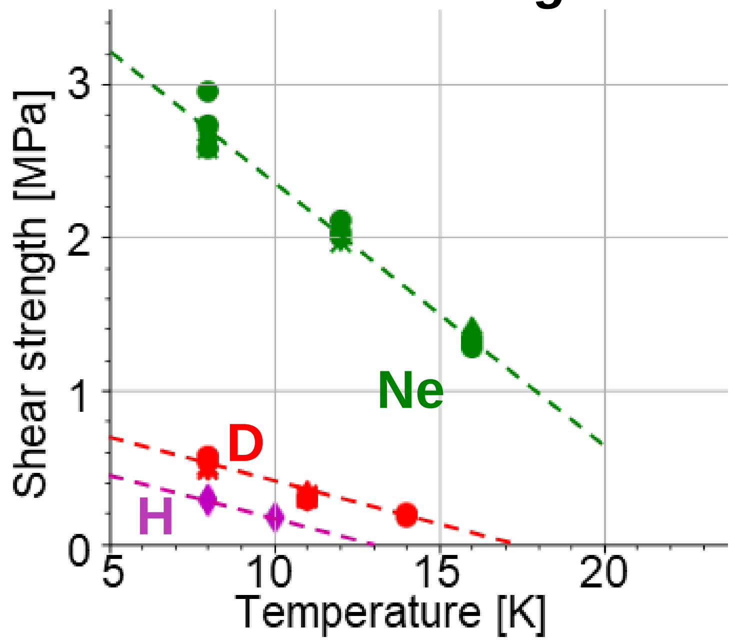
- Fast propellant valve development
- First 28.5 mm pellet formation and shattering
- Pellet flight path assessment
- <u>Shear strength for dislodging pellets</u>

Experimental set up



ORNL/USIPO)

Shear strength



Shear strength depends on pellet material and decreases with increasing temperature

US IPO ITER DMS support

Oak Ridge National Lab (see paper by T. Gebhart this conference)

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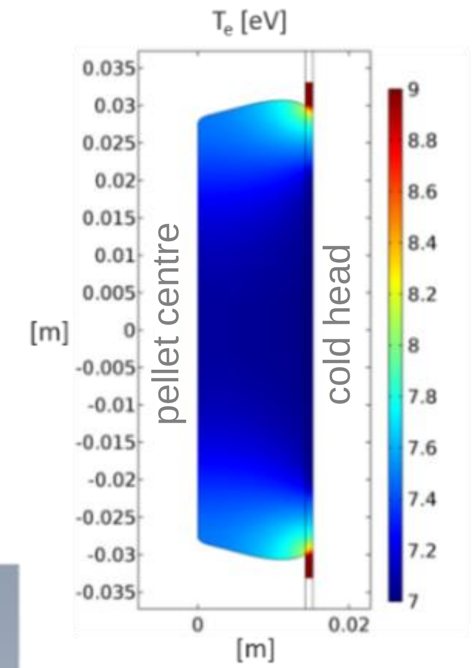
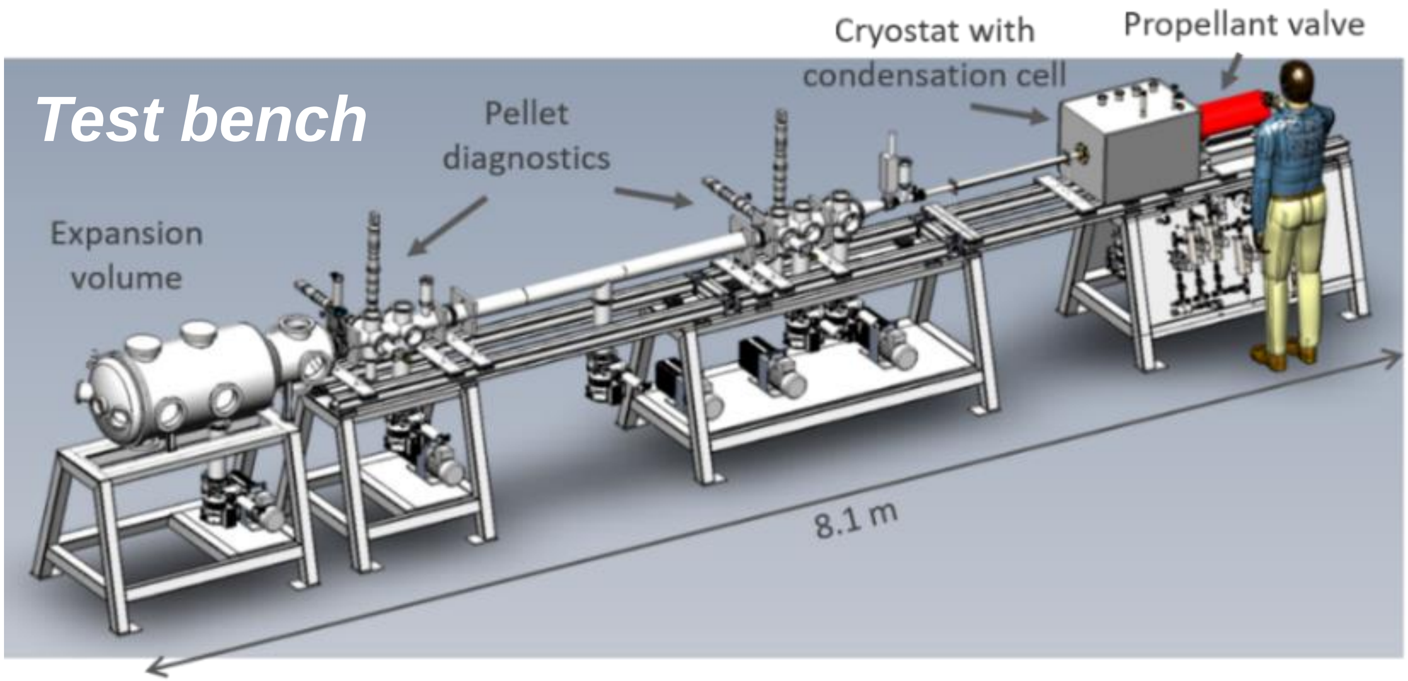
DMS Engineering Studies - II

