# *ITER Disruption Mitigation System Conceptual Design Review Highlights - Options for ITER*

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Input from:
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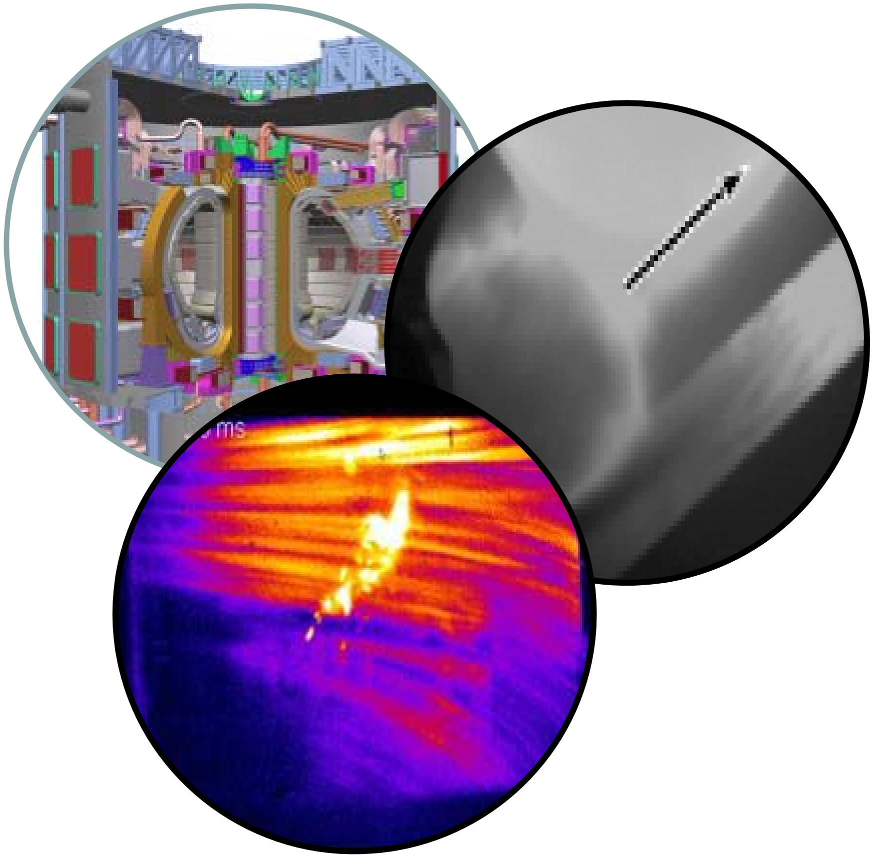
ITER Organization



Presentation for:

VLT Conference Call

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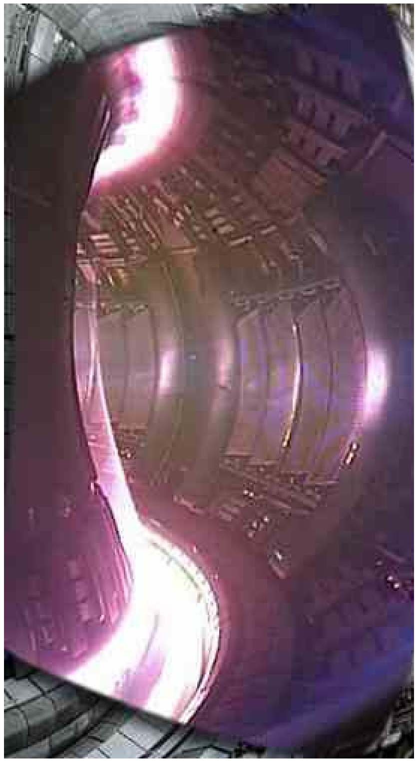
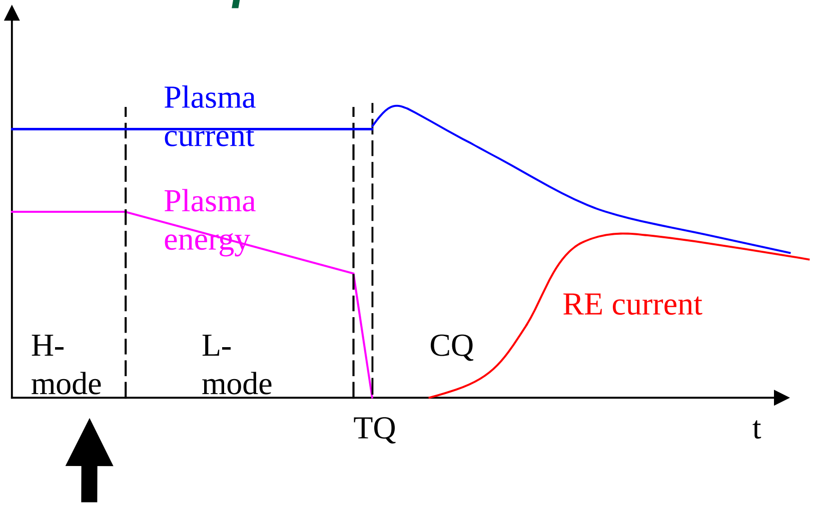
# *What is a Plasma Disruption?*

- **MHD instabilities can cause the plasma to become unstable and violently collide against the walls. (This is a disruption)**
- **3 primary threats from a disruption:**
  - **Thermal load during thermal quench**
  - **JxB Forces from halo currents**
  - **Thermal load from runaway electrons during current quench**
- **ITER plasma current (~ 1 GJ) and ~350 MJ of thermal energy is dissipated in ~30 ms in a disruption causing thermal and structural design challenges.**
  - **Structural problems can be handled by careful design**
  - **Thermal excursion of first wall can lead to damage**
- **Runaway electrons can be generated by Coulomb collisions during the current decay phase of the disruption**
  - **ITER could have up to 10 MA of RE current in 15 MeV range of energy**
  - **Component melting and water leaks could result**

# *What is a Plasma Disruption?*






Typical chain of events during plasma disruption

- The largest thermal loads occur during Thermal Quench (must be reduced by factor of 10 by preventive material injection)
- Major mechanical forces act on plasma facing components during Current Quench (CQ time shall be controlled by DMS within limits 50-150 ms)
- Runaway electrons can be generated during Current Quench (RE current must be suppressed to less than 2 MA)

