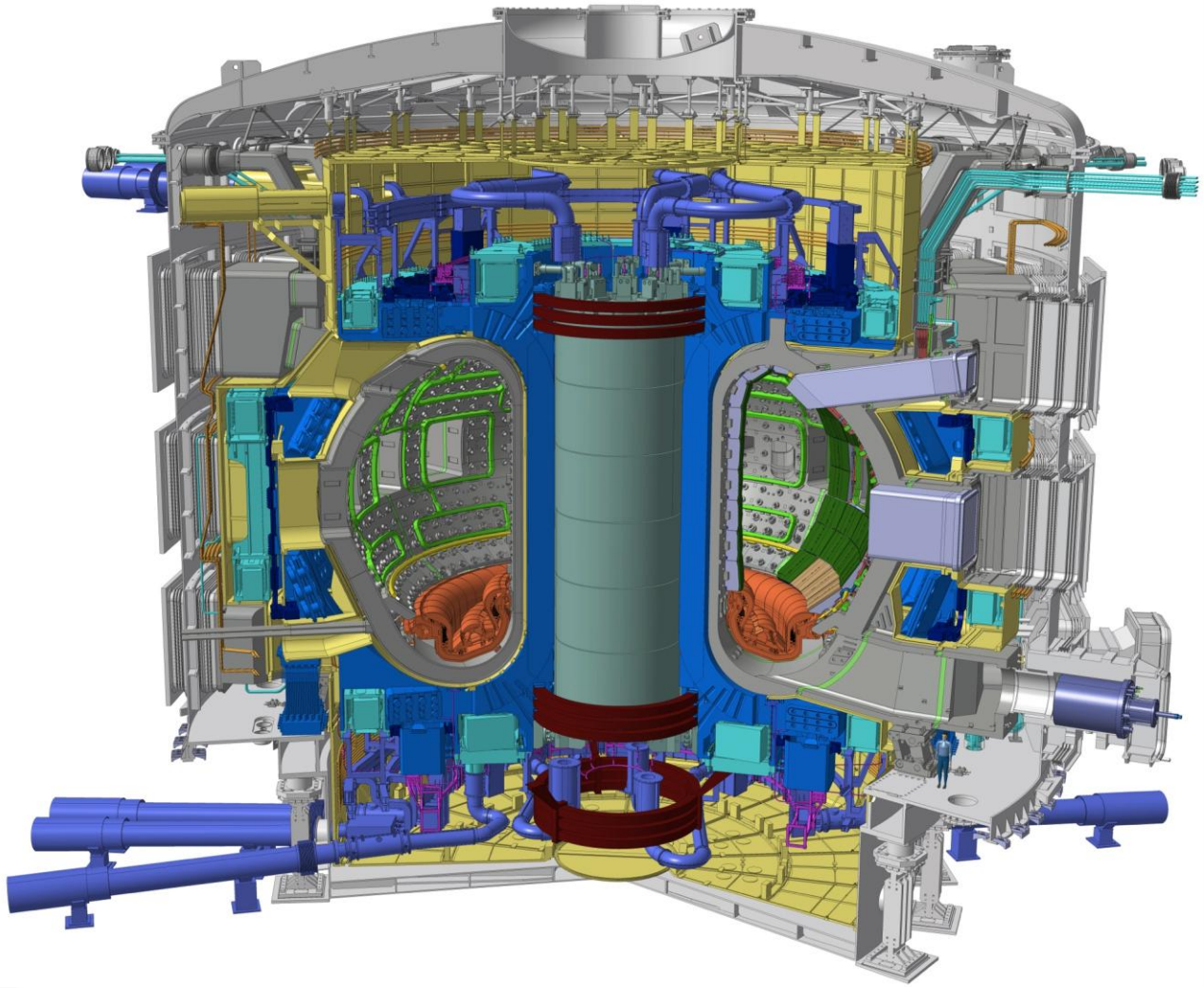


VSB TECHNICAL UNIVERSITY OF OSTRAVA | IT4INNOVATIONS NATIONAL SUPERCOMPUTING CENTER

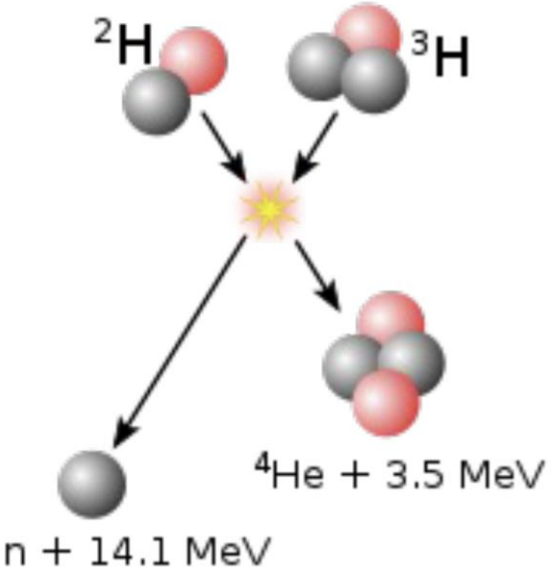
Small dust particle bombardment of a fuzz covered W surface

T. P. C. Klaver, D. Legut

Nuclear fusion energy in tokamaks



D-T fusion

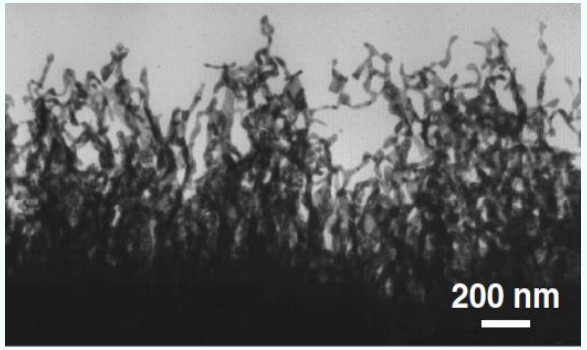


- The W divertor is subjected to intense, low-energy (< 100 eV) He bombardment of ~$10^{23\text{-}24}$/(m^2s), 10 MW/m^2 heat load, 14.1 MeV neutron bombardment, high energy photons, and fast dust particles.

