Plasma Wall Interactions in Tokamak

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Outline

1. Conditions for Fusion in Tokamaks

2. Consequences of plasma operation on in vessel materials:
   - Development of new technology to sustain High Heat Loads (Tokamak success story)
   - Erosion of material leading to micro particles creation

3. Dust physical properties

4. Processes under development to control the fuel cycle

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Main conditions for fusion plasmas

Deuterium + Tritium • Helium + neutron (+17.6MeV)

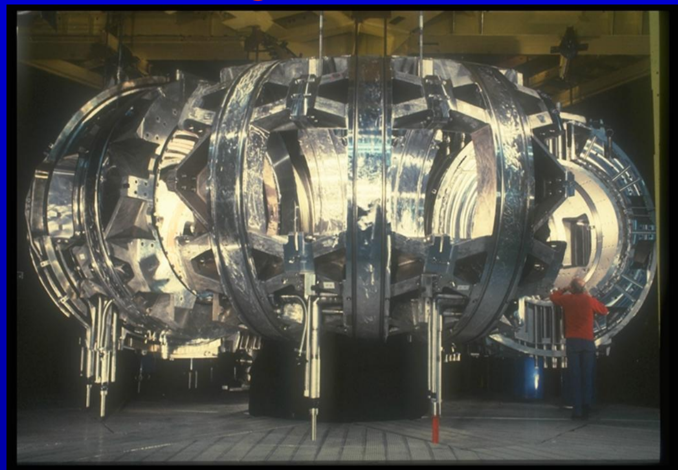
Conditions for fusion reactions (max probability of reaction)

$$Ti \; ni \; t_E > 5\ 10^{21}\ (KeV\ m^{-3}\ s)$$

High T° needed
ITER : 200 10^6K

High purity needed
ITER :
> 5% of C & > 10^{-4} of W stop the plasma

High particles/energy confinement
On Earth, magnetic confinement

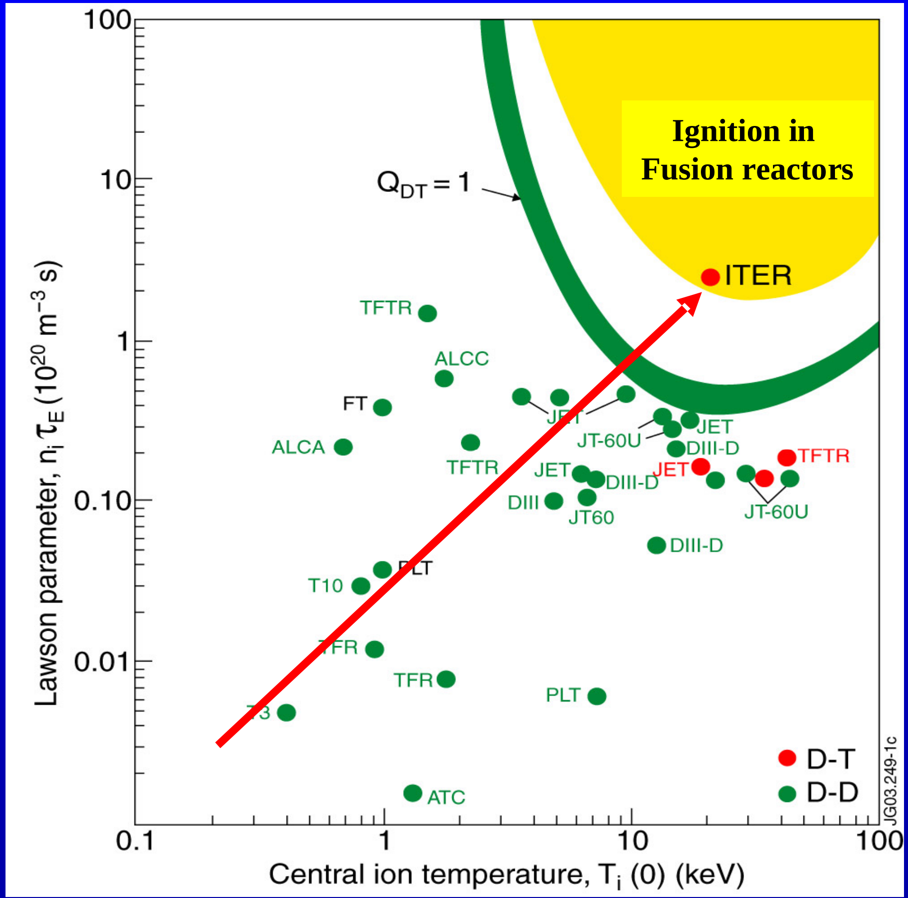


all conditions obtained on # Tokamaks. **Tokamak = mature solution to produce fusion energy**

