Requirements and progress in vacuum modeling on ITER.

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Summary

- Introduction to ITER
- Divertor design and torus operational pumping optimisation.
- Mitigation and Abnormal event modeling.
- Modeling of plasma breakdown.
- Modeling of leaks
- Wish list for codes

Introduction to ITER

International Thermo Nuclear Reactor (ITER)

ITER ("the way" in Latin) is the essential next step in the development of fusion.

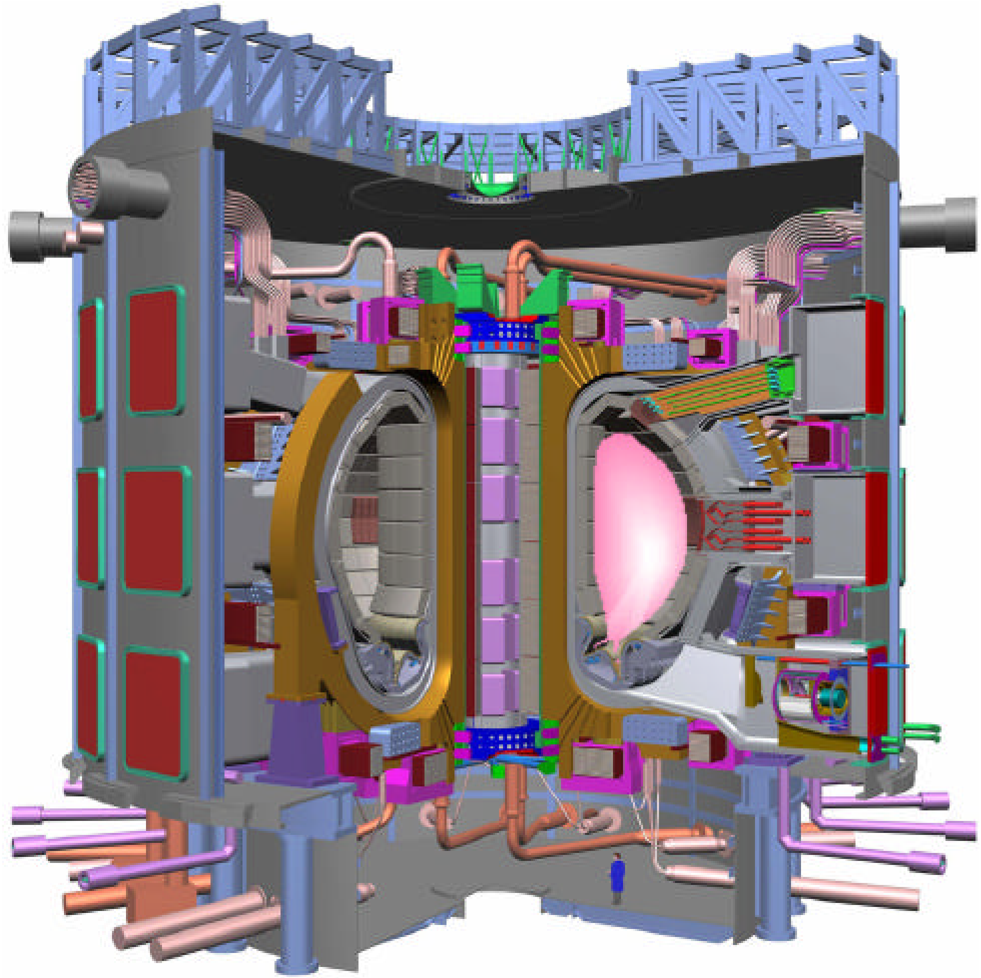
Objective is to demonstrate the scientific and technological feasibility of fusion power.

Will take over from JET as the world's largest fusion energy research project.

Biggest international scientific project since the space station

Will be built at Cadarache near Aix-en

-Provence, France.



International Collaboration

7 Parties, signed up, November 2006

Represents approx. half the worlds population

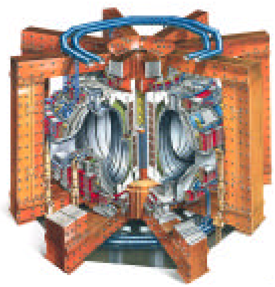
Main supply for ITER is split between the Parties.

Technological split will produces interesting   challenges.

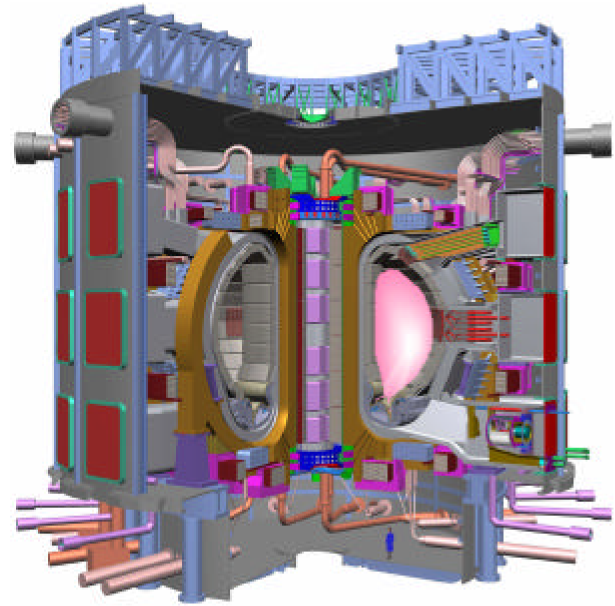
Current target is to achieve first plasma in March 2016

