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JÜLICH FORSCHUNGSZENTRUM

Association EURATOM – FZJ

Material challenges for plasma facing components in future fusion reactors

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Institute of Energy and Climate Research (IEK)

5th INTERNATIONAL CONFERENCE ON THE FRONTIERS OF PLASMA PHYSICS AND TECHNOLOGY

18-22 April 2011, Singapore

Nobel Prize in Physics 2007 - Peter Grünberg, FZJ

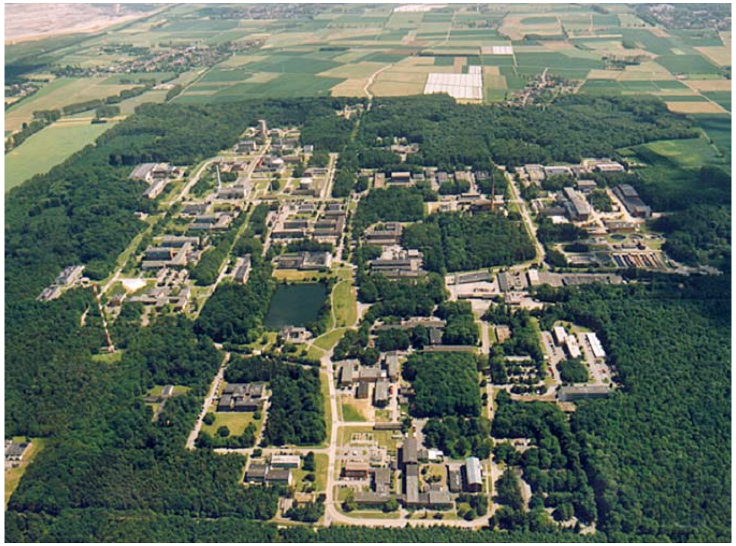
Giant Magnetoresistance - GMR

Peter Grünberg and Albert Fert won the 2007 Nobel Prize in physics for a discovery that has shrunk the size of hard drives found in digital devices.

Research Centre Jülich
Research & Development on 2.2 km^2

Total budget: 532 million €

Employees: 4 608



Research Areas

Health

Energy & Environment

Information

Key technologies

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Outline

A **Wall loading conditions & materials**

B **Quasi-stationary loads & thermal fatigue behaviour**

C **Intense transient loads & thermal shock resistance**

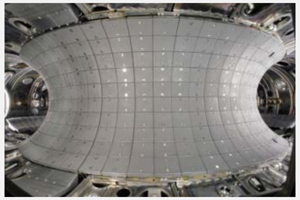
D **Neutron induced material degradation**

A

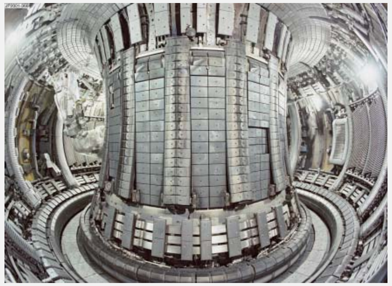
Wall loading conditions & materials

Plasma facing components

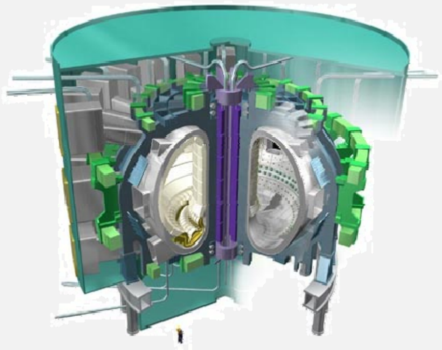
fusion devices:



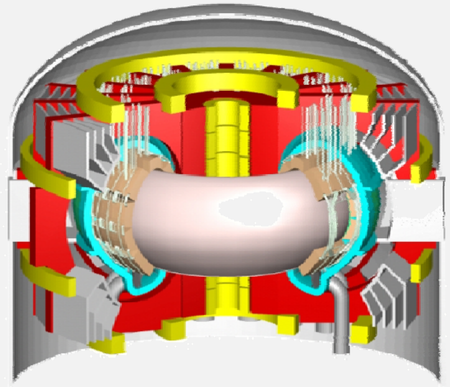
TEXTOR



JET



ITER

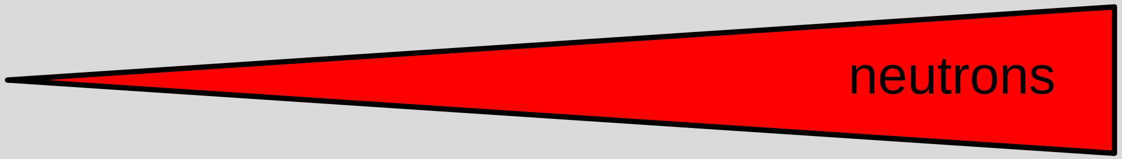


DEMO

heat removal:

passively cooled PFCs	actively cooled PFCs	
	water	He, liquid metal

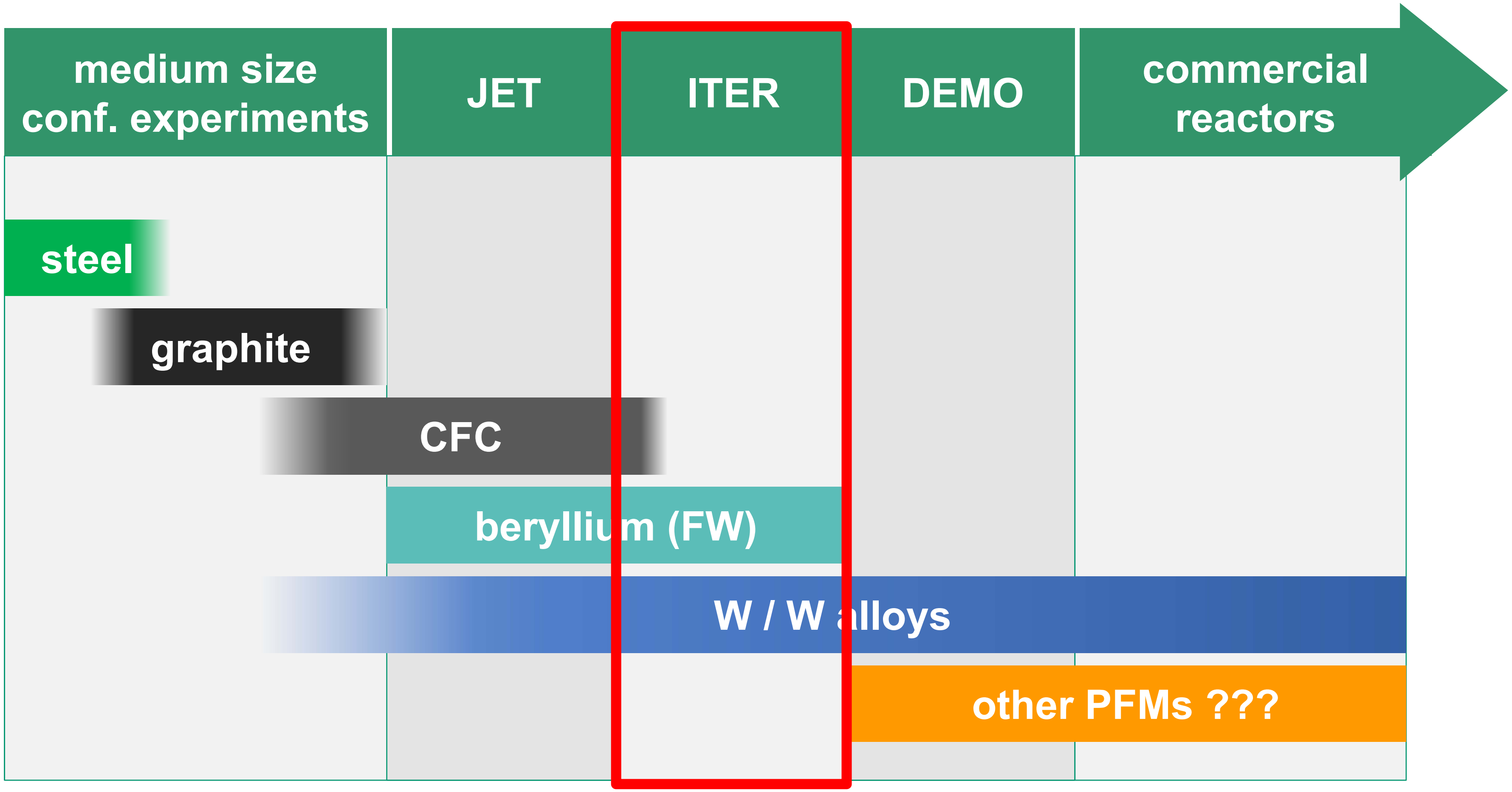
tritium fuel:
- increased T inventory
- n-induced material degradation



