EUROfusion

EU Strategy to Fusion Power

Presented by Xavier Litaudon for EUROfusion

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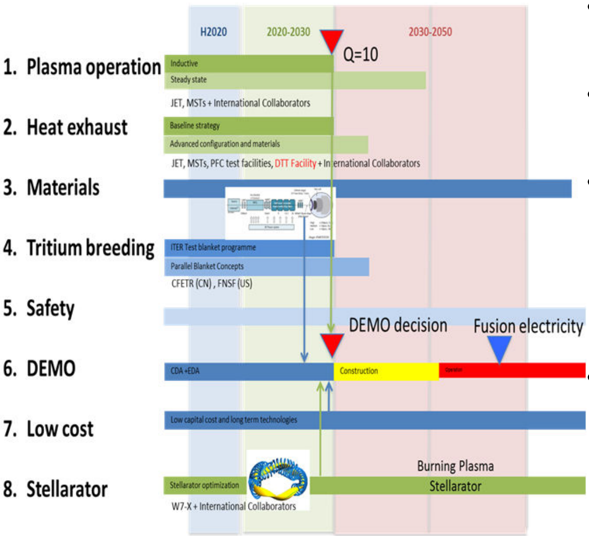
EU Roadmap to the realisation of fusion energy (2012)

http://www.euro-fusion.org/



[F. Romanelli et al 2012]

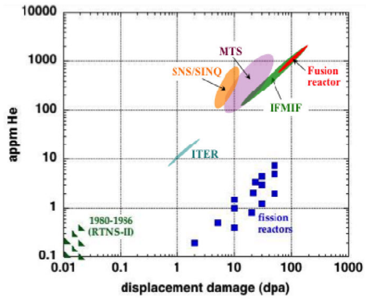
- Joint EU programme with clear goal
- ITER: the key facility & critical path
- DEMO construction after ITER Q=10 and a single step to a commercial fusion power plant
- 2016 EU roadmap adaptation with revised ITER schedule

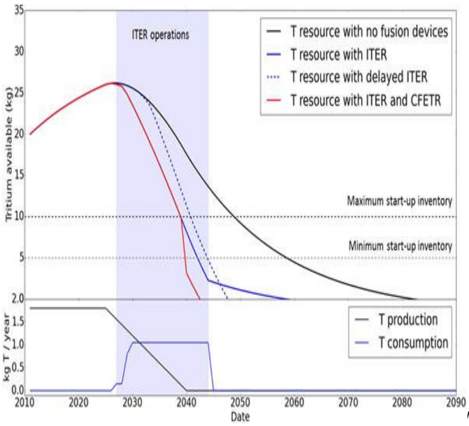
Gaps to Fusion Energy

1) Sustainment of high gain burning plasma

- Control of Burning plasma, long duration, heat exhaust

2) Materials resistant to high heat fluxes and neutron fluence



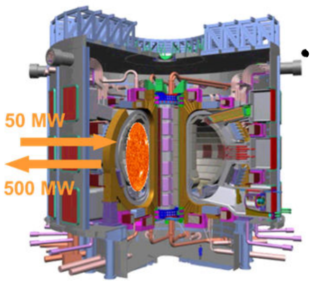


3) Tritium cycle & T self-sufficiency

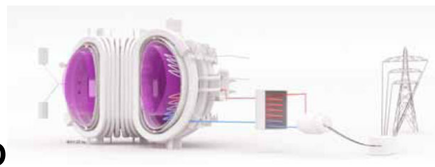
- ~112kg T/year for 500MWe reactor
- Efficient breeding & extraction
- DEMO MUST operate and produce its own tritium around 2050

Outline: Europe doing all possible to

Exploit recent advances in physics and technology to minimise the impact of the revised ITER timeline on the demonstration of fusion electricity:



- **Support ITER construction and Optimise ITER operation**
  - Risk mitigation for ITER by doing supporting research in contemporary devices



- **Ensure minimal delay to DEMO**
  - Conceptual design System Engineering Approach
  - Address universal technical challenges with gaps beyond ITER
    - safety, T-breeding, power exhaust, remote handling, component lifetime and plant availability

Research Issues* during ITER Construction

Key issues for the supporting Physics Research Programme accompanying ITER construction

- Plasma-Wall Interaction
- H-mode and access conditions to high confinement
- Scenario development
- MHD stability control

Issues strongly linked: integrate results into 'flight simulator' for ITER experimental preparation & validation

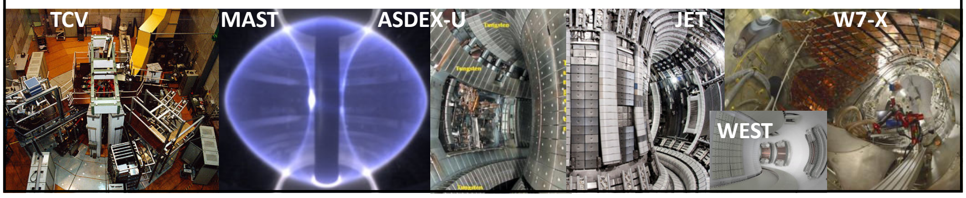
Impact on ITER by

- affecting the design of 'permanent' components
- affecting 'upgradeable' components
- leading to improvements in scenarios & experimental plan towards Q=10

[*ITER Council-Science and Technology Advisory Committee, 8th Meeting 2010 ITER_D_346RPL_v1-1 IC-STAC-8/2.5]

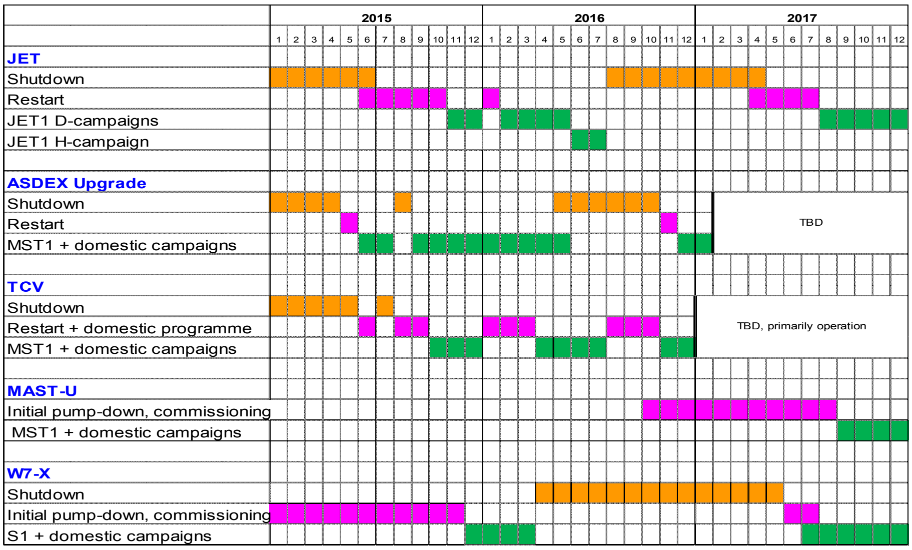
Prepare ITER operation: increase EU coordination

- **JET, Medium Size Tokamaks ASDEX Upgrade, TCV, MAST-U, WEST, linear PFC facilities and W7-X**
- **Address issues where EU coordination brings added value:**
  - Scaling to JT-60SA, ITER and reactors conditions
  - Operation with core & edge integration, High power steady-state
  - Divertor & PWI issues, ELMs mitigation, Disruptions
  - Diagnostics, Shaped configurations, Tight aspect ratios physics, …
- **Integration of knowledge through theory and modelling**
- **Systematic extrapolation for JT-60SA, ITER and DEMO**
- **Prepare EU to JT-60SA operation**
- **Internationalization of JET to prepare ITER Q=10 operation**