Main Parameters

JET



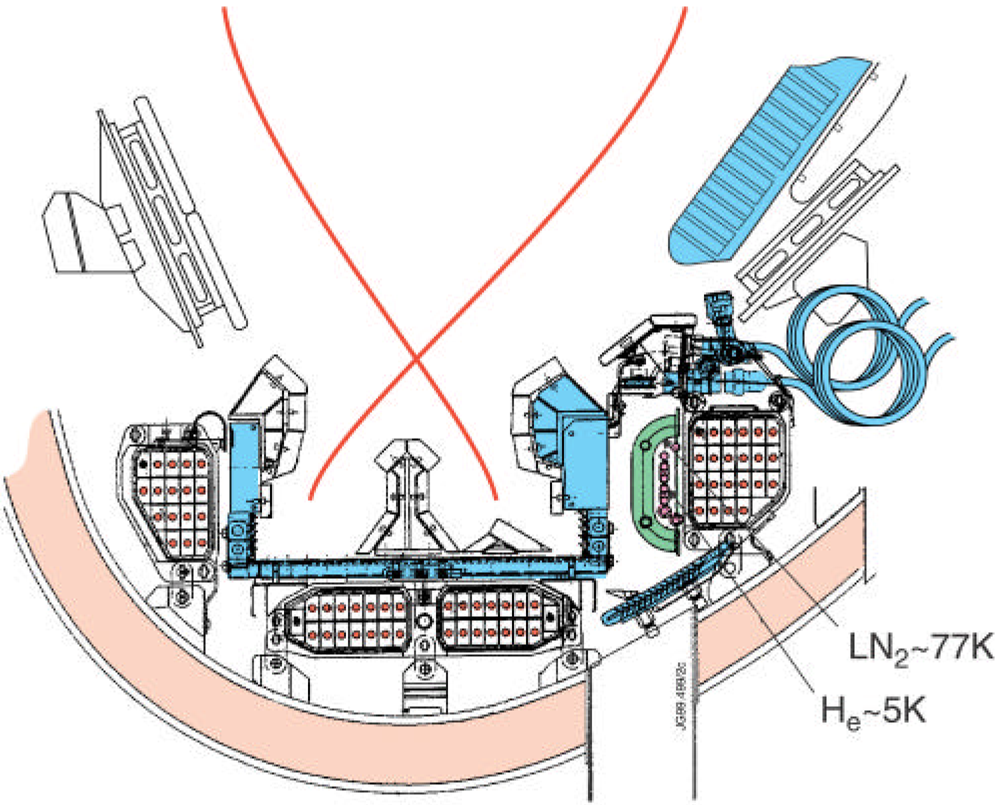
ITER



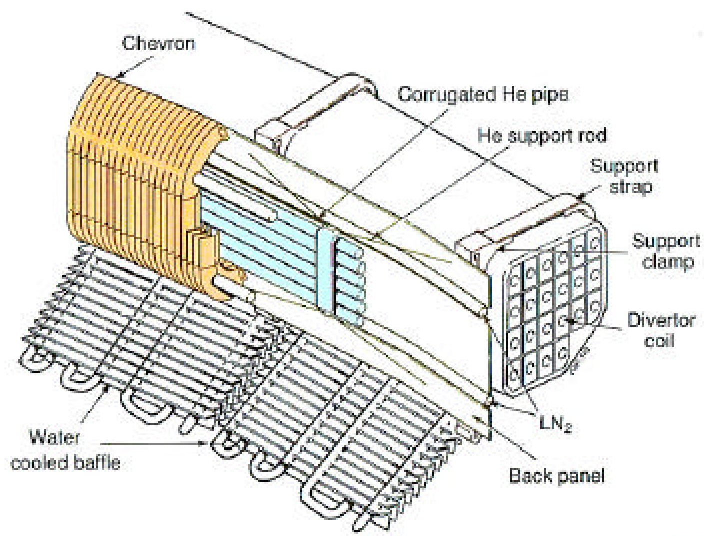
Vessel major radius	3m	Plasma major radius	6.2m
Vessel minor radius	1.2m	Plasma minor radius	2.0m
Vessel height	4.2 m	Vessel height	10.2m
Vacuum volume	$189m^3$	Vacuum volume	$1400m^3$
Plasma volume	$\sim 100m^3$	Plasma volume	$\sim 837m^3$
Plasma current	to 4.6MA (7MA)	Plasma current	to 15MA
Toroidal Magnetic field	to 4 T	Toroidal magnetic field	5.3 T
Pulse length	~30s	Pulse length	~400s
Additional Heating	~30MW	Additional Heating	~73MW
Fusion power (1997)	16MW	Fusion power (expected)	500MW
		Cryostat volume	$8000m^3$