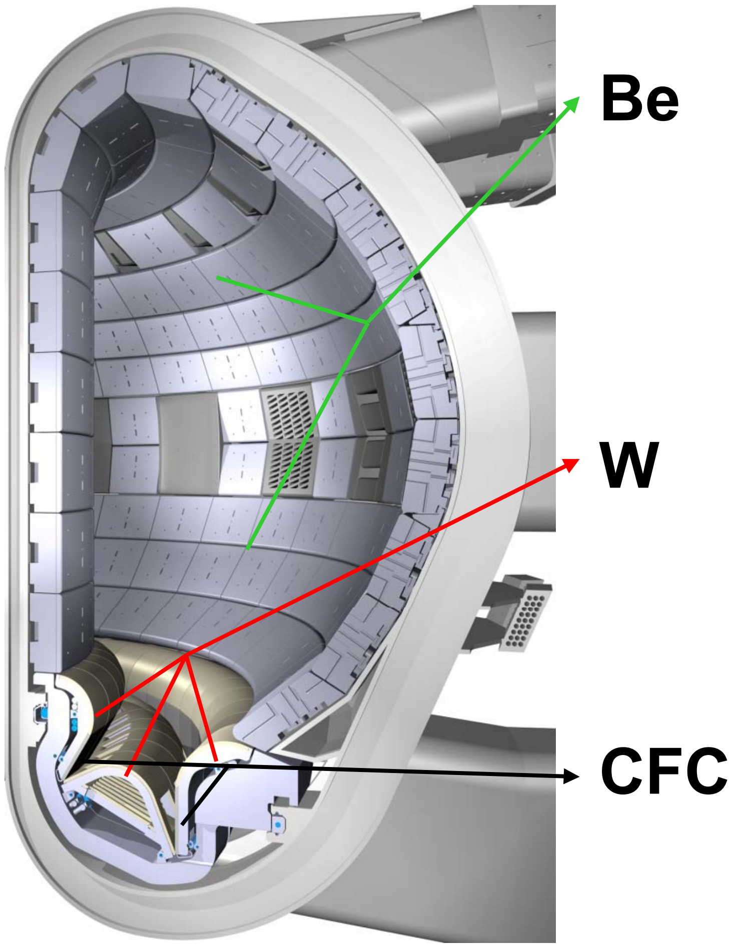
life time fluence:

0 dpa | 10^{-9} dpa | 1 dpa | 10^{2} dpa

Plasma facing materials in magnetic confinement experiments

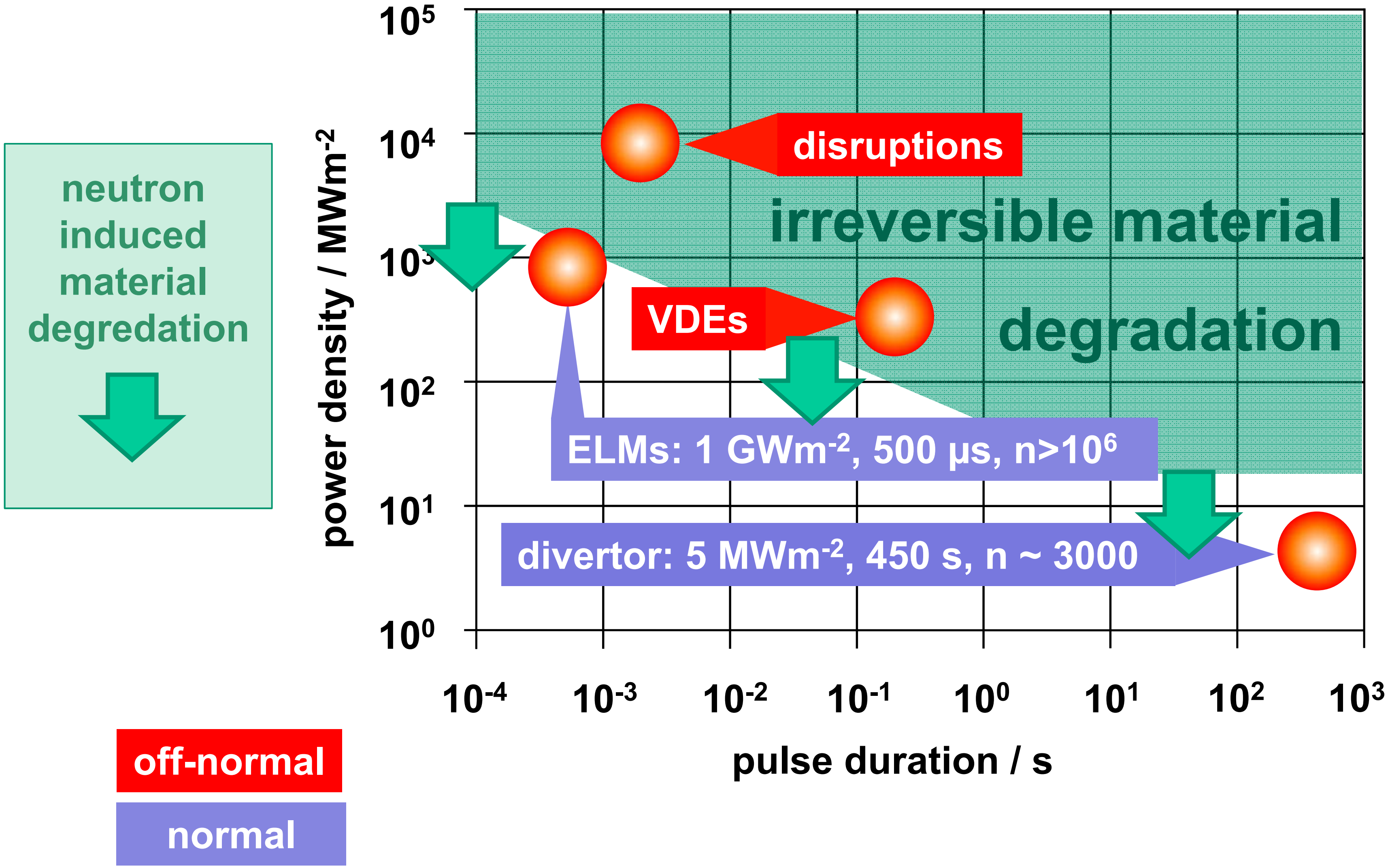


Plasma facing materials for ITER

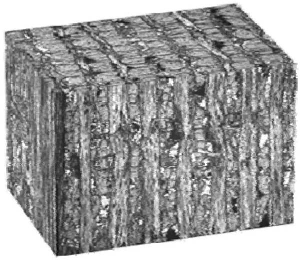


	Advantages	Disadvantages
Be	• low Z • no chemical sputtering • high thermal conductivity	• low melting point • toxicity • short erosion lifetime • low neutron radiation resistance
W	• high melting point • good thermal conductivity • low tritium retention	• high Z • high DBTT • neutron embrittlement
CFC	• low Z • high thermal shock resistance • high thermal conductivity • no melting	• high erosion rate at high temperatures • tritium retention • reduction of thermal conductivity after neutron irradiation

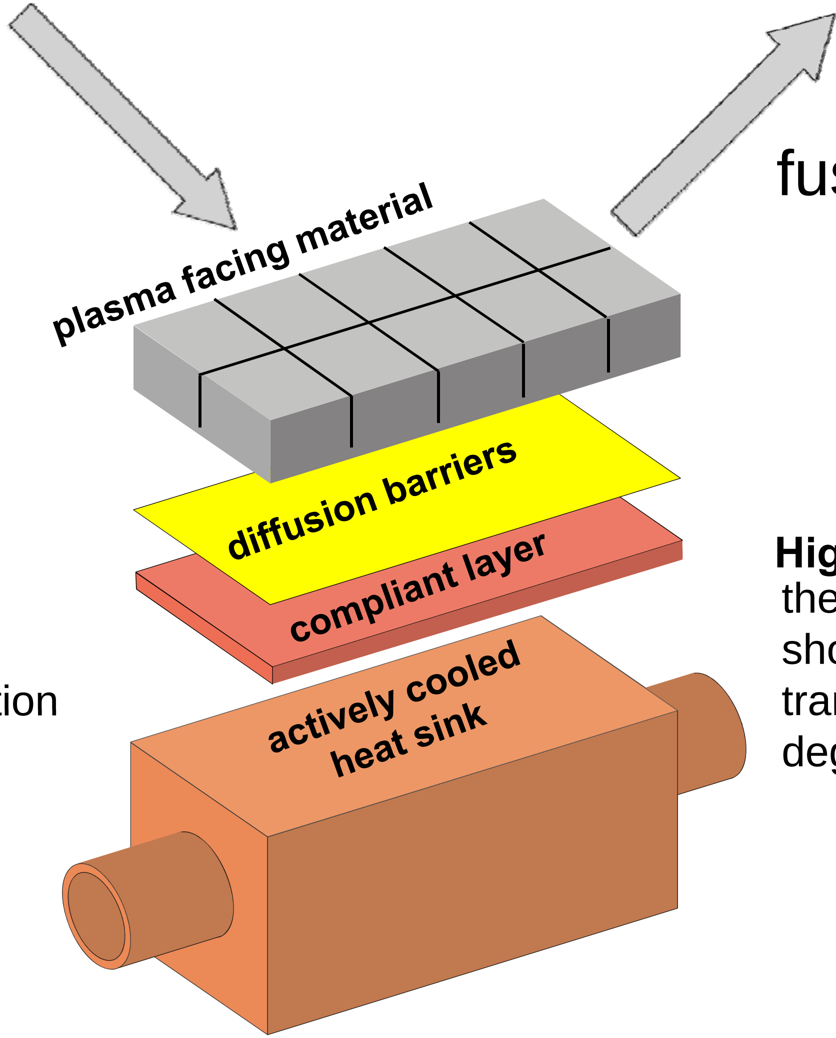
Wall loads on plasma facing components in ITER