2015/2016 Planning JET, ASDEX-U, TCV , W7-X

EU Task Force Leaders have prepared an experimental programme to implement on each device: common General Planning Meeting early 2015 in Lausanne

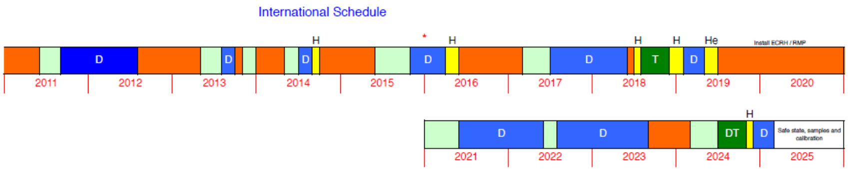


Proposal for ITER risk mitigation

- **Use contemporary fusion devices as ITER risk mitigation**
  1. lower the risk for further ITER delays
  2. reduce the time needed to achieve ITER Q_{DT}=10
  3. identify potential obstacles early enough, allowing time for alternative strategies
- **Reduce the ITER non-active phase by proper preparation and training on JET and JT-60SA**
  - Make longer use of JET as risk mitigation for ITER and train the ITER generation of operators, session leaders, sci-techs, etc.
- **Impact on ITER by leading to improvements in operation, scenarios & experimental plan**
  - Prepare ITER non-active phase and Q_{DT}=10 operation:
    - JET He, D, H, T, DT with ITER materials, T cycle, remote handling
    - JT-60SA with controlled long pulse baseline/hybrid operation
  - Prepare ITER Q_{DT}=5 operation and DEMO scenarios on JT-60SA

Proposal: JET internationalized

- **JET as an international ITER test bed, run by the international community**
- **Train ITER scientists, engineers and technicians**
- **Develop ITER technology and scenarios of operation using ITER control tools**
  - Upgrades in 2019/2020 with e.g. ECRH, RMPs, refurbishment of divertor, shattered pellet injector, diagnostics,….
- **Test ITER schemes for organising and implementing scientific campaigns**

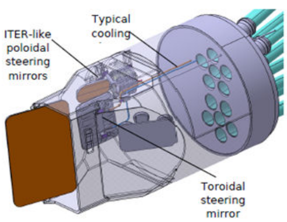


[Donné et al., J. Fusion Energy (2015)]

* Decision to proceed with major enhancements
Allow six months to establish project teams for enhancements
Details of post-enhancement schedule not yet agreed

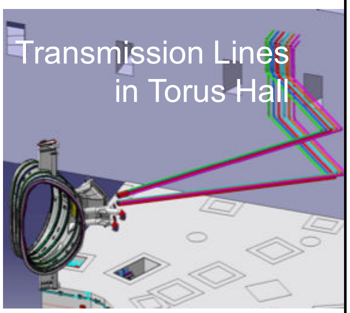
Prepare of ITER operation: ECRH for JET

- **10MW (12 Gyrotrons) at 170 GHz (ITER gyrotrons)**
- **Antenna: Toroidal and Poloidal steering**
- **Time to power in plasma: 4 years (7MW), 5-6 years (10MW)**
- **Prepare ITER operation with similar control strategy: NTM, sawteeth, W control, q-profile etc**



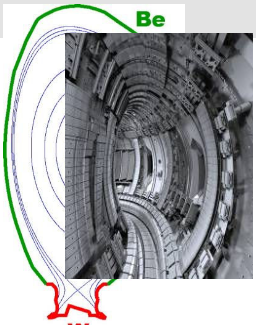
Launcher design

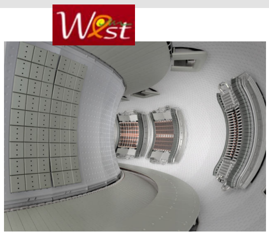
[Giruzzi et al., Nucl. Fusion 51 (2011) 063033)]



JET

EU Tokamaks with a metallic wall



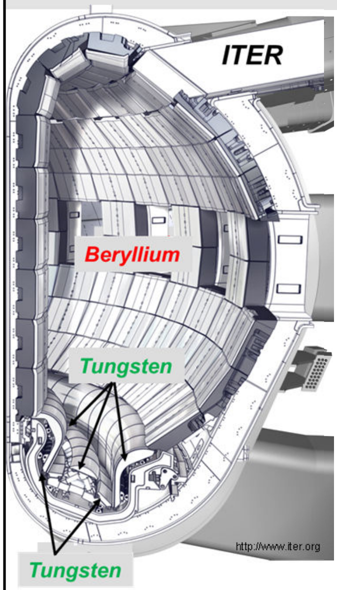


- ASDEX Upgrade
  - Conversion to all W PFCs complete gradually over 7 years
  - Massive outer W-divertor and new divertor manipulator (2014)
- JET
  - ITER-like Wall (Be wall and W divertor) change in one shutdown
  - Integrated test with T, D-T scenarios in 2019
- Tore Supra→ WEST (2016)
  - from limiter to divertor configuration, from carbon to W environment,
  - Long pulse operation with actively cooled ITER W-monoblocks components

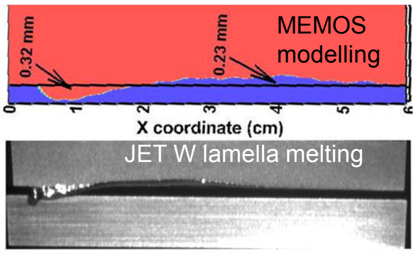
EU contribution: Metallic Walls

- ✓ Provide input to the decision on ITER divertor, wall shaping and DEMO main chamber
- ✓ Demonstrate low fuel retention, migration, dust production and fuel recovery
- ✓ Develop tools and diagnostics (IR) for improved plasma control and heat load mitigation (disruption)
- Demonstrate scenario plasma compatibility with metallic walls
- Test actively cooled ITER mono-block in linear devices and in a plasma environment

Impact on ITER W divertor



- ITER Plasma-Facing Material selection (till 2013)
  - Be/W/C in H/He and Be/W in DD/DT
- AUG and JET-ILW experiments
  - New ITER material selection: Be/ W divertor in all operational phases
- Key input from AUG, JET for divertor PFC change: dedicated melting of a leading edge W lamella