Objective for 2016

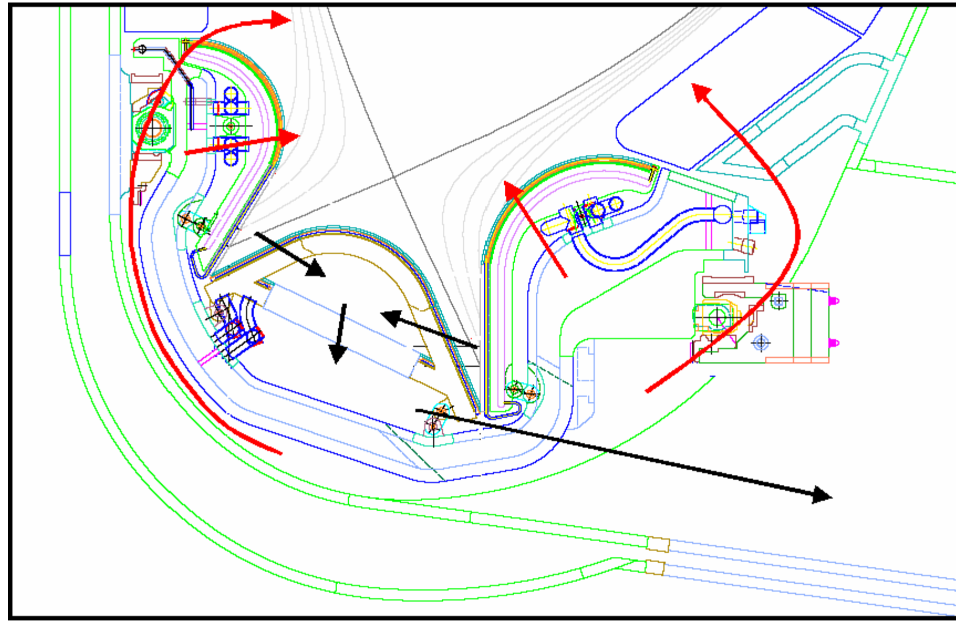
Divertor design and torus operational pumping optimisation.



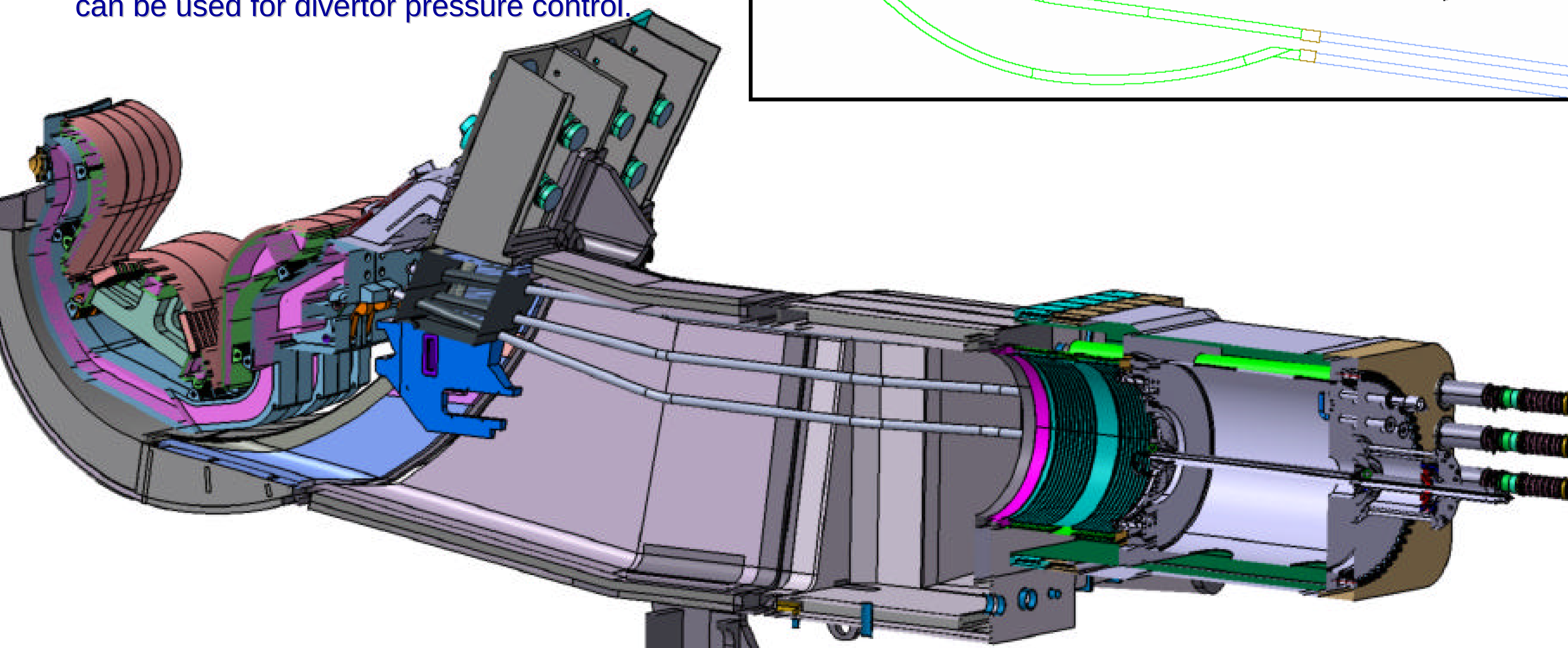
- Divertor used for impurity, and helium ash removal.
- On JET you have high pumping speed + ability to have very high fueling rate in divertor.
- Neutral pressure in divertor lead to “detachment” hence power flux control.
- Polyamide mesh used on JET to try to reduce conductance on neutrals back from divertor to main chamber.