Main conditions for fusion plasmas

Conditions to sustain fusion reactions: the Lawson Criterion

$$Ti \cdot n_i \cdot t_E > 5 \cdot 10^{21}\ (keV \cdot m^{-3}\ s)$$



20KeV = 200 10^6 K

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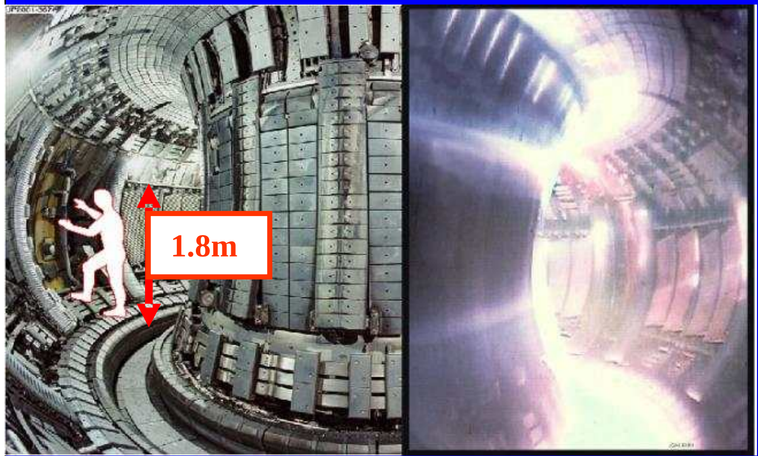
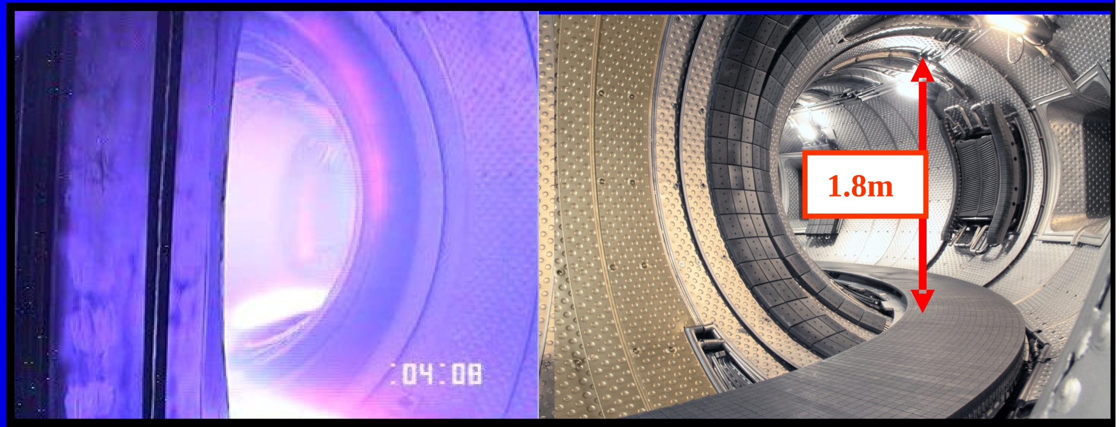
Fusion on earth : magnetic box and plasma facing components

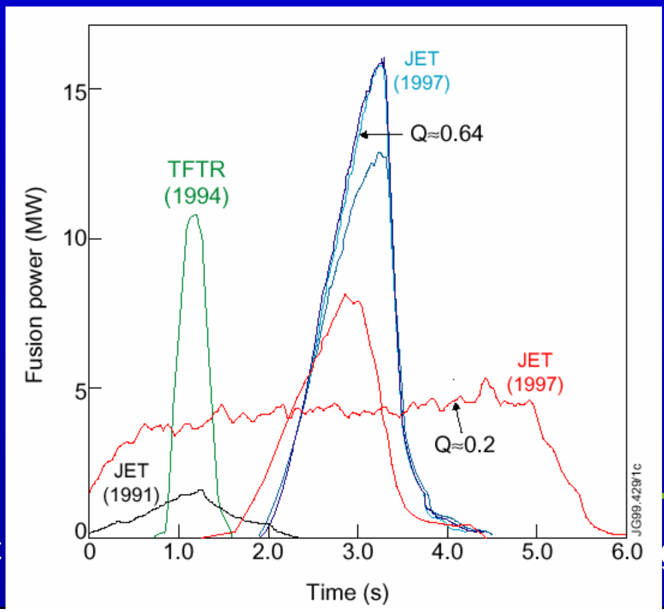
JET (T compatible) | Tore Supra (no T compatible)