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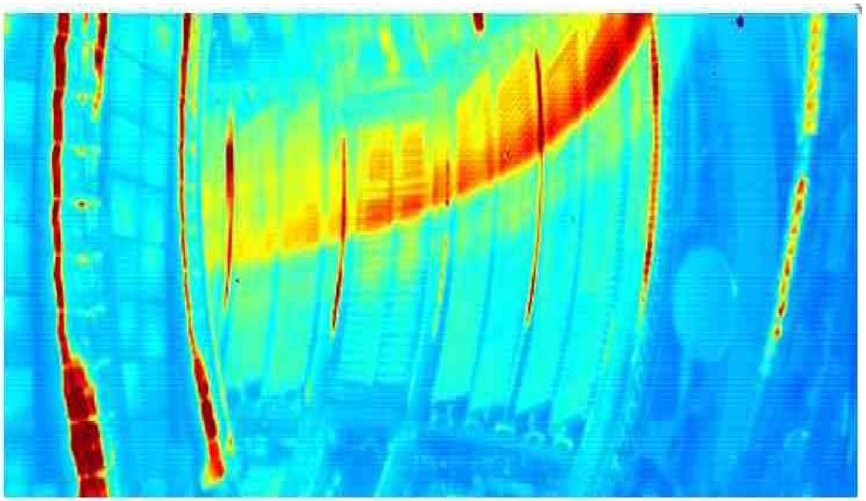

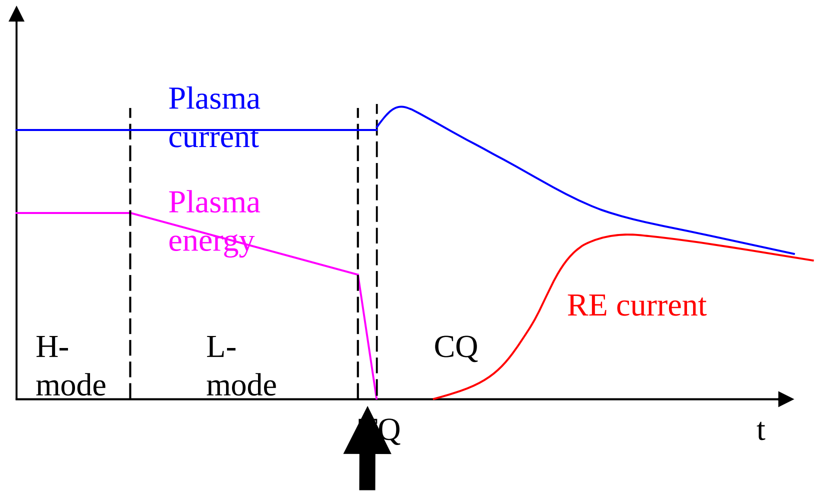


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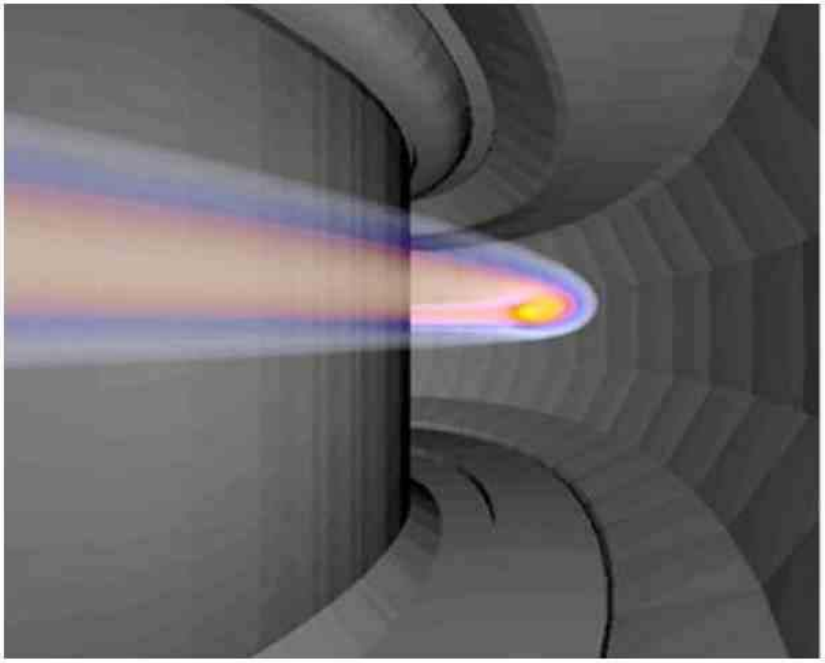

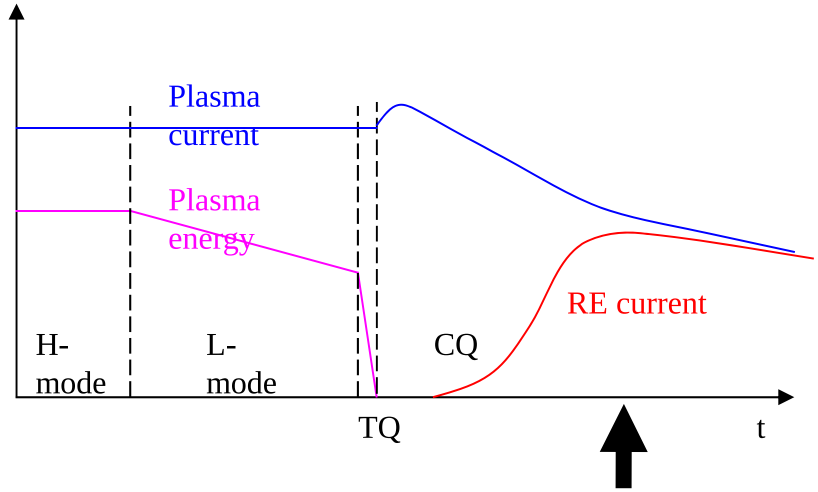


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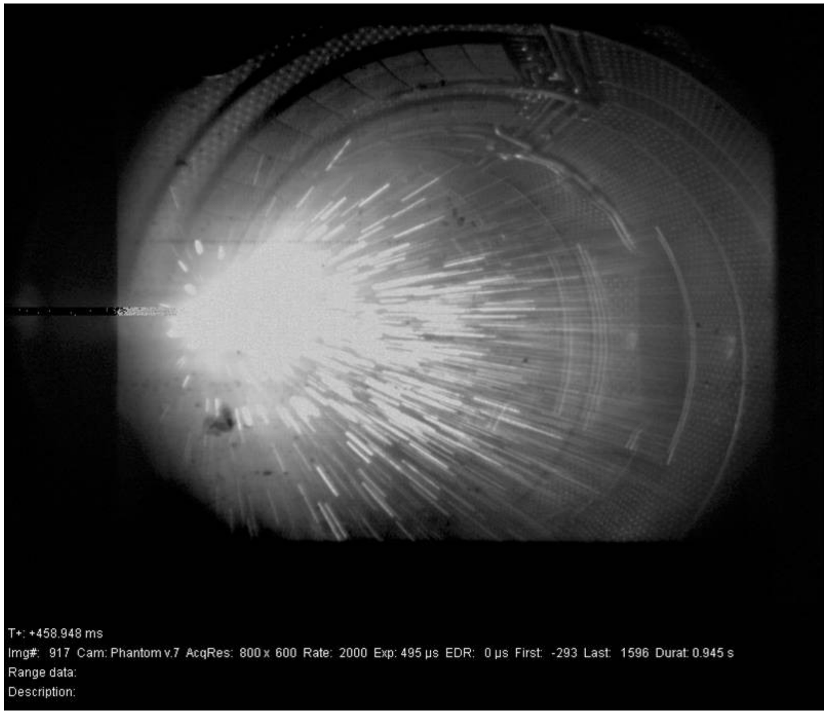