ITER divertor

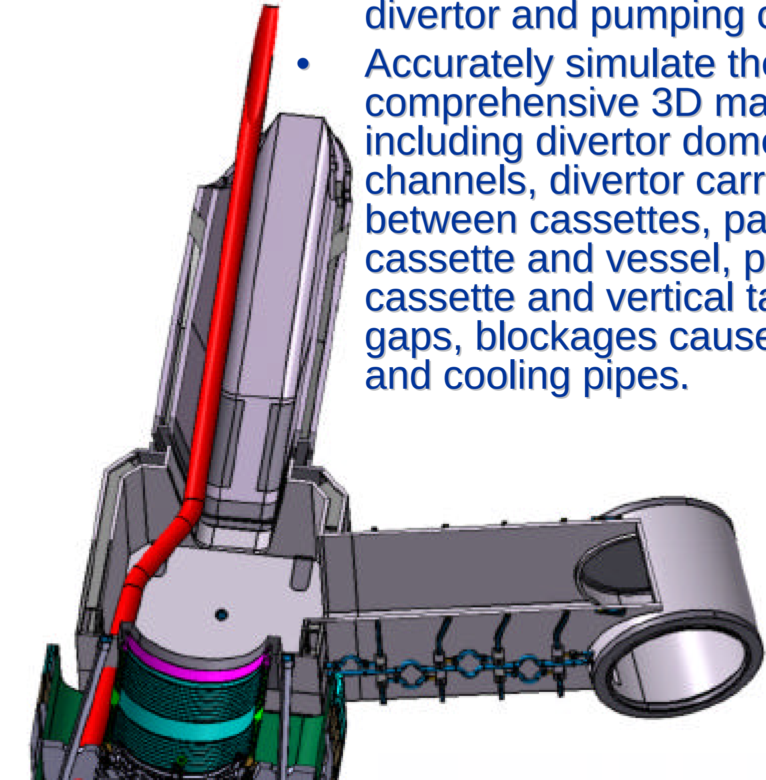


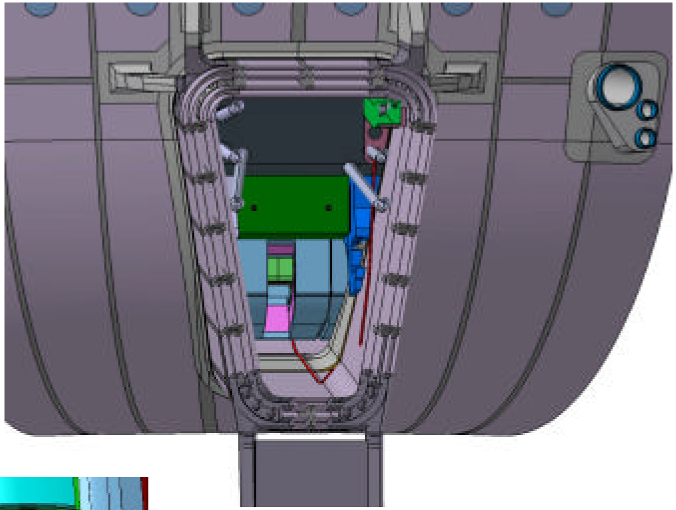
- On ITER the there is lower pumping speed than JET.
- Maximum average fuelling rate is also limited (currently 120 Pam ^{3} S for DT)
- Expected that Pressures 1-10 Pa required in divertor for desired detachment.
- Expect to have to optimize divertor design for “gas leakage”
- Require conductance to torus cryo pumps for molecular and transition flow.
- Require to understand if cryopump entry valve can be used for divertor pressure control.

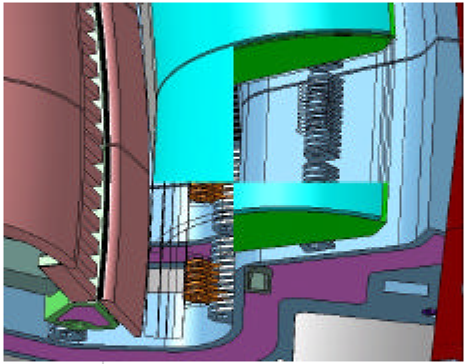


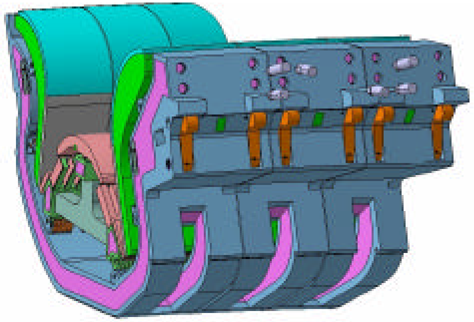
FZK will use ITERVAC to :-

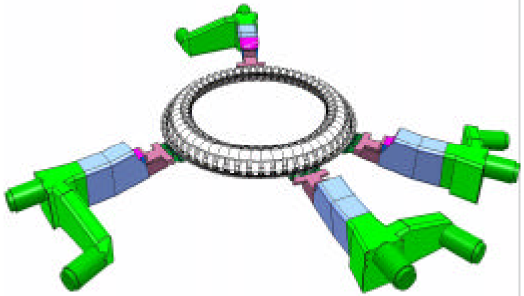
- Develop a full network model of the ITER divertor and pumping connections.
- Accurately simulate the divertor region a comprehensive 3D matrix is required including divertor dome slots, toroidal channels, divertor carrier slots, gaps between cassettes, paths between cassette and vessel, path between cassette and vertical targets, mountings gaps, blockages caused by diagnostics and cooling pipes.

