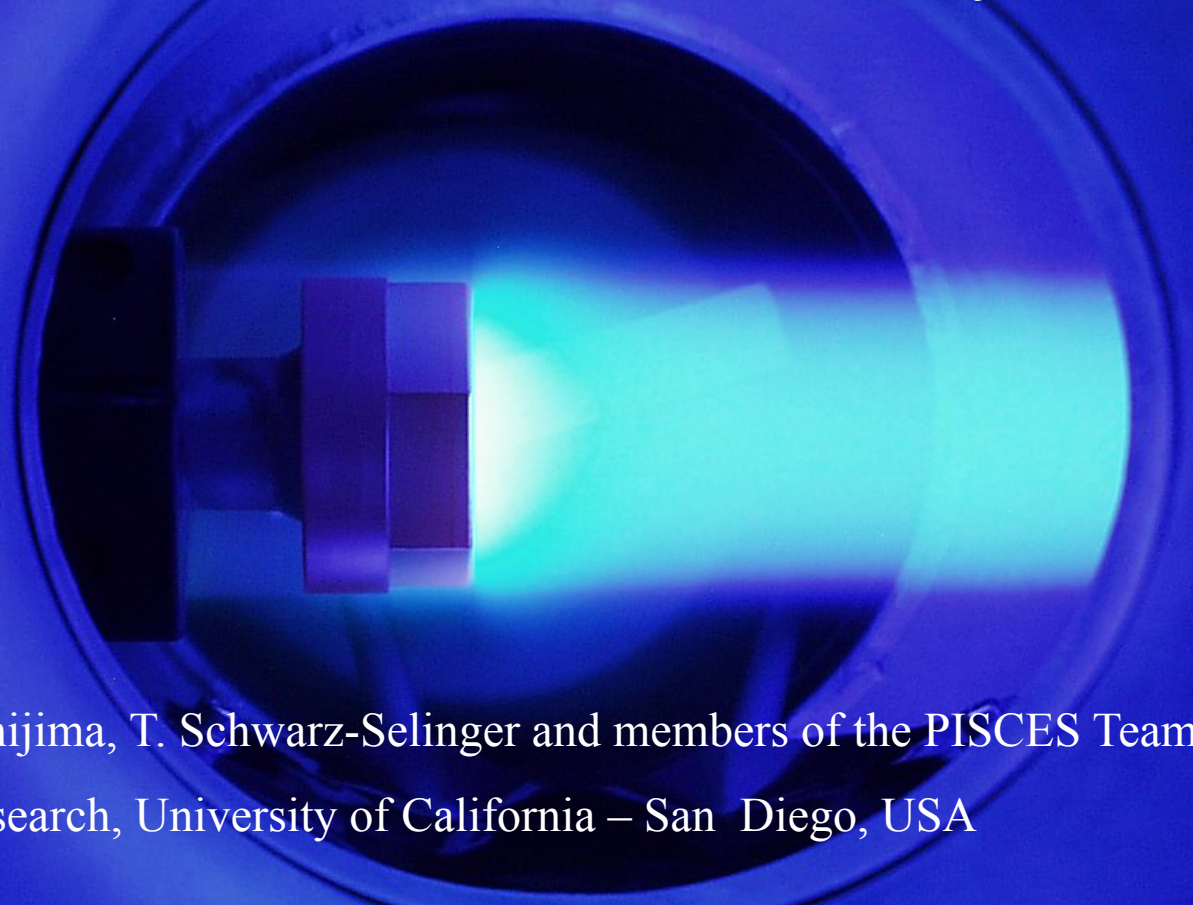
Plasma interactions with Be surfaces



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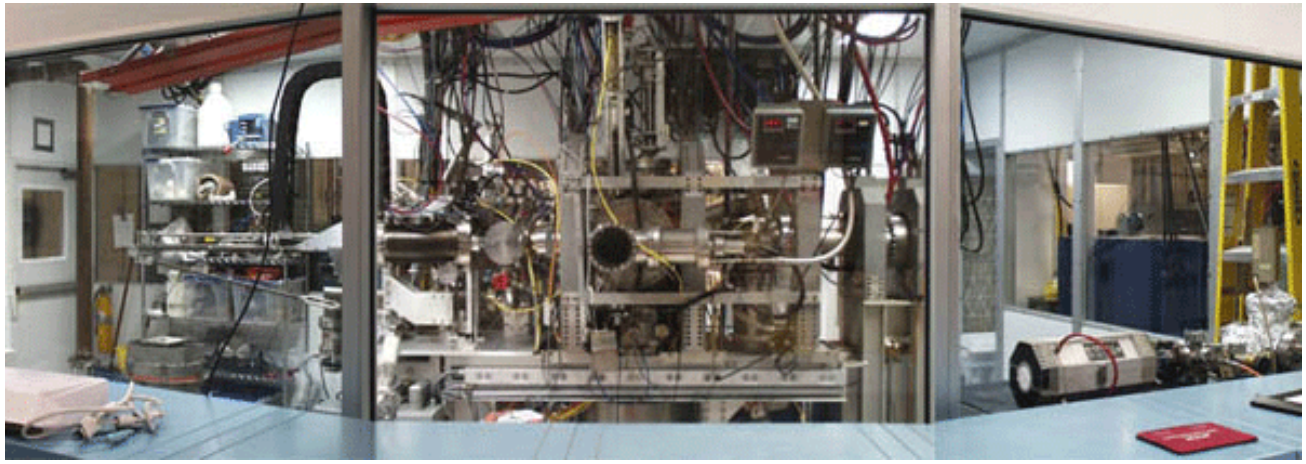
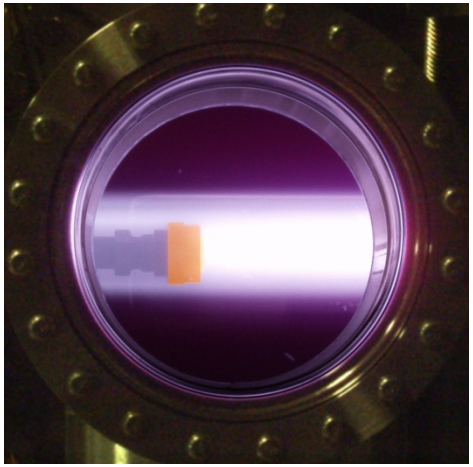
Center for Energy Research, University of California – San Diego, USA

Work performed as part of: Plasma-Surface Interaction Science Center (MIT and UTenn)

US-EU Collaboration on Mixed-Material PMI Effects for ITER

The PISCES-B divertor plasma simulator is used to investigate ITER mixed materials PSI.

