IAEA 2011

H isotope retention in Be and Be mixed materials

Wolfgang Jacob

IPP
Plasma Edge and Wall Division

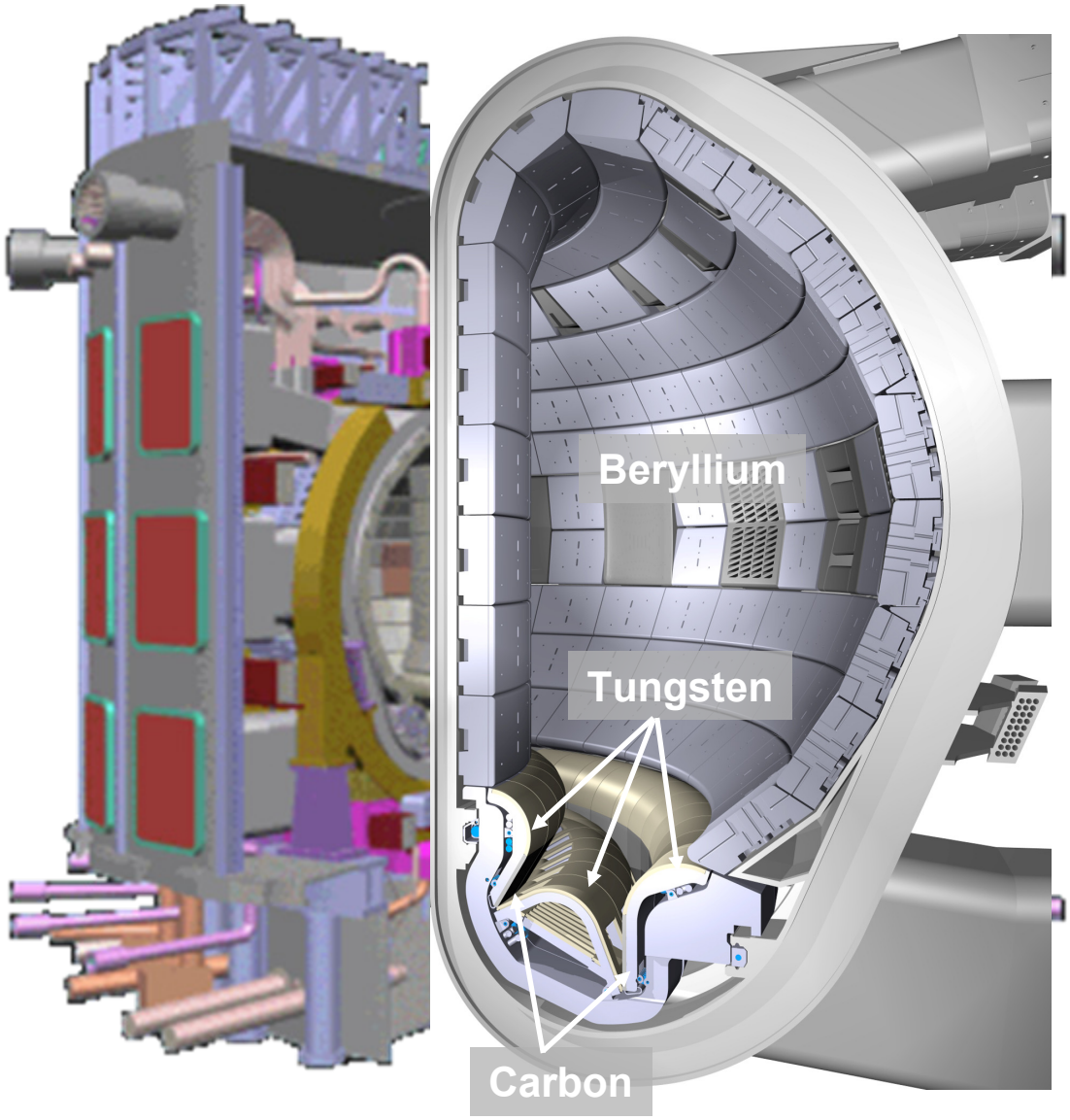
Introduction: Challenges for ITER and beyond

Fusion reaction:	T(D,α)n
Central Temperature:	20 keV
Typical Density:	10^{20} m^{-3}
Fusion Power:	500 MW
Plasma Volume:	840 m^3
Plasma Current:	15 MA

700 m^2 Be first wall

100 m^2 Tungsten divertor

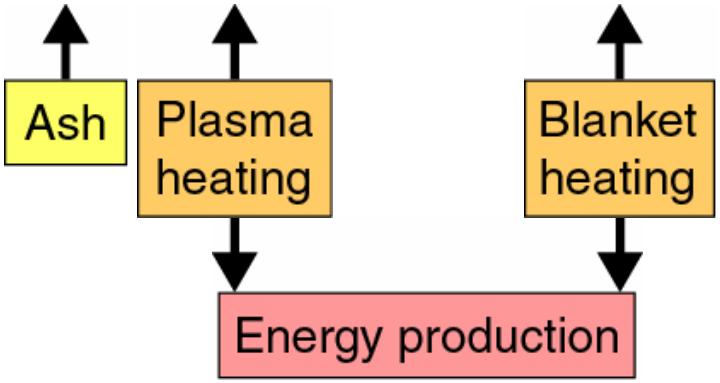
50 m^2 CFC strike point

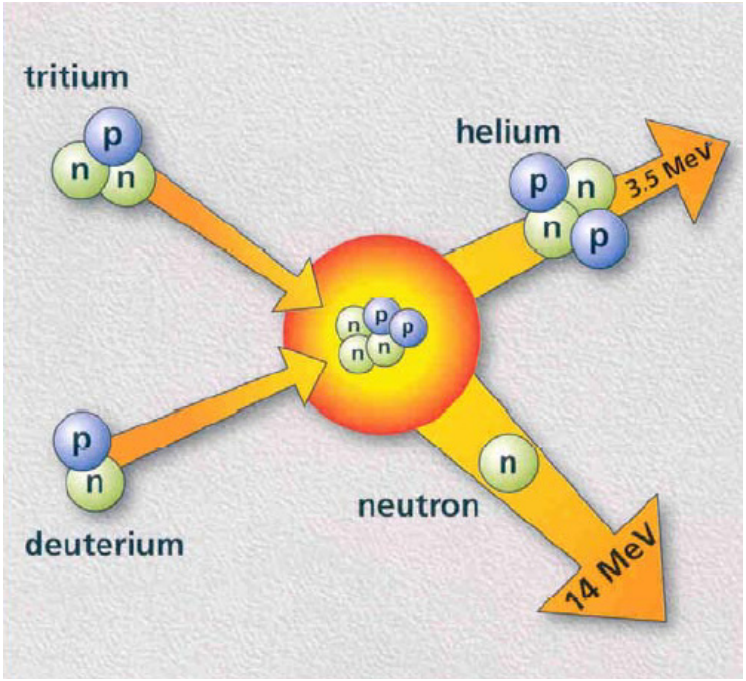


Nuclear Fusion Reaction

Most promising reaction (highest $\langle\sigma v\rangle$):

