Formation of radiation damage and helium release in yttria-stabilized zirconia under dual ion beam irradiation

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Content

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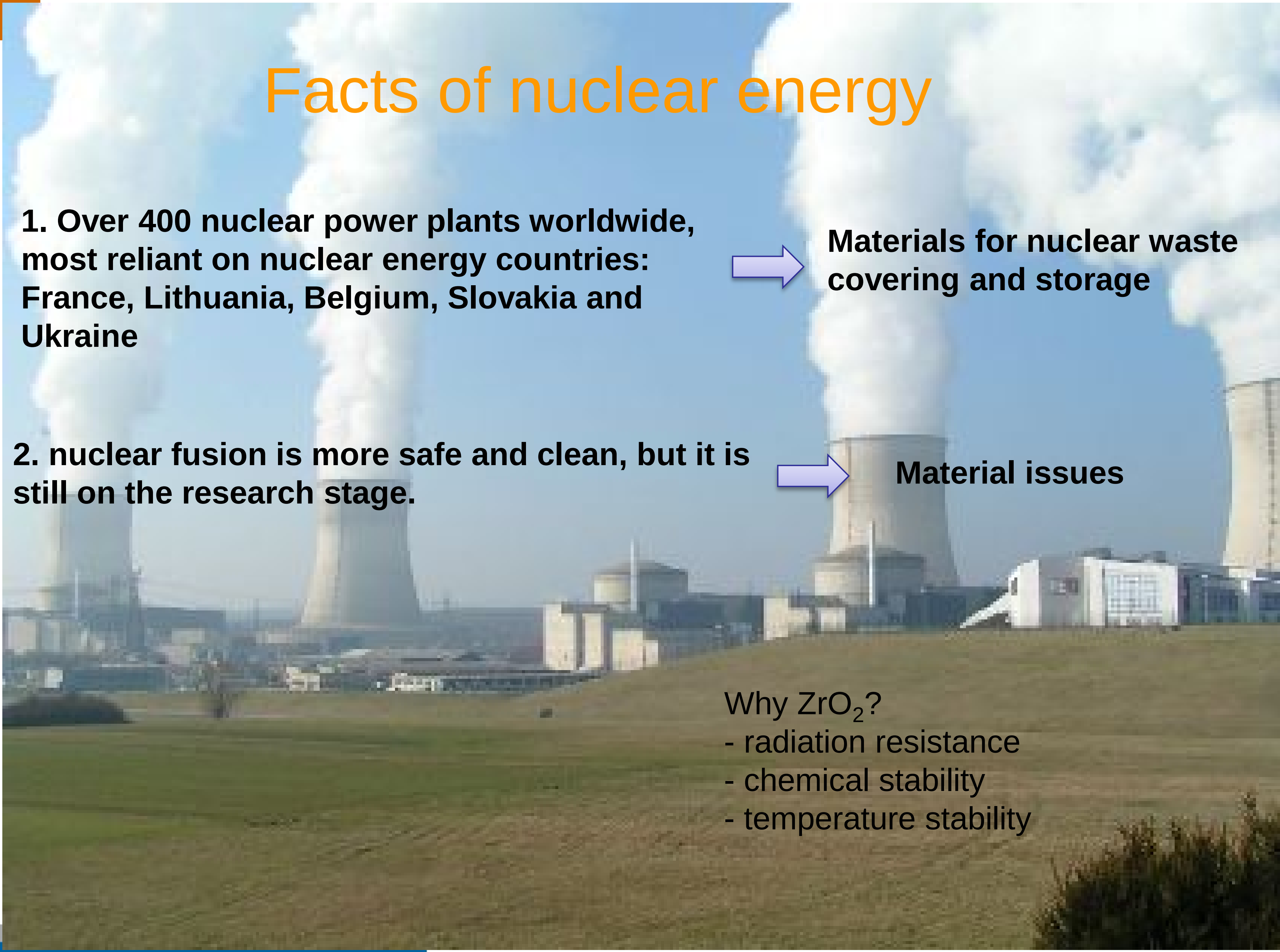
- Experimental details: dual beam implanter & mono-energetic e^+ beam
- Simulation of radiation induced defects by SRIM
- Results of depth-dependent Doppler broadening measurements
- Summary