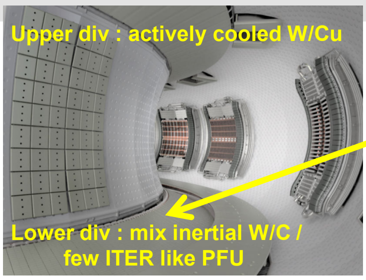
B. Bazylev IAEA2014

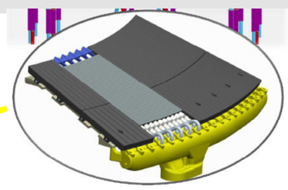
JET

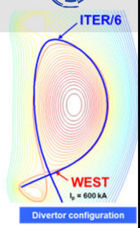
J.W. Coenen NF2015

- Operation with damaged lamella possible
- MEMOS benchmark for ITER predictions

WEST: test of ITER W-divertor components







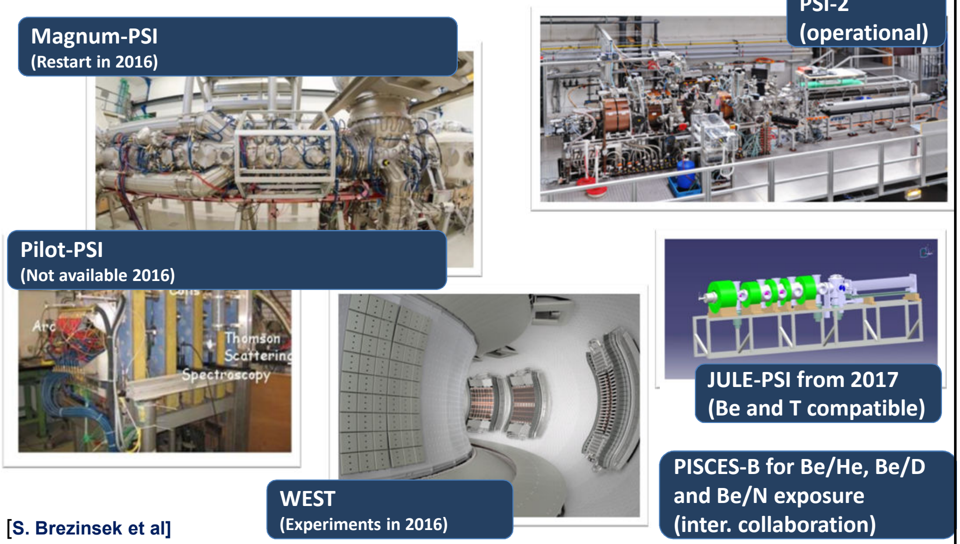
- WEST : ITER relevant steady state heat loads (10 MW/m^2) and incidence angle (2-3°)

Phase 1		Act. Cool.	Shaping	Material	Limit
Upper div.		Yes	Yes	W coating / Cu	Flux
Lower div.	Start up	No	Yes	W coating / C	Energy
	ITER like PFU	Yes	No	Bulk W / monoblock	Flux

- **2016-2017:**
  - High power test (10 MW/m2) of ITER components
  - shaping comparison
  - test of damaged or below specs components
  - long pulse experiments on W coatings (upper div)

Plasma Facing testing Facilities

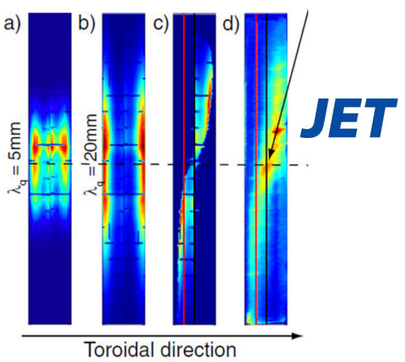
- **Plasma facilities (+ e-beam, ion beam facilities)**



[S. Brezinsek et al]

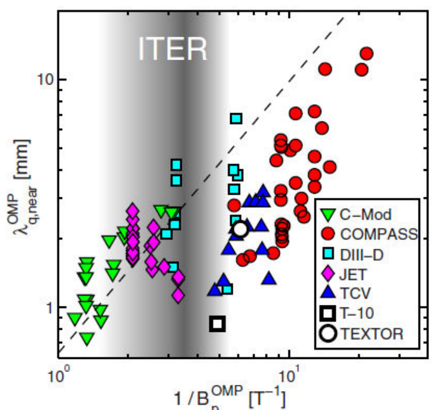
Impact on ITER Be wall

- Be PFC power-handling exp. in limiter: unexpected narrow power-decay length at the limiter centre
- **parallel heat flux not described in SOL with a single decay length λ_q**



[Arnoux et al Phys. Scr. 2014,
Arnoux et al N.Fus 2014]

- Multi-machine scaling (ITPA) : no scaling with machine size

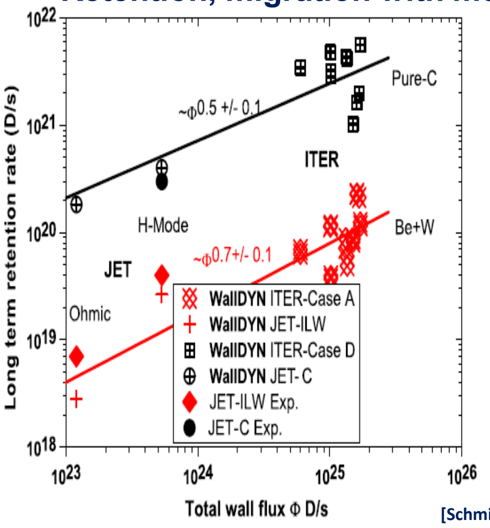


[M. Kocan Nucl. Fusion 55 (2015) 033019]

ITER has chosen λ_q = 4 mm for narrow feature and has redesigned the inner wall toroidal shape in 2014

D retention in AUG, JET and ITER

Retention, migration with metallic wall

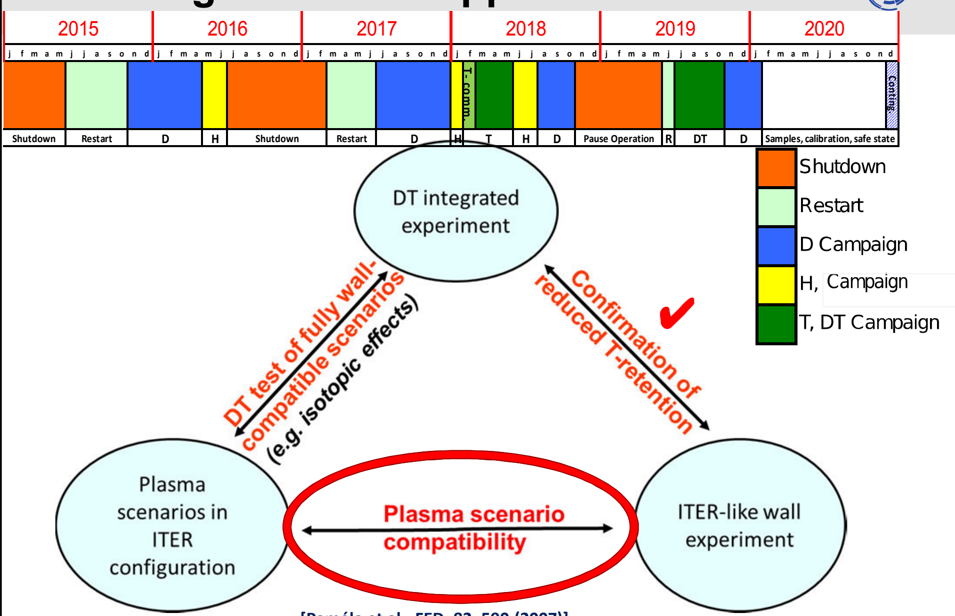


- **Retention rate divided by ~10**
- **Reduction of dust production by factor 100**
- **Simulations reproduce retention reduction**
- **ITER T retention limit (400s D-T): 3 000-20000 discharges vs 100-700 for C-Wall**

[Schmid et al NF 2015 , Brezinsek et al J. of Nuc. Mat. (2015) 11, Rubel SOFT 2014]

Xavier Litaudon | Fusion Power Associates, 36th meeting | Washington | 16-17 Dec. 2015 | Page **17**