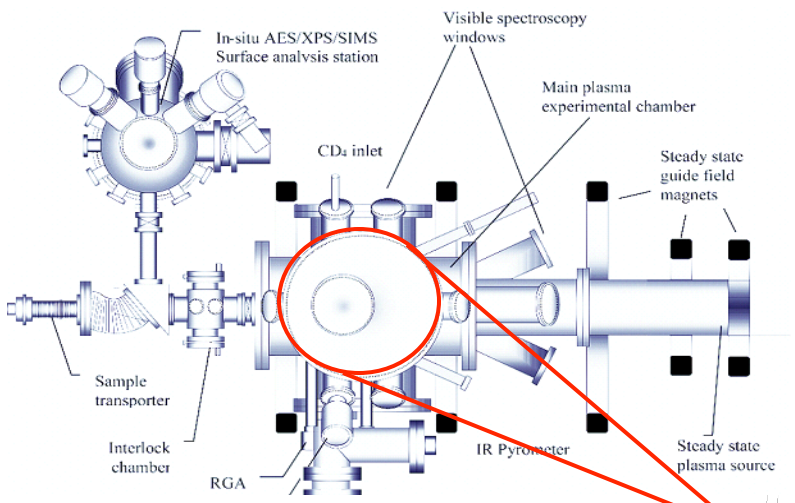


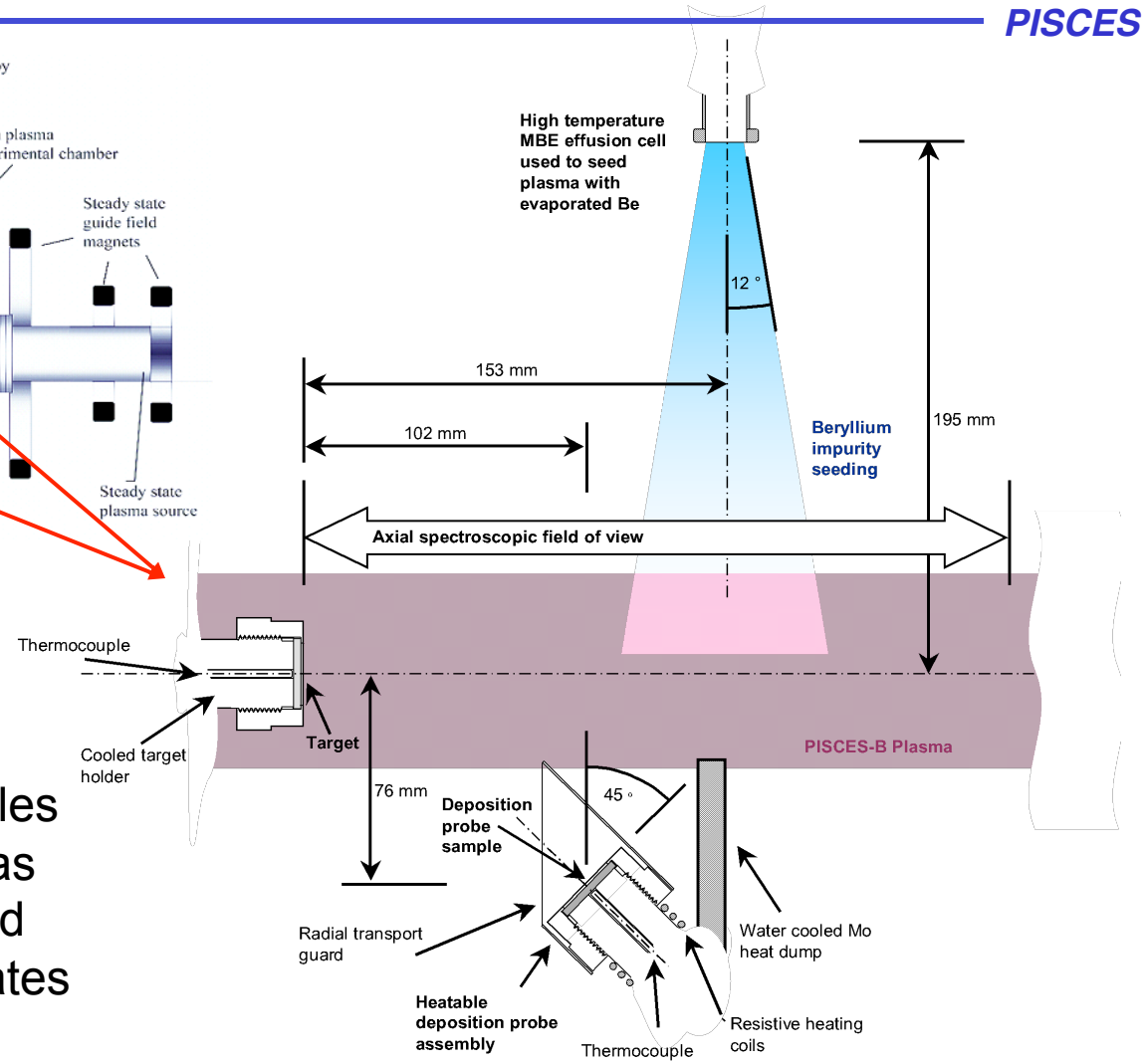


- PISCES-B is contained within an isolated safety enclosure to prevent the release of Be dust.

	PISCES	ITER (edge)
Ion flux (cm^2s^{-1})	**10^{17}–10^{19}**	**~10^{19} - 10^{20}**
Ion energy (eV)	**20–300 (bias)**	**10–300 (thermal)**
T_e (eV)	4–40	1–100
n_e (cm^{-3})	**10^{12}–10^{13}**	**~10^{13}**
Be Imp. fraction (%)	**Up to a few %**	**1–10 (ITER)**
Pulse length (s)	**Steady state**	**1000**
PSI materials	C, W, Be	C, W, Be ..
Plasma species	H, D, He	H, D, T, He

PISCES-B has been modified to allow exposure of samples to Be seeded plasma





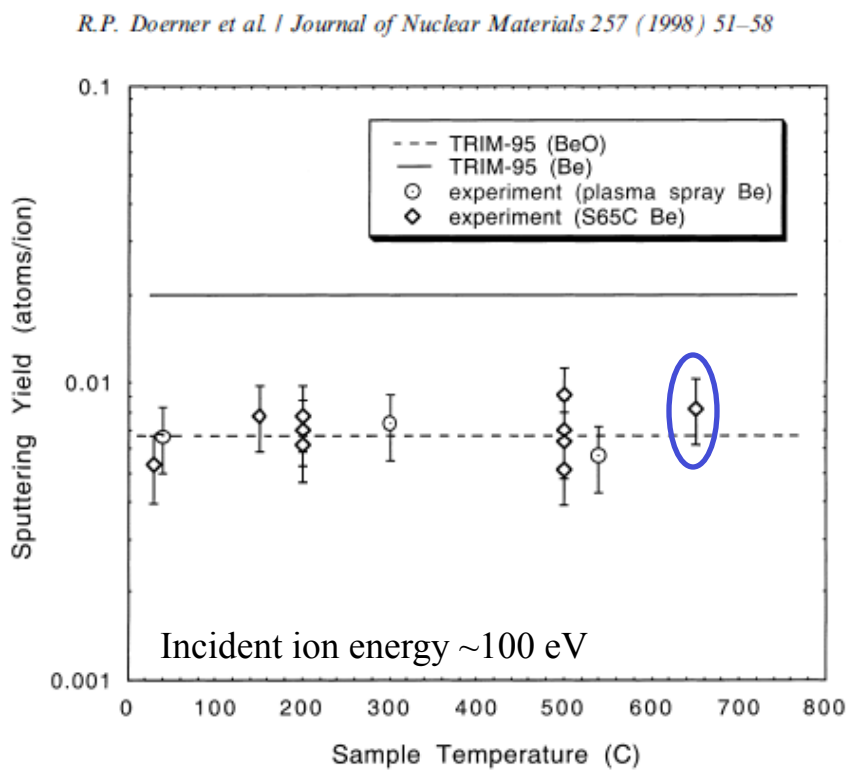
P-B experiments simulate Be erosion from ITER wall, subsequent sol transport and interaction with W baffles or C dump plates, as well as investigation of codeposited materials using witness plates