$$D + T \rightarrow \alpha\ (3.5\ \text{MeV}) + n\ (14.1\ \text{MeV})$$

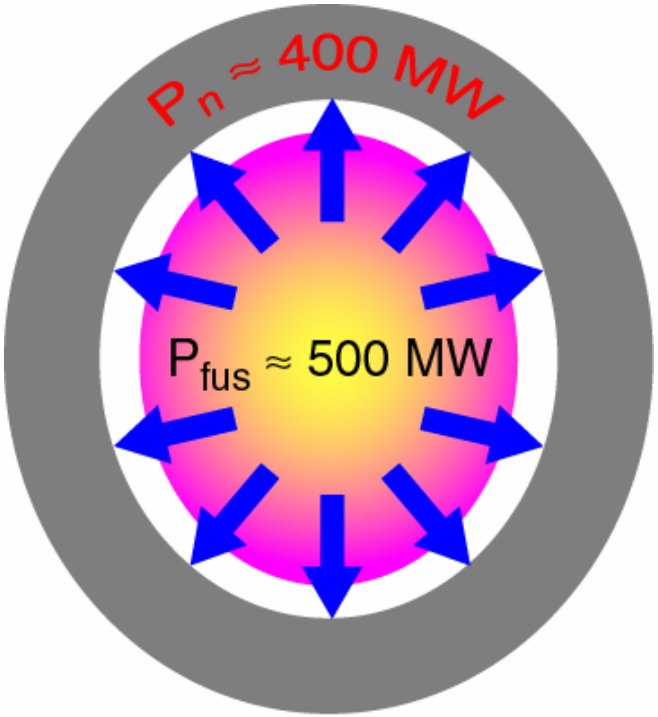




Implications for reactor operation

- Energy and particle exhaust
- Radioactivity (fuel&structure)

The role of material walls



$P_\alpha \approx 100$ MW

$P_{aux} \approx 40$ MW

1. VACUUM CONDITIONS

Unlike the sun, a fusion plasma can only be maintained under ultra high vacuum conditions -

base pressure $\approx O(10^{-8}$ *mbar)*

2. EXTRACTION OF POWER

The α-particle power and auxiliary injected power used to heat the plasma must be finally extracted through the plasma facing wall

Power carried by neutrons is converted to heat in blanket wall

neutrons also breed tritium in blanket

3. HELIUM REMOVAL

The removal of the helium ash requires thermalisation and neutralisation of plasma ions

Power flux densities in ITER

ITER: 400 MW in neutrons,
100 MW from alpha particle heating
about 50 MW auxiliary heating
→ about 150 W heating power to walls
About 50 % go to divertor, rest to main chamber walls

Main chamber wall:
700 m^2, about 450 to 500 MW, about <1 MW/m^2

Divertor:
About 75 MW
Radial extend of power carrying layer O(cm)
Inclined target plates increase strike area by about a factor of 6

→ **Mean power flux density at divertor strike areas in ITER: 10 MW/m^2**
(in transient events [ELMs, disruptions] up to factor of 10-100 higher)

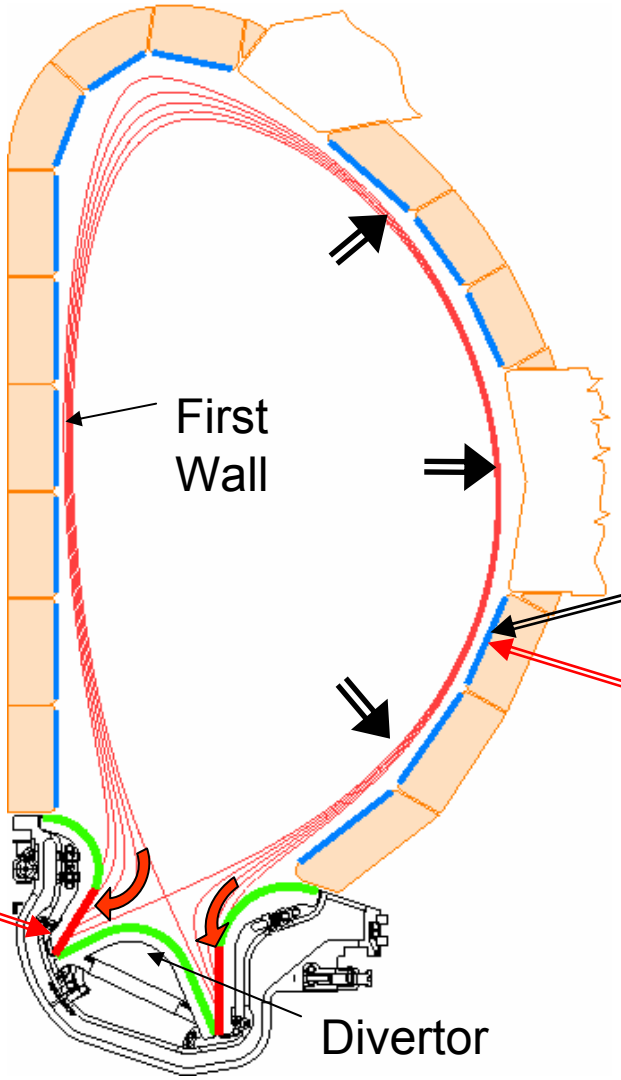
→ Radiative cooling to distribute power over a larger area

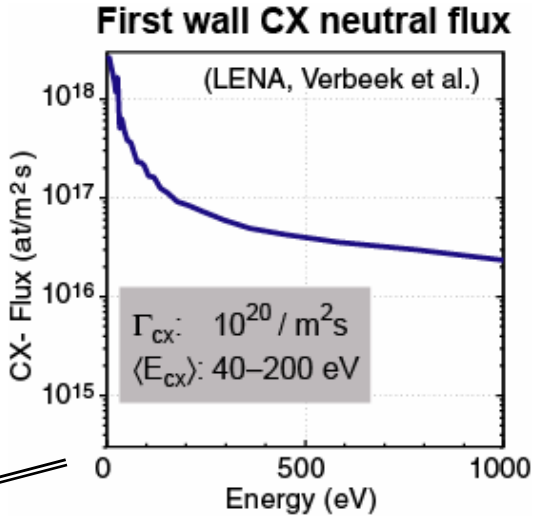
Requires development of appropriate plasma-facing components

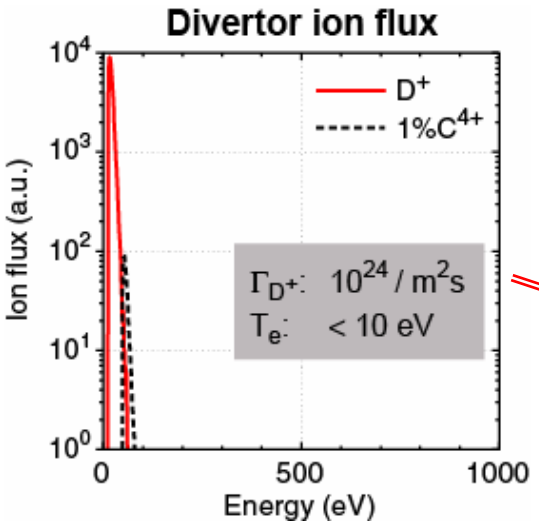
For comparison:

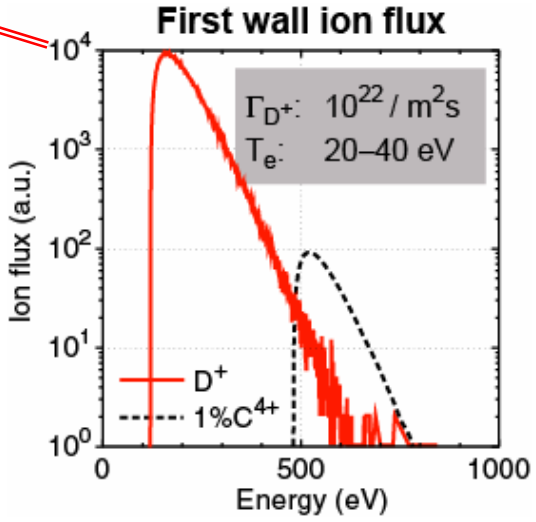
Hot plate	0.05-0.1 MW/m^2
Oxy-acetylene torch	100 MW/m^2