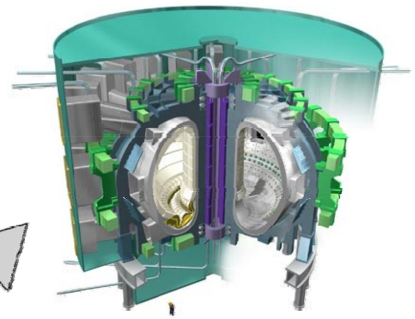


Components for fusion devices



material





fusion reactor wall

Plasma wall interaction
erosion (chem. and phys. sputtering), redeposition, material mixing, fuel retention

High heat flux performance
thermal fatigue, thermal shock (ELM-induced transients), neutron induced degradation

B

Quasi-stationary loads & thermal fatigue behaviour

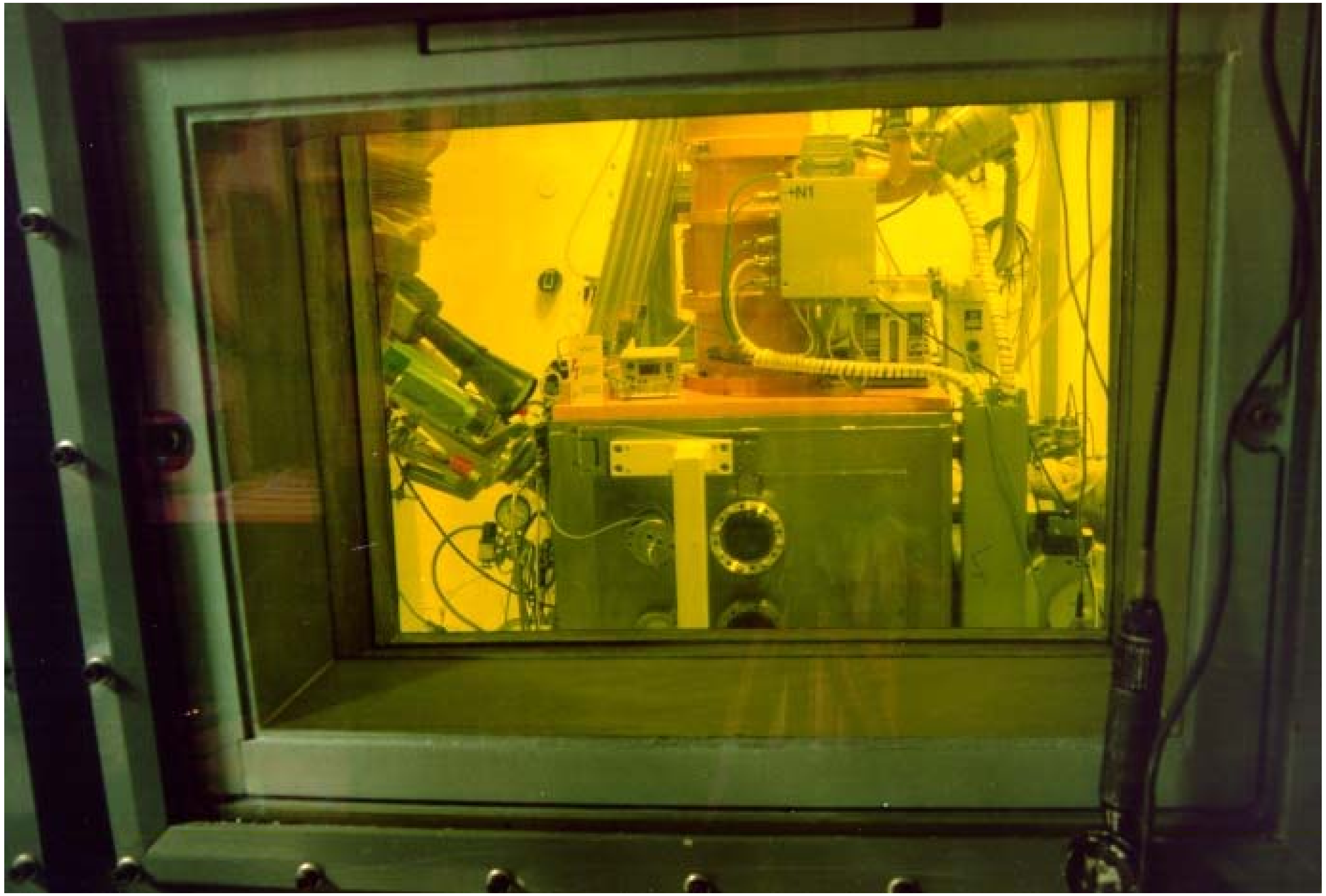
JUDITH

Juelich Divertor Test Facility Hot Cells (JUDITH)

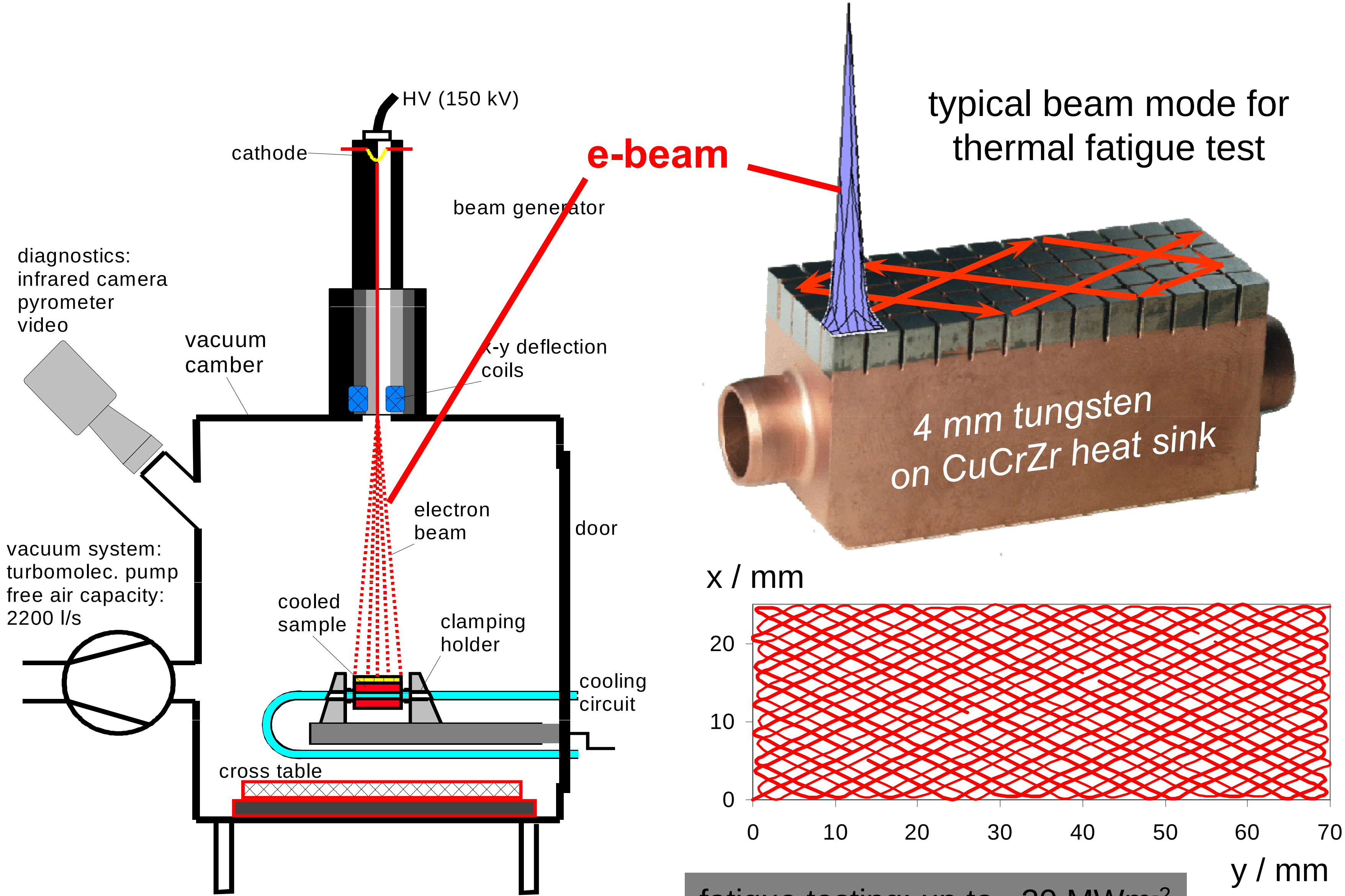
Judith was an Old Testament Jewish heroine. In the Apocryphal 'Book of Judith', she is portrayed as a widow who made her way into the tent of Holofernes, general of Nebuchadrezzar, cut off his head, and so saved her native town of Bethulia.