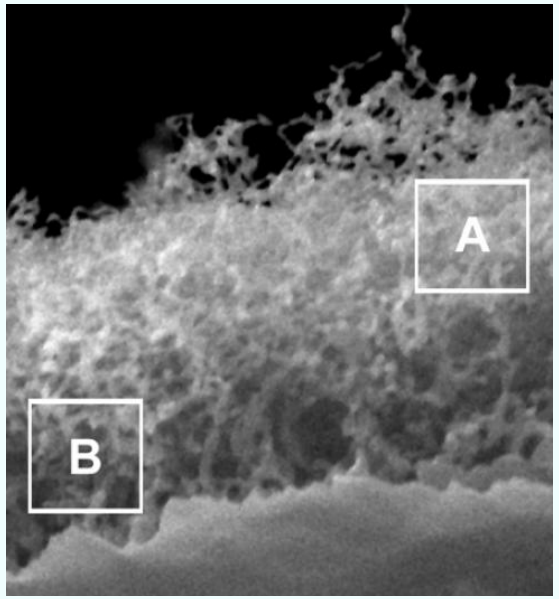
Materials science issues in fusion

1 Fuzz formation

- He bombardment transforms the W surface to a low density (< 10 vol%) structure



S. Kajita et al, Applied Physics Express 3 (2010) 085204

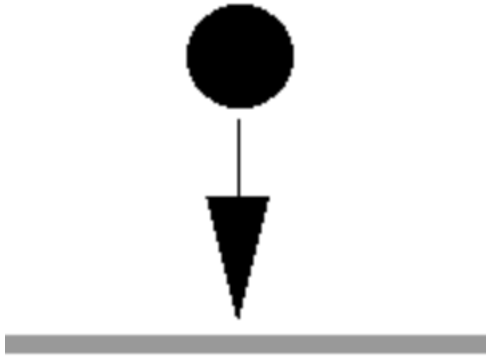


M. Baldwini et al, Nucl. Fusion 48 (2008) 035001

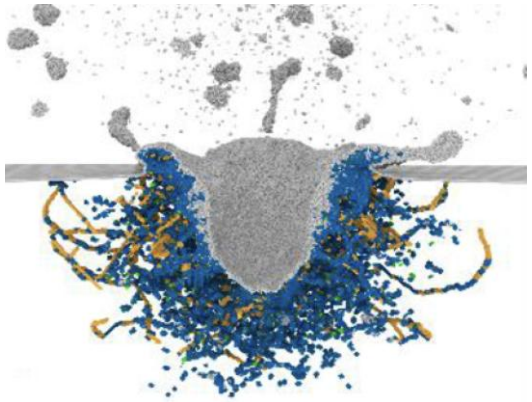
- Fuzz formation lowers W heat conduction by orders of magnitude, among other concerns

2 Fast dust particles

- Runaway electron terminations lead to 10 nm – 100 μm dust particles with velocities of several km/s



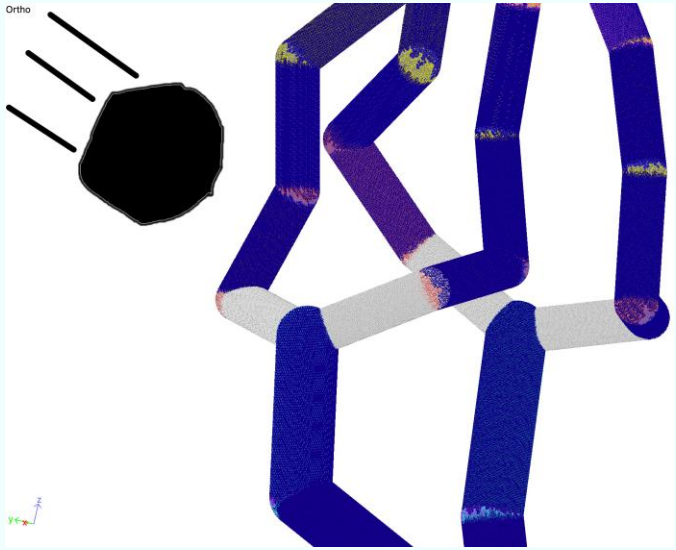
P. Dwivedi et al, J. Nucl. Mater. 629 (2026) 156695

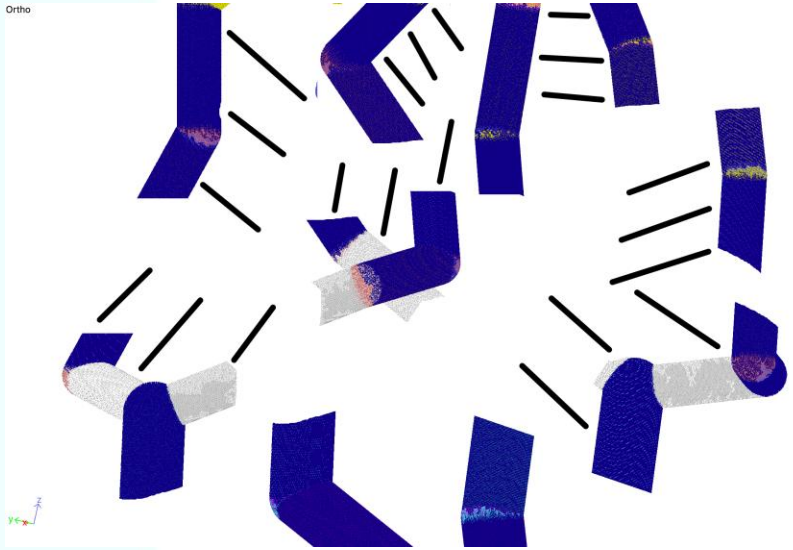


- The debris volume from a high velocity dust particle impact is smaller than the dust particle volume.