JET Programme in support of ITER

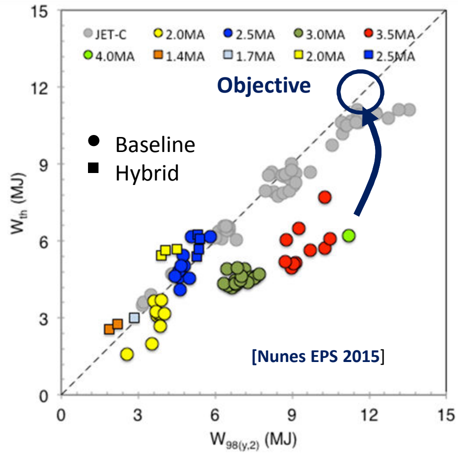


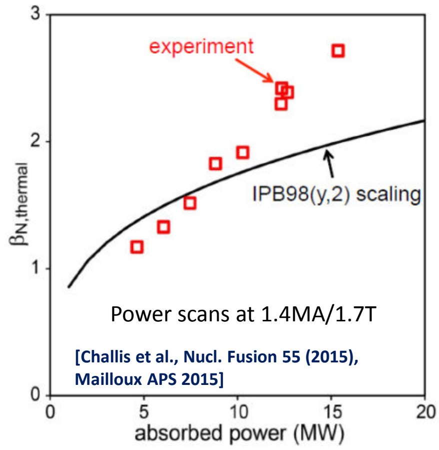
[Paméla et al., FED. 82, 590 (2007)]

JET

Xavier Litaudon | Fusion Power Associates, 36th meeting | Washington | 16-17 Dec. 2015 | Page **18**

Plasma Regimes of Operation for ITER





↑ power (~40MW) to sustain (~5s) at β_N ~2 or β_N >2

Divertor Heat exhaust control: sweeping, impurity seeding

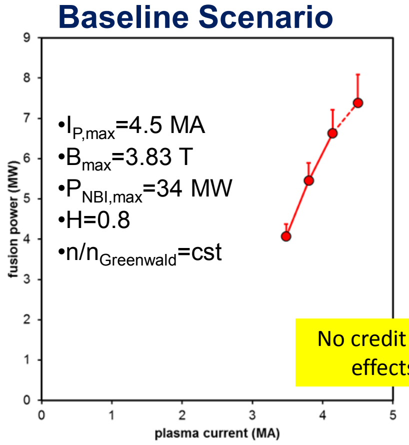
Understanding is critical for optimizing ITER DT operation

JET

D-T Fusion Performance Prediction

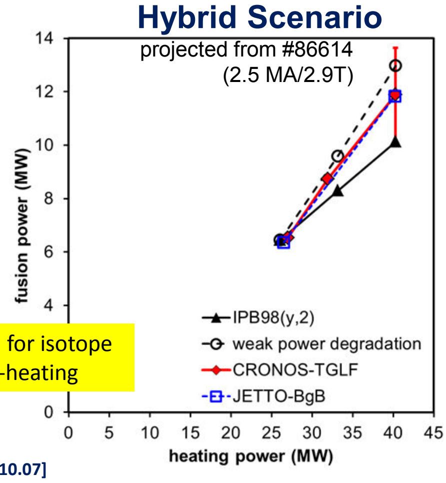
- **JET unique contribution to fusion research due to its capability to operate ITER scenarios with H, D, T and D-T with an ITER-like wall**
- **Understanding is critical for optimizing ITER DT operation**

Baseline Scenario



No credit taken for isotope effects or α-heating

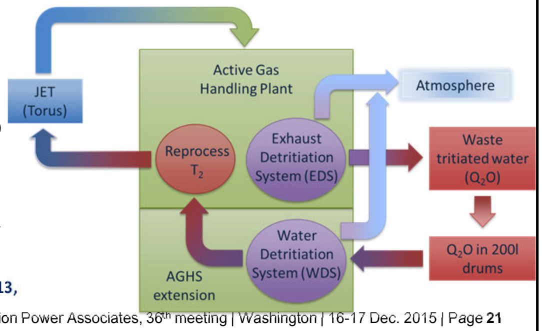
Hybrid Scenario



JET [C. Challis et al EUROfusion Science Meeting 2015.10.07]

Tritium studies and Fuel Cycle in JET DT

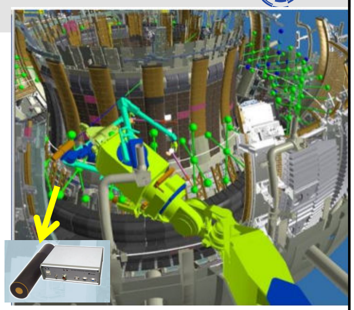
- **The next DT campaign:**
  - 16 increase in T throughput & feed requirements on the Active Gas Handling System (AGHS) vs 1997
  - 'Tritium Rehearsal' in 2015: exercise AGHS plant & procedures with D2
  - T fuelling with NBI and new gas valves injection
- Demonstrate T accountability & clean-up techniques with ILW
  - ➢ Upgrade Instrumentation for T measurement
  - ➢ Accuracy for T-inventory in AGHS below 0.1g T
- New water detritiation system: T waste on-site processing and close loop
- Train for ITER
- Data for Nuclear regulator

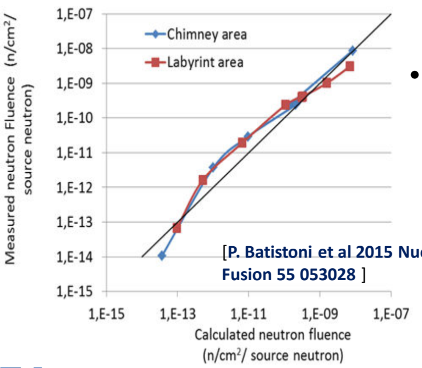


[R Smith, S Knipe, 10th Int. Conf. on T, Nice, 2013, B. Wakeling et al 2013]

Neutronics for ITER: measurement and code validation

- **Benchmark ITER calibration procedure for fusion power (≤10% accuracy) and T accountancy**
  - Accurate 14MeV calibration of JET neutron detectors: DT neutron generator deploy by remote handling





[P. Batistoni et al 2015 Nucl. Fusion 55 053028]

- **Technological exploitation of JET DT**
  - Nuclear design, activation, Safety
  - ITER materials radiation damage studies
  - Neutronics code validation for ITER and DEMO: Neutron streaming and shutdown dose rate experiments

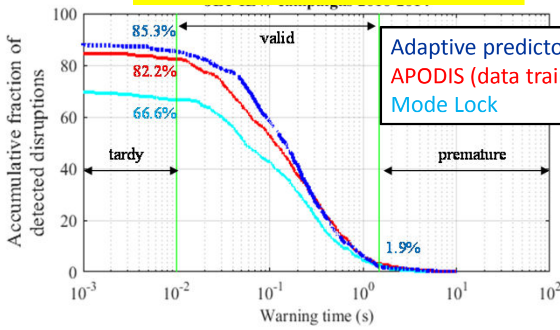
JET

Disruption Physics for ITER

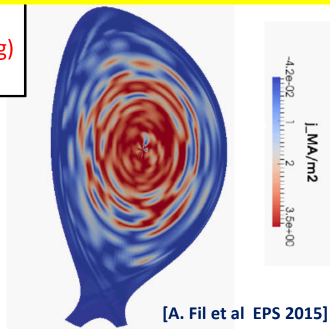
Highest risk in ITER Research Plan

- Dynamics of disruptions different with metallic walls
- Develop avoidance, prevention and mitigation schemes
- Validation and prediction to ITER