Facts of nuclear energy

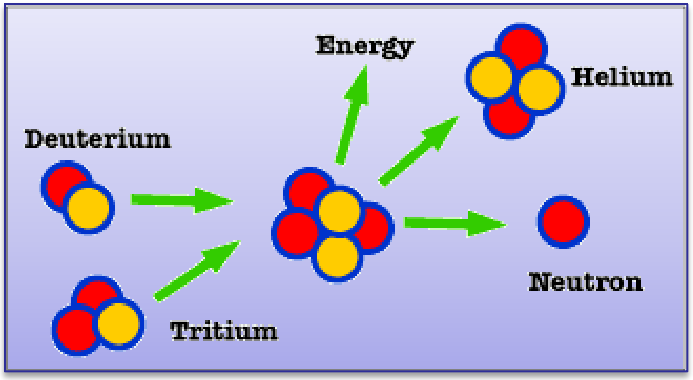
1. Over 400 nuclear power plants worldwide, most reliant on nuclear energy countries: France, Lithuania, Belgium, Slovakia and Ukraine → **Materials for nuclear waste covering and storage**

2. nuclear fusion is more safe and clean, but it is still on the research stage. → **Material issues**

Why ZrO_2?
- radiation resistance
- chemical stability
- temperature stability

Nuclear Reactions

Nuclear fusion



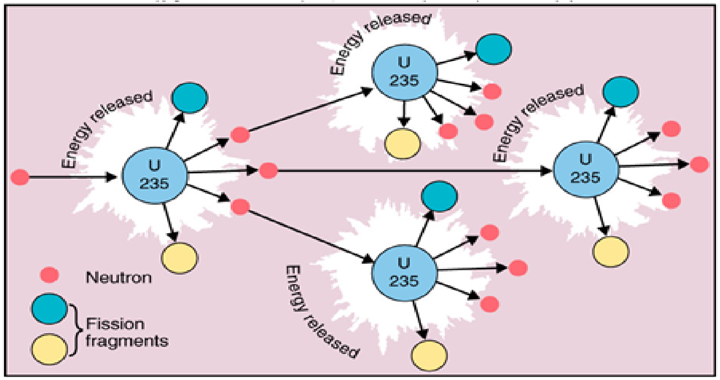
$${}^{2}_{1}D + {}^{3}_{1}T \rightarrow {}^{4}_{2}He + n$$

α-particles irradiation

Impurities (He)

Voids or bubbles

Nuclear fission



n+ fragments+α-decay of actinide elements

Neutron irradiation

Vacancies and interstitials

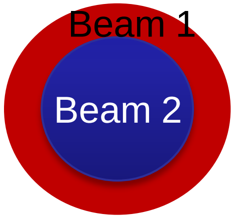
Defect clusters
Dislocation loops
Stacking fault

Application of ion beam in nuclear materials research

Simulation of the radiation damage induced by energetic particles in the nuclear environment.

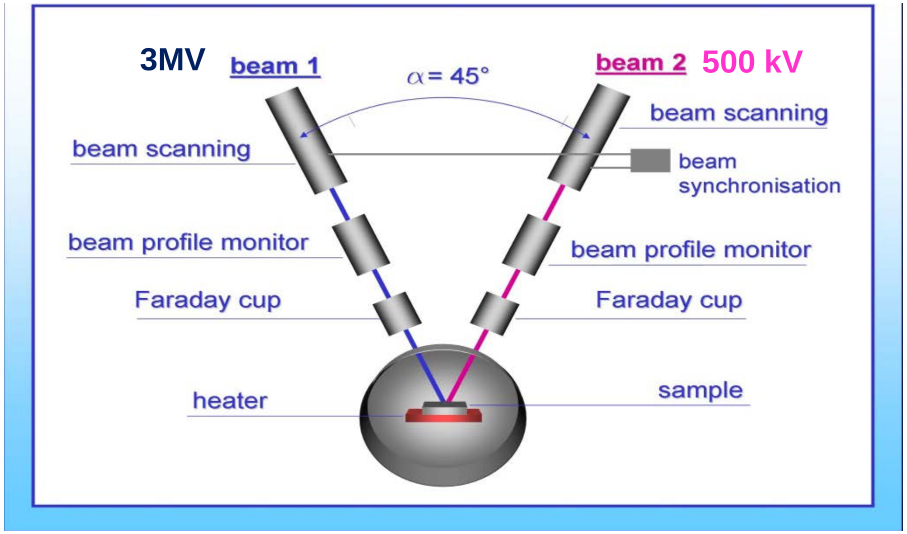
He imp. → α-particles irradi.

