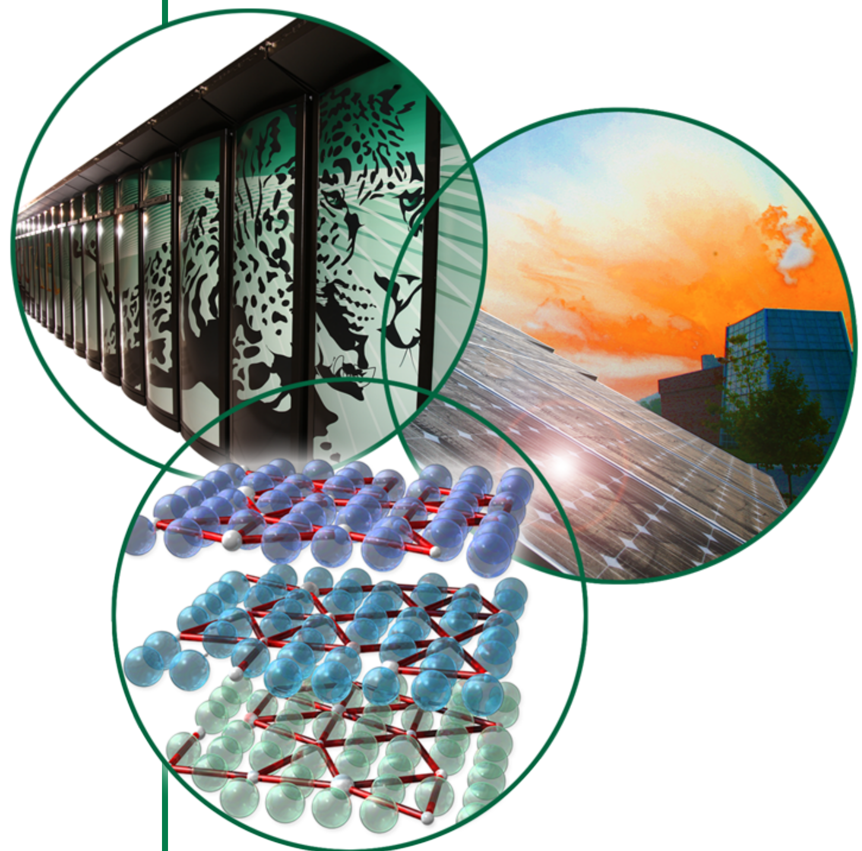
Addressing PMI Science and PFC technology for ITER, FNSF and DEMO



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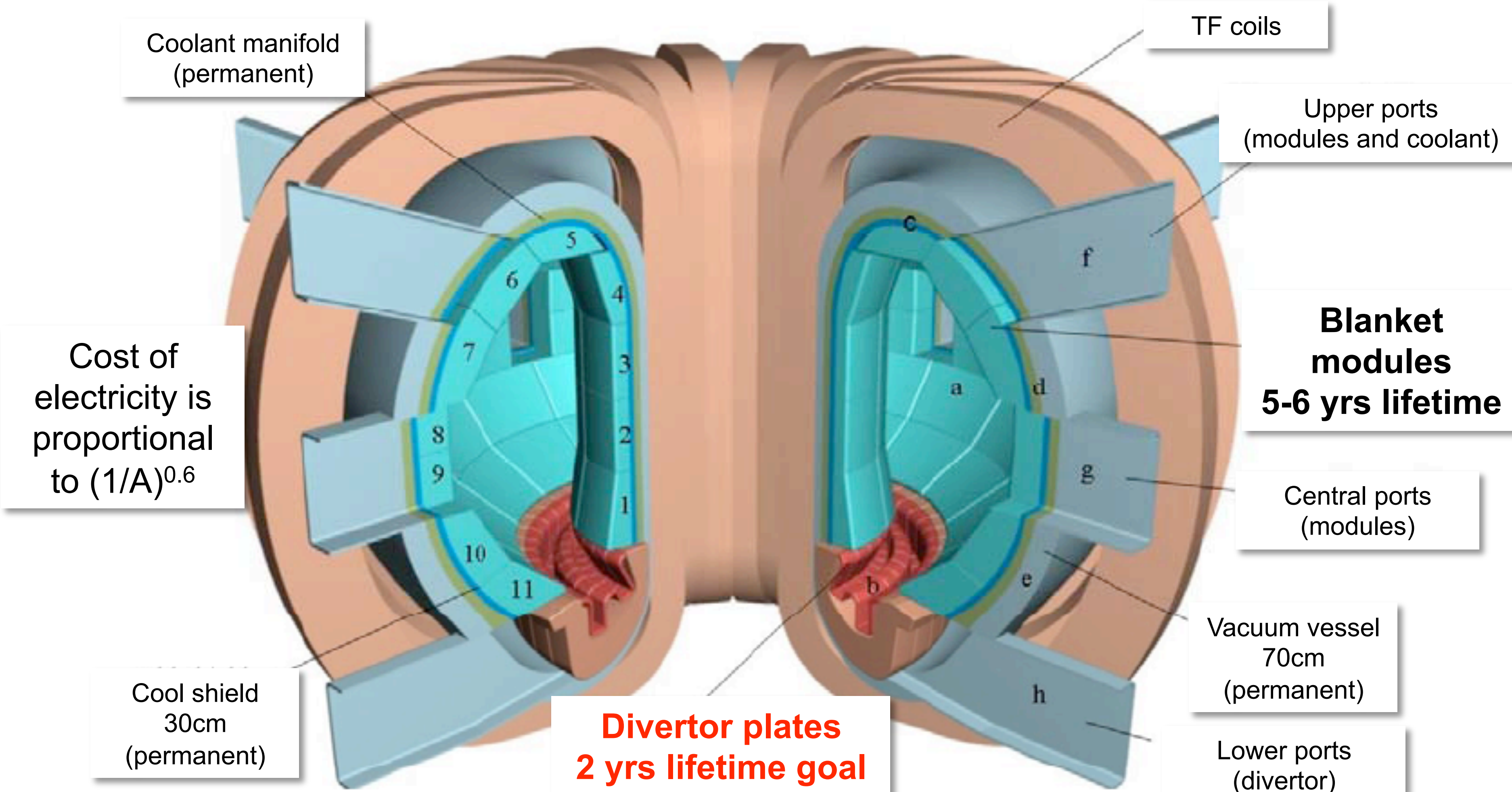
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Lifetime of divertor will determine availability of reactor