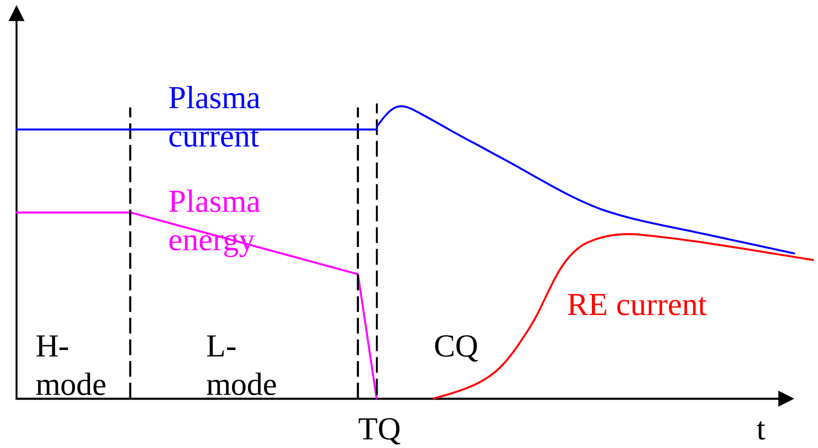


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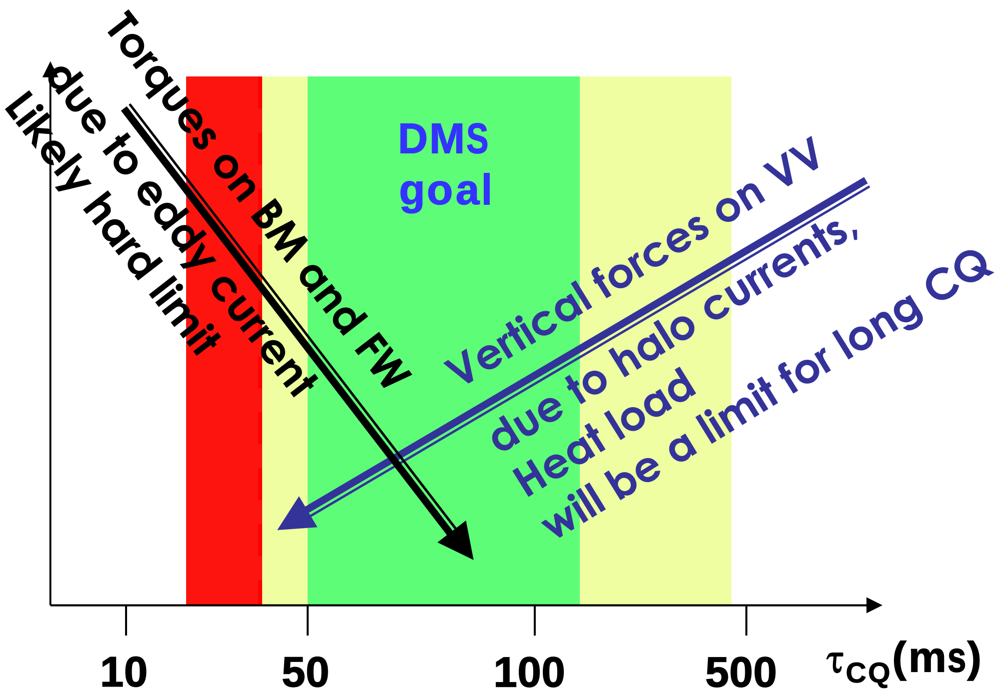
# 2.2 General technical constraints on DMS systems

## Current quench time limit

- EM loads and heat loads during current quench are strongly influenced by the CQ time duration
- DMS goal is to transform very short and very long CQ into disruptions with CQ time in the range of 50 - (≈150) ms




## Short CQ

- $\tau_{CQ}$≈36 ms is the absolute lower boundary
- When fatigue is considered, $\tau_{CQ}$≈50 ms is required for majority of disruptions.
- This is one of the hard limit for $\tau_{CQ}$ ⇒ Constraint for DMS

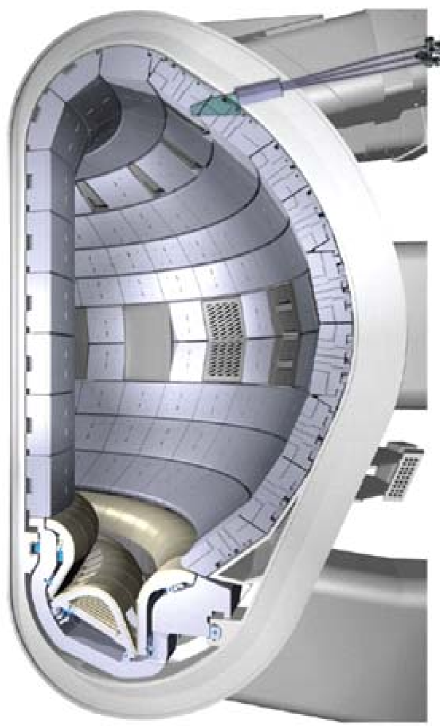
## Long CQ

- Halo current tends to increase
- Heat load by particles tends to increase (localized) due to reduced radiation (boundary is not rigid and may not be hard limit)

# How is a Disruption Mitigated ?

- Large increase of plasma density during disruption can lower the plasma temperature and thus mitigate effects of thermal damage during TQ
- Particles must penetrate into the current channel during the current quench to prevent runaway electron formation
  - » If REs form, then inject material to stimulate dissipation
- Methods to increase the density and to mitigate disruptions are:
  - » **Gas injection**: Large burst of gas from fast valves
  - » **Pellet injection**: Solid pellets accelerated into the plasma
  - » **Liquid jet**: Cryogenic liquid forced through a nozzle
  - » **Solid particle injection**: Shattered large pellets or Be particles (ITER)