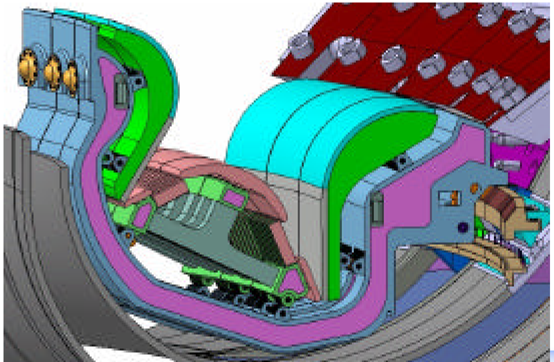












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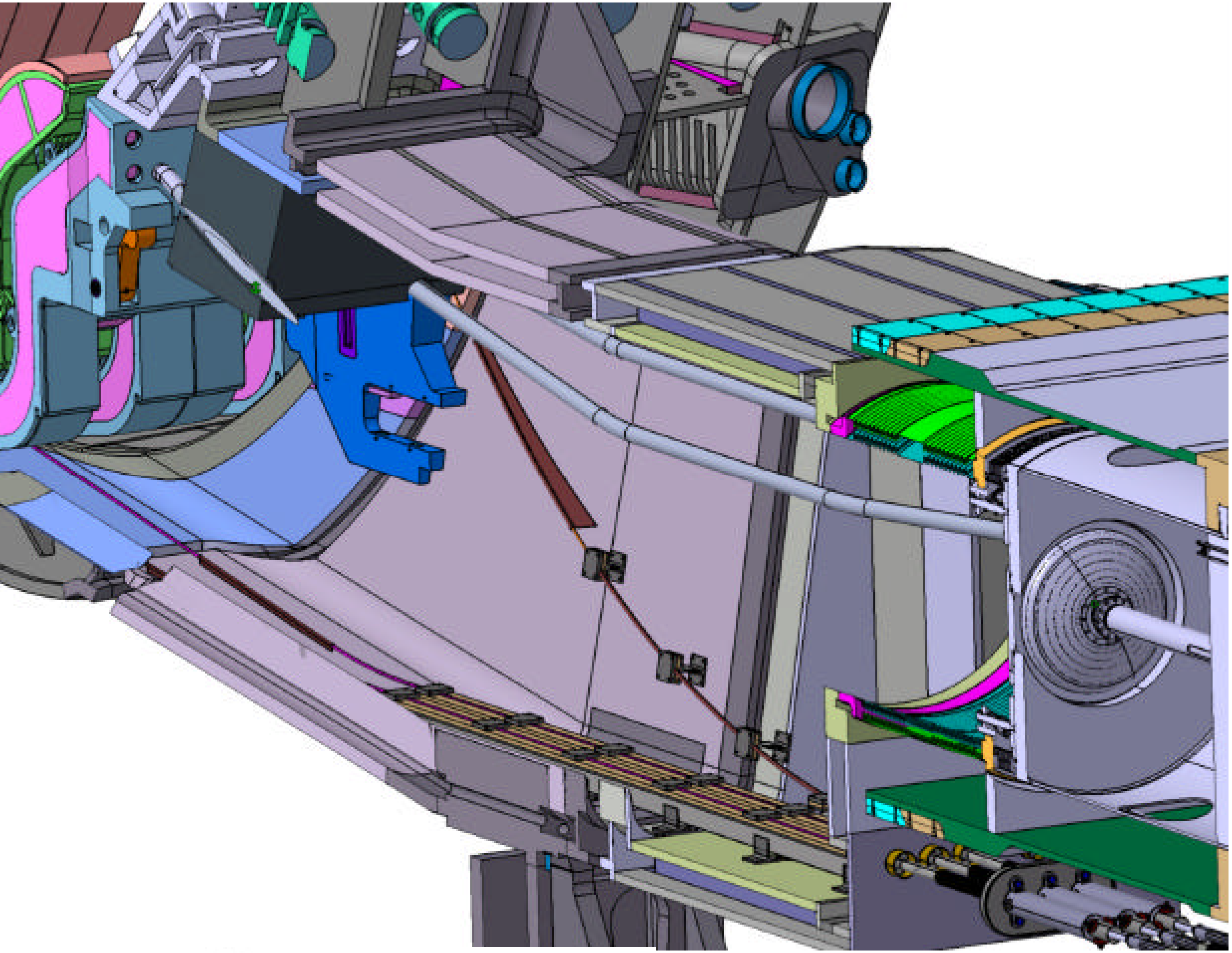
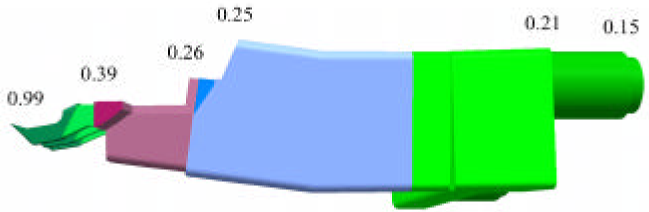
EUROPEAN FUSION DEVELOPMENT AGREEMENT

Molecular Flow Conductance



Await MOVAK3D calculations for total molecular flow pumping speed for current reference design.