Particle fluxes









PSI and PMI topics

Material erosion – life time of components and plasma impurities

Transport and redeposition of eroded material

Tritium inventory (in particular in redeposited layers)

Handling of power fluxes (plasma-facing components)

Neutron damage and activation of materials

Physical sputtering yield and harmfulness of elements in the plasma are main selection criteria for first wall material

PSI/PMI processes

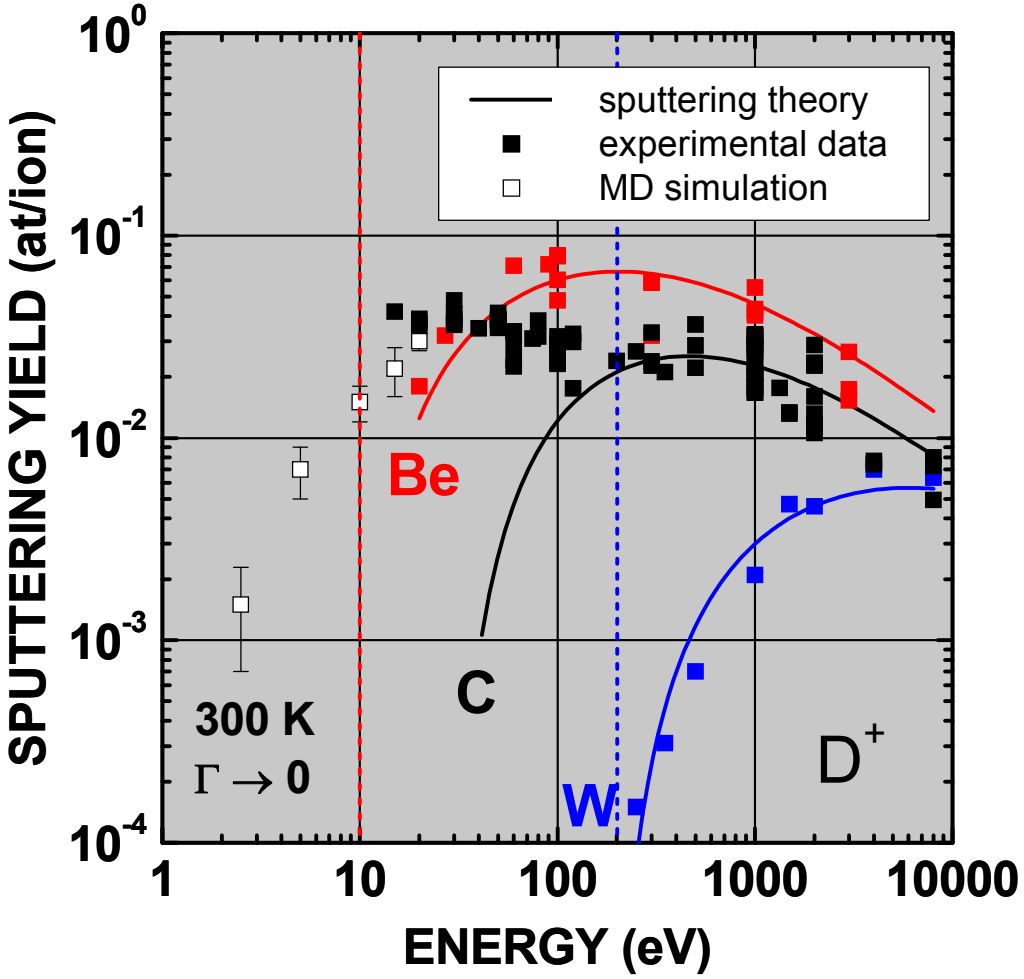
- Physical Sputtering
- Chemical Erosion
- Radiation Enhanced Sublimation
- Photon Induced Desorption
- Evaporation & Sublimation
- Brittle destruction
- Melting & Splashing
- Arcing
- Neutron Induced Damage

Erosion by energetic D ions: physical and chemical sputtering

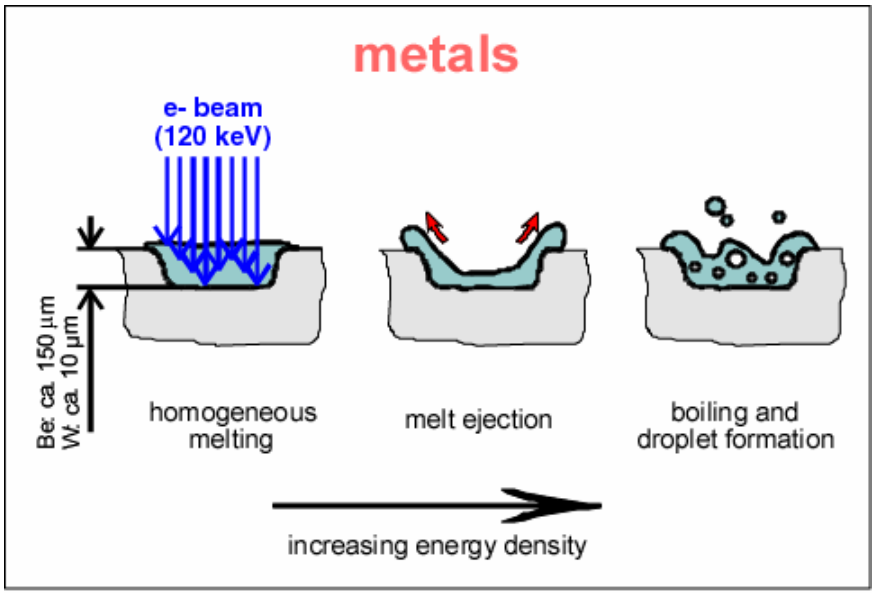
For beryllium and tungsten theoretical and experimental yields agree very well

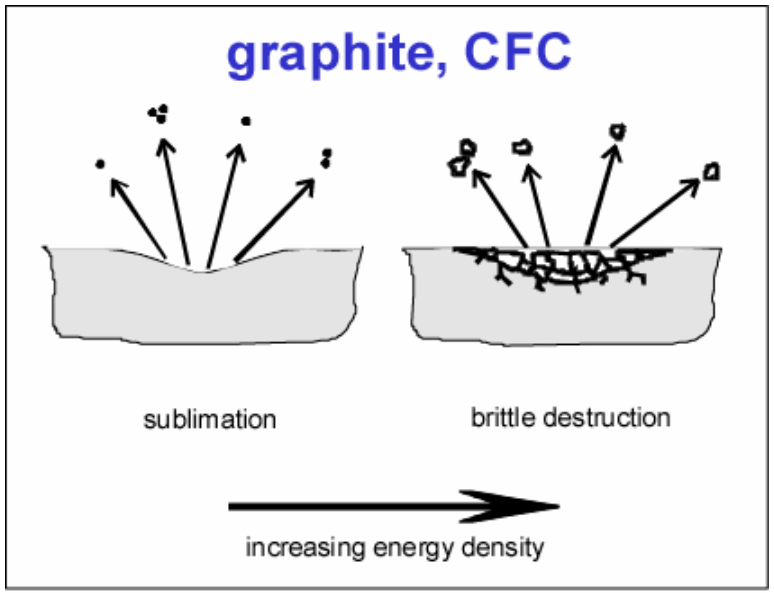
Carbon shows additional erosion with only weak dependency on impact energy

CHEMICAL EROSION



Material erosion under extreme power load





FOR METALS:

Splashing

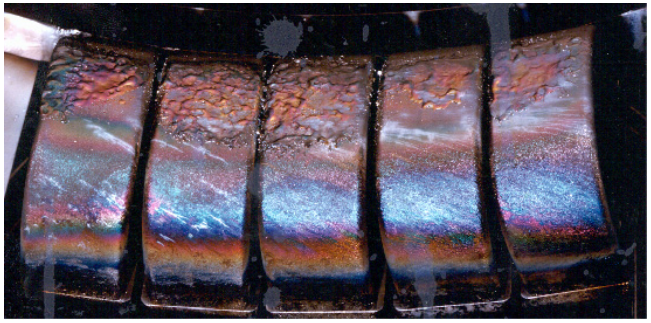
Formation of droplets

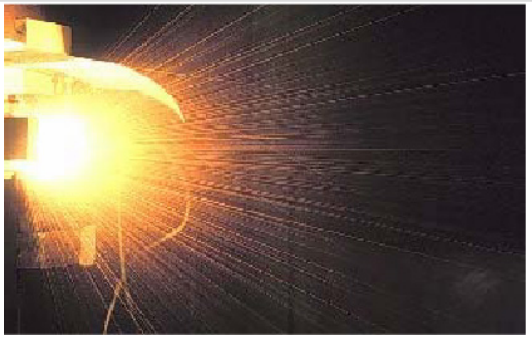
Formation of dust

FOR CARBON:

Above a certain power load (threshold) emission of debris

⇨ BRITTLE DESTRUCTION





Scientific programme at IPP

4 main topics:	Devices:
Surface Processes	Tandem Acc. Laboratory
Tritium inventory	AUG, TS, ITER
Migration in fusion devices	AUG, JET
Materials and components	High heat flux test facility, GLADIS, JET, W7-X

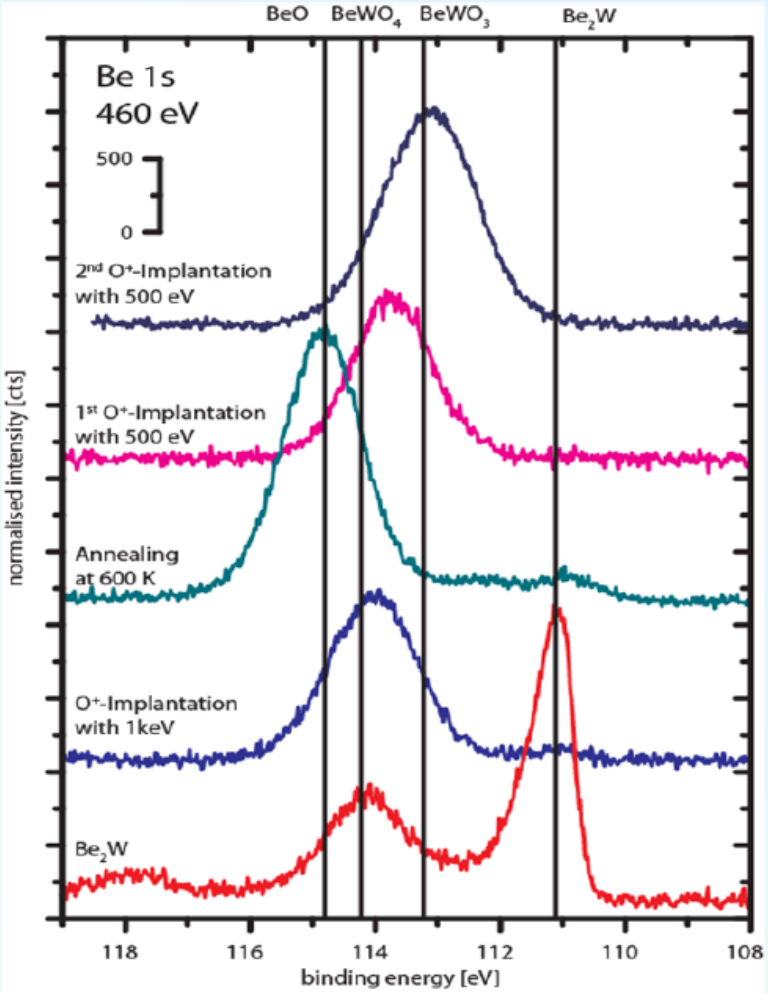
I. Surface Processes

Formation of mixed materials:

Here: Be – W – O system

- Investigation of surface alloys and mixed phases by XPS
- Lab experiments and experiments at BESSY (Berlin Electron Syncrotron)
  - ➢ Chemical information from peak position
  - ➢ Compositional information from intensity
  - ➢ Depth information from variation of photon energy

- Which chemical phases do form?
- What are reaction temperatures?
- What is the role of diffusion?
- How do these phases interact with the boundary plasma?

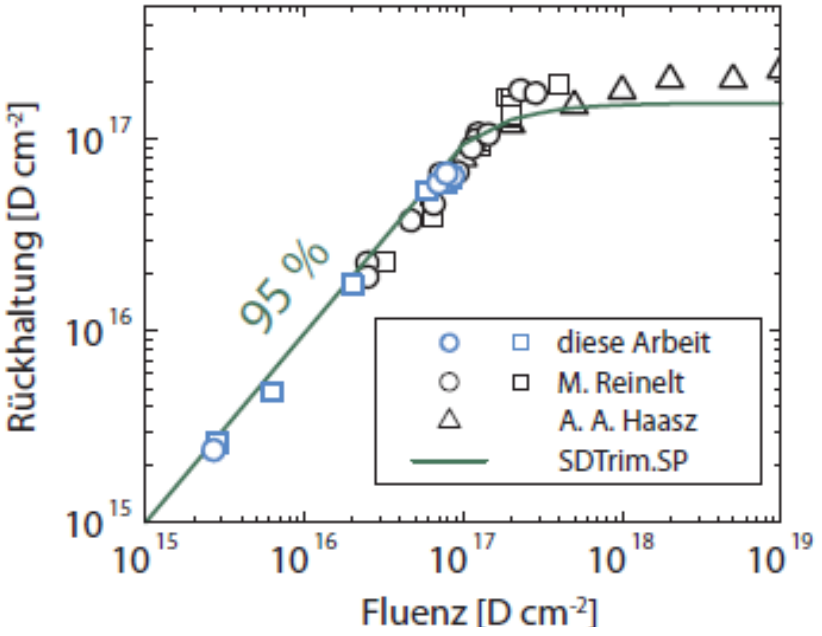


II. H retention and release in pure Be

Prior work:

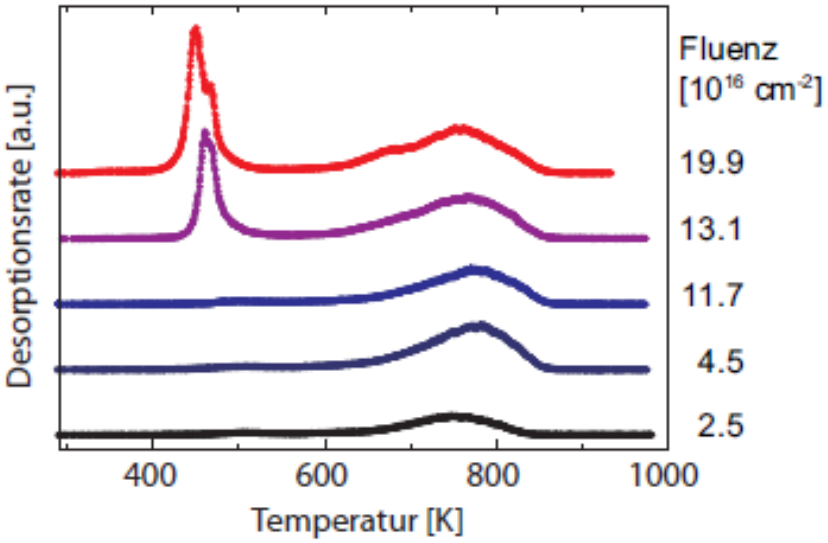
Be – W system and pure Be

- PhD thesis work of Matthias Reinelt
  - ➢ H retention in Be single crystals
  - ➢ TMAP simulation of desorption spectra
- PhD thesis work of Martin Oberkofler (just finished)
  - ➢ H retention in polycrystalline Be
  - ➢ TMAP simulation of desorption spectra