Worse than the sum of problem 1 + problem 2?

- What happens if a dust particle hits a fuzz covered surface?
- Fuzz is said to be fragile, will it shatter into many pieces, multiplying the W pollutant volume in the plasma?





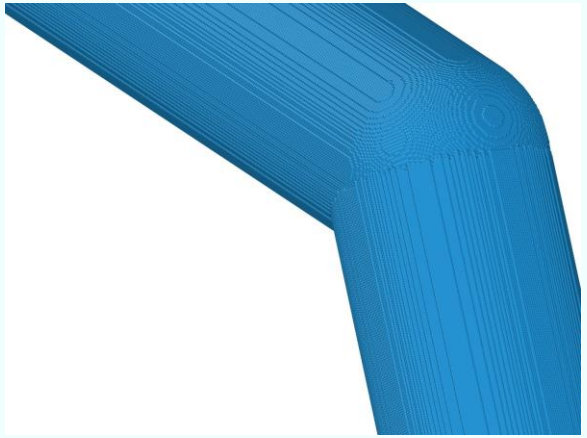
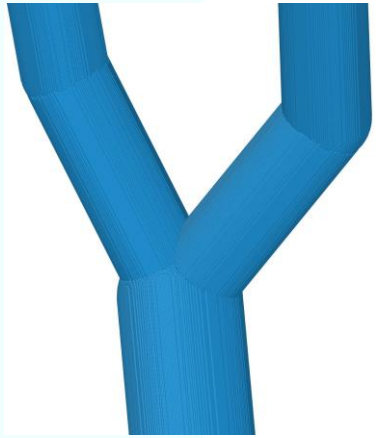
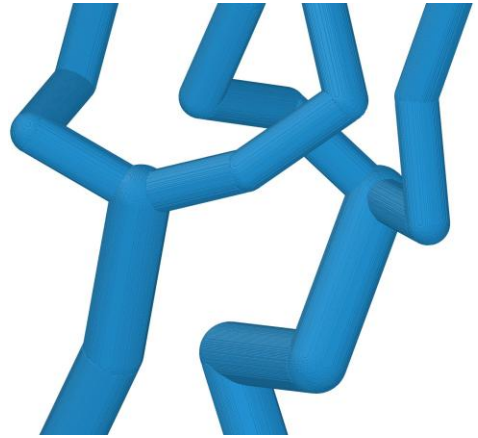
- Even medium velocity dust particles might have enough energy to cause a fuzz structure to shatter into many pieces?

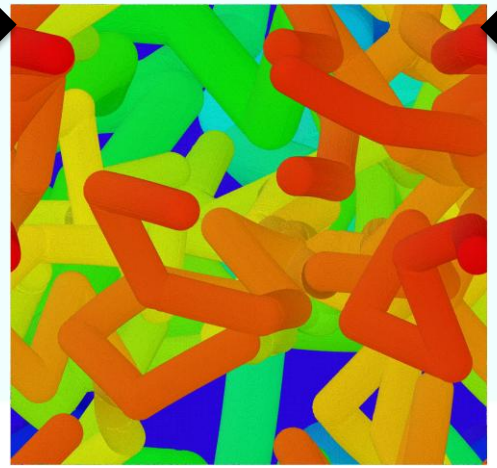
➔ use molecular dynamics simulations to get a sense of how bad it is