# *DMS Injection Locations for ITER*



**3x UPP Thermal Mitigation**

**1x EQP RE Mitigation**


2 kPa m$^3$ per injector

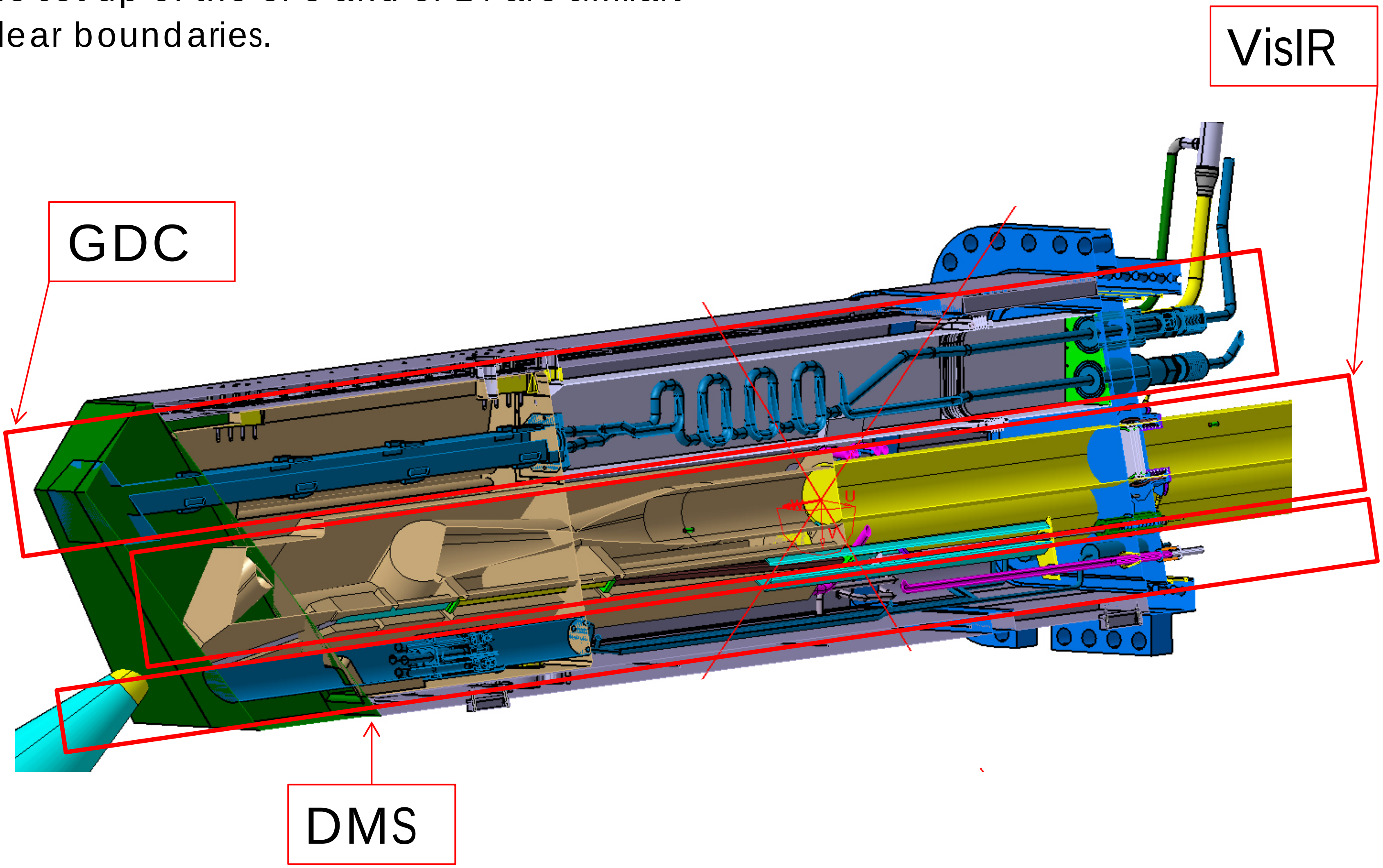
up to 100 kPa m$^3$ for RE suppression

**EQUATORIAL PORT**

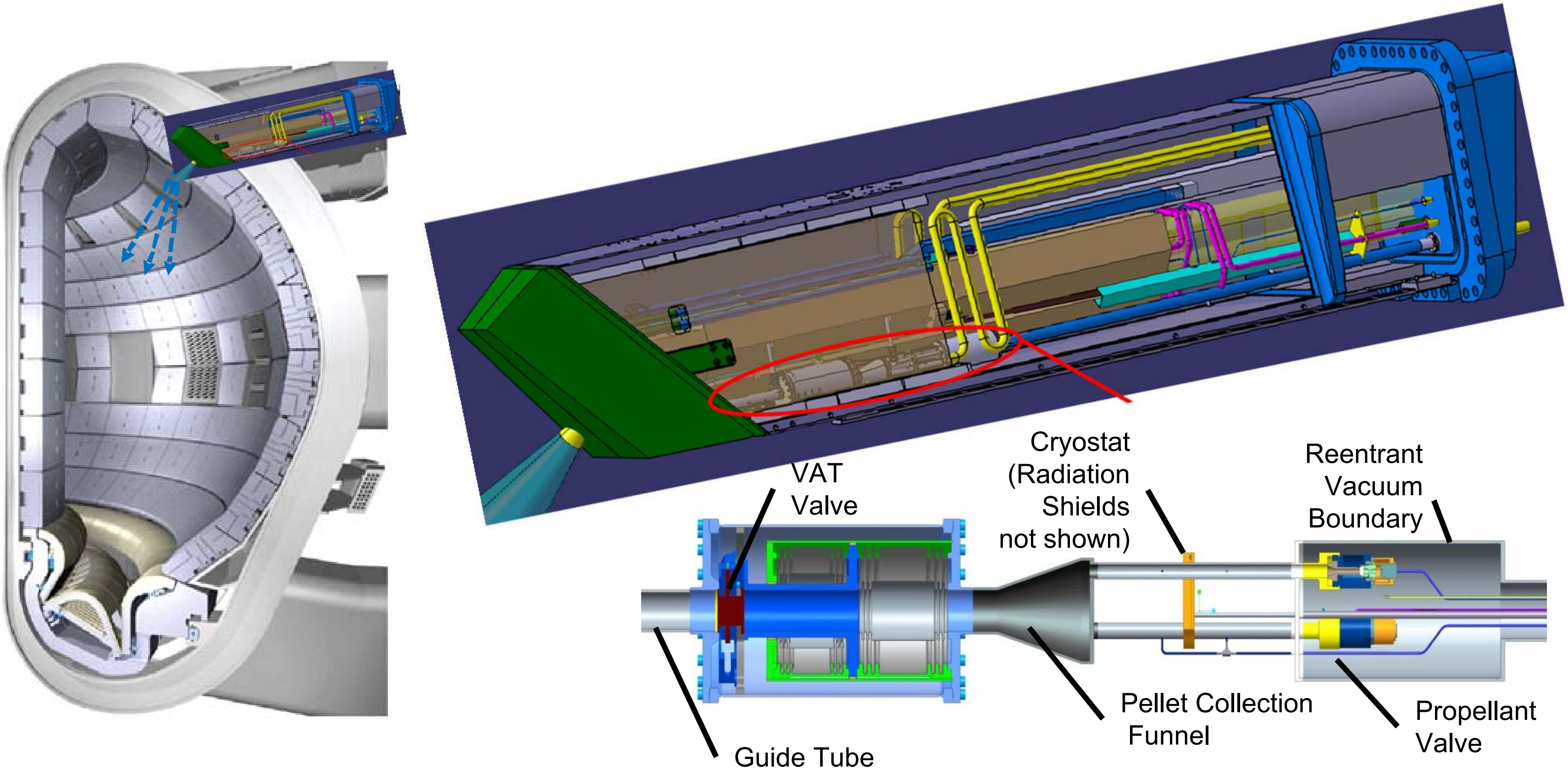
- **For fastest time response the DMS injectors are to be located inside the port plugs**