Reinelt et al., New Journal of Physics 11 (2009)

Oberkofler et al., Nucl. Instrum. Methods 267 (4) (2009)



low flux/fluence implantation at 0.3-3keV:
retention saturates above 10^{17}D cm^2

change in release pattern:
low fluence: only high-T release
high fluence: + low-T release

II. H retention and release in pure Be

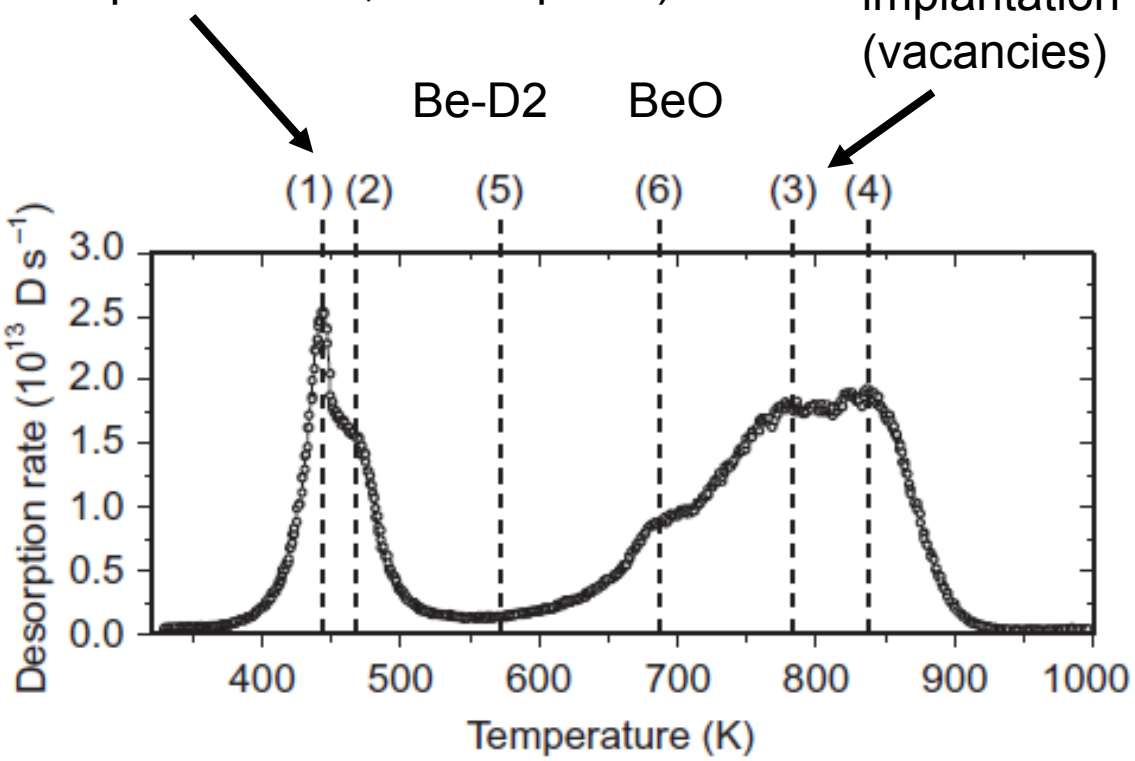
Reinelt et al., New Journal of Physics 11 (2009)

Oberkofler et al., Nucl. Instrum. Methods 267 (4) (2009)

low flux/fluence implantation at 0.3-3keV with 10^{15}D cm^{-2} s^{-1}:

supersaturated, structurally modified
(D_2 in bubbles / amorphous Be-D, D/Be up to 1)

defects created by the implantation cascade (vacancies)



II. H retention and release from mixed materials

Formation of mixed materials:

Here: Be – W – C system

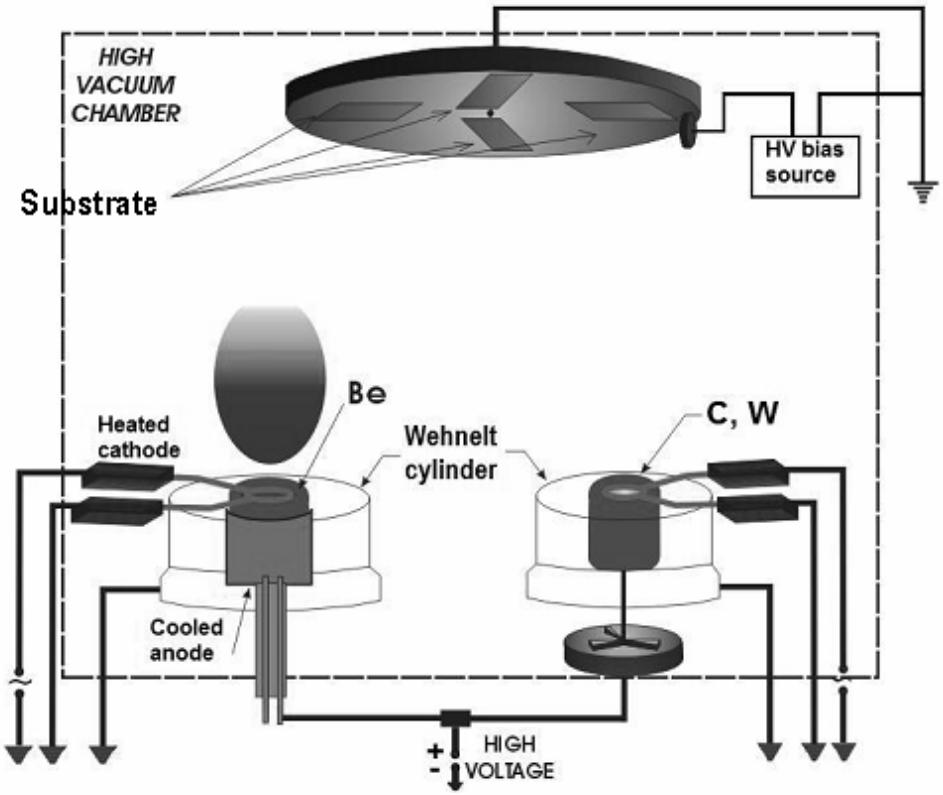
- Some model systems as themodynamically stable phases (Be_2C and $Be_{12}W$)
- Deposition of mixed material films with arbitrary composition in Romania (MEdC, C. Lungu et al.)
- Characterisation at IPP
  - Ion beam analysis
  - XPS

- H implantation in HCS

  600 eV D_3^+ (200 eV/D)

- Thermal release (TESS)