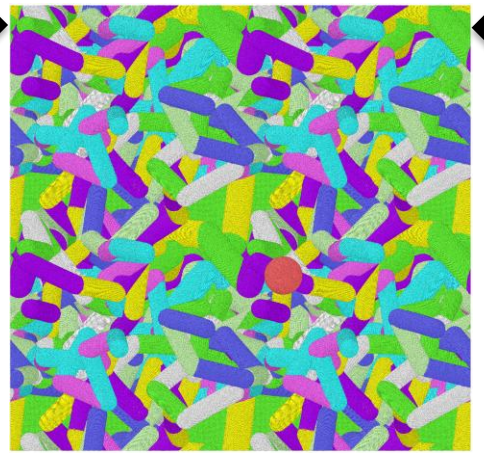
Creating a fuzz structure

VSB TECHNICAL UNIVERSITY OF OSTRAVA | IT4INNOVATIONS NATIONAL SUPERCOMPUTING CENTER

- Create building blocks 15-30 nm thick, rotate them randomly, stick them together head-tail, branch into thinner nanorods, cut away overlap between nanorods:

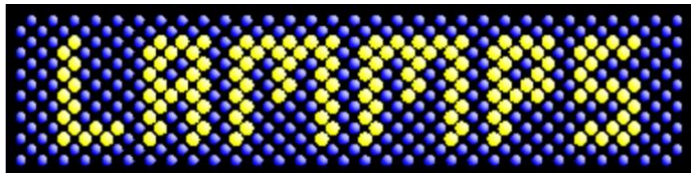





Simulation details

- 206M or 826M atom fuzz systems
- Spherical dust particles of 10-40 nm, up to 2M atoms
- Dust particle velocity -1.0 or -3.17 km/s



- LAMMPS MD code*
- Embedded atom method potential**, no electronic stopping
- Low density system, not efficient on GPUs
- Linear performance scaling on up to 40 cpu nodes on Barbora
- Visualisation (of thin surface shells) using OVITO

- Both the least methodologically innovative and most optimally efficient project in OPEN ACCESS-33?

* S. Plimpton, J. Comput. Phys. 117 (1995) 1

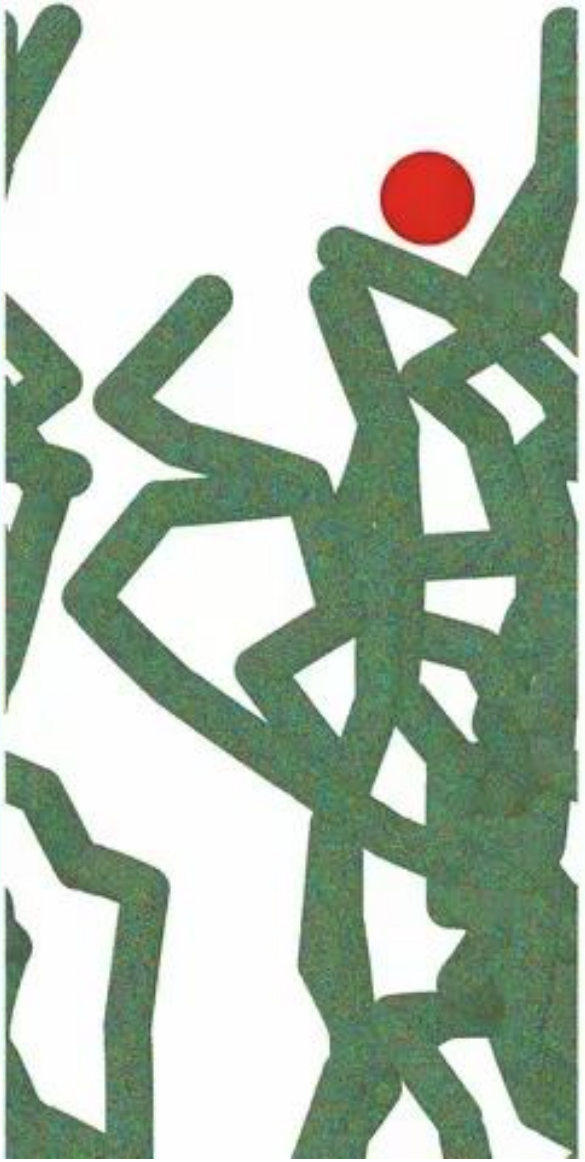
** N. Juslin, B. D. Wirth, J. Nucl. Mater. 432 (2013) 61–66