Main driver of scheduled maintenance: divertor (and blanket)

Challenge: thermal loads

PWR

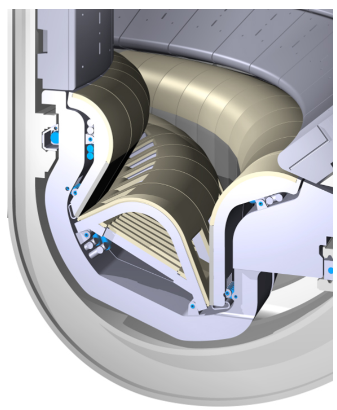
Re-entry vehicle

Space Shuttle rocket nozzle

~1 <10 85 2000

Power load [MW/m^2]

GE90-115B



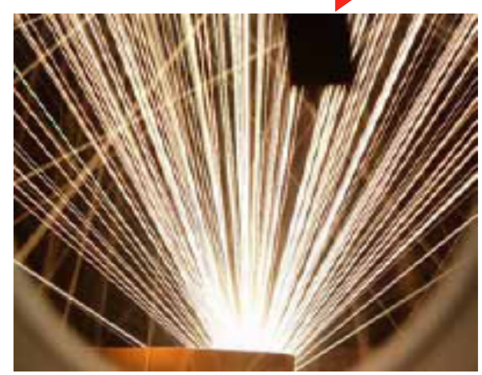
Outer divertor:

1200 C

Inner divertor:

800 C

ITER steady-state

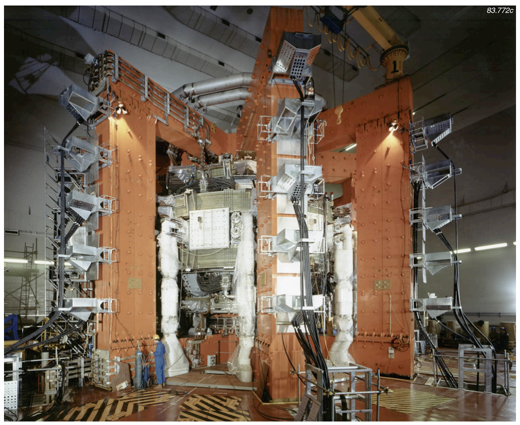


ITER transients

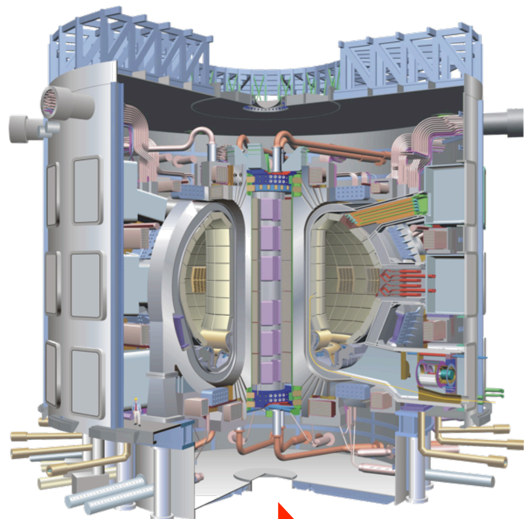
(1ms lifetime)