Improved disruption predictors (target > 95% for ITER)



Simulation of Massive Gas Injection (JOREK): unstable current profile by cold front penetration



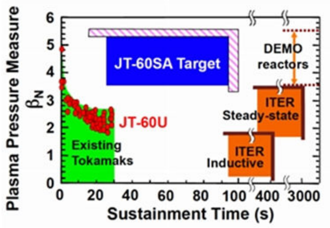
[J. Vega, A. Murari et al SOFE 2015 + Nuc Fus 2014]

[A. Fil et al EPS 2015]

JET

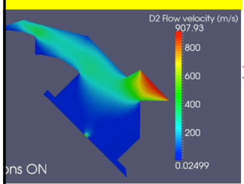
EU Preparation of JT-60SA Exploitation

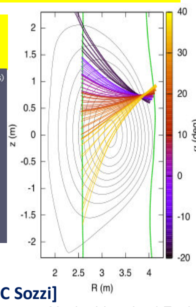
Prepare ITER non-inductive operation



ECRH antenna studies

Divertor pumping modelling





[C Day et al EPS 2015]

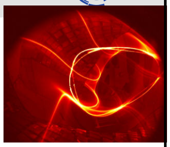
[C Sozzi]

- Prepare for a high level EU participation in JT-60SA scientific exploitation, integrated in the EU fusion programme
- Prepare the EU-JA research plan*
- Prepare access to data and analysis tools
- Prepare to play an active role in operation & campaigns management

[*M. Yoshida, G. Giruzzi et al http://www.jt60sa.org/]

JT-60SA

Stellarator - Wendelstein 7-X



Steady-state facility for physics and technology

European ECRH Expertise for ITER and prepare W7-X

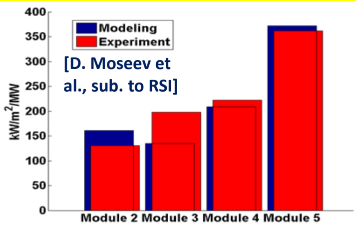
ECRH : ~ 8MW CW at 140GHz; X2, O2

Highest available CW ECRH power

Objectives for ITER

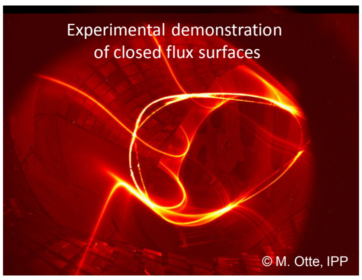
- protection and interlocks
- start-up studies
- Launcher technologies, RAMI

stray-radiation modeling: validation on W7-X



- HELIcal Advanced Stellarator, HELIAS, line
- Scientific exploitation W7-X including theory & modelling (Plasma operation 2016)
- **physics & technology in support of ITER**, e.g. ECRH, CW Diagnostics

First Plasma in W7-X



Wendelstein 7-X

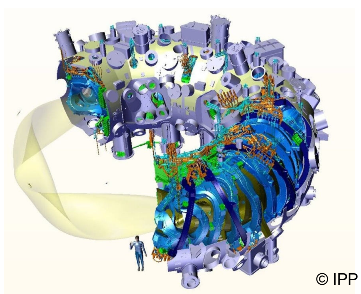
from assembly to operation

12.05.2014: Start of commissioning
16.07.2015: First flux surface measurements
09.12.2015: Operation permit granted
10.12.2015: First helium plasma

[W7-X Team , Greifswald, Germany]

Wendelstein 7-X

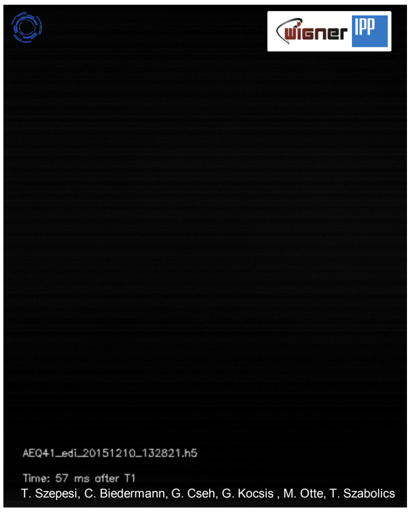
Max-Planck-Institut für Plasmaphysik
Greifswald (Germany)



HELIAS-type stellarator

- N_f=5, R/a = 5.5m/0.53m
  → **30 m³ plasma volume**
- 50+20 **superconducting** coils (2.5T)
- ~8+7MW (**ECRH**, NBI) + ICRH (later upgrades)

First Plasma in W7-X



Dec. 10th, 2015

First helium plasma in W7-X was created according plan

- Full field: B = 2.52 T
- P_{ECRH} = 1.3 MW
- τ_{pulse} = 50 ms

First measurements of plasma parameters conducted

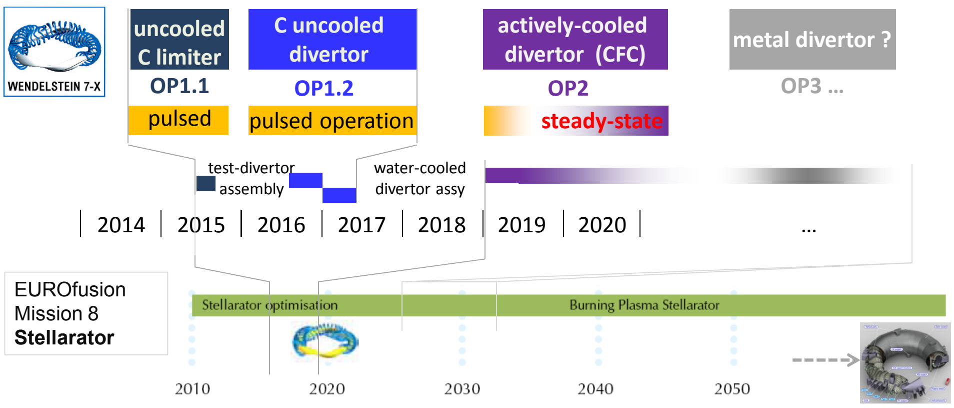
- T_e ~ 100eV
- n_e ~ few 10^{19} m^{-3}

First shot program (sequence of conditioning pulses) **w/ steady-state control system conducted on Dec. 11th**

[W7-X Team , Greifswald, Germany]

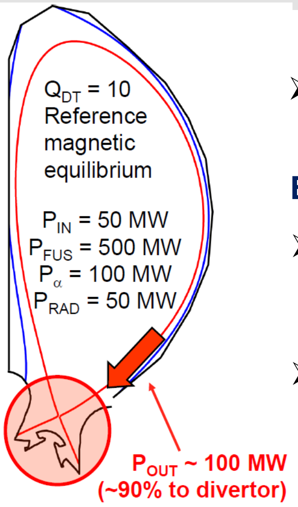
W7-X: bring the HELIAS line to maturity

Achieve reliable, steady-state, high –$nT\tau_E$ *operation*
gain predictive capabilites in view of burning 3D plasmas
and HELIAS Fusion Power Plant



[A. Dinklage et al 25th IAEA FEC, St. Petersburg, Russia (2014)]

Plasma Heat Exhaust



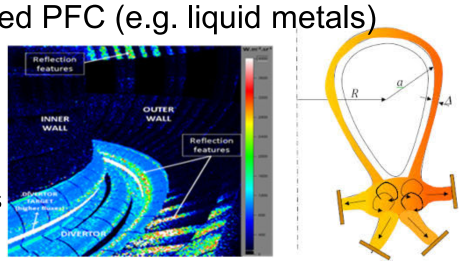
[D. J Campbell, ITER research plan]

Risk mitigation for ITER divertor

- Baseline strategy 'detached' divertor with radiative cooling

Explore innovative concepts for DEMO

- Alternative divertor solutions with higher flux expansion (Super-X, snowflake) on TCV and MAST
- Advanced PFC (e.g. liquid metals)



Existing Devices: JET, MST + Linear devices
+ international collaborations
Divertor Test Tokamak?