Fundamental Studies

Optimisation of pellet formation and release process through modelling and experimental validation

Modelling of pellet formation





CEA-Grenoble/DSBT

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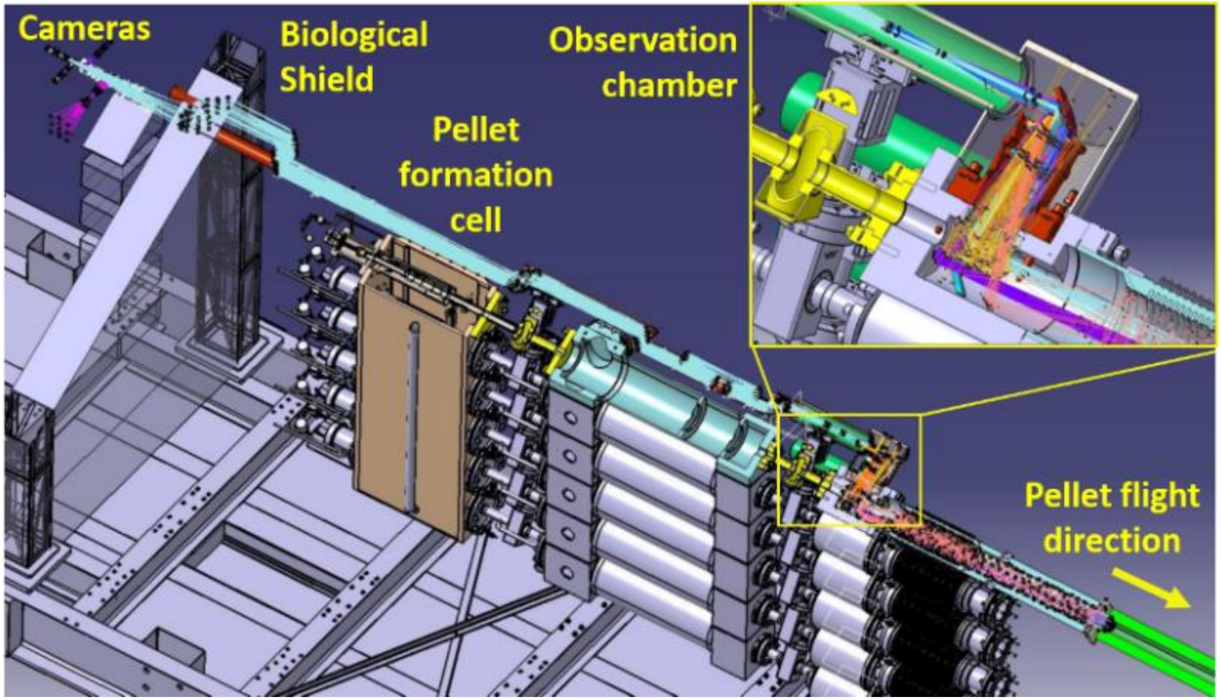
DMS Engineering Studies - III