Challenges for PFCs: fluxes and fluence

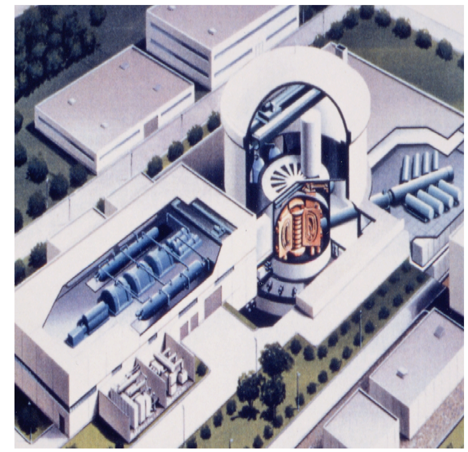
JET



ITER



Fusion Reactor



50 times higher ion fluxes

ce

ence

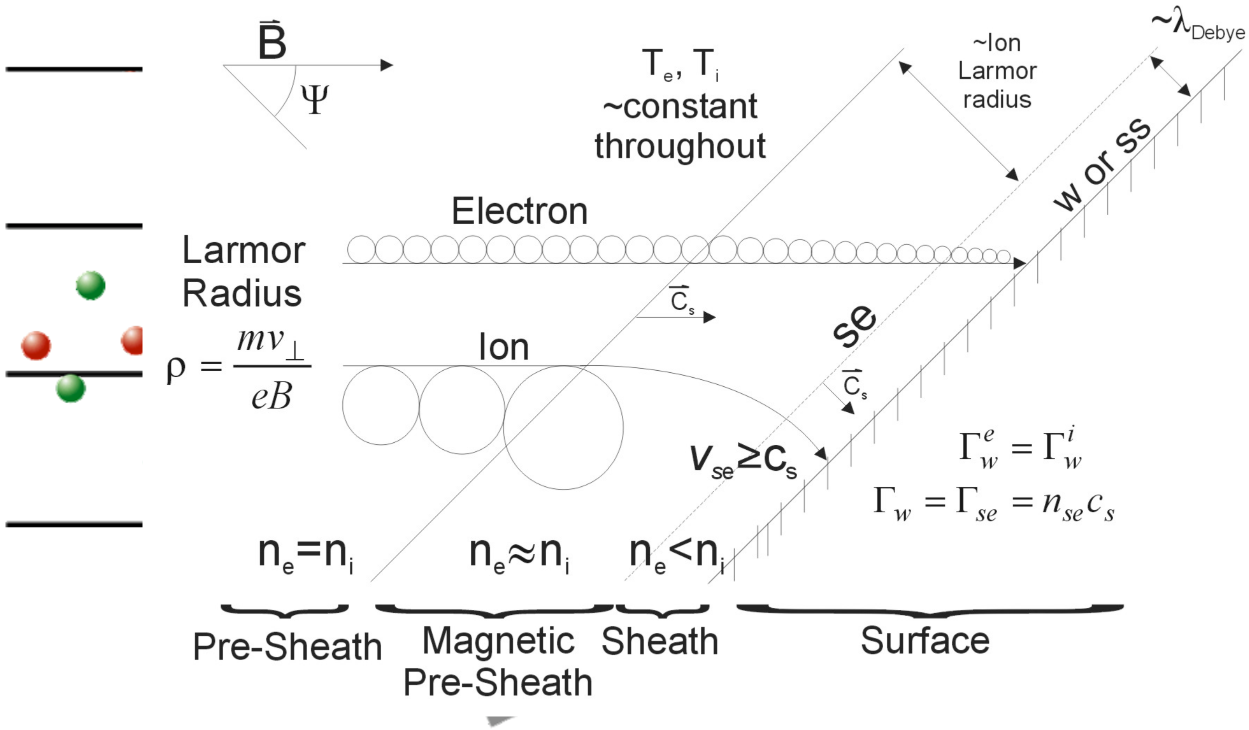
Material circulation due to gross erosion, rough estimations