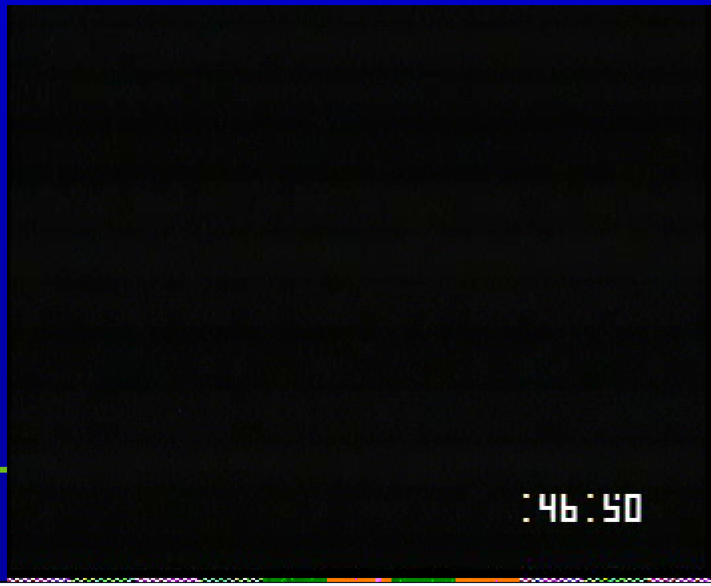




JET = high performances
(World record of Fusion Power)

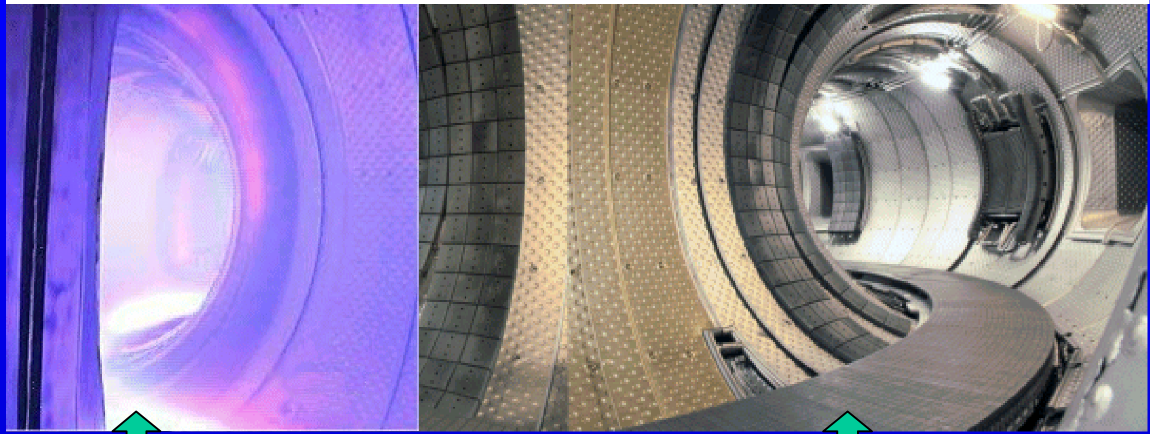
Tore Supra = steady state operation
(World record of steady state operation
No fusion power)