Fag packet calculations give >100m^3/s for 4 pumps.



Previous Restricted pumping configuration gave ~28 m^3/s for 4 pumps.

Mitigation and Abnormal Event Modeling

ITER is a very complex collection of inter related systems. We have to ensure that we design for fault tolerance an ensure that there problems do not cascade. Contract just being placed to analyze fault sequences and to model some key areas which may include: -

- Response of the cryostat cryo-pumps to a sudden high helium gas load caused by a cryogenic break.
- The cryo-pumps response to and recovery from water ingresses.
- Tritium permeation into the helium circuits during high temperature regenerations.
- Maintenance of pumping capability during increased gas loads for example from operation of the disruption mitigation massive gas injection system.

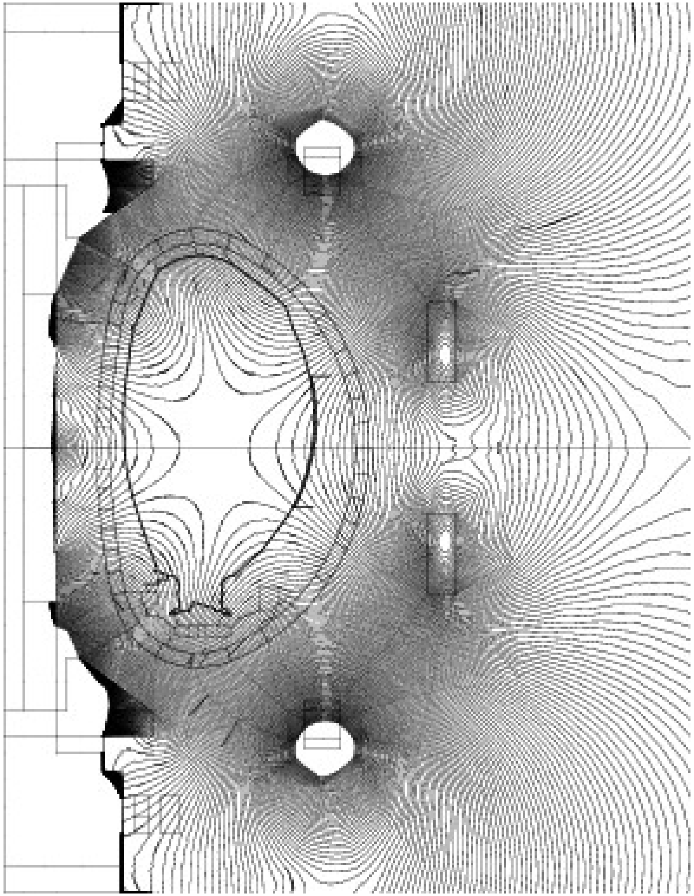
Application of Direct Simulation Monte Carlo (DSMC) would be appropriate for some of the transition flow situations.

Tritium permeation into helium circuit could be an important issue but complex to model due to surface effects.