Gustav Klimt, Judith I, 1901

JUDITH 1 in Juelich
Electron beam test facility



Simulation of ITER relevant thermal loads

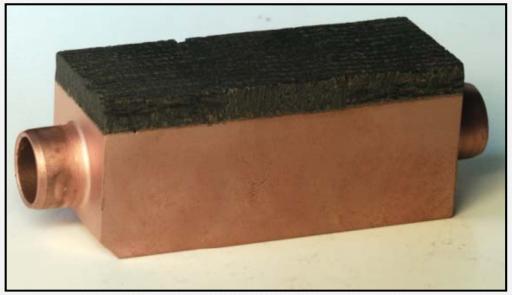


fatigue testing: up to ~20 MWm^{-2}
10 s on / 10 s off

Fatigue testing on plasma facing components for ITER

CFC armour | **tungsten armour**

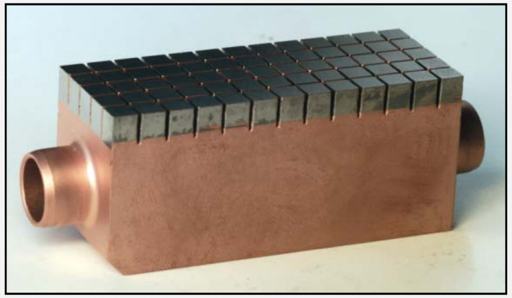
flat tile design



CFC flat tile

Silicon doped CFC NS31, active metal casting, e-beam welding to CuCrZr heat sink

1000 cycles @ 19 MWm^{-2}



W macrobrush

WLa_2O_3 tiles with OFHC-Cu, e-beam welding to CuCrZr heat sink

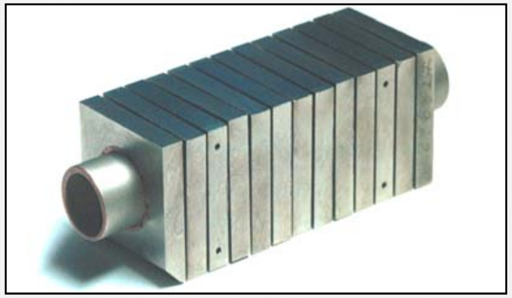
1000 cycles @ 18 MWm^{-2}

monoblock design

CFC monoblock

drilling of CFC tiles (NB31), active metal casting (AMC®) low temperature HIPing

1000 cycles @ 25 MWm^{-2}



W monoblock

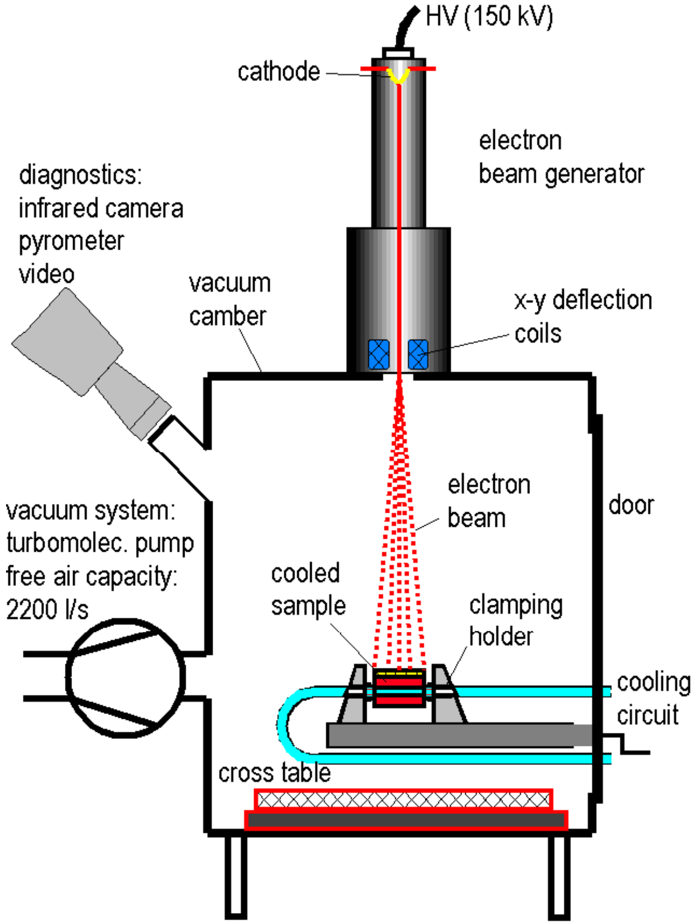
lamellae technique, drilling of WLa_2O_3 blocks, casting with OFHC-Cu, HIPing