# UPP 8 & 14

The set up of the UP8 and UP14 are similar.
Clear boundaries.

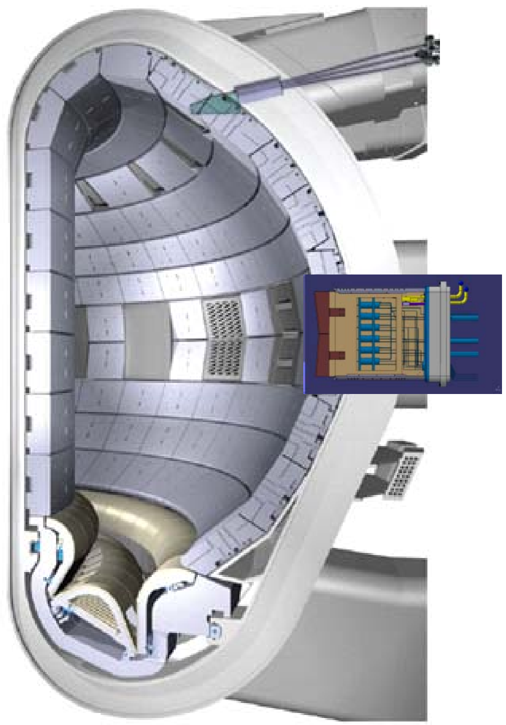


# *Shattered Pellet Concept for ITER*

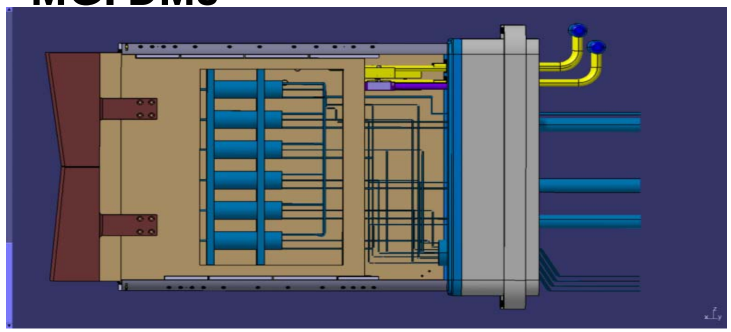



- **SPI located in upper port plug(s) with pellet ~1.5m from plasma edge**
- **Injector has multiple barrels for redundancy and adjusting amount injected – combination of MGI and SPI is possible**
- **Bent tube for shattering located inside shield block**

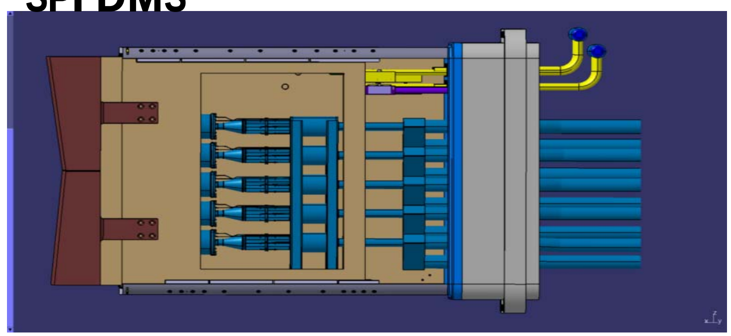
# *Equatorial Port for DMS RE Suppression/Dissipation*