Thermionic Vacuum Arc deposition device



C. P. Lungu, I. Mustata, V. Zaroschi et al., Phys. Scr. T128 (2007) 157

II. H retention and release from mixed materials

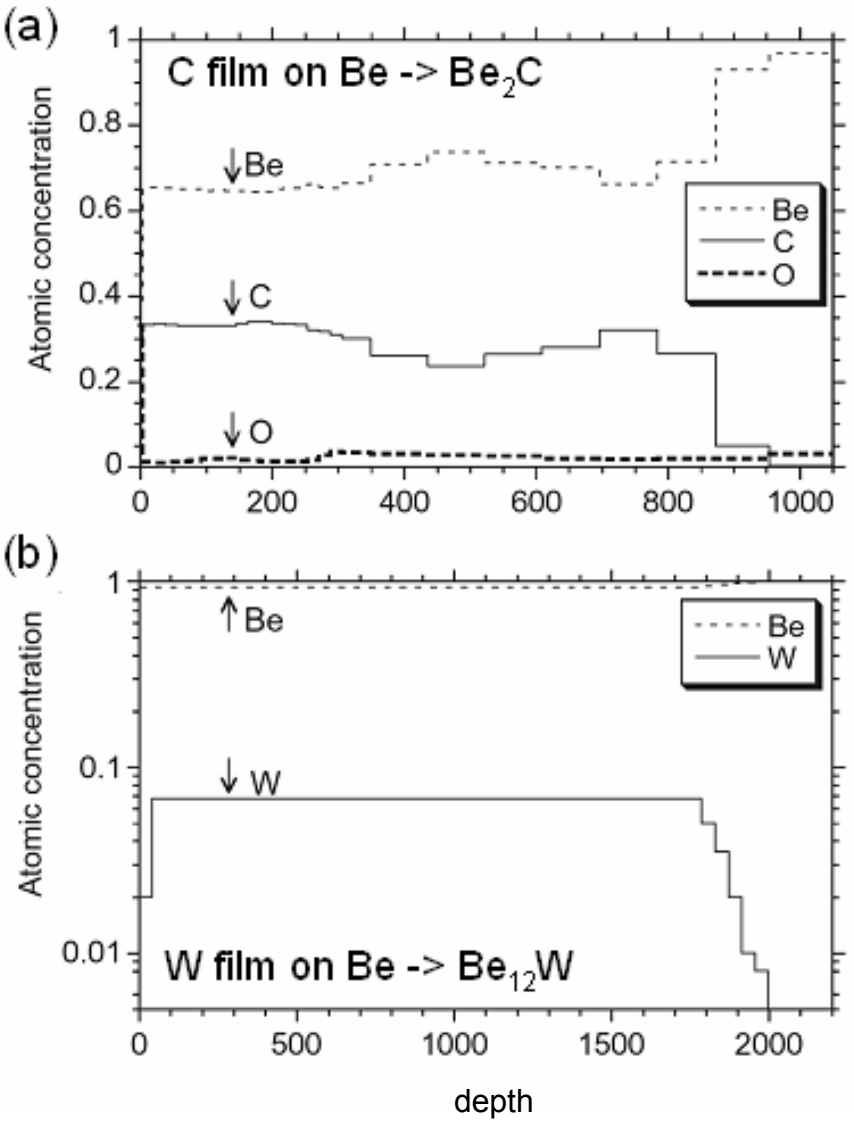
Formation thermodynamically stable phases:

Be_2c

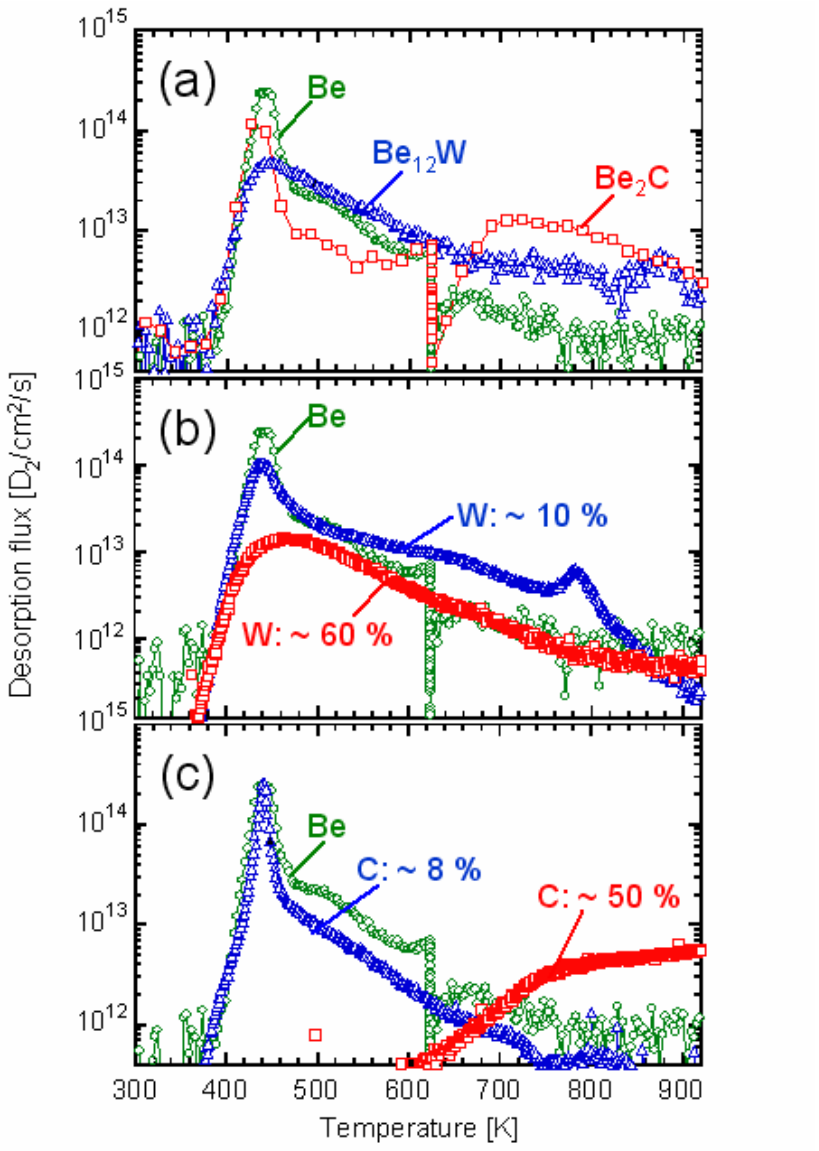
- Evaporation of thin C film onto Be substrate
- Annealing at about ? K

$Be_{12}W$

- Evaporation of thin W film onto Be substrate
- Annealing at about 1200 K



II. H retention and release from mixed materials



Thermal desorption spectra of D from:

(a) Be and compounds (Be12W and Be2C),

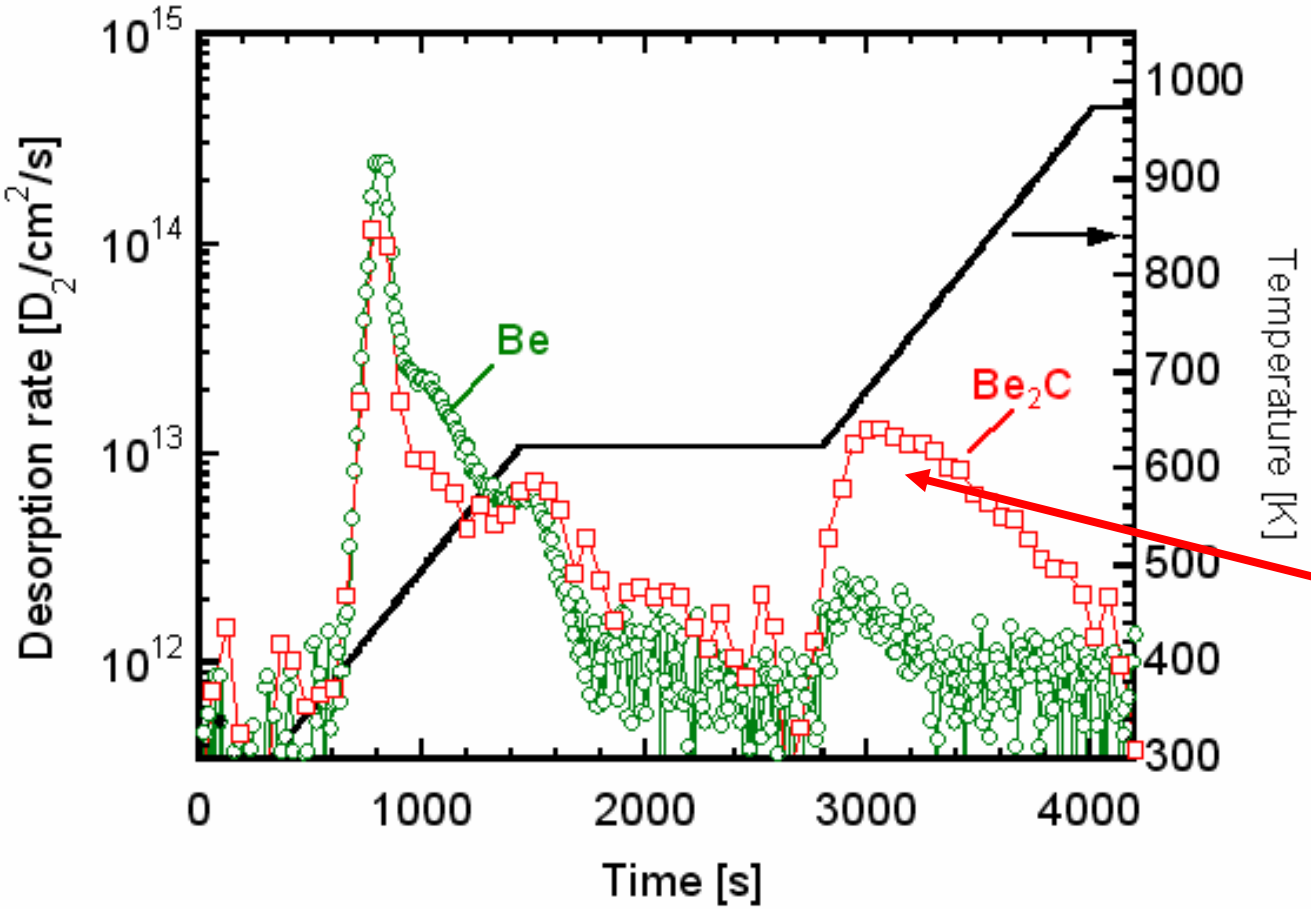
(b) Be and Be-W mixed deposited layers (W concentrations of ~10 % and ~60 %)

(c) Be and Be-C mixed deposited layers (C concentrations of ~ 8 % and ~ 50 %).

For pure Be and Be_2C samples the temperature was held for 20 min. at 623 K

D implantation to samples was performed at room temperature.

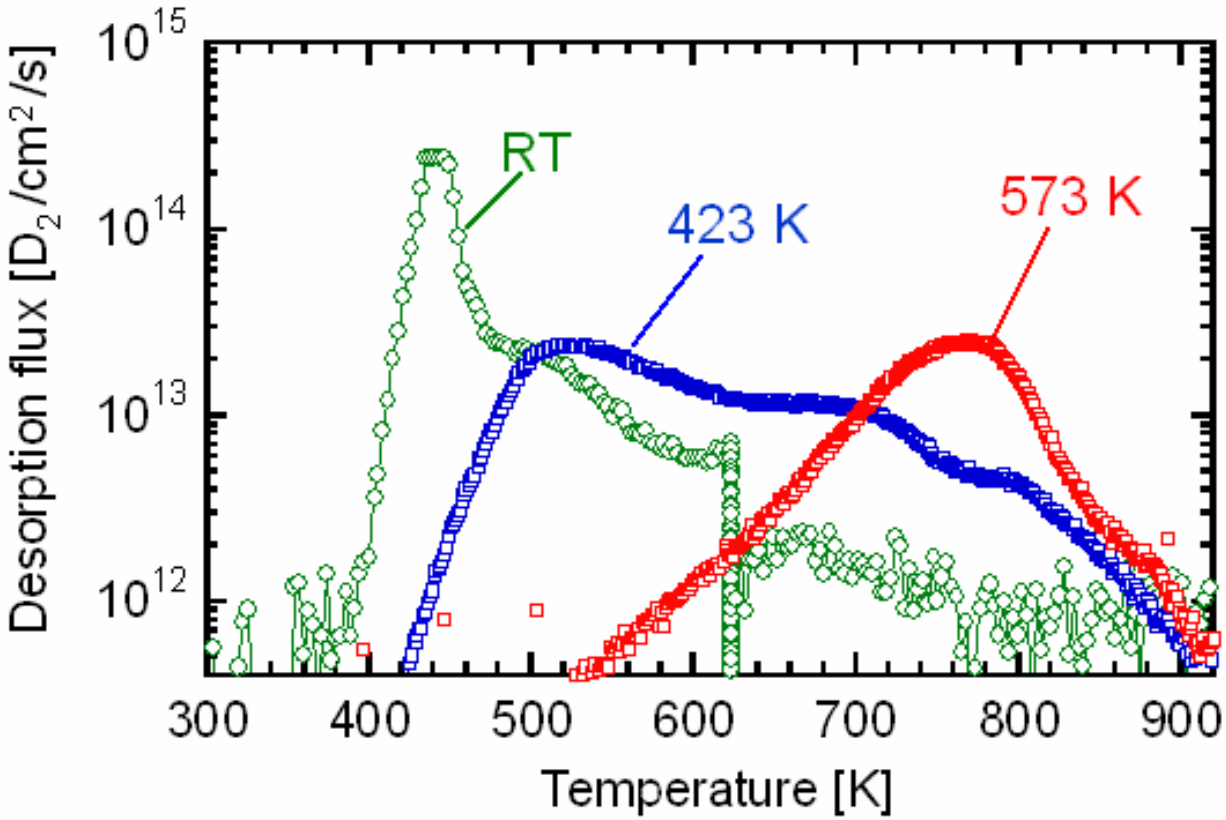
II. H retention and release from mixed materials



Enhanced retention at T > 620 K

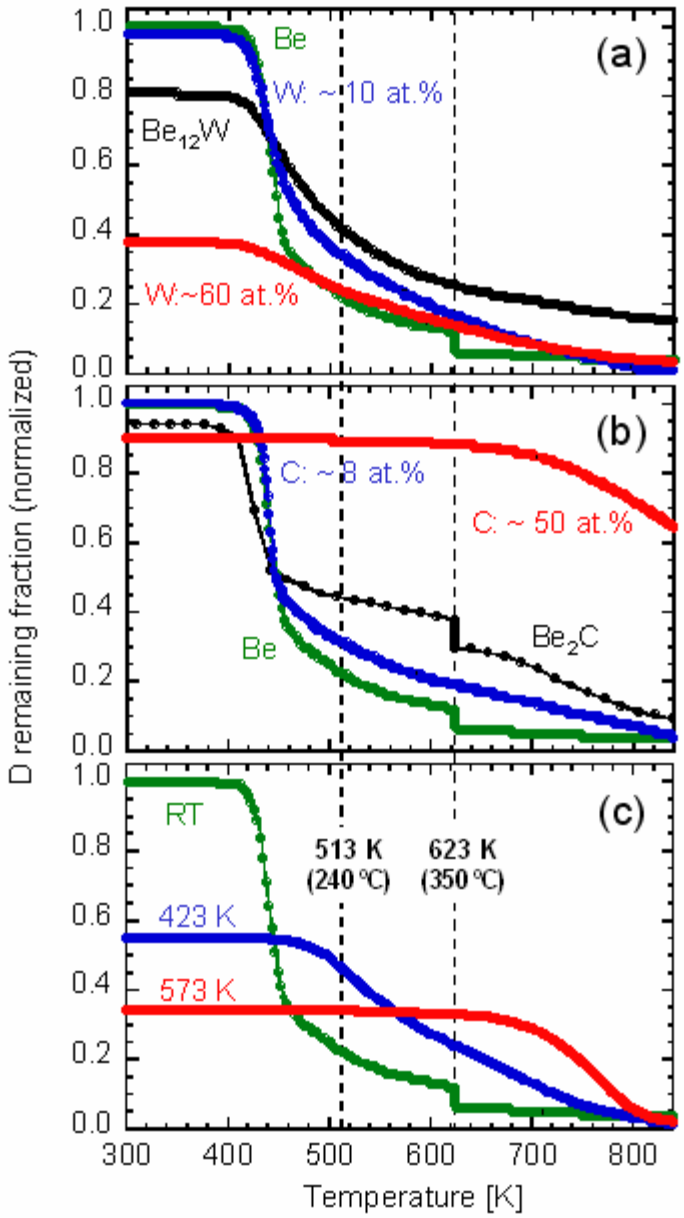
Thermal desorption spectra of D from Be and Be_2C layers as a function of time