Outline of Presentation

- Erosion in the plasma environment
  - Comparison to TRIM and ion beam data
  - Surface characterization
  - Role of morphology
- Redeposition/sticking efficiency
- Summary

Significant variations in the Be sputtering yield are measured

discrepancy between - JET - PISCES-B - ion beam – TRIM - sputter yields
(< 45%) (< 0.4%) (< 8%) (< 3.5%)



J. Roth et al., FED 37(1997)465.

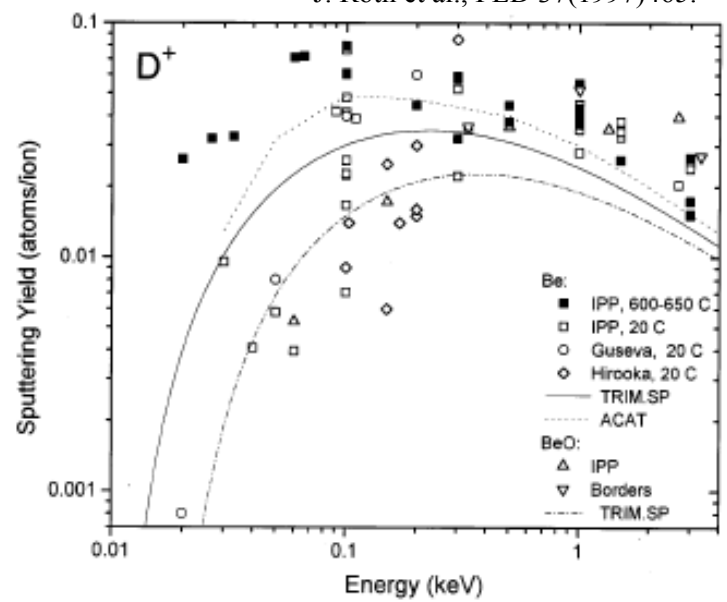
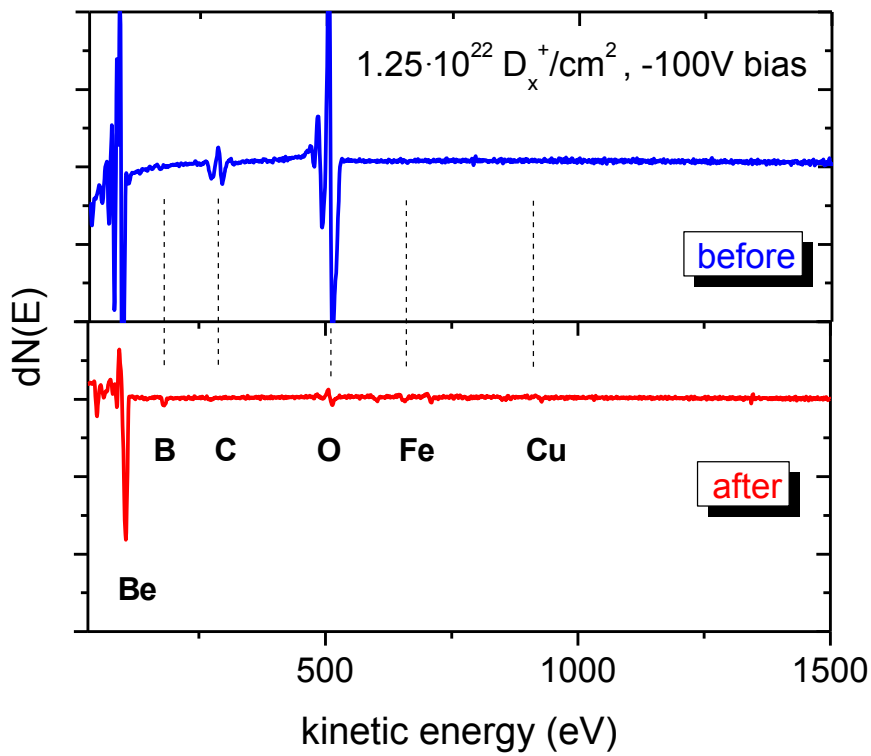
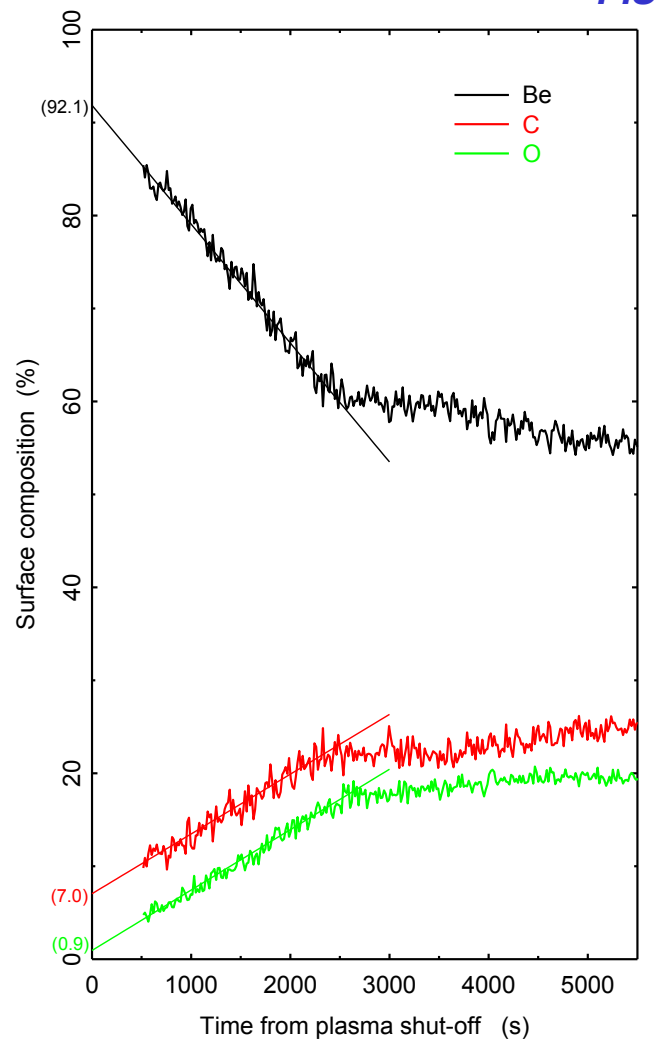