Medium velocity impacts



- No fracturing of nanorods, no debris gets ejected to the vacuum
- Extensive plastic deformation instead
- Fuzz is not at all fragile, it absorbs dust particles over a longer time and over a much greater depth than solid W
- 40 nm particle came to rest ~400 nm deep into the fuzz, after more than 1 ns

High velocity impacts



- Dust particle and nanorod liquefy on impact
- Some debris goes back to the vacuum, most of it keeps moving down
- Energy is again absorbed over longer time and over much greater distance
- Debris from impacts deep inside the fuzz will often not have line of sight to the vacuum
- Less debris reaches the vacuum than from impact on solid W, 0.01-0.1 x dust particle volume

Conclusions

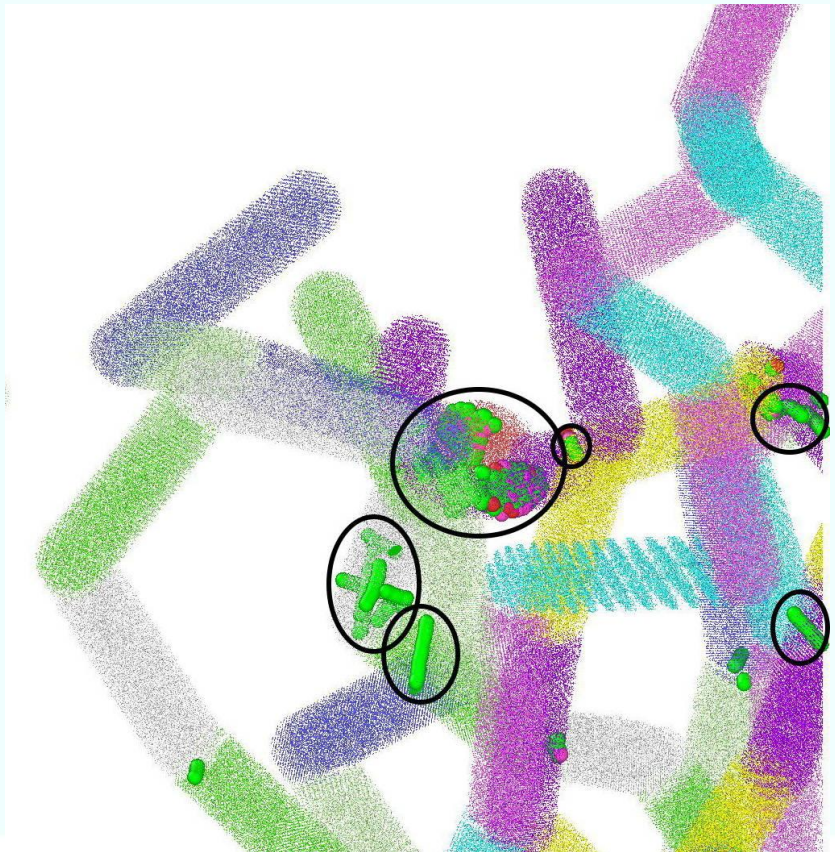
- Medium velocity dust particles dissipate their energy through extensive plastic deformation, no fragmenting of nanorods
- High velocity dust particles dissipate their energy by melting of the dust particle and (part of) the impacted nanorod
- Both medium and high velocity dust particles dissipate their energy over longer times and much greater depths than on solid W
- High velocity impacts on fuzz eject less debris to the vacuum than on a solid W surface. ☺

- MD simulations offer easy, detailed insight that might be quite difficult to obtain experimentally

T. P. C. Klaver, D. Legut, “Small dust particle bombardment of a fuzz covered W surface”, under revision for Nuclear Fusion

Plastic deformation

- Few dislocations after impact?



- Many dislocations eliminated at surfaces, forming slip bands

17 Burgers vectors ➔