Tore Supra operation: high heat fluxes & material erosion

Tore Supra steady state operation



High Energy and Particle fluxes On surfaces

- High heat flux components (<20MW/m^2)
- Material erosion

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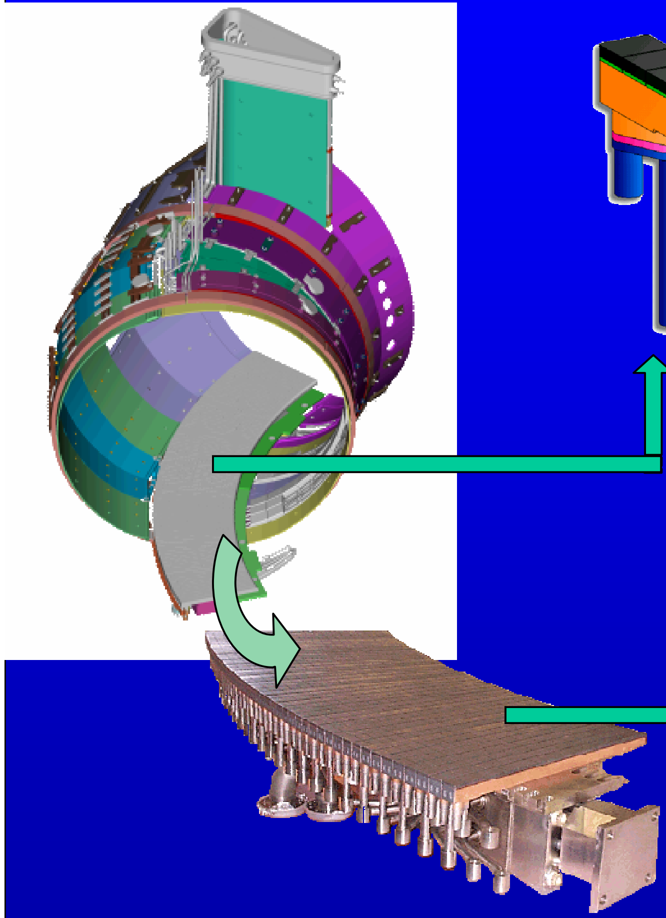
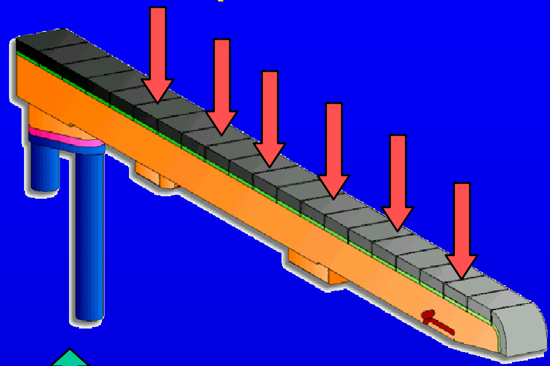
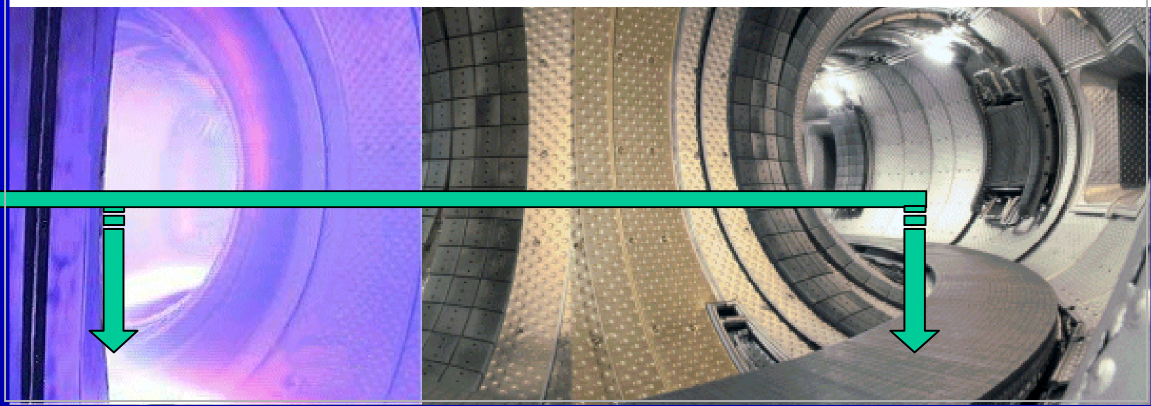
High Fluxes: High Heat Flux Components

Limit = 20 MW/m²
(Sun surface ~ 60MW/m²)





Record discharge (04/12/2003) :
1.1 GJ injected et extracted during 6.5 minutes



Conclusion : Tokamaks = <u>complex</u> machine to operate.
But Tokamaks = success story g ITER operation