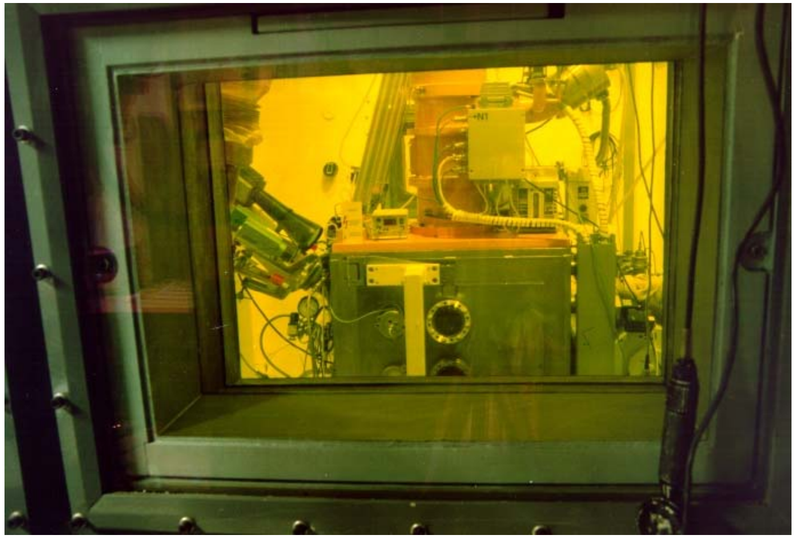
1000 cycles @ 20 MWm^{-2}

C

Intense transient loads & thermal shock resistance

JUDITH 1: Electron beam test facility

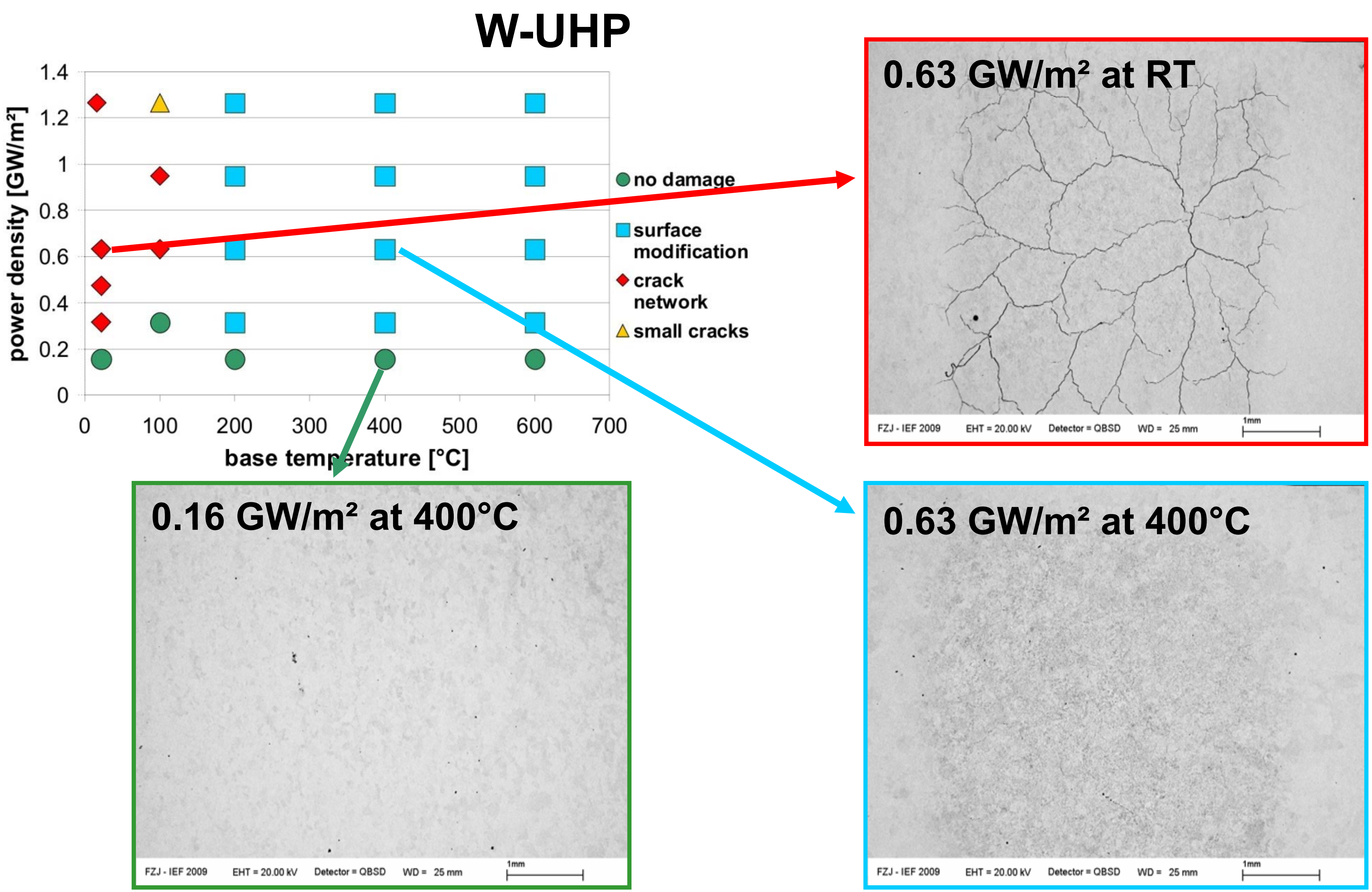




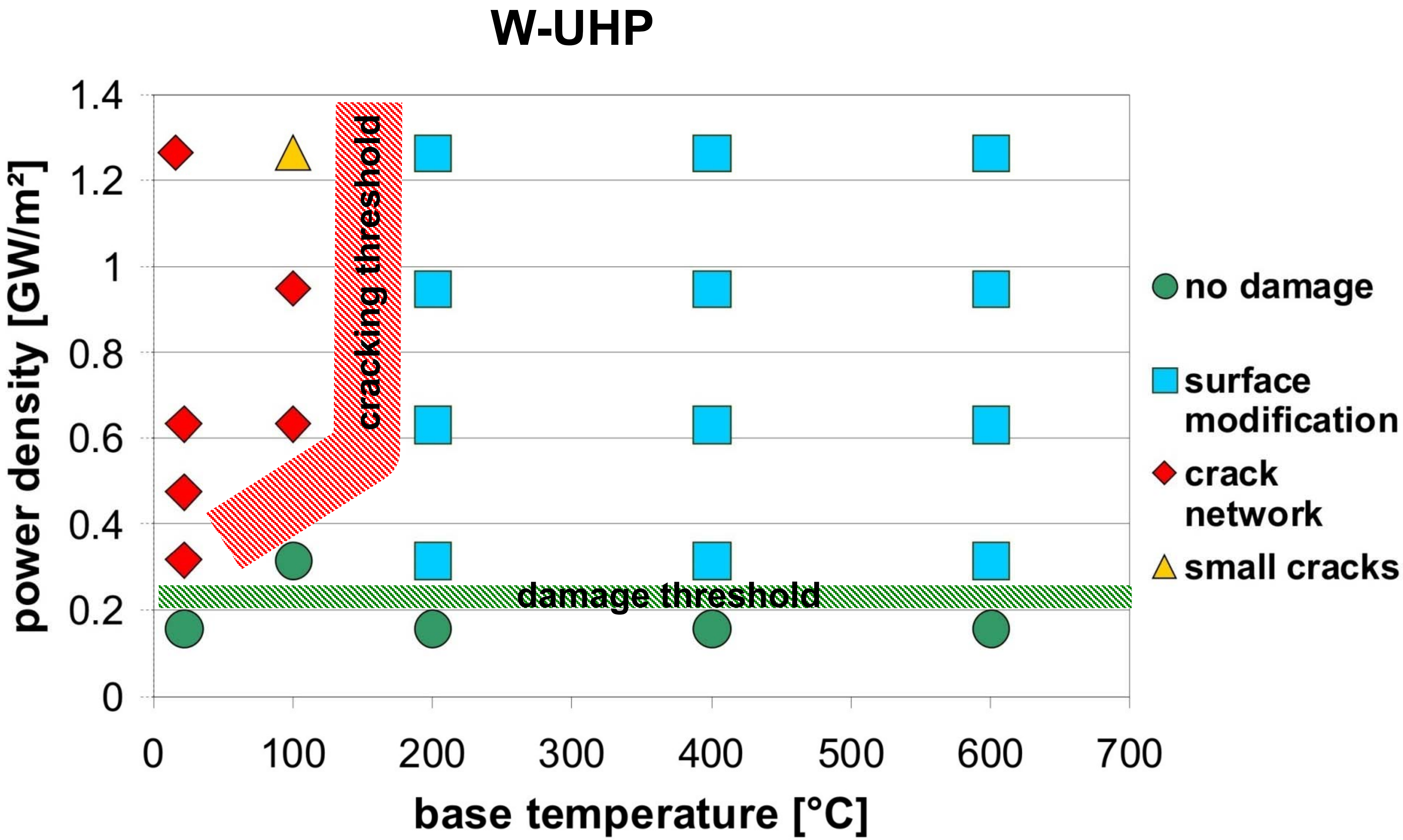
Acceleration voltage: 120 kV
Loaded area: 4 x 4 mm^2
Pulse duration: 1 ms
Inter pulse time: 2 s
Number of pulses: 100
Electron absorption coefficient: 0.46
Absorbed power densities: 0.16 – 1.28 GW/m^2
Base temperatures: RT - 600 °C
Scanning frequencies: 31 kHz, 40 kHz (x/y)

Transient heat load tests on tungsten

Electron beam simulation of ELM-specific thermal loads (Δt = 1 ms; n = 100)