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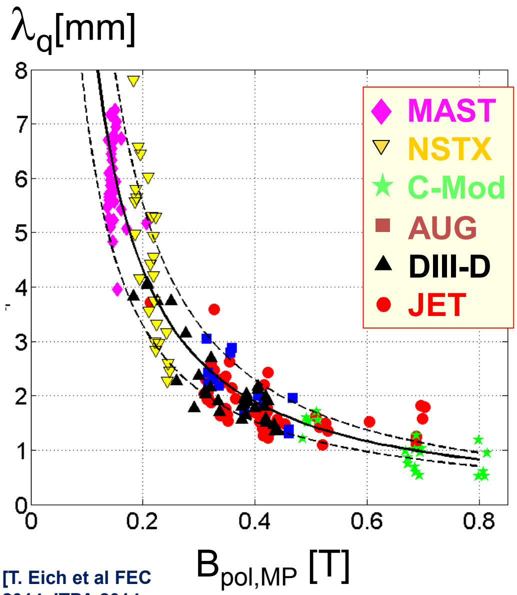
ITER Power Decay Length λ_q ?



[T. Eich et al FEC 2014, ITPA 2014, PRL 2011]

- λ_q scales $1/I_p$
- ITER $\lambda_{q,ITER}$ = 0.9±0.3mm
- Dissipation to reduce heat flux?
- Heat load mitigation
  - Radiation in the SOL
  - Increase divertor broadening

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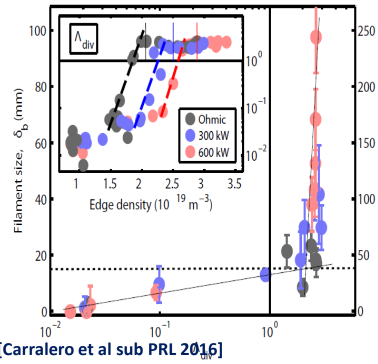
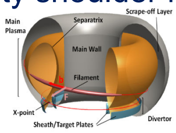
Experimental validation of filament transport model in AUG and JET SOL

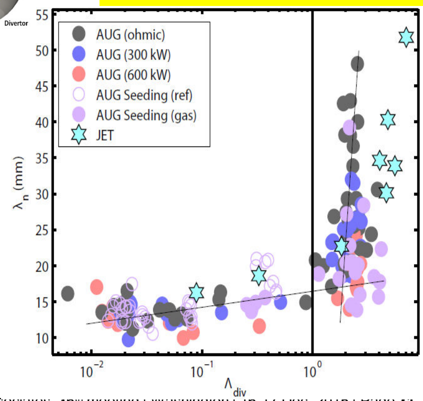
Collisionality is the control parameter: change in SOL turbulence is accompanied by large increase of the perpendicular particle flux leading to SOL density shoulder formation

Size of filaments vs. SOL collisionality





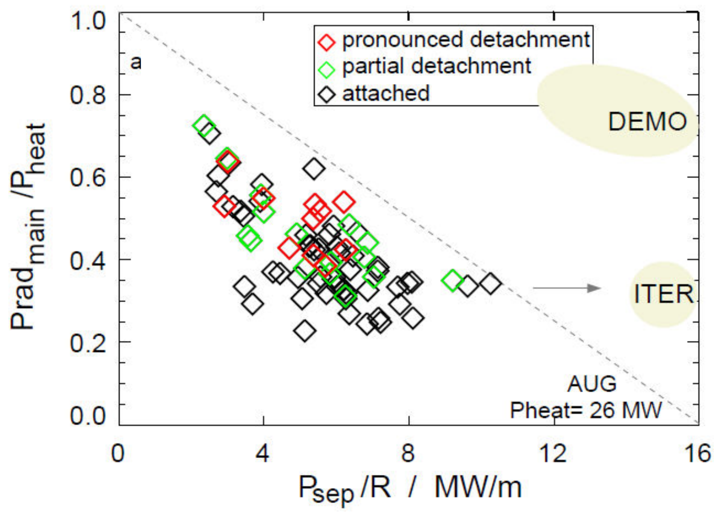
Density e-folding length vs. SOL collisionality



[Carralero et al sub PRL 2016]

Heat load mitigation with radiative cooling

Divertor detachment is a critical issue for ITER and DEMO

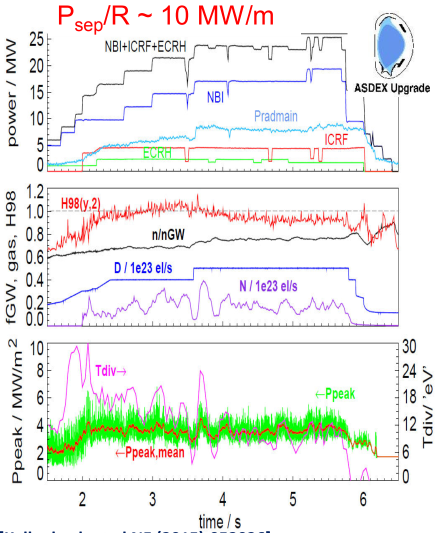


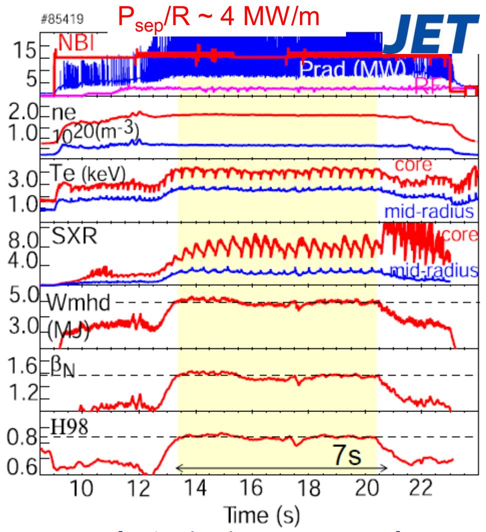
ASDEX Upgrade

[Kallenbach, Nuc Fus. 2015, H Zohm Nuc Fus. 2015]

Integrated scenarios for ITER Q=10

Stationary core performance integrated with divertor heat load control (≤ 5MW/m²) : impurity injection (nitrogen)





[Kallenbach et al NF (2015) 053026] [C. Giroud et al FEC 2014, PPCF2015]

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EU Integrated Modelling for ITER operation

- **Generic approach: not specific to transport simulator problem, to a machine…**
- **Modular, flexible, code, language and machine independent**
- **New data and communication ‘ontology’ for standardizing the data exchange between codes, with a generic data structure incorporating both simulated & experimental data**
  - modules describing the same physics is easily interchanged
  - eases code coupling & rigorous code verification / benchmark
  - enhanced quality / reproducibility
- **Multi-machine capability: local cluster, GRID, HPC**
- **New HPC in EU for exploitation in 2017**

EU approach adapted by ITER
⇨ IMAS ITER Modelling & Analysis Suite

[G. Falchetto et al NF 2014]