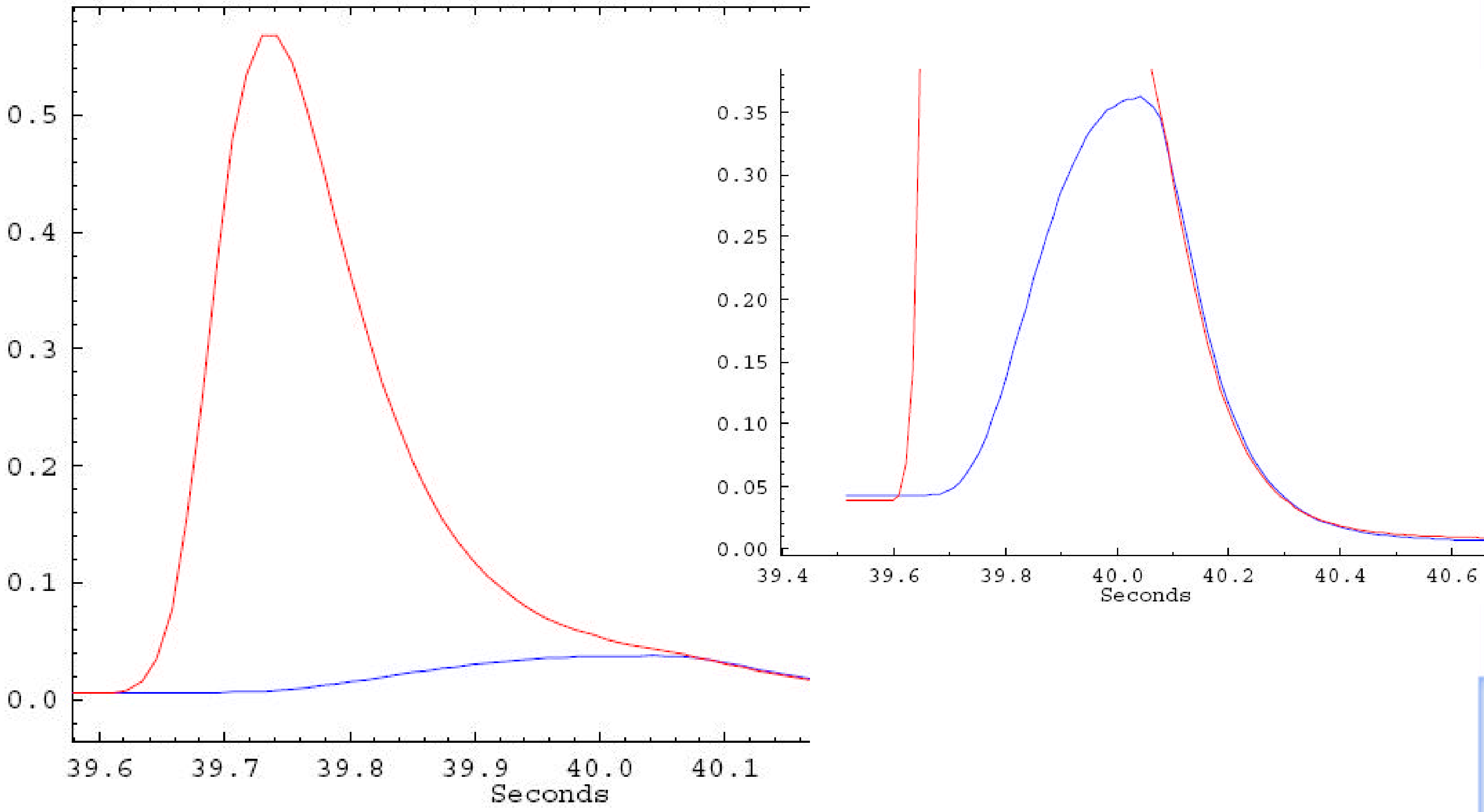
Initial breakdown and formation of a tokamak plasma

On JET the first consequence of poor vacuum or surface conditions is failure to maintain plasma breakdown.

- A long ion path length (~1000m) is created by creating a magnetic hexapolar null. A loop voltage of ~0.6 V/m is induced, allowing Paschen breakdown with a deuterium pressure of order $5x10^{-3}$ Pa in an initial volume of ~ $7m^3$.
- There is some flexibility on loop voltage and pre-fill pressure and the initial impurity content of the gas is not so critical for the formation of this initial Townsend discharge as ionization probabilities for air and hydrogen isotopes are not so different.
- As the fraction of ionized particles increases the interactions become coulomb dominated and impurity radiation peaks.
- An increase in plasma current ("burn through") is required to produce a stable, confined, plasma.
- The success of the transition is dependant on wall conditions.



Gas injection on JET for plasma breakdown



- On ITER the reference is to initiate the discharge using ECRH power, with either a outboard plasma initiation 100m^3 or a central plasma initiation of 340m^3 and a loop voltage of ~0.3 V/m.
- Generally this requires lower pressure ~10^{-3} Pa. The ECRH can also be used to assist the energy balance in the "burn through".
- Modeling from an electro-magnetic/radiation using TRANSMAK [A Mineev of RF] and plasma resistance using SCENPLINT gives limits for the maximum impurity content for a particular ECRH power and pressure.
- The big unknown for which there is not an effective model is the hydrogen isotope and impurity influx from the first wall. This is complex because it must :-

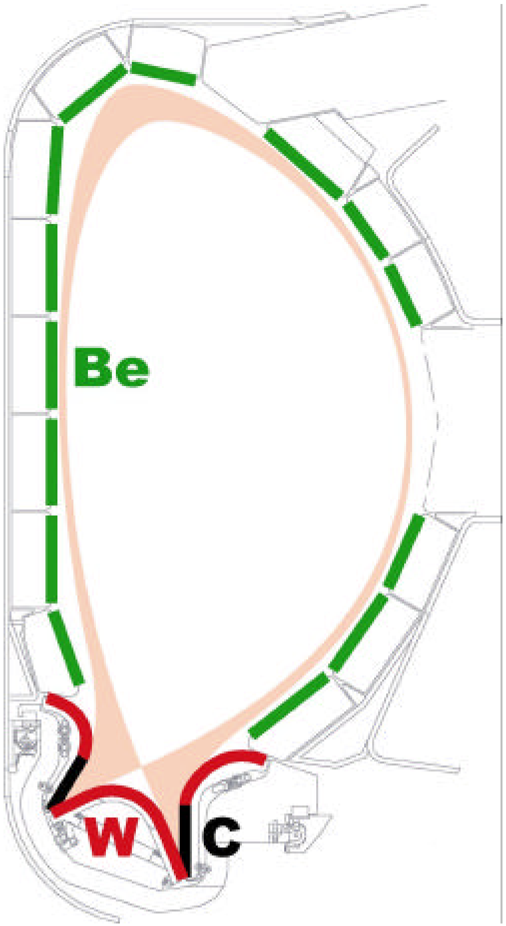
  Consider outgassing from different materials (Beryllium, tungsten, Carbon, Stainless) with different surface properties and implantation histories.