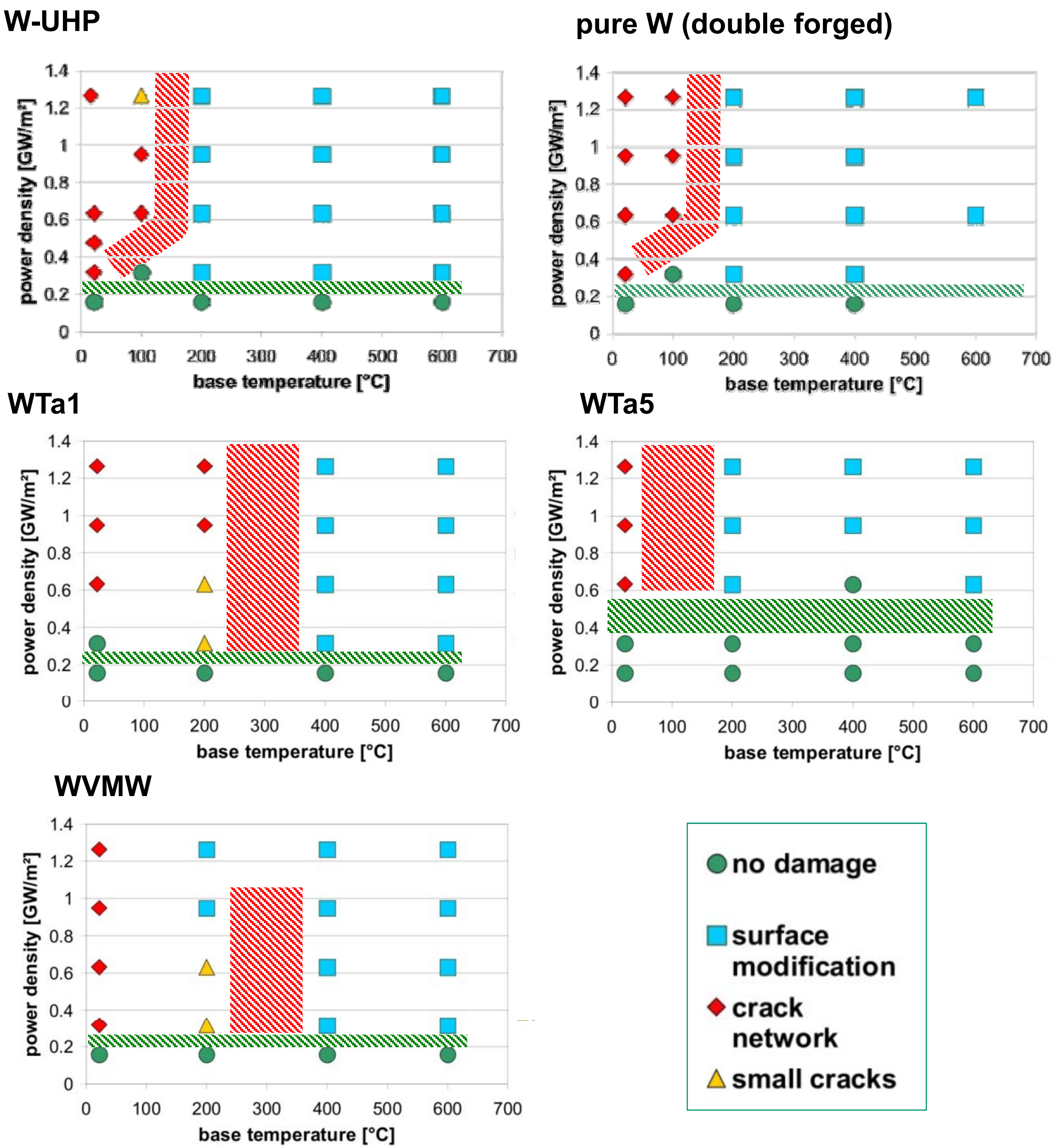


Transient heat load tests on tungsten

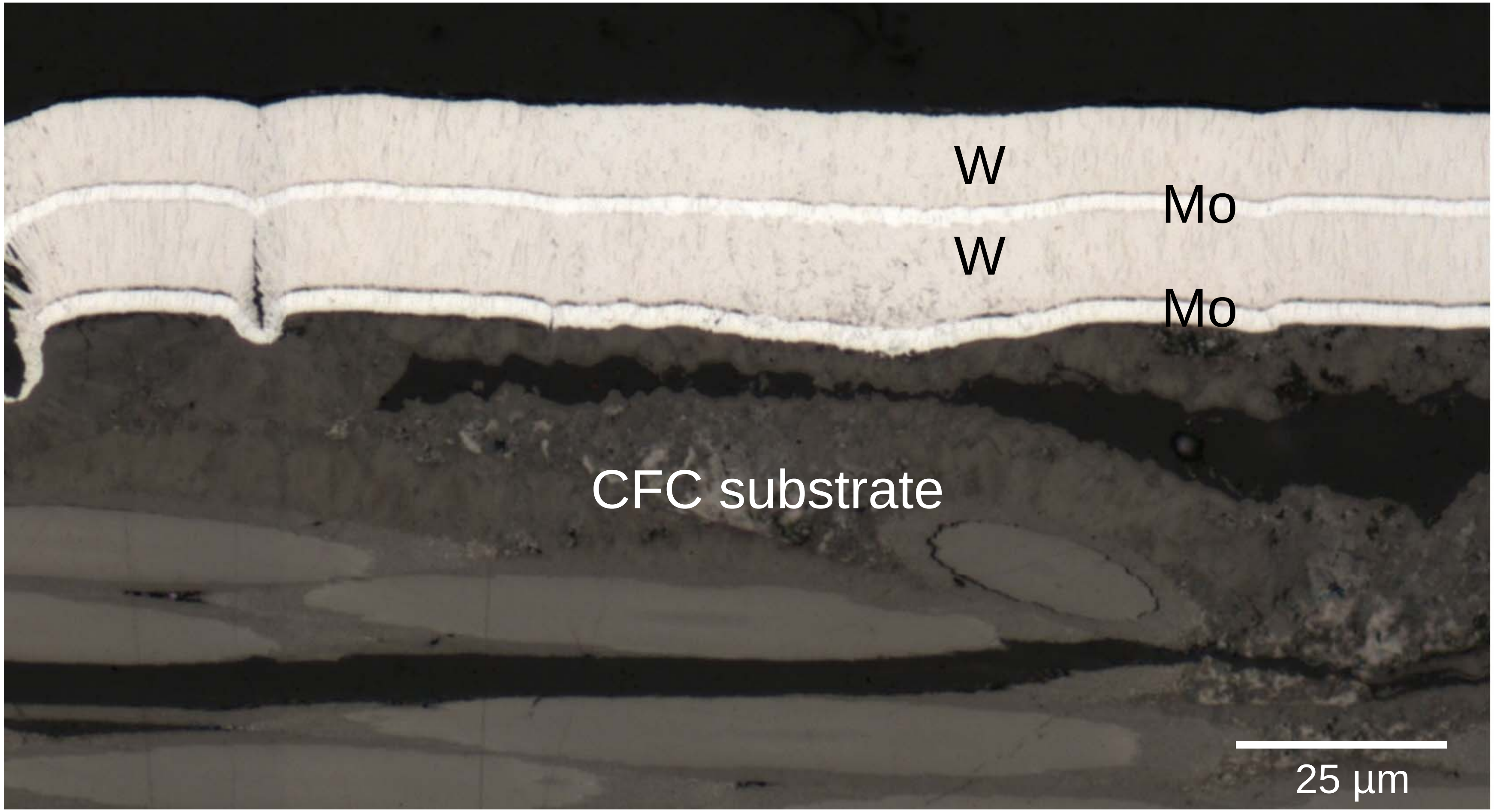


100 cycles with a duration of 1 ms; absorption coefficient: 0.46

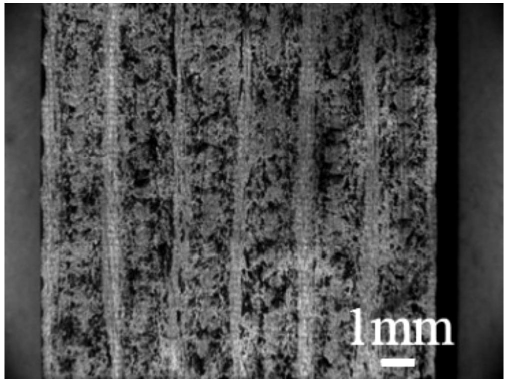
Transient heat load tests on tungsten



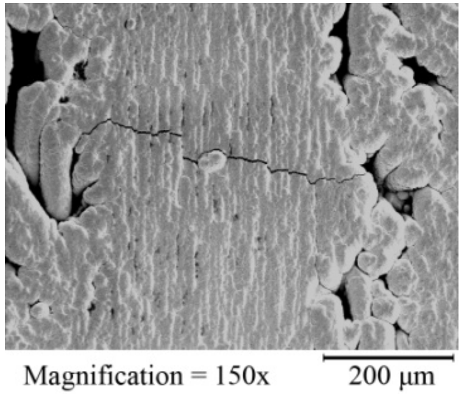
Tungsten coatings on CFC substrate



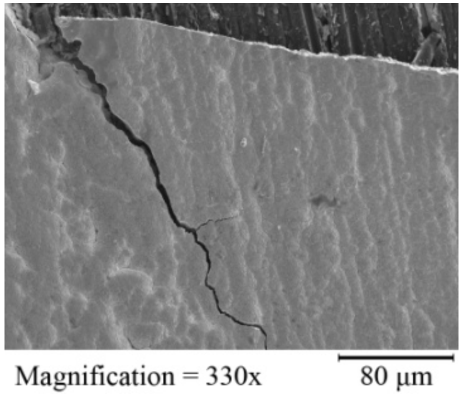
Damage types



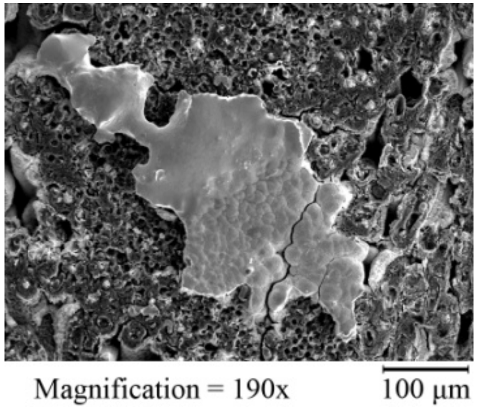