Optical Pellet Diagnostic

System to diagnose pellet integrity, volume, and velocity orientation as well as pellet flight line alignment

- Environment with limited space availability
- Relay optics must be compatible with radiation environment

Optical Pellet Diagnostic integrated into the injector line



(Fusion Instruments, Hungary)

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DMS Engineering Studies - IV

Support Laboratory

Main facility for integrated testing of components:

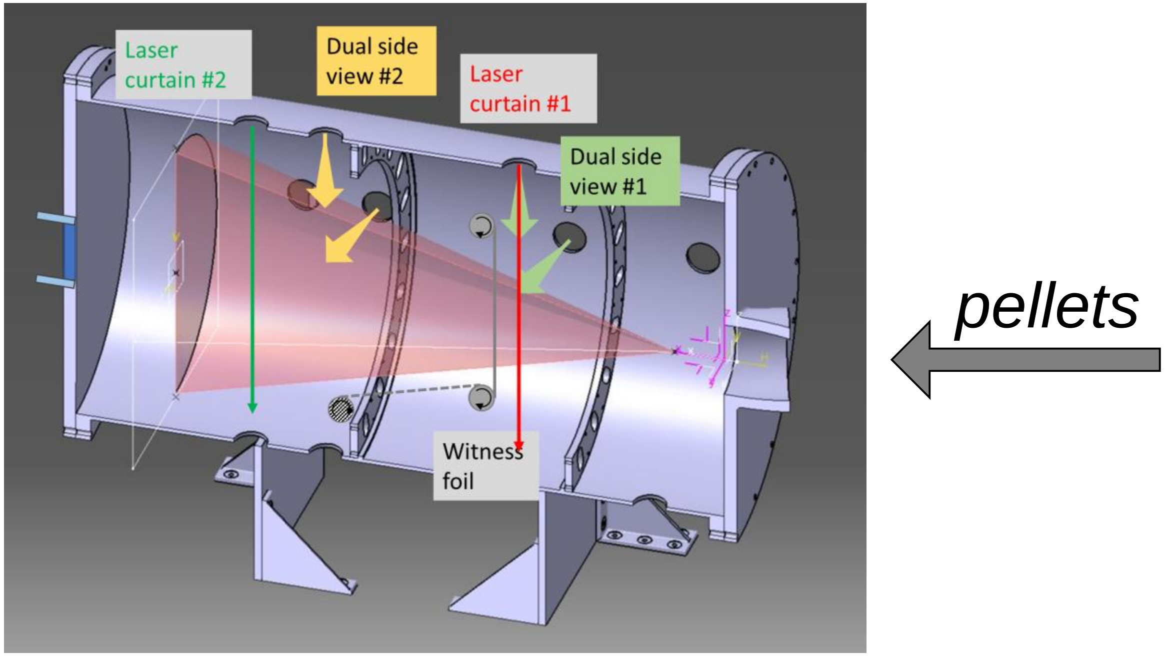
Shattering unit, pellet launching unit, optical pellet diagnostic, cold head

Operational in Q3/2021

First Task:

Development and testing of shattering units to deliver the required fragment sizes

Shattering analysis chamber



(Centre for Energy Research, Hungary)