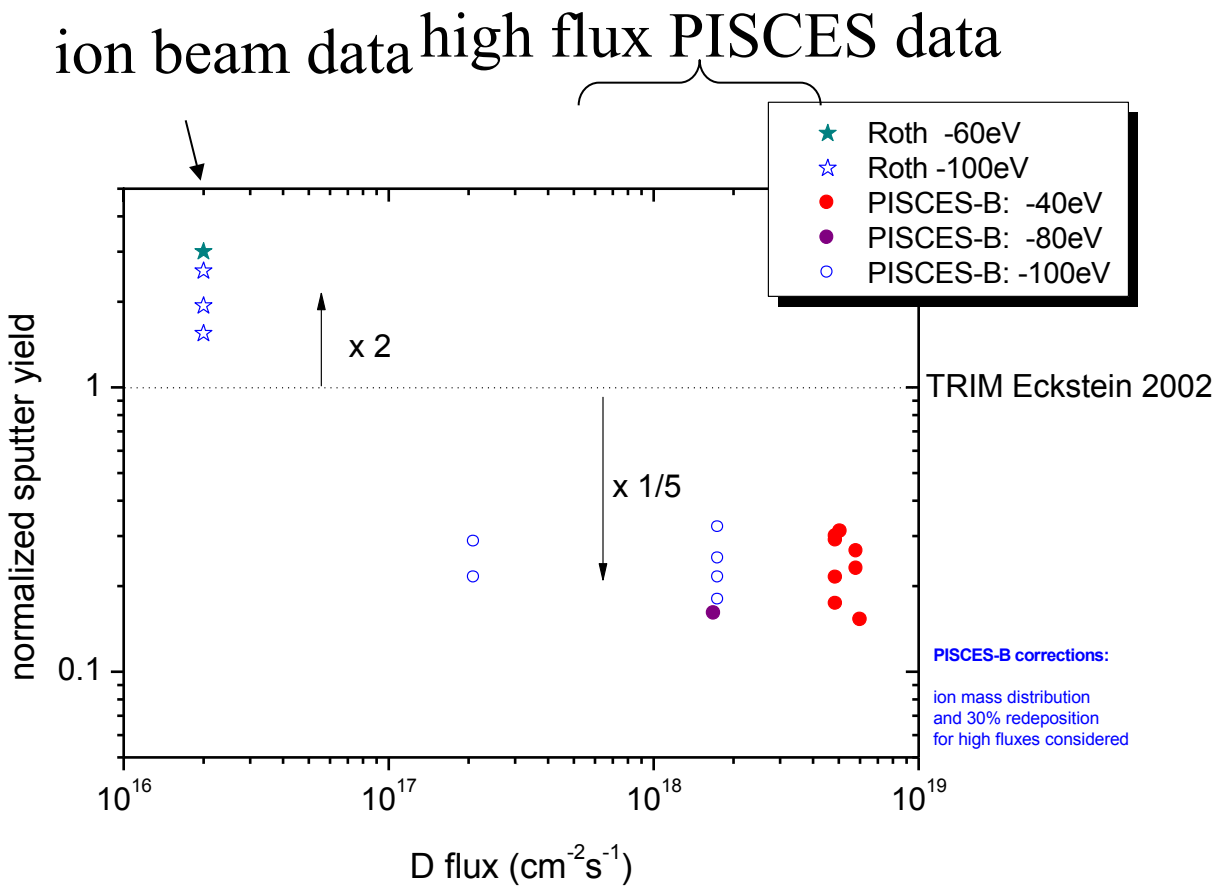
Fig. 2. Energy dependence of the sputtering yield of Be and BeO bombarded with D at normal incidence. Experimental data [6,13,23–26] and results obtained with computer simulation [6,22].

AES reveals a relatively 'clean' Be surface during sputtering yield measurements





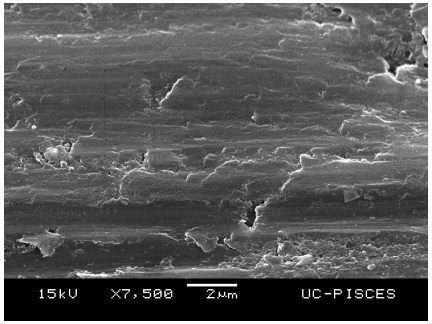
Sputtering of Be with D: discrepancy in total yield



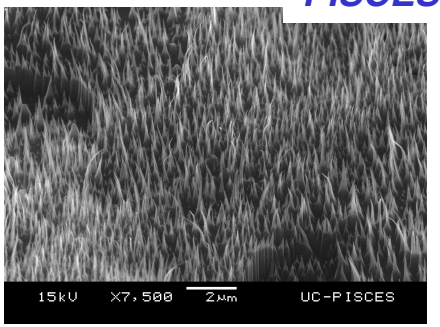
High JET yield can be explained by angle, Be self-sputtering & impurities.
PISCES yields are a factor of 5-10 lower than TRIM. Why?