Surface modification



Cracking

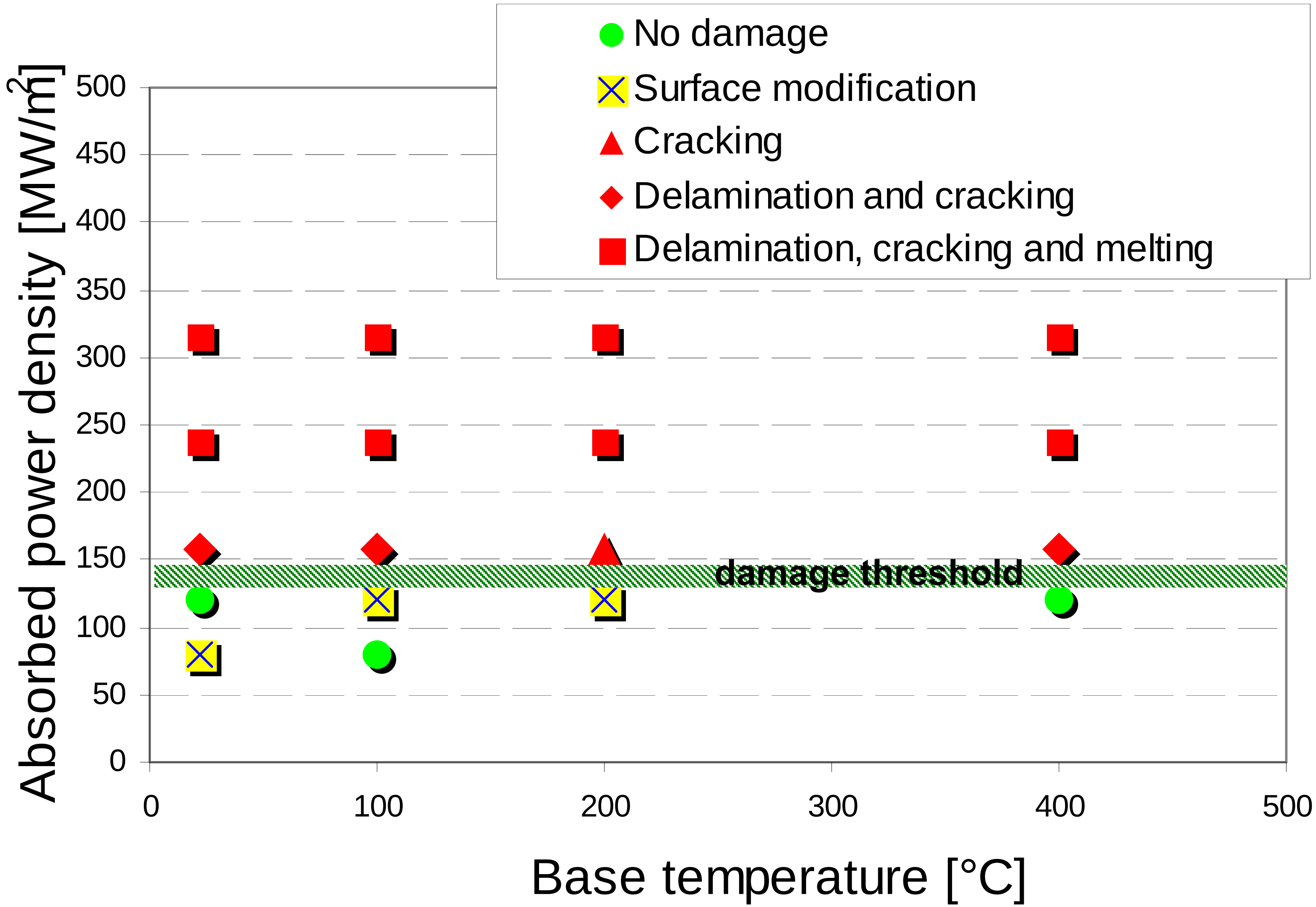


Cracking / delamination



Cracking / delamination / melting

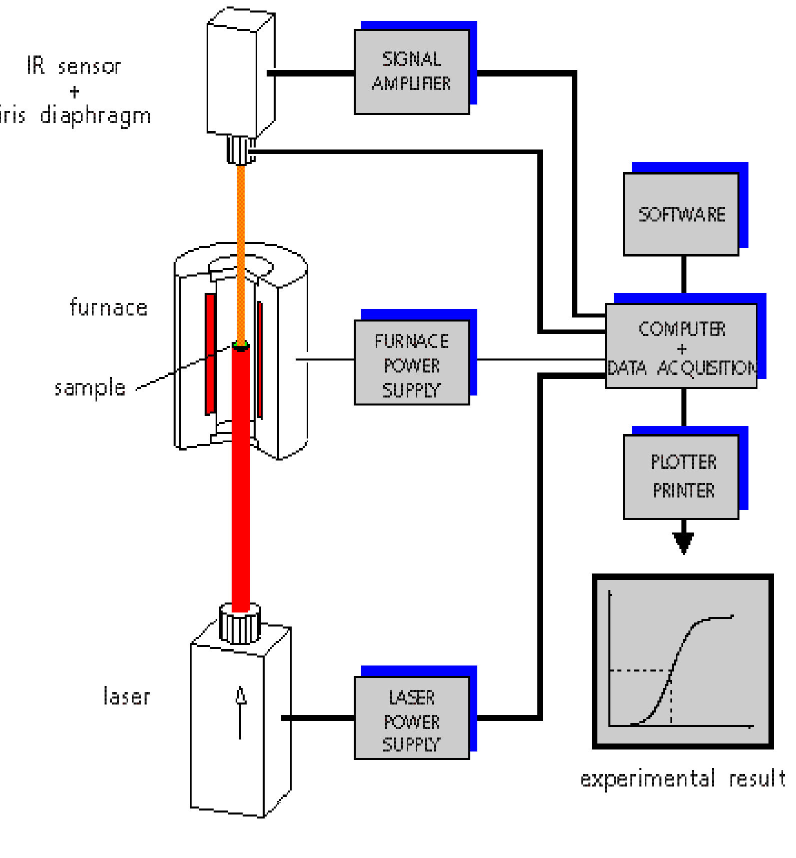
Tungsten coatings - test results



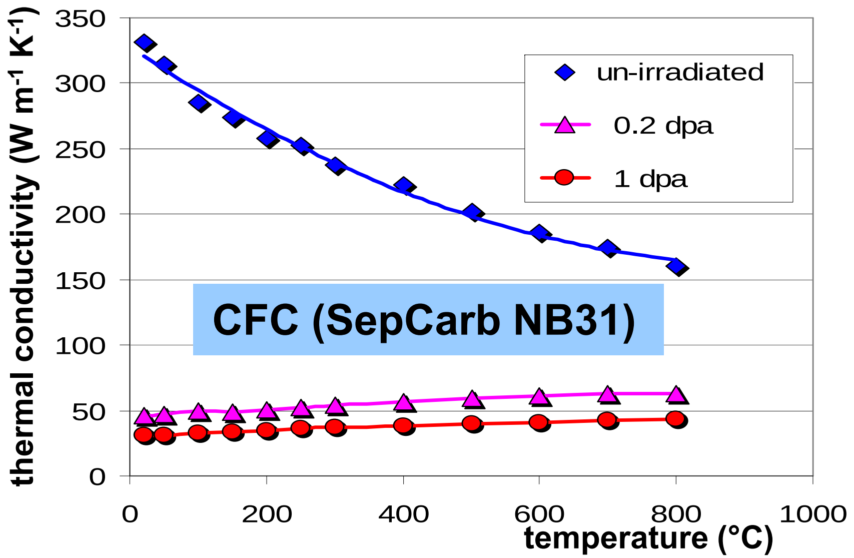
D

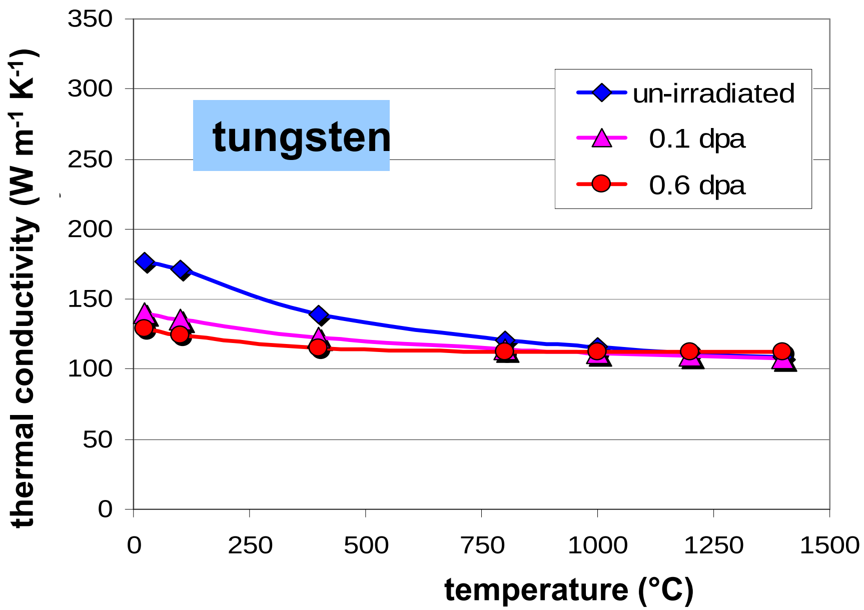
Neutron induced material degradation

Neutron irradiation effect on thermal conductivity



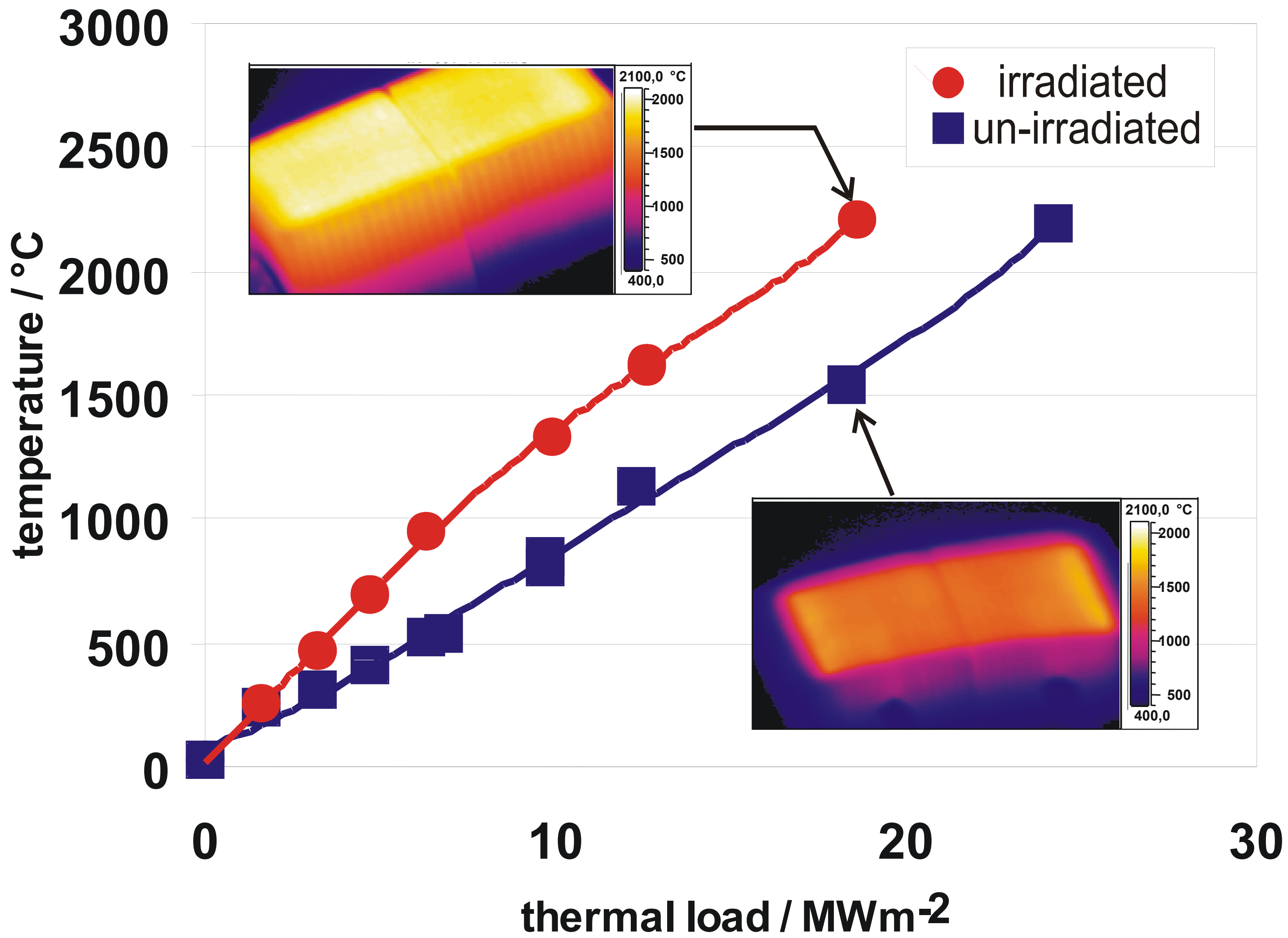
Laser-flash-apparatus (schematic)