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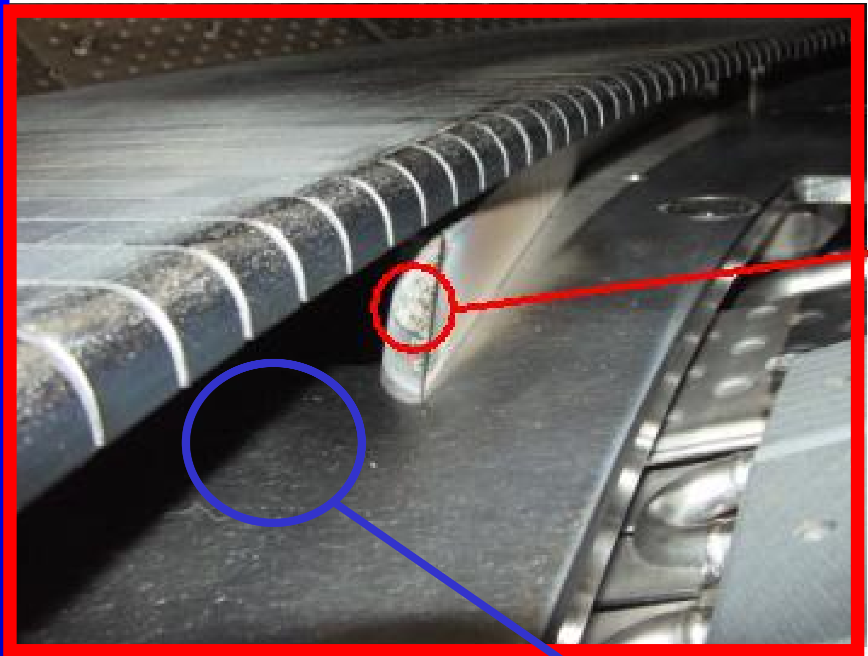
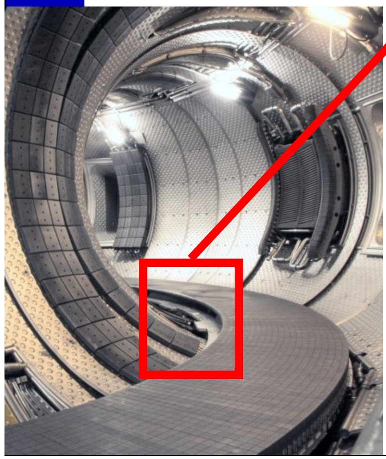
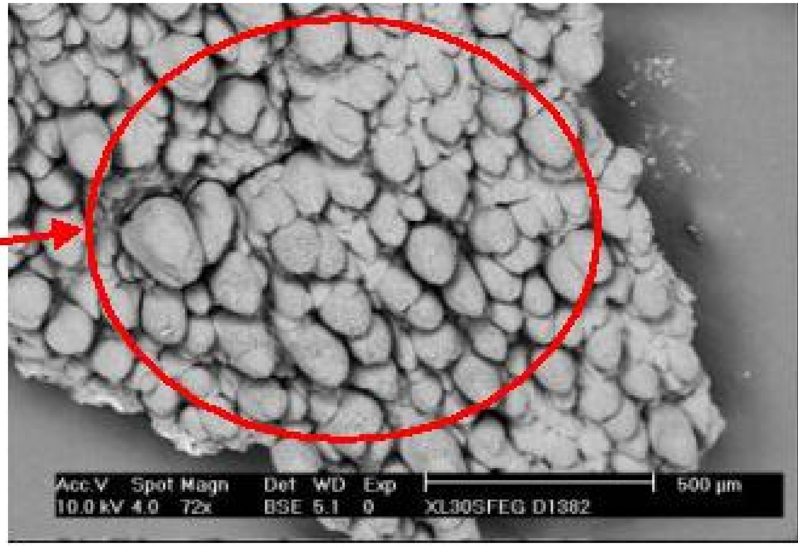
High fluxes: Material erosion (layers and dust)