sputtering yield: evolution with time / fluence

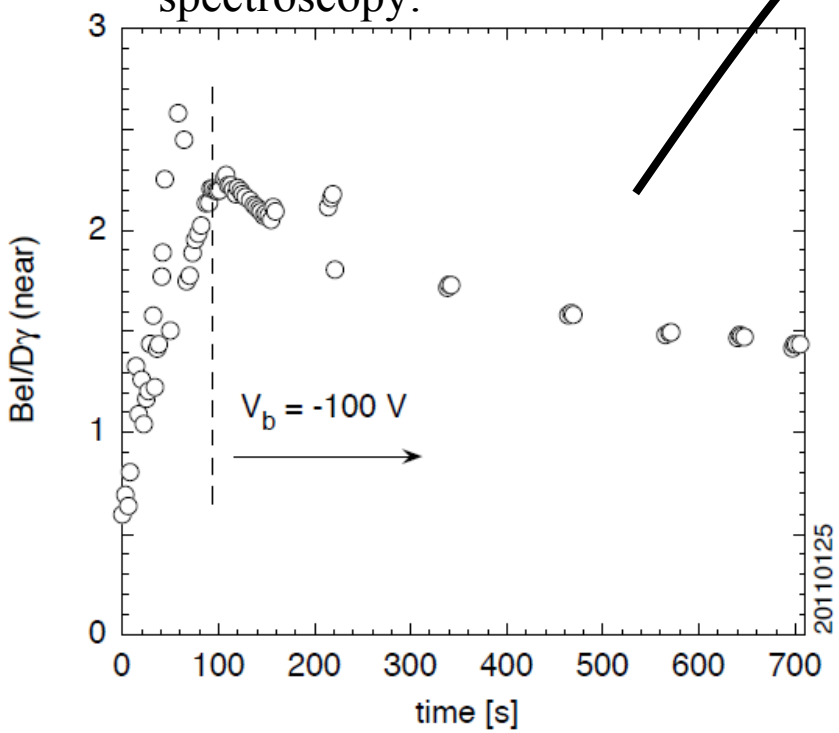
before



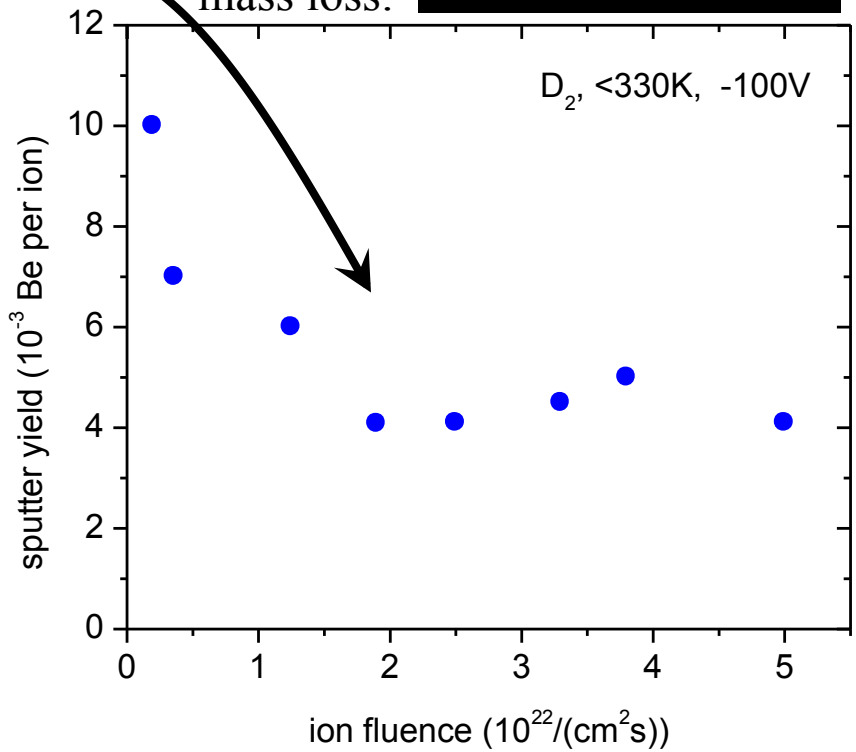
after



spectroscopy:



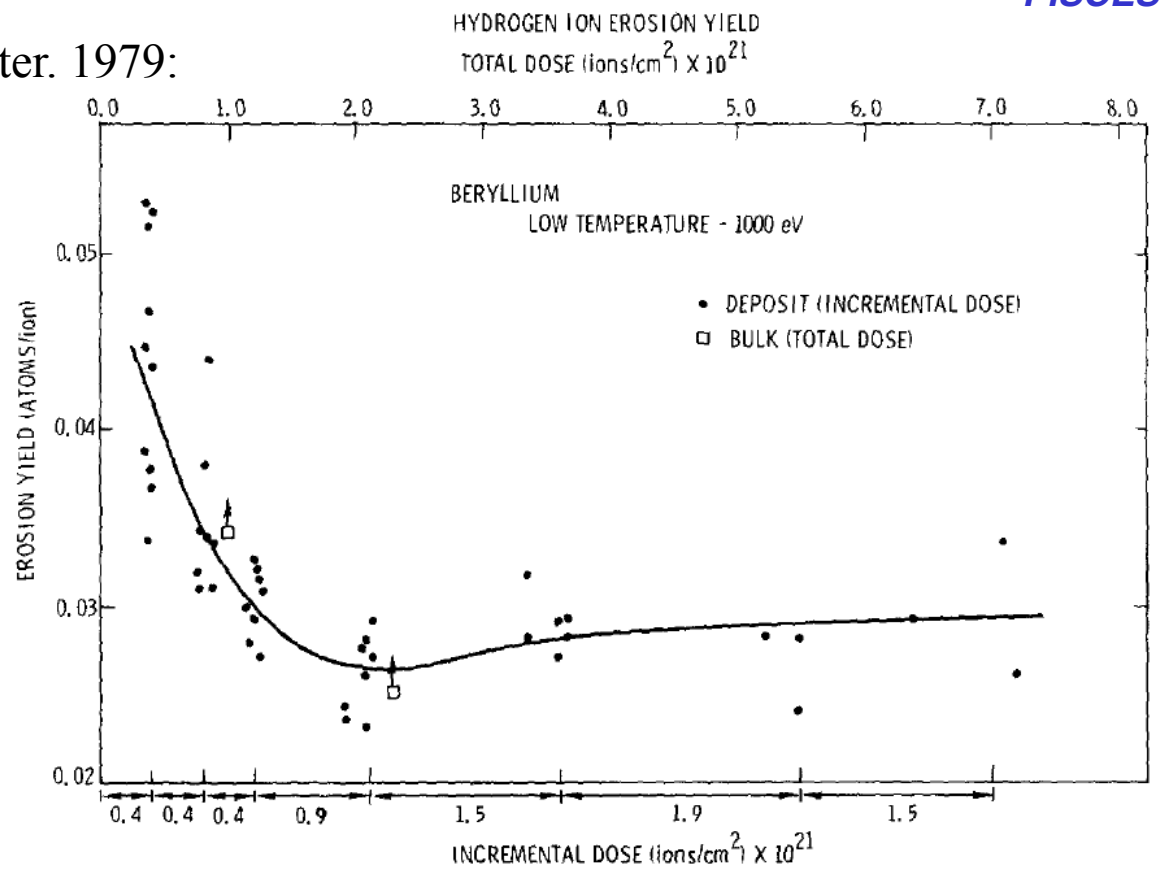
mass loss:

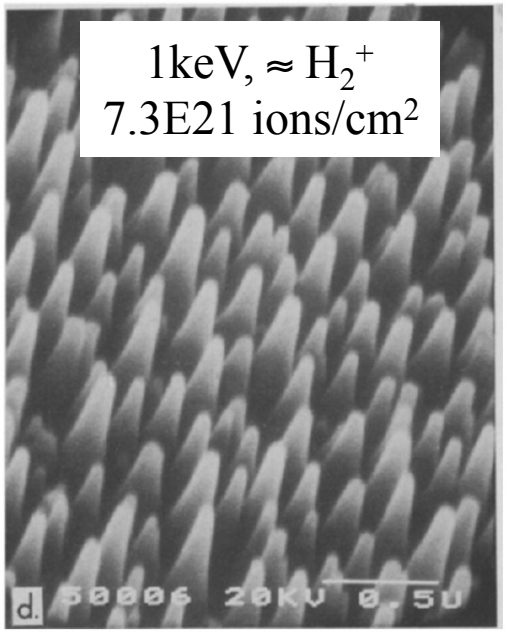


⇒ **morphology change can account for a factor of 2 in reduction of the yield**

Similar yield evolution with time/fluence is documented in the literature

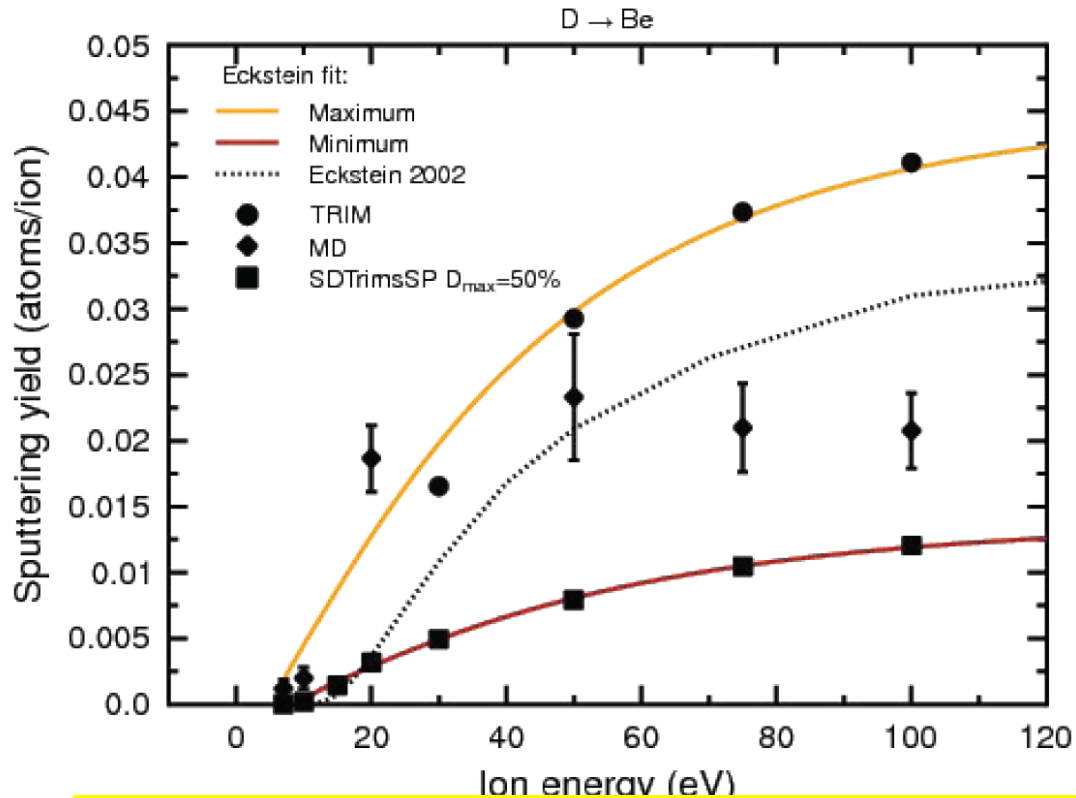
Mattox and Sharp, J. Nucl. Mater. 1979:





⇒ morphology change can account for a factor of 2 reduction of the yield

Plasma atoms remaining in the near surface also can reduce the sputtering yield by a factor of 2-3

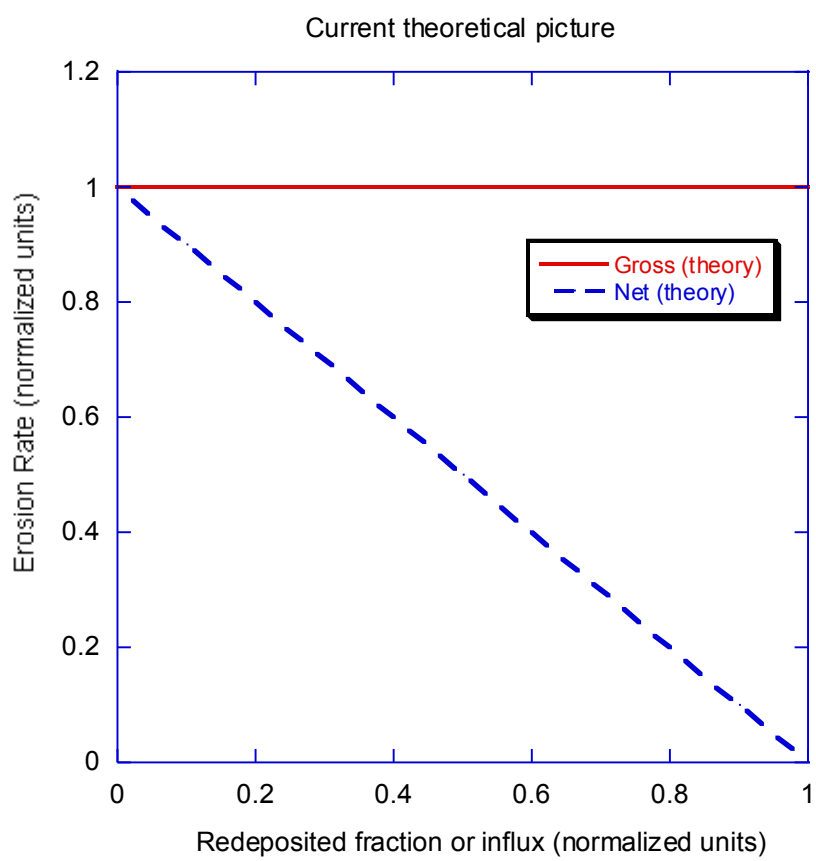


From C. Björkas

1) "maximum" – static TRIM + MD
2) "minimum" – SDTrimSP with 50% of D (reasonable limit)

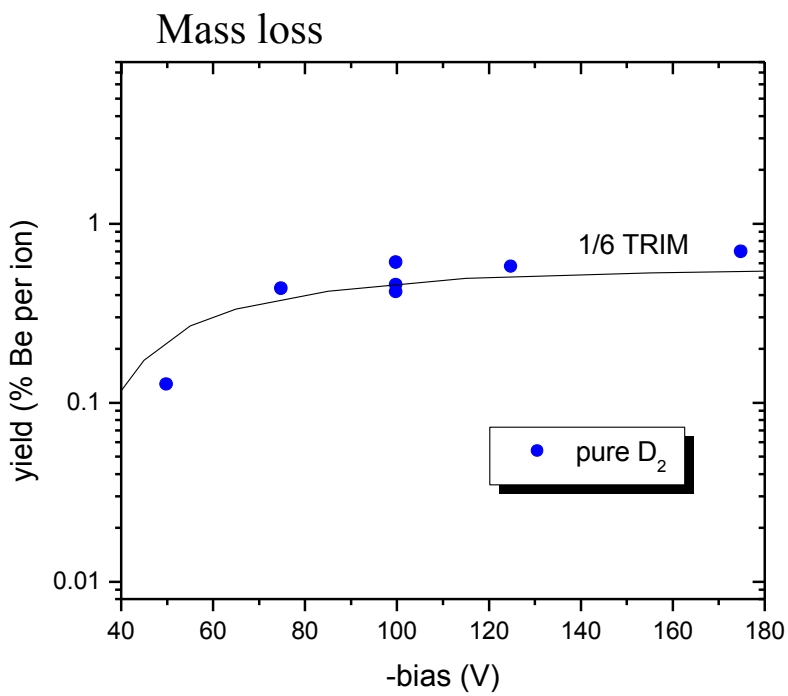
Morphology evolution and 20-50% D in implantation zone can account for 4-8 reduction from TRIM estimation of sputtering yield