MGI DMS



SPI DMS

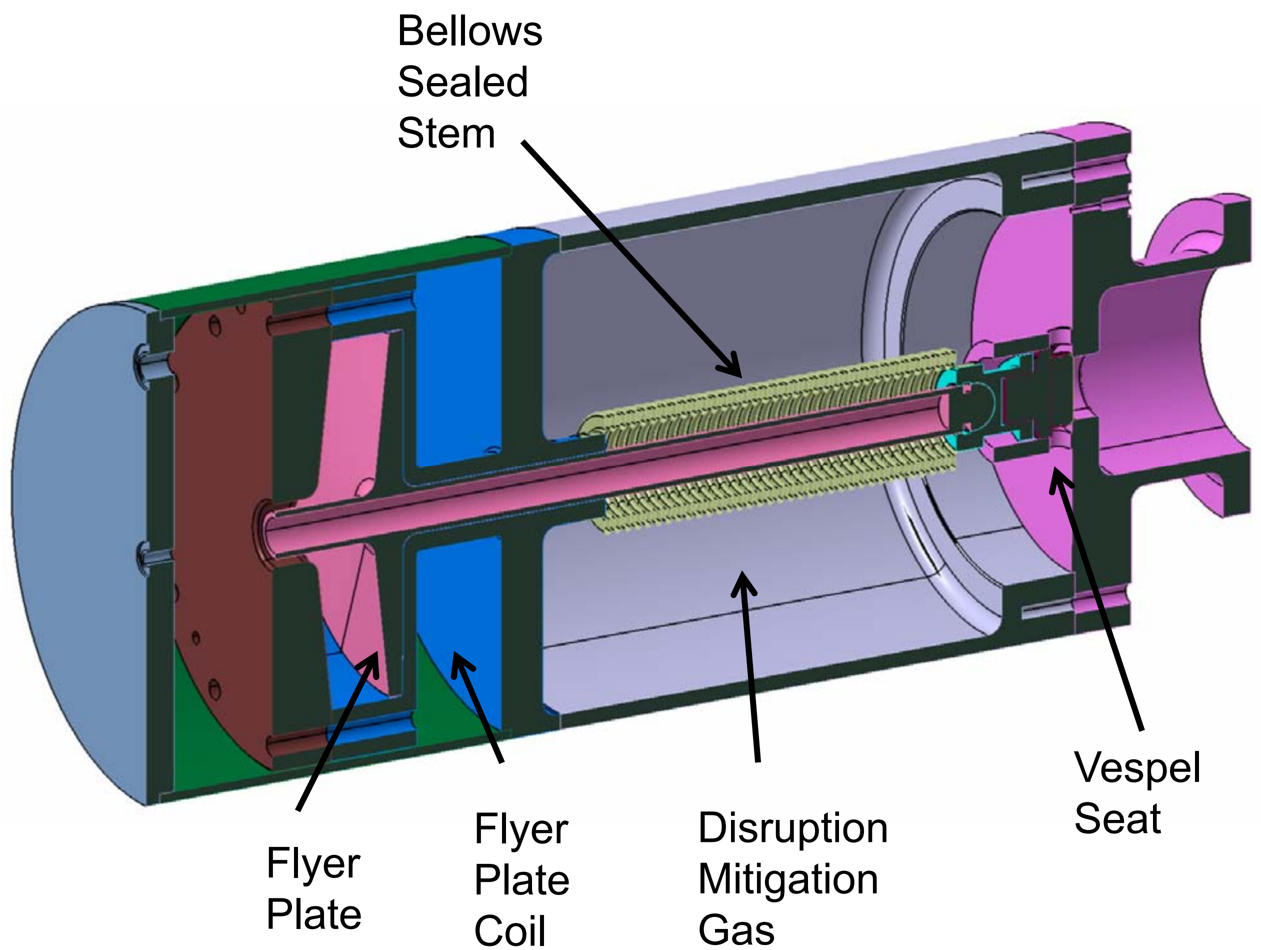


up to
100 kPa m$^3$
for RE
suppression

- **SPI or MGI systems to be located in one equatorial port plug for runaway electron mitigation**
- **Injector has multiple barrels for redundancy and adjusting amount injected – combination of MGI and SPI is possible**
- **Bent tube for shattering located inside shield block**

# *MGI Gas Valve Concept for ITER*

- **Valve seal is Vespel on stainless steel.**
- **Otherwise most similar to design of DMV-30 Juelich valve used on JET.**
- **Assume Vespel sealing force of 10 N/mm.**
- **Sealing force estimated at 1005 N (226 lbs).**
- **Coil is isolated from flyer plate by a stainless steel valve housing.**



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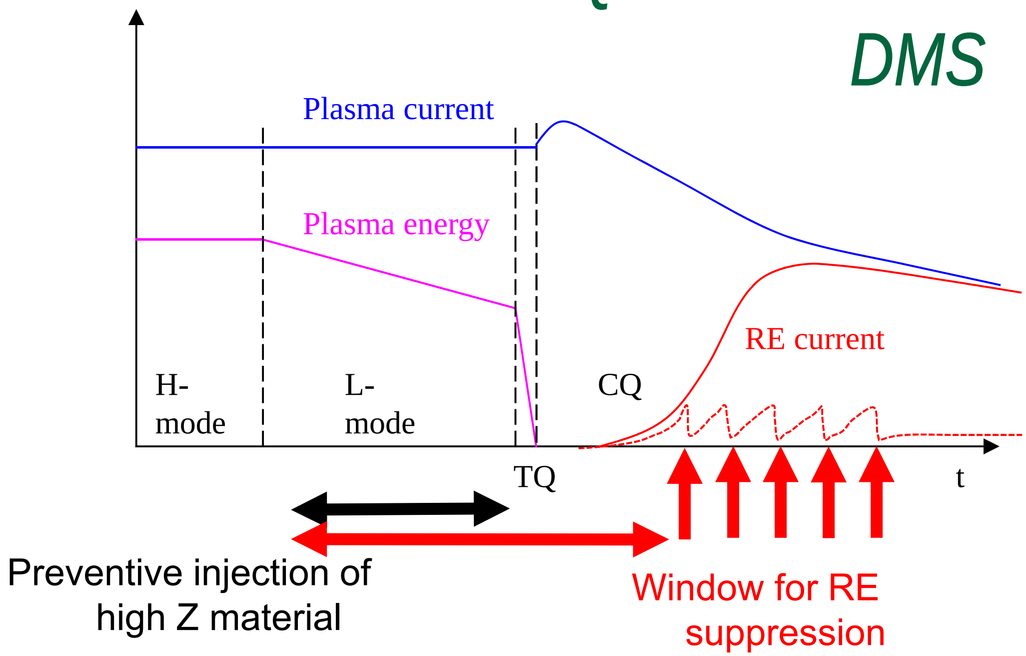
# *Time Scales and Quantities of Material Estimated for ITER DMS*