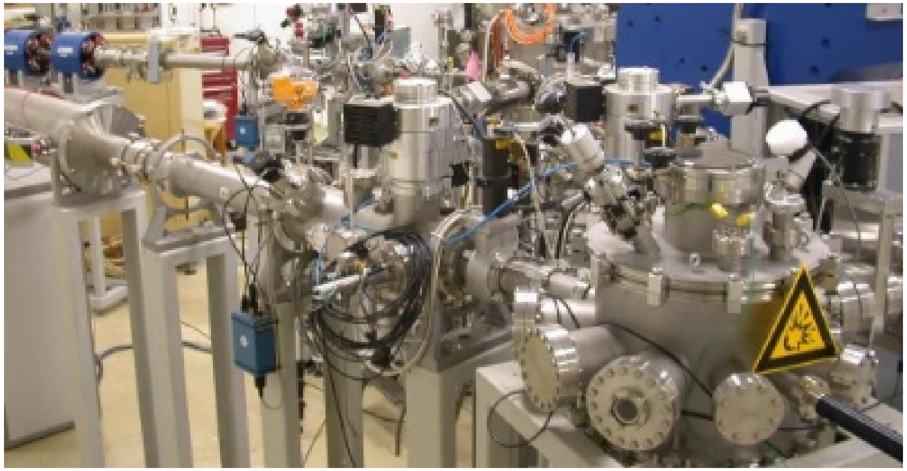
Heavy ion imp. → Neutron irradi.