Gross erosion is expected to remain constant with increasing Be redeposition/influx



- N = G * (1-R), where N = net erosion, G = gross erosion, R = redeposited fraction
- In PISCES-B, Gross = net erosion with no Be seeding (λ_{ion} is large compared to r_{plasma}, so redeposition is small)
- Ion influx from Be oven is identical to sputtered atoms that are ionized in the plasma and redeposited on the target, this allow a controlled and independent variation of the Be influx to the target

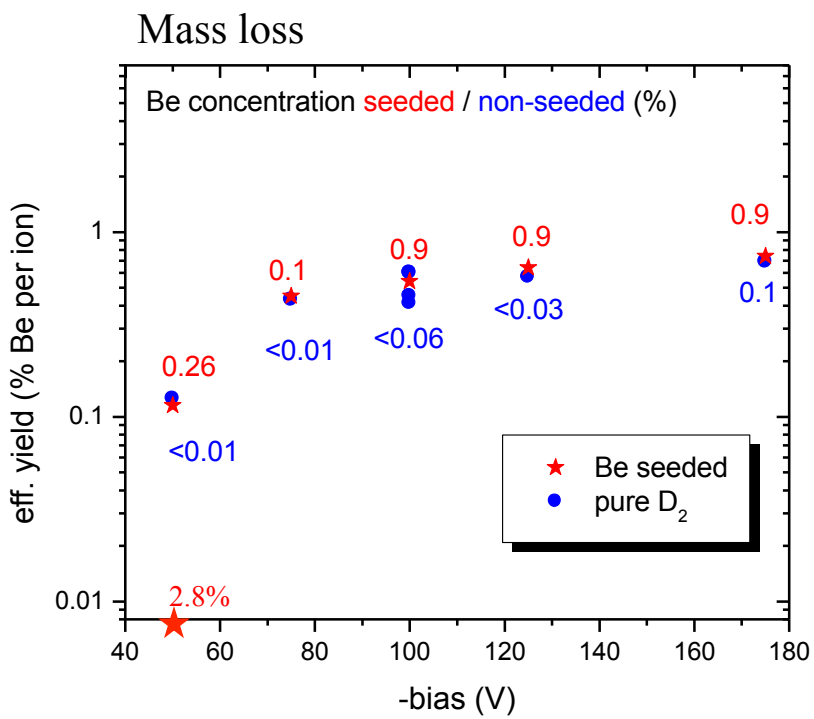
Erosion/deposition balance in Be seeded high flux D discharges



ion fluence: $\approx 10^{22}/cm^2$
target temperature < 320K

- Use Be oven seeding to balance surface erosion to test input parameters of material migration models
- Mass loss measures net erosion
- Spectroscopy measures gross erosion (Be I line)
- $Y_{Be \rightarrow Be} \approx Y_{D \rightarrow Be}$, and low concentration of Be
- When incident/seeded Be ion flux = sputtered flux of Be, net erosion should = 0.

No change in mass loss is measured when Be seeding flux equals sputtering of Be by D

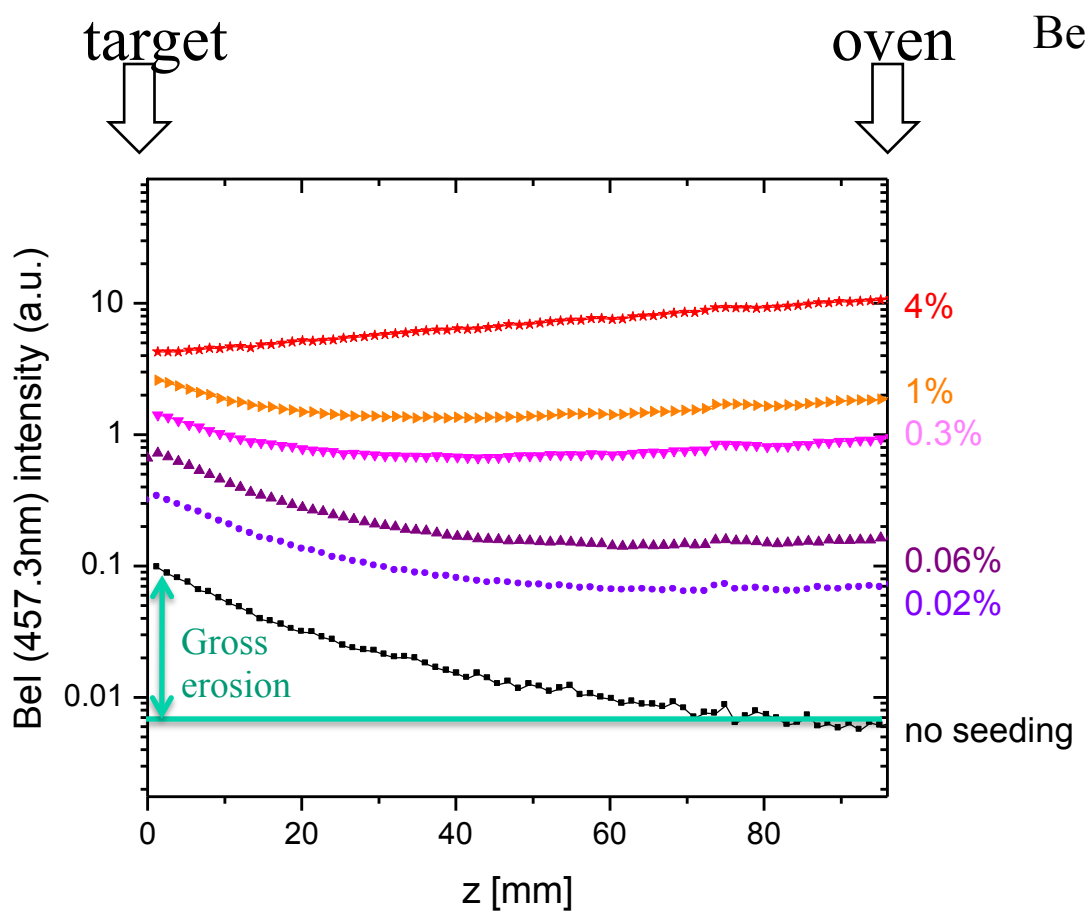


ion fluence: $\approx 10^{22}/cm^2$
D/Be plasma
target temperature < 320K

- ADAS database is used
- Be flux from Be II (313.1 nm) and background plasma flow velocity (E. Hollman JNM, PSI-19)
- Be ion flux is verified during no bias discharges, when weight gain is measured (net deposition)
- Net erosion stays constant, implying gross erosion must increase
- Erosion yield of 0.15% can only be compensated by seeding 2.8% Be