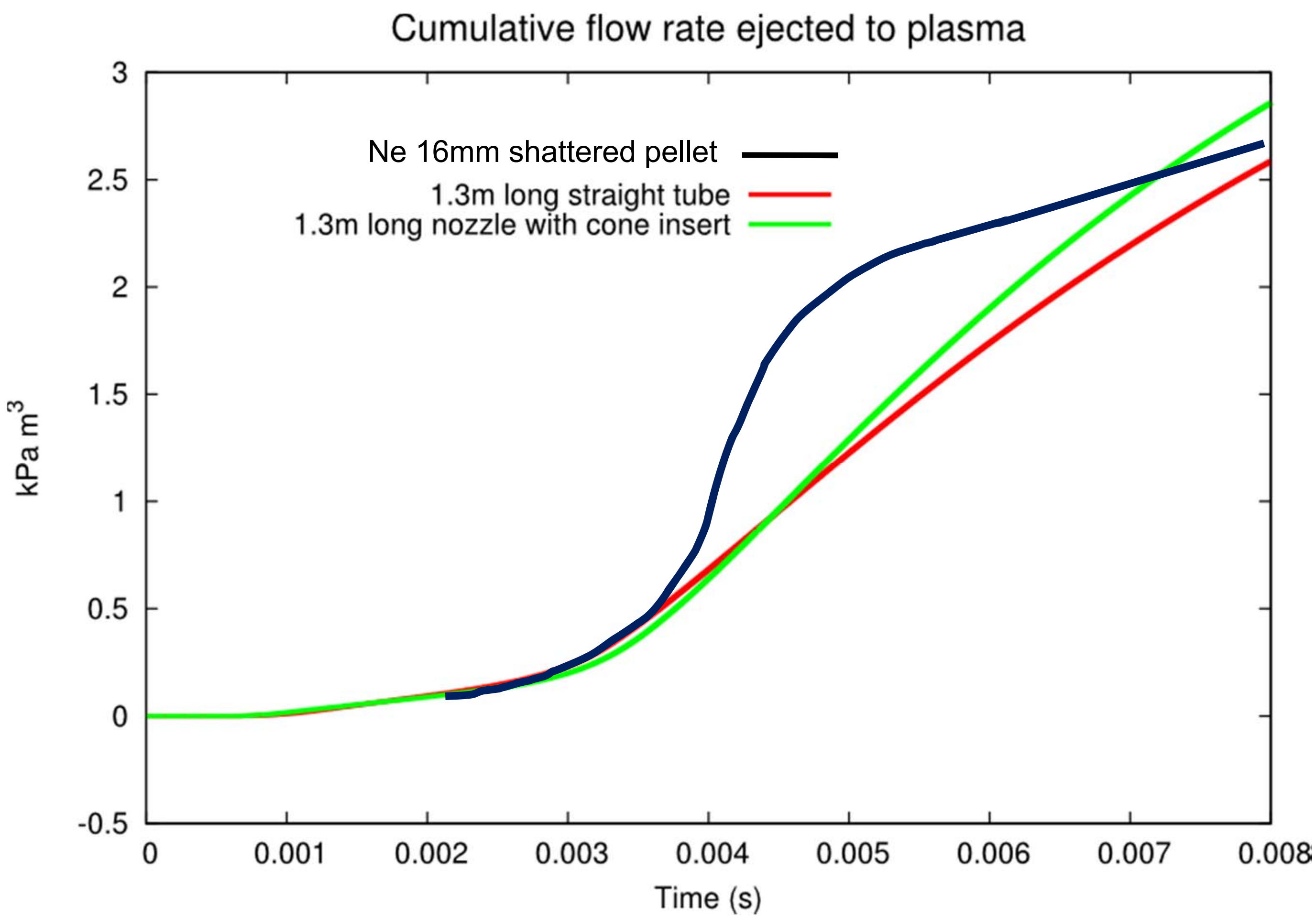

- **Advance warning: 20-50 ms**
- **TQ time: ~3 ms**
- **CQ time: 50-150 ms (requirement)**
- **RE generation time: 20-40 ms**

- **Response time for needed for TQ mitigation (actuation + gas arrival delay) < 10 ms**

- **For RE suppression:**
  - collisional suppression – 10 ms
  - repetitive injection in CQ – 1-3 ms

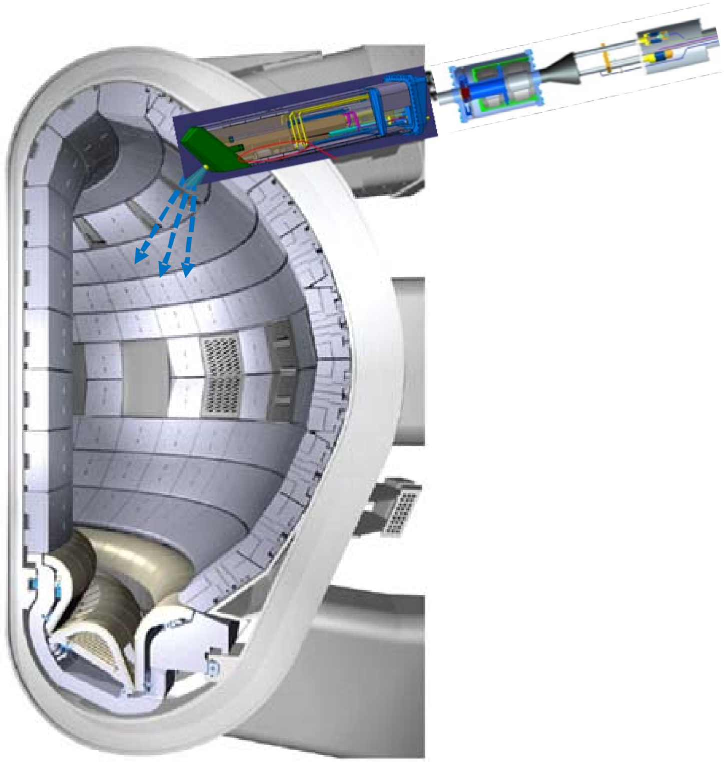
- **RE dissipation needed if RE suppression fails**

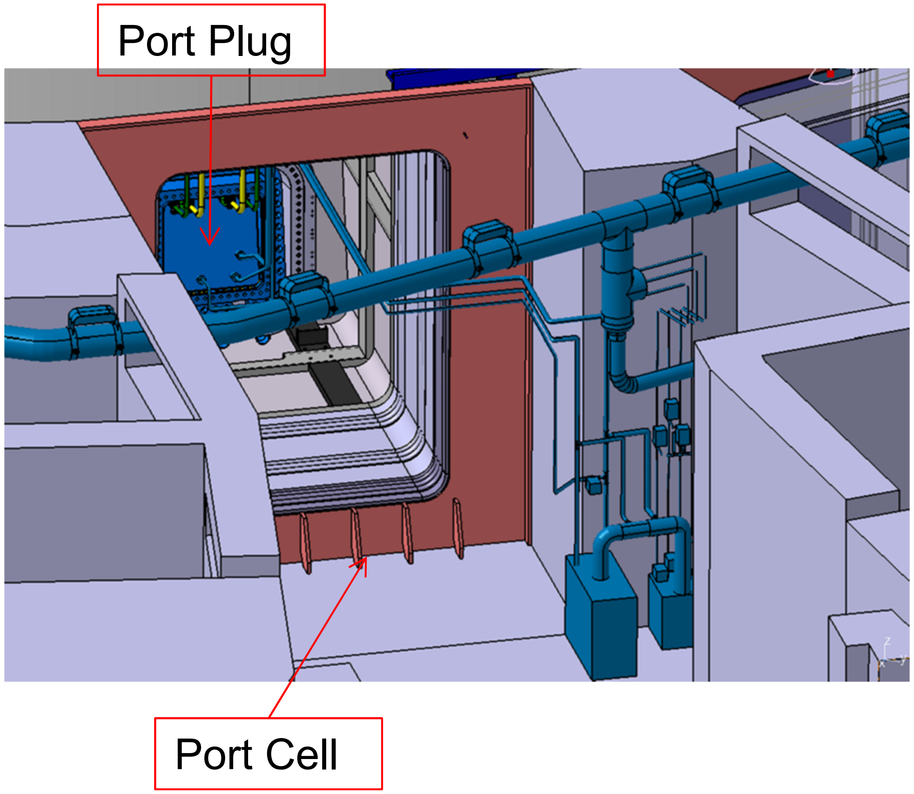
# *ITER Time Scales for Neon Gas/Pellet to enter the Torus (TM system in UPP)*