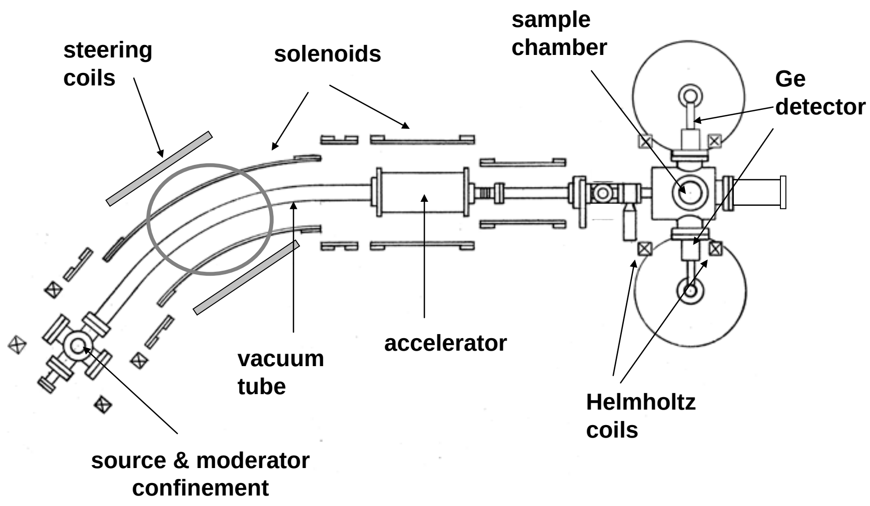
Alignment of both beams

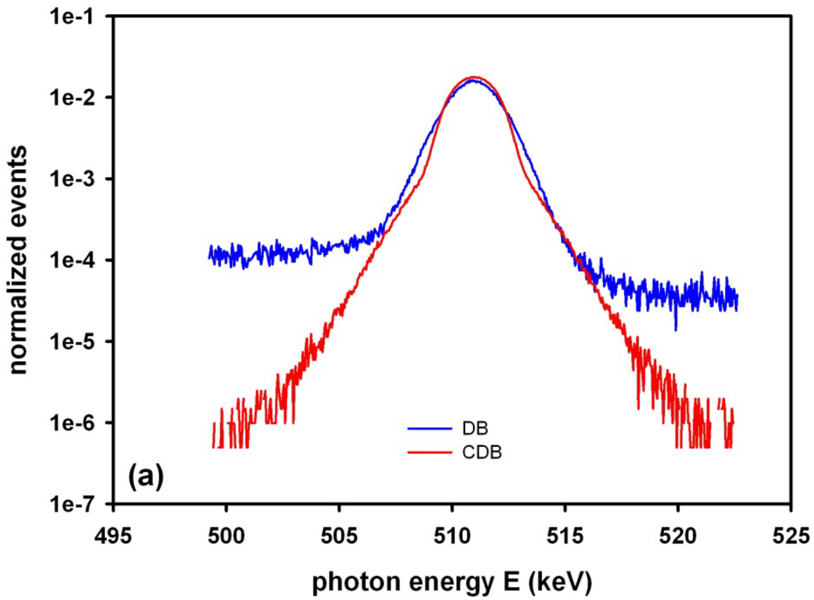
Dual Beam Facility @ HZDR





Positron annihilation spectroscopy
Mono-energetic slow positron beam



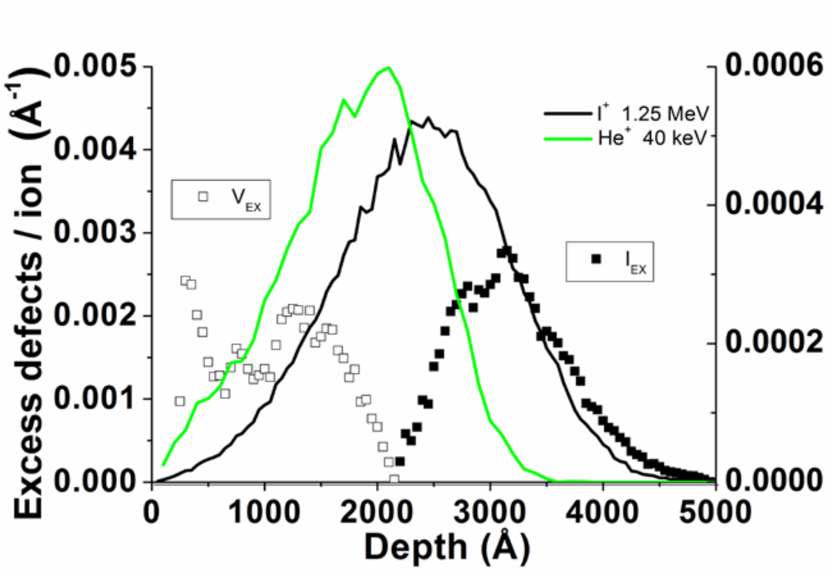


main parameters

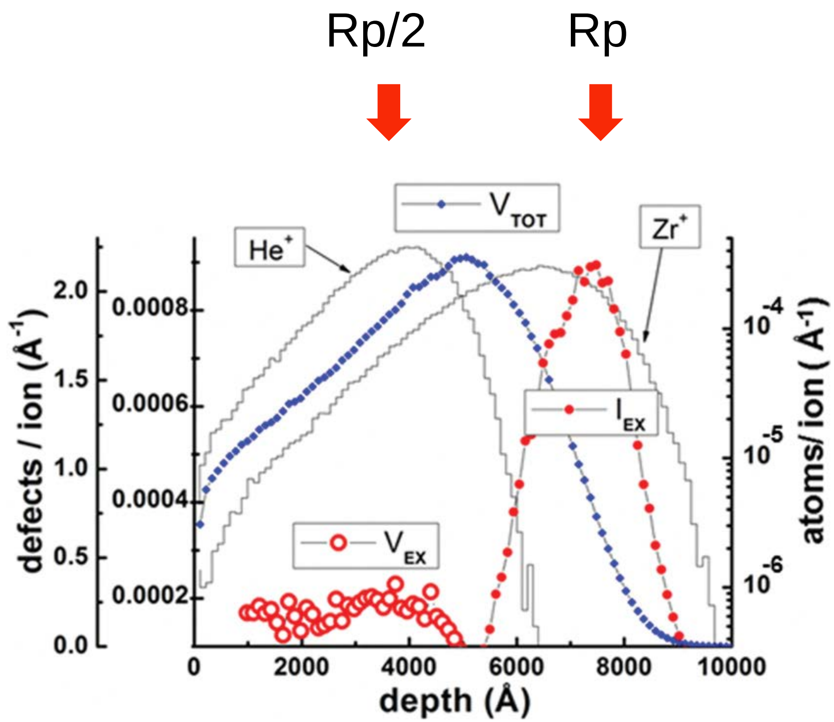
- ^{22}Na source => measured 10^2 e^+/s below 511keV
- positron energy: 30 eV $\leq E_{positron} \leq$ 37 keV