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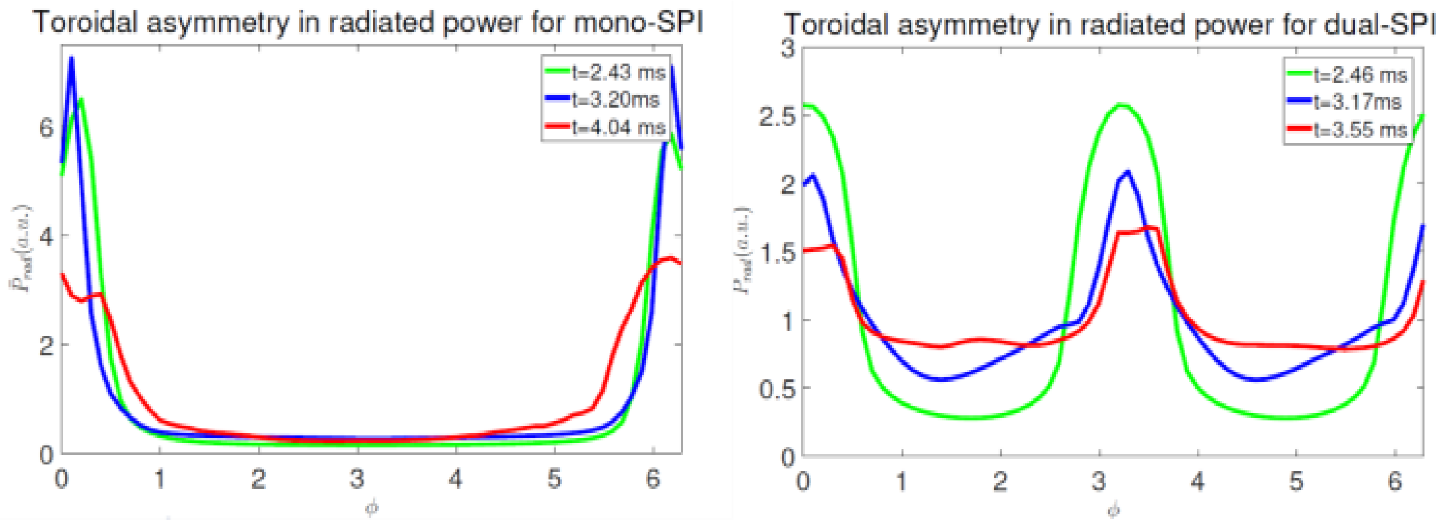
DMS Design Specification - Modelling

- **Theory and modelling programme providing physics-based extrapolation from experimental results to ITER**

  (see papers by E. Nardon, C. Kim and A. Matsuyama, this conference)

- 3D MHD simulations with JOREK, M3D-C1, NIMROD
- Simulations of generation and mitigation of runaway electrons
- Simplified modelling for ITER DMS parameter studies
- Shattering process in support of engineering studies

Example: JOREK SPI simulations for ITER: reduction of radiation asymmetry



(courtesy of D. Hu, Beihang University)

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DMS Design Specification - Experiments

❑ Key questions addressed:

- ➢ Can the density be raised efficiently by superimposing multiple pellets?
- ➢ Can the required radiation levels be reached with sufficient symmetry to avoid first wall melting?
- ➢ What is the optimum fragment size for maximum mitigation efficiency?
- ➢ How much mass must be delivered in ITER?

❑ SPI data from 5 tokamaks by end of 2021:

ASDEX, DIII-D, JET, J-TEXT, KSTAR
(see papers by D. Shiraki, S. Jachmich, U. Sheikh, Z. Chen and J-H. Kim, this conference)

- ➢ These experiments have complementary physical characteristics and SPI capabilities to define as completely as possible the ITER design specifications

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Conclusions

- Design and integration of DMS into ITER tokamak and ancillary systems has progressed since 2018 IAEA FEC:
  - Configuration for ITER DMS ports established
  - Installation of networks to supply vacuum, gases and cryogenic services starting in 2021
  - Integration of DMS into ports underway; re-design of diagnostics sharing ports with DMS underway
  - Technology studies launched for the reliable formation, injection and shattering of pellets
  - Improved specification of the design basis through experiments in tokamaks and model validation
- Main ITER DMS project milestones set in 2018 have achieved → coordinated effort across IO departments and extensive support from ITER Members institutes
- DMS project is on route to deliver a fully functional DMS system for operation in PFPO-1

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