- **This assumes DM system is 1m from the plasma with realistic valve opening times.**

# *Backup Plan to Locate Injector Outside of Port Plug*





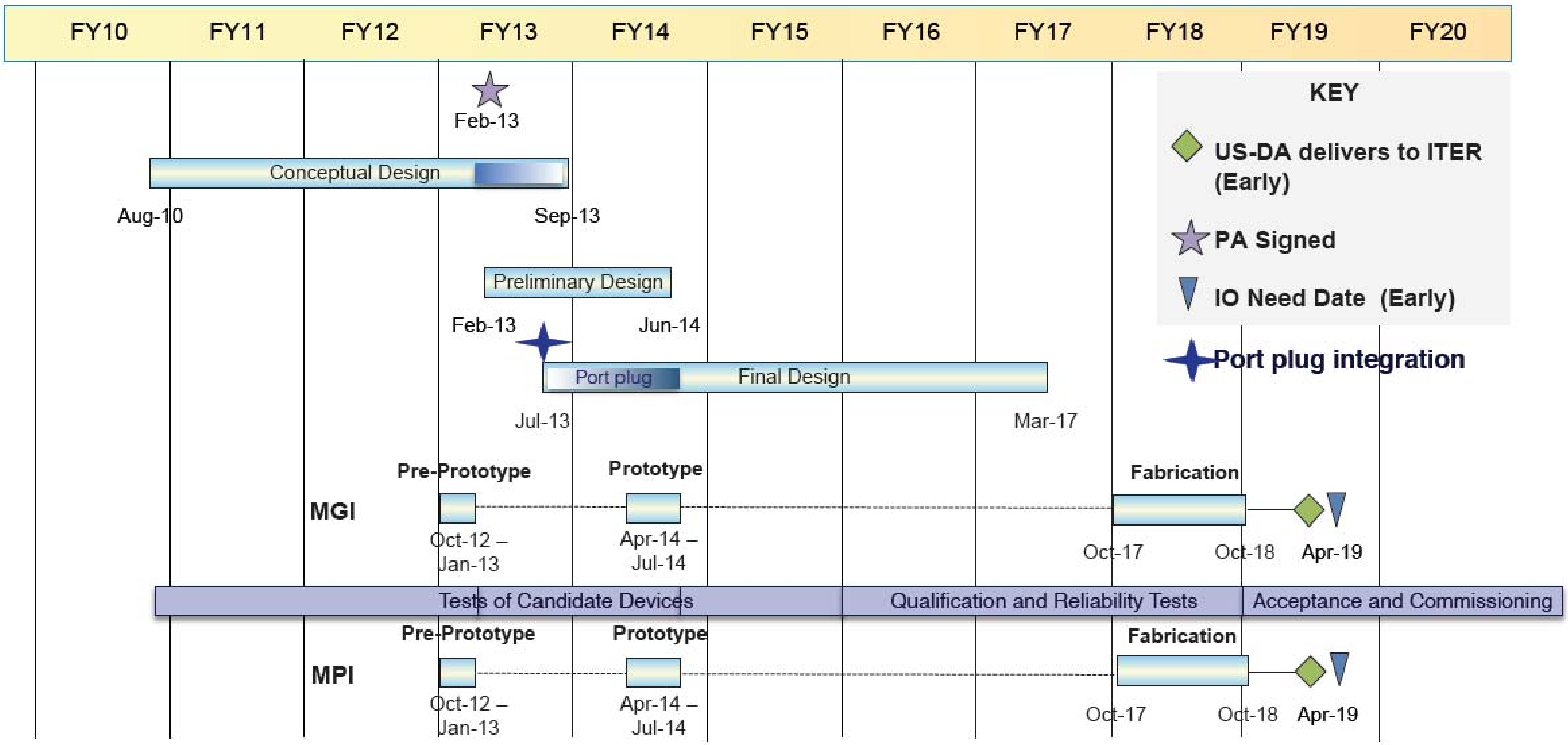

- **Injector inside of port plugs cannot be maintained.**
- **Injectors located outside of port plug in port cell can be maintained, but is 11m away from plasma.**
- **This adds some 10- 30 ms to the response time for injection, but with enough precursor warning this may be enough.**

# *Pros and Cons of the Most Favorable Techniques*

- **MGI of Ne, Ar, and $D_2$ (ITER – DCQYNS, 4H6CJQ)**
  - Proven technology for mitigation of thermal loads – ITER size an issue?
  - Ne does not activate, Ar activation is tolerable. $D_2$ might be needed to optimize gas mixture
  - Does no harm to the wall
  - Injection in CQ is possible - (Works on DIII-D/TS for RE dissipation)
  - Pumping system limit ~100 kPa-m$^3$
  - Fast reliable delivery system yet to be developed for ITER environment
- **SPI Large cryogenic shattered pellets (ITER – DCR5DE)**
  - Mature technology tested in DIII-D experiments
  - Needs testing for RE dissipation (pellets do not ablate in CQ plasmas ) (Gas, Liquid)
  - Requires SCHe connection in the port plug - Remote injector has longer response, but is maintainable.
  - Gas propellant valve needed for ITER environment.
- **Solid Be particles (ITER-DCQ2LE)**
  - Easy to inject – short delivery time but long disruption triggering time (!)
  - No load on pumping system, produce some dust, consistent with wall material
  - No runaway electrons produced (based on calculations)
  - Can be used only preventively (pellets do not evaporate in CQ plasmas)
  - Can result in wall damage or large fragments (hollow bullets to mitigate impact?)
  - Can result in too long CQ and large forces (must be evaluated)
  - Has not been tested. Reloading system needed. Need experimental tests on JET

(S. Putvinski)

# Disruption Mitigation Schedule



# *Summary*

- **Disruption mitigation for ITER is an important capability needed to maintain the first wall (JET Be wall shows what can happen)**
- **Material injection on a fast time scale has been proven to mitigate most disruption effects and is planned for ITER**
- **Time scales and material quantities are a challenge for DMS material injection ITER.**
- **DMS concepts for ITER are:**
  - **Massive Gas Injection (TM, RE)**
  - **Shattered Pellet Injection (TM, RE)**
  - **Be Particle Injection (TM)**
- **CDR went well and concepts are now being engineered and tested by US ITER/ ORNL for ITER port plug environment.**

# Disruption Terminator

Jan2013 LRB