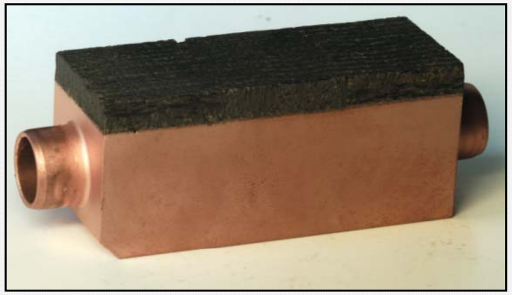
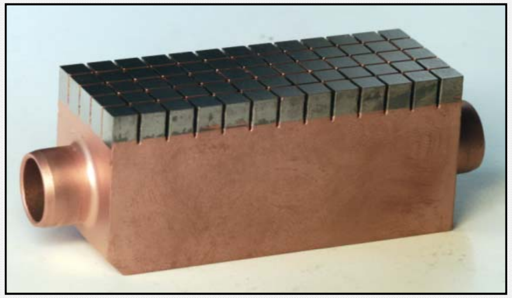
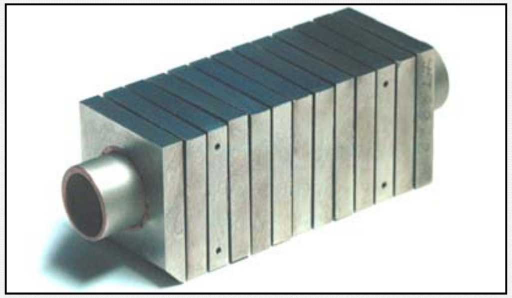


High heat flux performance of neutron irradiated divertor modules

CFC monoblock design / CuCrZr, T_{irr} = 350°C / 0.3 dpa

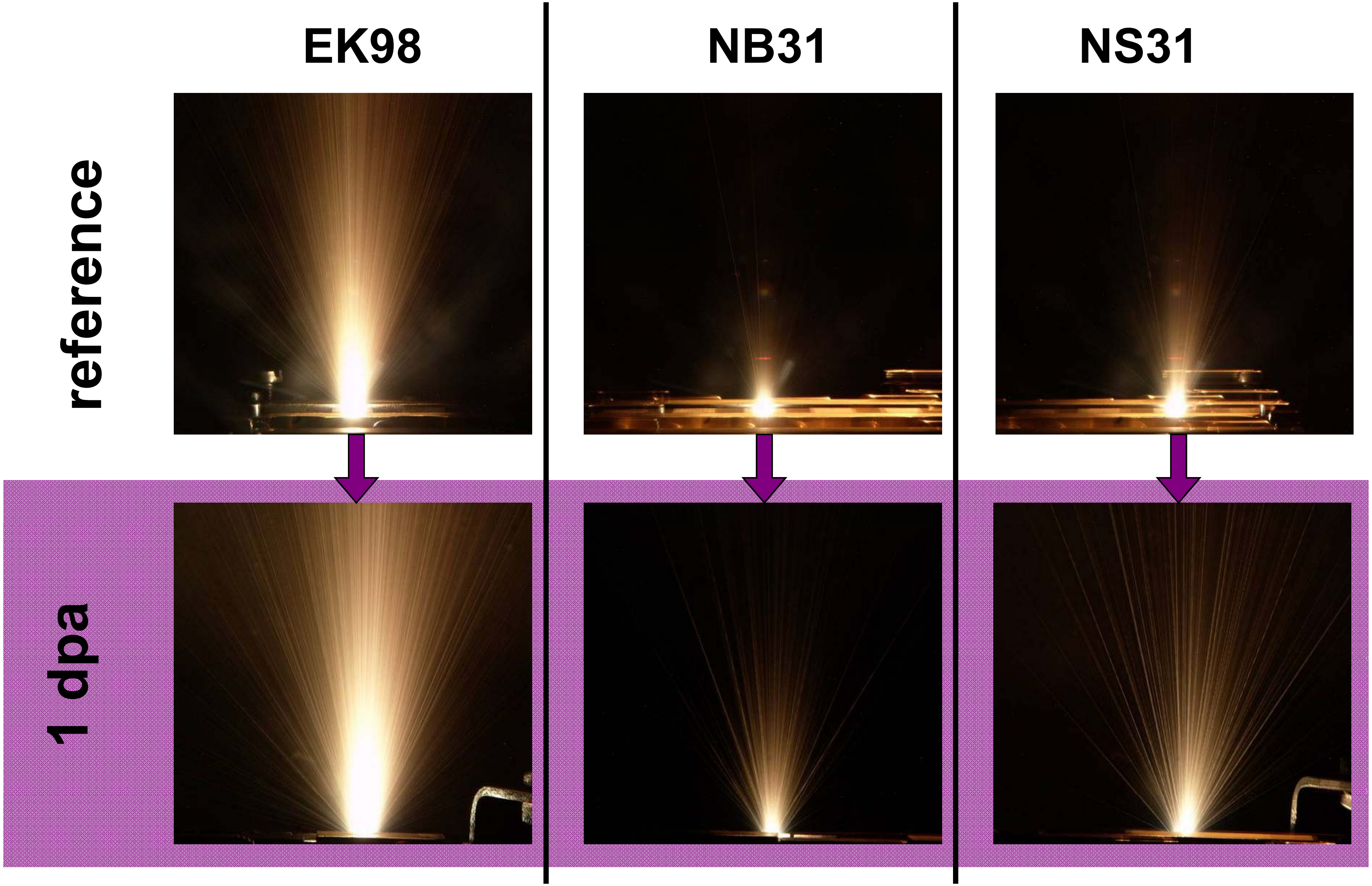


Fatigue testing on plasma facing components

	CFC armour	tungsten armour
flat tile design	 **CFC flat tile** 0 dpa: 1000 cycles @ 19 MWm^{-2} 1 dpa: 1000 cycles @ 15 MWm^{-2} (no degradation)	 **W macrobrush** 0 dpa: 1000 cycles @ 18 MWm^{-2} 0.6 dpa: 1000 cycles @ 10 MWm^{-2} (increasing of T_{surf})
monoblock design	 **CFC monoblock** 0 dpa: 1000 cycles @ 25 MWm^{-2} 1 dpa: 1000 cycles @ 12 MWm^{-2} (substancial evaporation @ 14 MWm^{-2})	 **W monoblock** 0 dpa: 1000 cycles @ 20 MWm^{-2} 0.6 dpa: 1000 cycles @ 18 MWm^{-2} (no degradation)

Thermal-shock tests: C-based materials

particle trajectories of eroded carbon particles during the 10th shot



Summary

Materials characterization

- an extensive data base is required including microstructure and all physical properties (mechanical, thermal, electrical, optical etc.)
- these parameters are required for monolithic materials, coatings and interlayers for a wide temperature range & different material treatment

Thermal fatigue and thermal shock

- technical solutions for cyclic thermal loads up to ~20 MWm^{-2} are available (CFC- or W-monoblocks represent a very robust design solution)
- effect of ELMs needs further analyses

Material degradation by energetic neutrons

- the thermal conductivity is decreased significantly (e.g. graphite / CFC)
- the surface temperature of carbon based high heat flux components is significantly increased after neutron irradiation