II. H retention and release from mixed materials



Enhanced retention at high T if implanted at elevated T

Thermal desorption spectra of D from Be layers implanted at different temperatures (RT, 423 K and 573 K).

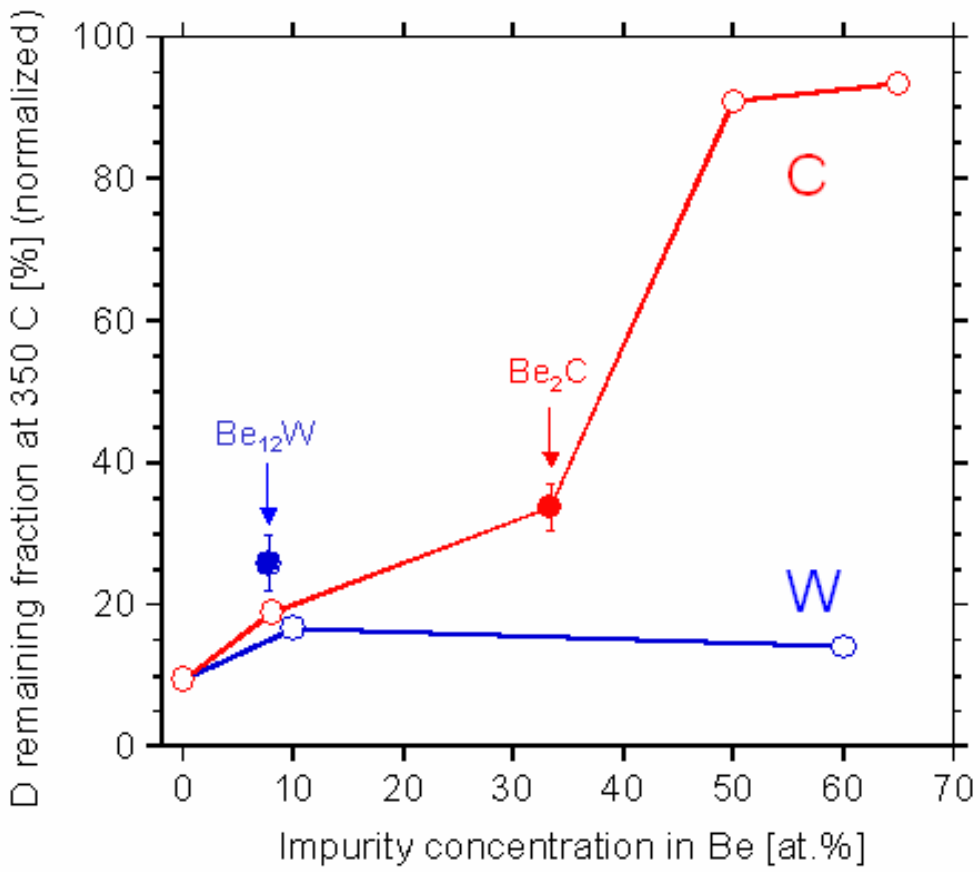


Remaining fraction of D derived from TDS spectra of

(a) Be-W system,
(b) Be-C system
(c) Be implanted at different temperatures (320 K, 423 K and 573 K).

Note that each curve is normalized to retention in pure Be implanted at RT.

II. H retention and release from mixed materials



D remaining fraction at 623 K (350 ºC) in Be-containing samples as a function of each impurity (W or C) concentration in Be.
Note that each number is normalized to retention in pure Be.

II. H retention and release from mixed materials

- Deuterium retention and release behaviour of Be-containing materials were investigated for the ITER wall (240 °C, 513 K) and divertor (350 °C, 623 K) baking temperatures
- In pure Be loaded with D at T < 340 K, D is predominantly released around 420-470 K within a relatively sharp desorption peak.
- Operation at elevated temperatures reduces the retained D amount, but the remaining D is less efficiently out-gassed at 623 K.
- Admixture of W or C changes the D release behaviour resulting in less efficient D removal by baking.
- Especially the presence of C in Be shifts the D release to higher temperature

II. H retention and release from mixed materials

Missing information:

- Release at increased holding times (so far max. 20 min)
- Release from thick films (so far only implanted films)

<u>New experiments:</u>

- Investigation of redeposited films produced in PISCES and magnetron sputtered Be/D films (D/Be ratios up to 0.3) with thickness up to 1 μm (Invited talk T. Schwarz-Selinger, PFMC-13)
- Influence of longer holding times at ITER temperatures (planned for 2011)

summary

⇒ magnetron sputtered Be/D films are suited as a model system to study retention and release

⇒ release of D from Be at 240°C and 350°C has a very large time constant

⇒ even a several hours bake at 240°C or 350°C does not release all D
(a D/Be of 0.8% or 0.2% remains, respectively)
(deeper trap sites that cannot be drained)

⇒ codeposits grown in different ways (energies, growth rates) show similar release features

⇒ the total amount of D released above 350°C is the same for all codeposits investigated, equivalent to D/Be ≈ 1%

⇒ multilayer codeposits show the same release as single layer codeposits (BeO interface is no transport barrier)

Further activities at IPP

- investigation of surface processes in ternary systems (Be – W – O, Be – N)
- H retention in Be materials
- Modeling of Be release (TMAP and new code developments) (& collaboration with A. Allouche - DFT calculations of e.g. Be migration energies)
- D retention in mixed materials (increased holding times)
- Thick film model systems? (collaboration with MEdC Bucharest)
- MD simulations (W-Be-H potential, first tests performed)
- Global impurity transport modeling (Schmid /Reinelt) – needs better input data

III. Needed data (personal view)

Sputtering yields (H, D, T, He, Ne, Ar, N, …)

- energy dependence
- flux dependence
- fluence dependence
- temperature dependence

Compare plasma erosion vs. ion beams

more individual ion species in plasma additional neutral species

e.g., H_2 plasma: H^+, H_2^+, H_3^+, & H^0

laboratory plasmas: $H^0/H_{ion} \approx 100$

Projectile enrichment in near surface layer (= retention) may lead to reduction of sputter yields (e.g., W/N) or enable chemical sputtering (e.g., C/H, enhanced yield!)

Don‘t forget possibility of impurity sputtering in plasma experiments

Redeposition in high flux plasma experiments requires proper modeling of net yields

III. Needed data (personal view) cont. …

Different types of redeposited layers

- Intensive characterization required
- Stoichiometry (IBA)
- Chemical states (XPS)
- Phases, crystalline phases, alloys, …
- Microstructure porosity, impurities, surface structure and morphology
- ….

Mixed materials!