Deposits on Tore Supra



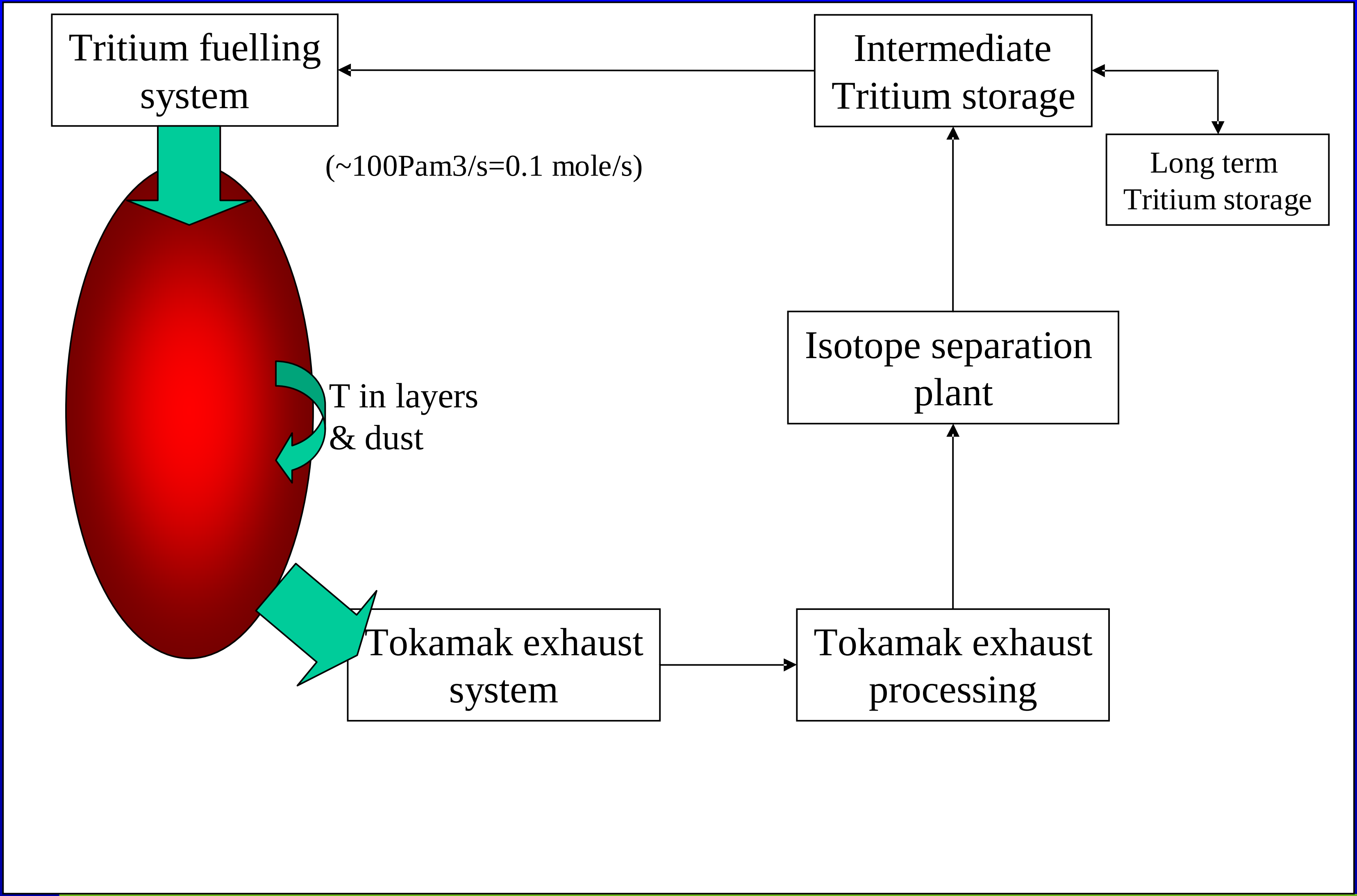


Deposits: fuel trapping



Flaking: Dust creation

Tokamak Fuel cycle (JET, ITER relevant)



Tokamak operation with Tritium (summary)

Plasma operation = high heat fluxes on Plasma Facing Components

è extracted energy + erosion of Plasma Facing Components

Consequences:

- Layers deposition and Tritium trapping
- Micro-particles production

(~10-15% of eroded material converted in μ-particles)

Control of fuel cycle (including T in dust): part of the ITER Work program

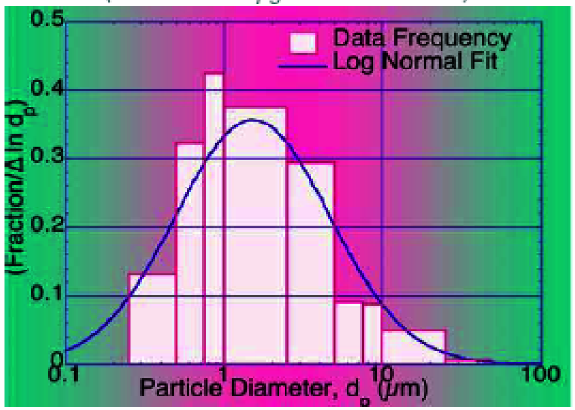
Tokamak operation with/without T: work done

Dust characteristic (Physical properties):

Particle Size Distribution

Count median Diameter (CMD)

Typical Count-based Size Distribution
(from ASDEX-Upgrade vessel bottom)



Comparison of Size Distributions

Machine	CMD (μm) ± GSD Lower Regions	Middle Regions	Upper Regions
DIII-D	0.66 ± 2.82	0.60 ± 2.35	0.89 ± 2.92
TFTR	0.88 ± 2.63	1.60 ± 2.33	-
Alcator-Cmod	1.58 ± 2.80	1.53 ± 2.80	1.22 ± 2.03
JET	27 ± (-)	-	-
JT-60U	3.08 ± 3.00 (all regions)		
TEXTOR	5-20 ± (-)	-	-
Tore Supra	2.68 ± 2.89	2.98 ± 2.94	3.32 ± 2.94
ASDEX-Upgrade	2.21 ± 2.93	3.69 ± 2.81	3.59 ± 3.08
LHD	8.59 ± 2.67	6.31 ± 2.39	8.73 ± 2.09
NSTX	3.68 ± 2.44	3.21 ± 2.55	2.75 ± 2.47
NOVA	1.12 ± 1.90	0.76 ± 2.03	0.90 ± 1.93

Observations

- expected size range is 0.5 - 10 μm
- no significant size-based trend found in location of dust

JET tritiated dust characteristics:

- sampling during maintenance (airborne dust)
- membrane filter air sampling or cascade impactor
- AMAD:
  - membrane: 1 - 7 μm
  - impactor: multi modal distributions
    - 1 – 20μm (20μm most abundant)