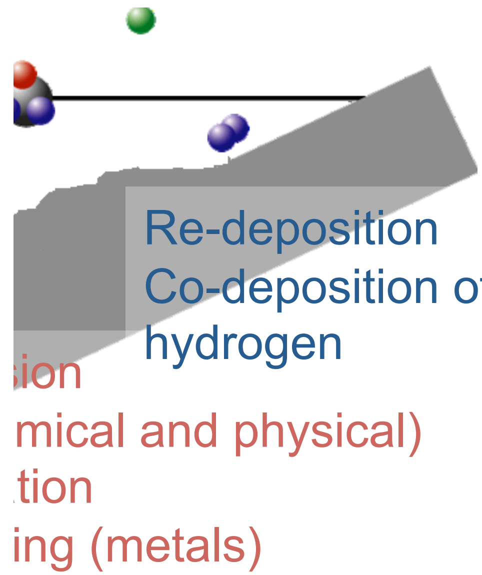
Device	P_{heat} (MW)	Annual run time (s/year)	Fluence of D/T ions to surfaces (TC/yr)[a]	Beryllium circulation rate (kg/yr)	Boron circulation rate (kg/yr)	Carbon circulation rate (kg/yr)	Tungsten circulation rate (kg/yr)
DIII-D	20	10^4	0.0007	2.8	1	0.5	0.7
JT-60SA	34	10^4	0.0017	4.8	1.7	0.9	1.2
EAST	24	10^5	0.01	34	11	5	8
ITER	100	10^6	0.4	1680	580	270	410
FDF	100	10^7	3	13 400	4600	2100	3300
Reactor	400	2.5×10^7	40	141 000	50 000	22 000	31 000

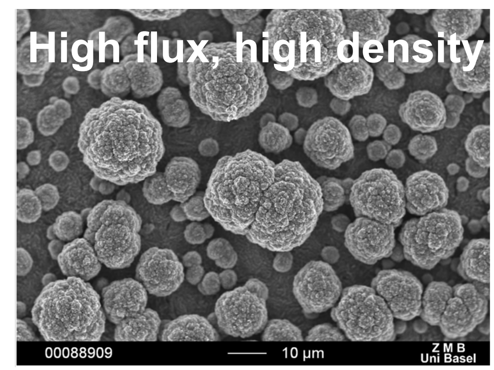
Worst case erosion rate ~ m/yr

PC Stangeby, AW Leonard, Nucl. Fusion 51 (2011) 063001

Plasma Surface Interactions







Strongly Coupled PSI regime:

1) Eroded material is trapped in plasma (highly collisional)
2) High fluence ⇒ thick layers of re-deposited material

Every surface atom is displaced ~ 10^7 times in a divertor lifetime

- **Material in a reactor divertor is NOT what was installed, we need a way to create and test plasma-reformed surfaces**

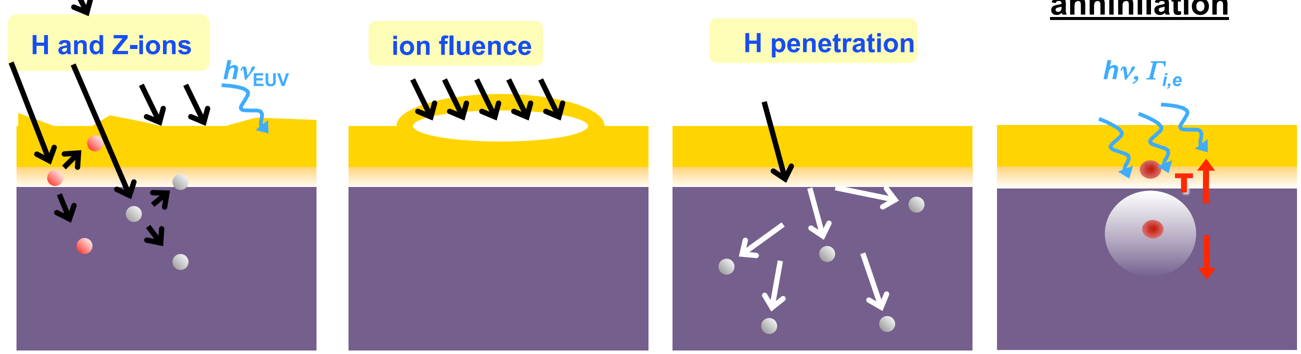
Plasma Surface Interactions

Complex systems with many species and layers

H, D ions plus low-Z and high-Z ions:

He, C, (Be), W, N, Ne, Ar

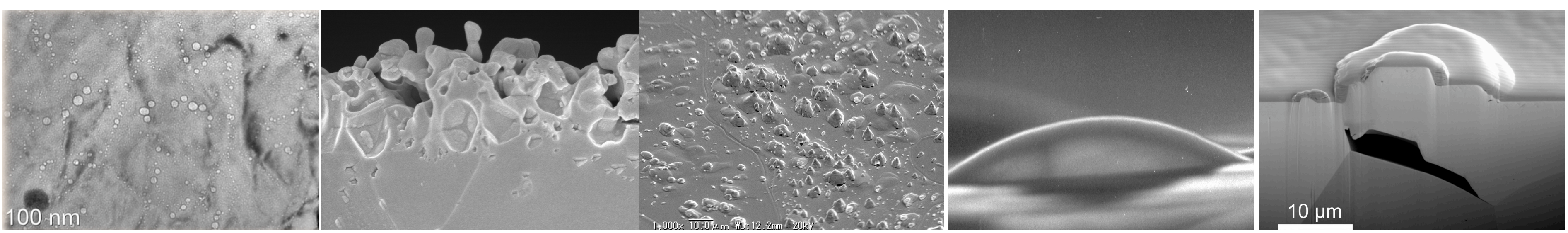
erosion/ intermixing & ion implantation | **blistering & flaking** | **H bombardment & retention** | **diffusion & permeation, annihilation**



Extreme conditions change materials considerably

Irradiation by neutrons and helium will enhance surface modification !

Note: At the end of the PFC lifetime the surface has moved through the bulk material



Void formation, 9 dpa | **Bubbles in W by He** | **Blisters within grains** | **Large Blisters due to voids at grain boundary**

Value of linear plasma devices, when compared to toroidal devices

- Good diagnostic access
- Diagnostics are readily exchanged (maintenance, upgrades)
- Surface diagnosis possible without breaking vacuum
- High flux (10^{24} $m^{-2}s^{-1}$), high fluence discharges possible (accelerated lifetime tests), like that of ITER, FNSF, DEMO
- Well controlled continuous plasma conditions vs. tokamaks enduring different conditions in short durations

  Inter-ELM, ELM, L-mode phase, ramp-up, ramp-down in different operation scenarios for many campaigns, venting…..

- Research objectives of tokamaks and stellarators rely on success of PSI, yet only a fraction of the time is allocated to active PSI research
- Damage and lifetime studies of PFCs in tokamaks, stellarators are mostly not allowed or discouraged due to excessive risks and expenses (change of wall components; shutdown times) and issues of reactor relevance
- Device and operation costs of linear plasma generators are small fractions than that of tokamaks and stellarators

➢ Linear plasma devices can complement power exhaust science carried out on toroidal devices in a synergistic way.

Need for Upgraded or New Linear Plasma Facility

- Upgraded capabilities should include but are not limited to:
  - Access to high density low temperature reactor divertor plasma conditions (n_e > 10^{21} m^{-3}, T_e ~ 1 eV)
  - Parallel power fluxes of up 40 MW/m^2
  - Ion fluxes of more than 10^{24} $m^{-2}s^{-1}$
  - Steady-state conditions for the above mentioned parameters (-> high fluence)
  - Capability to expose irradiated and toxic material samples
  - Ability to control electron and ion temperature separately
- Requirement: high density plasma source with sufficient power based on RF-technology
- Anticipated costs for such an Upgrade or New device are < $15M.

DOE acknowledges importance of Plasma Material Interaction (PMI) in fusion

DOE ReNeW (Research Needs Workshop) identified

First wall materials and compatibility with fusion reactor relevant plasmas (theme 3)

to be addressed for rapid and efficient realization of fusion energy i.e. Thrust 10:

Decode and advance the science and technology of plasma-surface interactions

DOE FESAC panel (Fusion Energy Science Advisory Comm.) recently identified the need of an

Upgrade and/or New Build of linear plasma test stands with medium scale facilities

Requirement	Thrusts
Diagnostic investment for edge characterization	1 and 9
Dedicated experimental time for edge characterization	1, 5, 9, **10**
Improved models and code components for edge region	9 and **10**
Innovative divertor concepts and testing	9 and 11
Transient impact on plasma facing components	2, 6 and **10**
Innovative design of solid surface PFCs	**10** and 11
Testing necessary to validate codes, improved physics models, and new designs	**10** and 11
Liquid surface development	11
Improved diagnostic parts in edge	1, 2, 9, **10**, 11
Antenna and launcher development	**10**
Internal coils	2 and 5
Integrated demonstration of taming plasma material interactions	12