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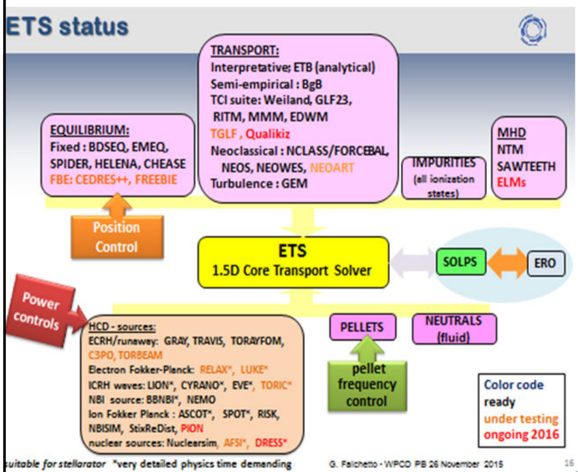
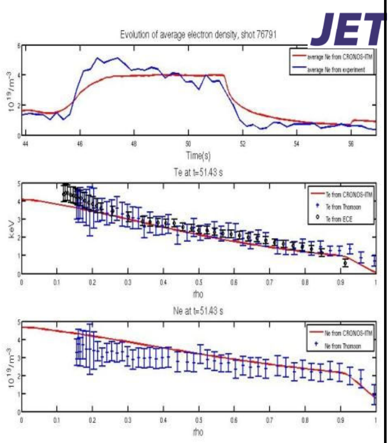
European Transport Simulator, ETS

European Transport Simulator, ETS, (multiple physics modules) validation on JET, AUG, TCV experiments

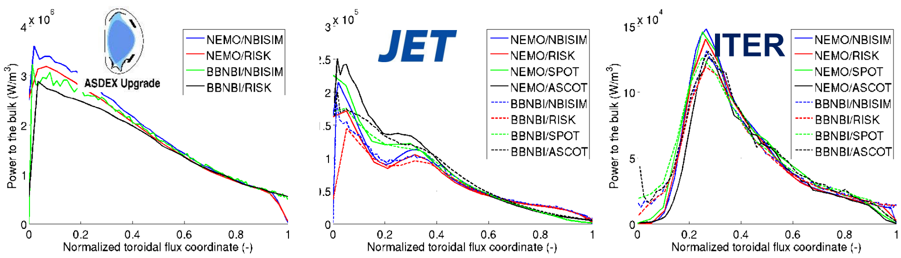
JT-60SA, ITER and DEMO machine description and modelling





...chetto NF 2014 , P. Strand, EU-US TTF2014]

NBI benchmark : Power to the bulk



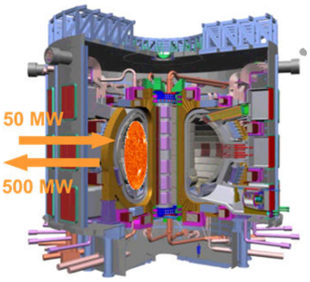
	AUG	JET	ITER
	Power to the bulk (MW)		
NEMO/NBISIM	19.6	3.8	33
NEMO/RISK	18.4	3.6	32
NEMO/SPOT	-	3.6	33
NEMO/ASCOT	-	3.8	33
BBNBI/NBISIM	19.4	3.8	33
BBNBI/RISK	18.3	3.6	32
BBNBI/SPOT	-	3.7	32
BBNBI/ASCOT	-	3.8	33

- **Good agreement** for total power to the bulk!
- Wide orbits in ASCOT & SPOT
  - causes losses at edge
  - reshapes central profiles
- NBISIM & RISK **no orbits**

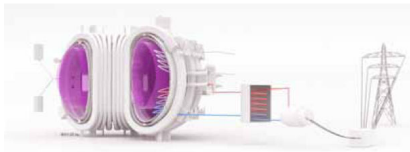
[M. Schneider, ITPA Fast Particles, 2015]

Outline: Europe doing all possible to

Exploit recent advances in physics and technology to minimise the impact of the revised ITER timeline on the demonstration of fusion electricity:



- Support ITER construction and Optimise ITER operation
  - Risk mitigation for ITER by doing supporting research in contemporary devices



- **Ensure minimal delay to DEMO**
  - Conceptual design System Engineering Approach
  - Address universal technical challenges with gaps beyond ITER
    - safety, T-breeding, power exhaust, remote handling, component lifetime and plant availability

Design Integration Approach: ITER and DEMO differences

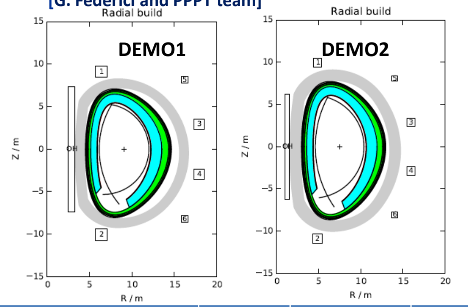
EU-DEMO the nearest-term reactor to demonstrate production of electricity with a closed fuel cycle.

	ITER	DEMO
Overall Mission	Experimental device	Approaching a commercial plant
Fusion Power	500MW	~ 2000MW (500 MWe)
Major Radius	6.2m	~ 9m
Pulse Length	6 minutes	~ > 2 hrs
Availability	Exp. campaigns - maintenance and upgrades	Maximize electricity generation
Complexity	Large number of sensors. 6 Test blanket modules, range of concepts Multiple H&CD systems.	Minimised set of sensors Single blanket concept Minimised H&CD mix
Heat Transfer	Cooling system optimized for min. stresses and sized for modest heat rejection.	Cooling system designed for electricity generation (e.g. much higher temp.)
Tritium	No Tritium breeding requirement.	T breeding needed for self-sufficiency.
Materials	Conventional 316 stainless steel structure. PFC: Be wall / W divertor	Novel low activation materials as structure. PFC: full W
Neutrons	n-fluence: ~3 dpa in Steel	n-fluence: ~20 dpa FW steel (1st blank)

[G. Federici and PPPT team]

Preliminary DEMO Design Choices under Evaluation

[G. Federici and PPPT team]



- 2000MW$_{th}$, 500 MW$_{e}$, > 2 hrs
- Single null water cooled divertor
- Full W PFC
- Low Temperture Super-Conducting magnets Nb_3Sn
- B_{max} conductor ~12 T (depends on A)
- EUROFER as blanket structure
- Vacuum Vessel made of AISI 316
- Blanket vertical RH / divertor cassettes
- starter blanket: 20 dpa (200 appm He); 2nd blanket 50 dpa;
- divertor: 5 dpa (Cu)

Open Choices:

- Operating scenario
- Breeding blanket design concept selection
- Primary Blanket Coolant/ BoP
- Protection strategy first wall (e.g., limiters)
- Advanced divertor configurations
- Number of coils

	ITER	DEMO1 (2015) A=3.1	DEMO2 (2015) A=2.6
R_0 / a (m)	6.2 / 2.0	9.1 / 2.9	7.5 / 2.9
K_{95} / δ_{95}	1.7 / 0.33	1.6 / 0.33	1.8 / 0.33
A (m^2)/ Vol (m^3)	683 / 831	1428 / 2502	1253 / 2217
H / β_N (%)	1.0 / 2.0	1.0 / 2.6	1.2 / 3.8
P_{sep} (MW)	104	154	150
P_F (MW) / P_{NET} (MW)	500 / 0	2037 / 500	3255 / 953
I_p (MA) / f_{bs}	15 / 0.24	20 / 0.35	22 / 0.61
B at R_0 (T)	5.3	5.7	5.6
$B_{max,conductor}$ (T)	11.8	12.3	15.6