Beryllium seeded He discharges

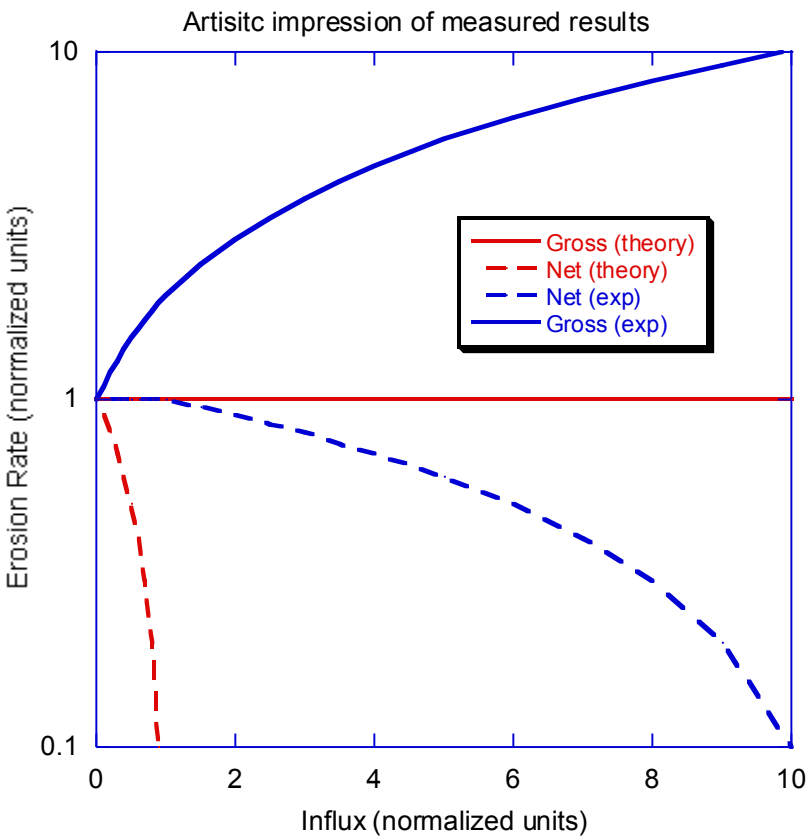
target:
bias: < -40V results in E ≈ 30eV
He ion flux: $5 \cdot 10^{18}\ cm^{-2}s^{-1}$
Be seeding: $n_{Be}/n_D = 0 – 4\ \%$



sputter yield He on Be @ 30eV:
Y = 0.15 % (measured)

: During 'no Be seeding' discharge,
Gross ≈ Net erosion

Different behavior is observed experimentally

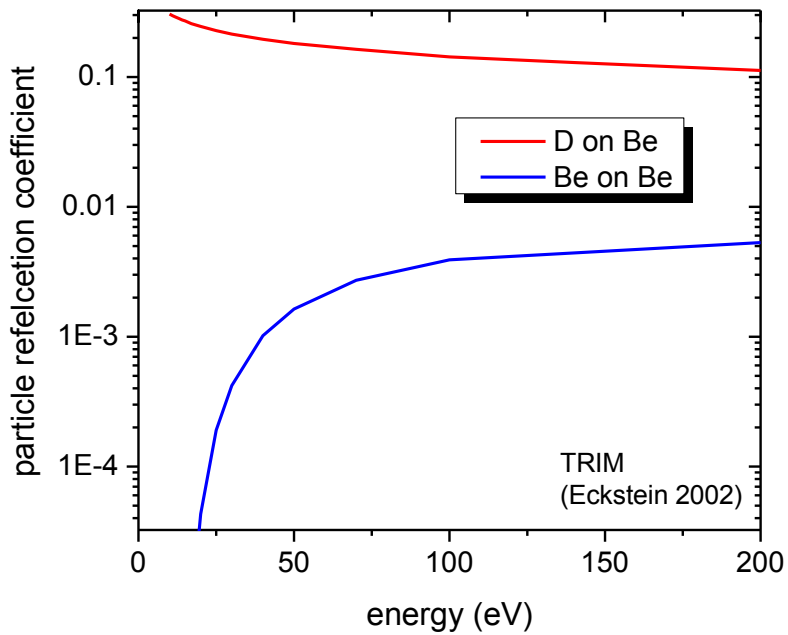


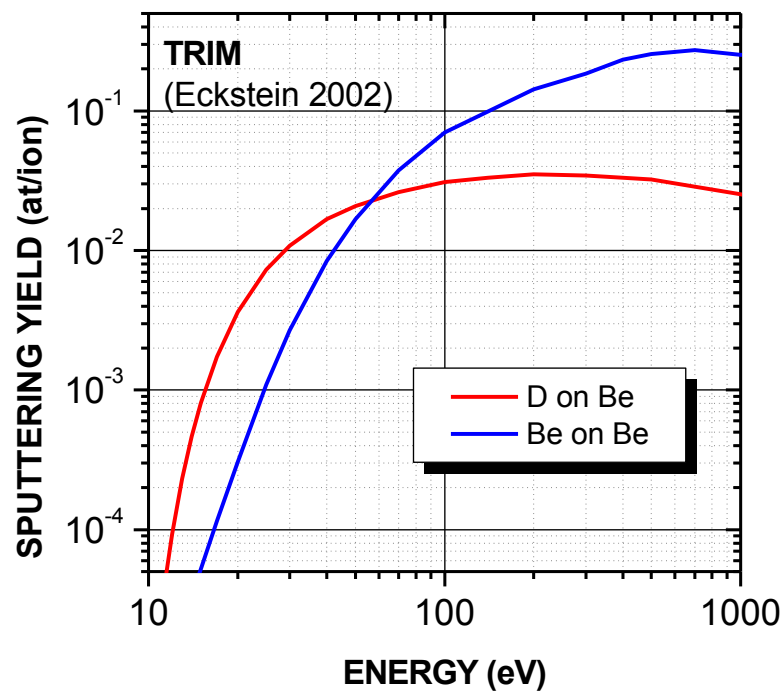
- Net erosion stays constant until influx >> sputtering rate
- Gross erosion increases with increasing Be influx to target
- Reduced sticking of depositing Be, or increased re-erosion could explain observations
- Similar reduced sticking needed to model CD_4 and WF_6 injection experiments in TEXTOR (from A. Kirschner)
- Possibly similar to C-MOD modeling difficulties reported by J. Brooks (PSI19)

What PMI issues are still unresolved

- Net Erosion – we believe we can explain the observed, low sputtering yields in PISCES-B, due to surface morphology and fuel atoms within the target surface (no Be seeding)
  - How many gas atoms are in the surface during exposure?

- Gross Erosion – drastic differences in behavior of gross erosion during Be seeding indicates the simple theory regarding the benefits of prompt redeposition may need to be revisited
  - 10 times more influx is needed to balance erosion and force net erosion to zero
  - Low sticking probability or high re-erosion possible explanations





Be seeding fraction (i.e. influx) is at most in the percent range, so Be self-sputtering and Be reflection can be neglected