AMAD = Activity Median Aerodynamic Diameter

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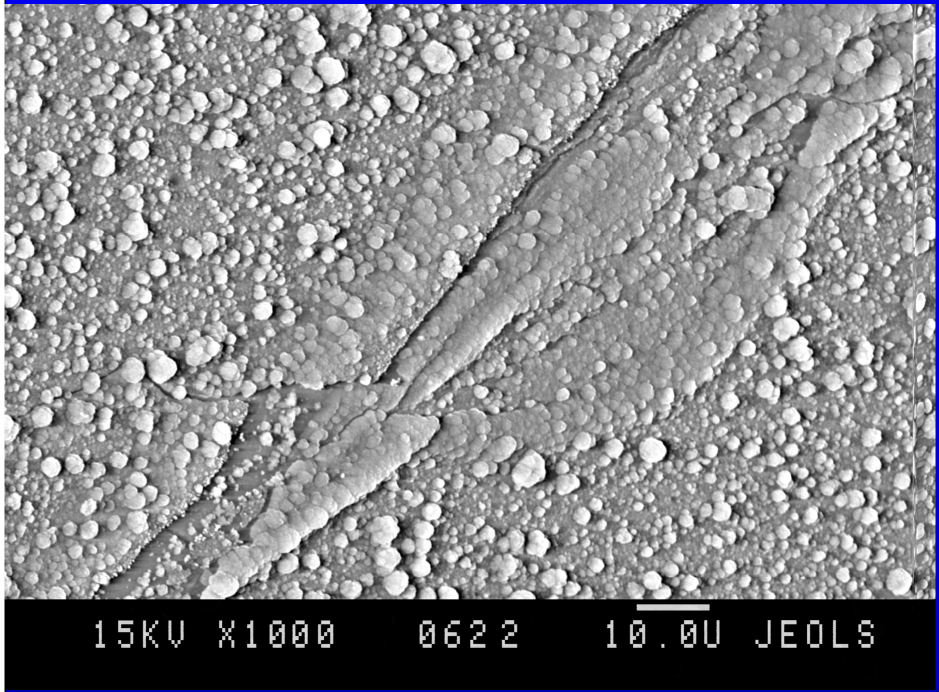
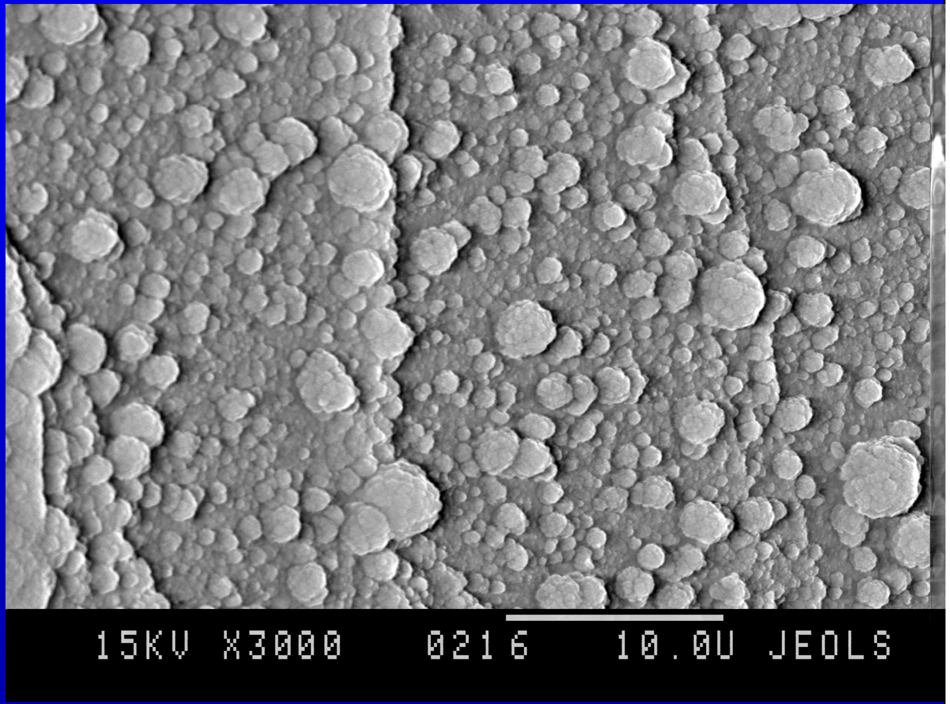
Tokamak operation simulation: work done

- Erosion simulation in Plasma gun device:
  Recovered samples after interaction with carbon (Carbon Fiber Composite) and Tungsten

Carbon, 1.0MJ/m^2



Tungsten, 1.5MJ/m^2



- New JET metallic plasma facing components: AMAD in metallic machine
  AMAD = Activity Median Aerodynamic Diameter