Key DEMO design and integration challenges

Physics & engineering studies with strong implications on parameter selection and architectural layout :

- **Impact of Aspect Ratio**
- **Sensitivity to plasma physics uncertainties: operating scenarios, radiative regime with no or small ELMS**
- **Tritium Breeding Ratio sensitivity**
- **Divertor Optimisation**
  - optimization of conventional ITER-like Single null divertor (strike point sweeping parametric scan, lower X-point height, larger flux expansion)
  - Exploration advanced divertor including double null Configuration
- **magnetic field ripple effects**
  - trade-off between Remote Handling access, coil size, NBI access.
- **Dwell time and trade-off on Central Solenoid, Balance of Plant…**

[G. Federici and PPPT team]

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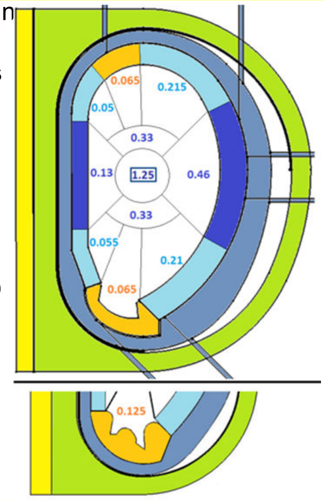
T Breeding Ratio sensitivity analysis

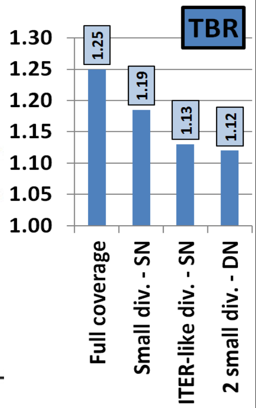
Blanket design:
•Breeder/multiplier materials within a box and covered by a FW.
•Box reinforced by stiffening grids
→ n-absorption by steel

Blanket size (radial thickness):
- Inb: ~80 cm / Out: ~130 cm

→ **Requirement: TBR ≥ 1.05**
(after integration of diag/ H&CD)
→ ~ 85% of the surface covered by breeding blanket.
→ Integration: limited space for divertor, auxiliary systems, limiters etc

Tritium breeding contributions:





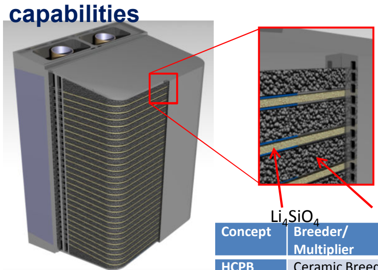
[P. Pereslavtsev et al, C Bachman et al]

- Improvement of TBR due to divertor size reduction.
- Double Null with two 'small' divertors possible regarding TBR.

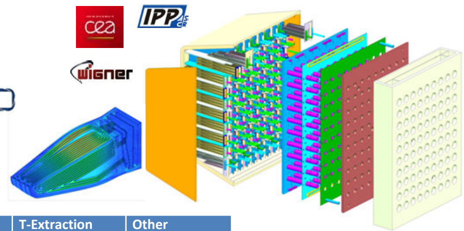
[G. Federici and PPPT team]

Tritium Breeding Blanket: four options

ITER TBM important: qualify fabrication technologies/validate tools, predictive capabilities

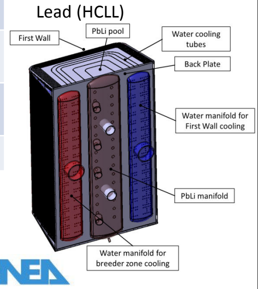


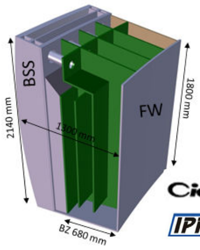
Helium Cooled Pebble Bed (HCPB)



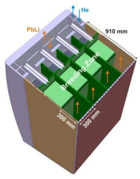
Helium Cooled Lithium Lead (HCLL)

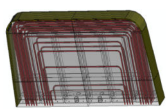
Concept	Breeder/ Multiplier	Coolant	T-Extraction	Other
HCPB	Ceramic Breeder / Beryllium	Helium	He low pressure purging	(Permeation control)
HCLL	PbLi	Helium	PbLi slow recirculation	(Corrosion-permeation barrier)
WCLL	PbLi	Water	PbLi slow recirculation	(Corrosion-permeation barrier)
DCLL	PbLi	Helium PbLi	PbLi fast recirculation	FCI of Allumina or SiC/SiC_f





Dual Coolant Lithium Lead (DCLL)





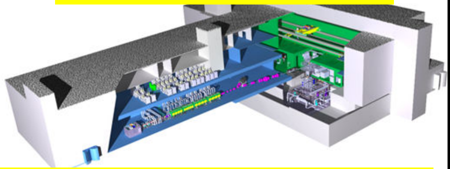
Water Coolant Lithium Lead (WCLL)

R&D on Material and Early Fusion Neutron Source

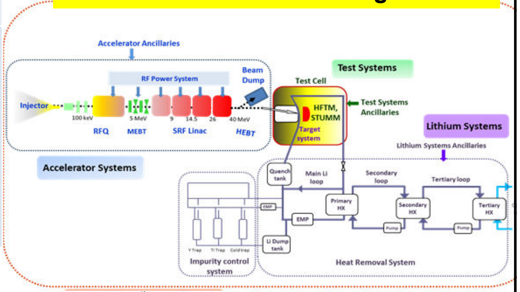
Develop the engineering design of IFMIF-DONES facility, DEMO Oriented Neutron Source

	IFMIF	IFMIF-DONES
Beam current	2 x 125 mA (Li target)	1 x 125 mA (Li target)
Beam energy	40 MeV	40 MeV
Neutron production	10^{18} n/s	5 x 10^{17} n/s
Typical Damage Rate	40 dpa/fpy @>60cm³ + 20 dpa/fpy @>400cm³	20 dpa/fpy @>60 cm³ + 10 dpa/fpy @>400 cm³

IFMIF-DONES preliminary conceptual design



IFMIF-DONES Plant Configuration



[A. Ibarra and WPENS Team]

R&D on Materials

- **Fill gaps in the database and develop design codes**
- **Development of new materials to mitigate requirements of advanced DEMO component designs**
- **Demonstration of production in processes scalable to industrial standards**
- **Characterization of material properties**
- **Develop models for neutron radiation effects**
  - microstructural evolution and embrittlement, in iron alloys, steels, tungsten, and degradation of functional materials
- **Develop Structural Design Criteria**
- **Open to international collaboration**

Conclusion: EUROfusion programme is in full swing

ITER Physics Programme:

- **Programmatic approach in a step-ladder vision for ITER**
  - 2015-2016 simultaneous operation of JET, AUG,TCV, W7-X, WEST and linear PFC
- **Integration of knowledge through theory and modelling for JT-60SA, ITER and DEMO**
- **Preparation for JET D-T operation with ITER-like wall**
- **Internationalization of JET to prepare ITER Q_{DT}=10 operation**
- **Prepare EU to JT-60SA operation**

Power Plant Physics & Technology Programme

- **INTEGRATED Systems Engineering Approach in the pre-conceptual Design**
- **Integration of Physics, Engineering and Materials science**