  Consider error fields and imperfections in confinement.

  Consider leaks

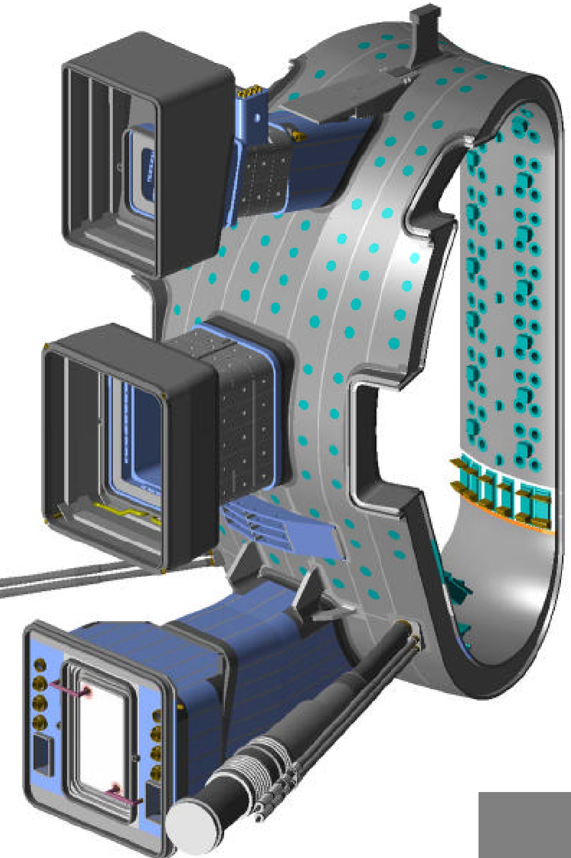
  Consider complex surface chemistry with impurities and oxides

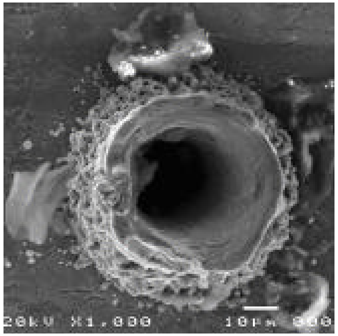
  Consider gas release by different mechanisms, ion induced (different energies, neutral induced, resonances near surfaces, etc)

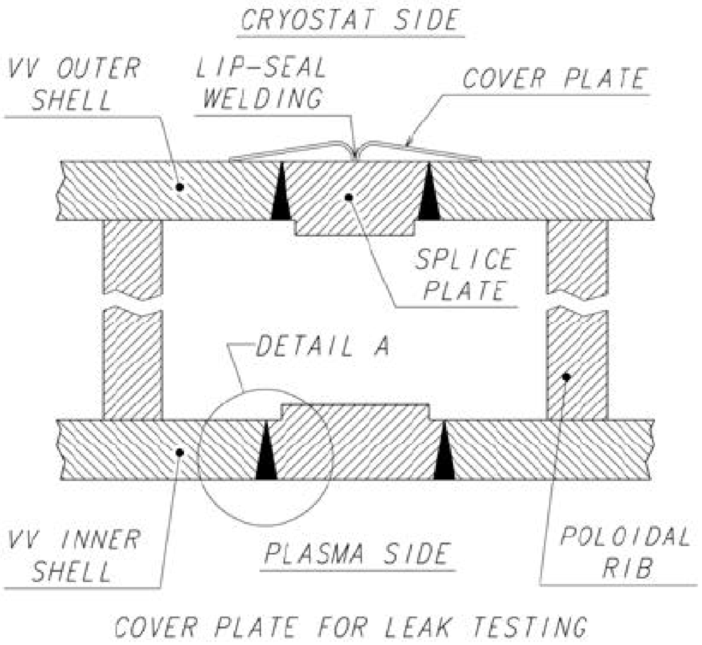


- JET will be converted to metal wall (Be) and hence it will be possible to partially validate a model for this if there is interest in producing such a model.

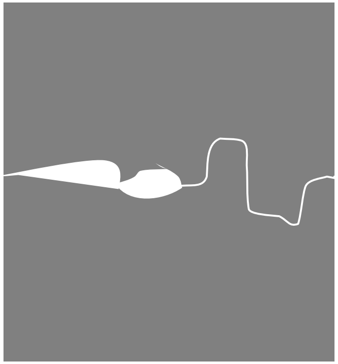
Modeling of leaks







80Km of MI cable



Helpful if we can get a handle on the responses we can expect from complex leaks.

Conclude with a “wish list” for a new gas modeling code

- Direct CAD interface for physical input (e.g. CATIA)
- Dynamic to take account of transient sources, static volumes and mechanical pumps.
- Surface temperature input to cope with multiple temperature zones
- Applicable across the pressure regimes (3MPa to 1 µPa)
- Possible to take into account absorption and desorption on surfaces
- Clear transparent outputs
- User friendly for non specialists

References

- [1] ITER PID see technical WEB site.
- [4] A Mineev RF ITER-D-2575N2
- ITER graphics