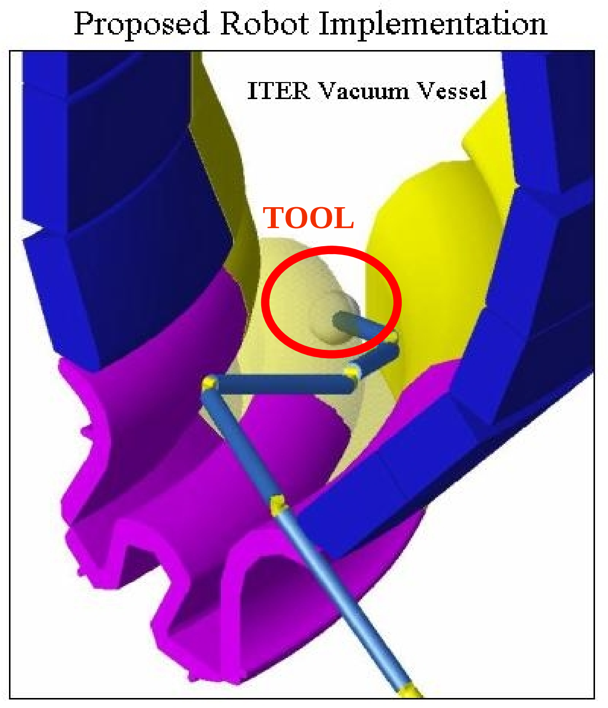
In preparation of T & dust in vessel recovery

New tools development

Current strategy:

- Integration of Robot in Tokamak carrying tools (for detritiation, dust removal,…) (**Operation under vacuum**, High T°, Magnetic field, neutrons, difficult maintenance)
- Experience feedback from JET (T) machine on Remote Handling

Proposed ITER Robot Implementation

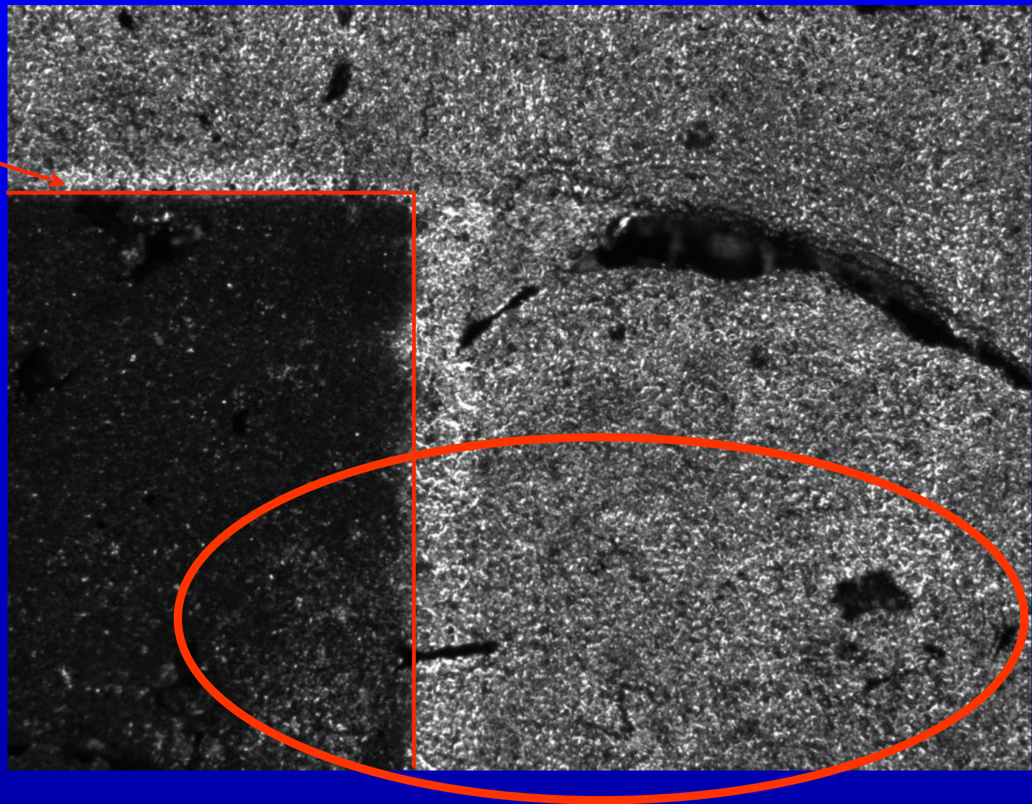


Articulated In vessel Arm (tests)

Dust in vessel recovery

One of the possible tools: Laser removal system

Laser impact



Carbon dust on Carbon Fiber Composite

Summary

1. Tokamak is a mature solution for fusion energy production

2. Current Tokamaks results allow ITER extrapolation and design

3. Concerning Plasma Wall Interaction in Tokamak :
   - Design exists to sustain High Heat Flux (>20MW/m^2) in steady state (extrapolation to ITER ok)
   - Plasma Wall Interaction leads to:
     - Plasma Facing Component modification (erosion)
     - T trapping in layers and Dust (part of T cycle)

4. Tools developed to control in vessel T cycle:
   - Laser techniques good candidate for ablation & dust removal

5. ITER objective (as a research device) is to demonstrate fusion feasibility: part of this: Control of the fuel cycle