  => (1nm $\leq$ d $\leq$ 5µm) penetration depth
- energy resolution at 511 keV:
  DB 1.09 keV and cDB 0.78 keV
- signal to noise ratio: DB 10^2 ; CDB: 10^4 - 10^5
- beam spot: d = 4 mm

TRIM Monte Carlo Simulation
Zr/I and He irradiation on ZrO_2

1.25MeV 1E16 cm^{-2} **I^+**
+ 40 keV 1E16 cm^{-2} **He^+**

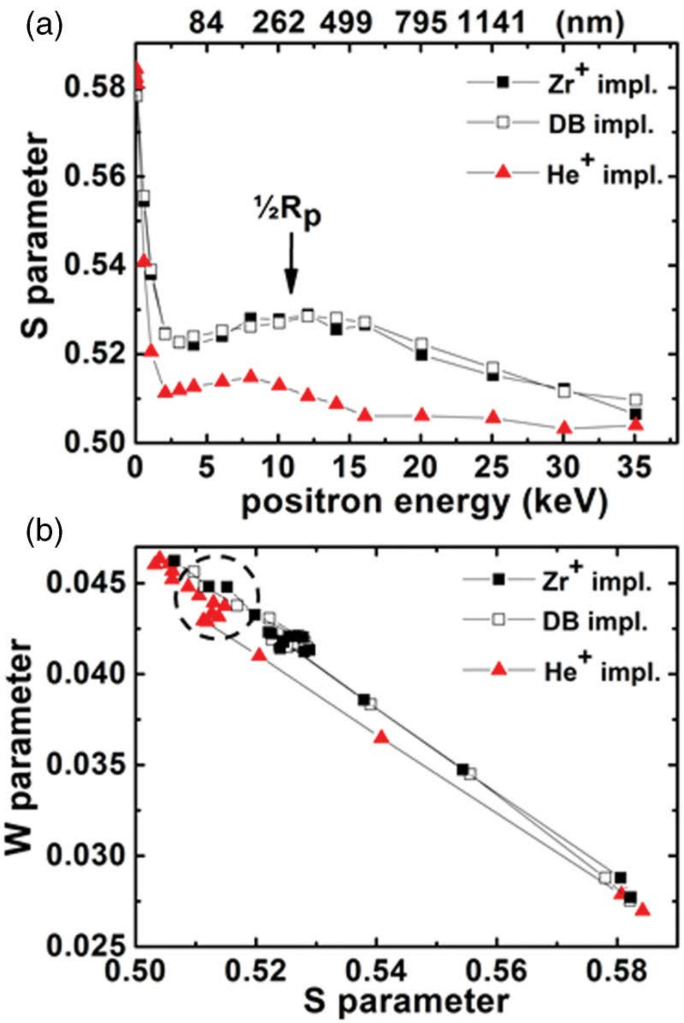


2.5MeV 1E16 cm^{-2} **Zr^+**
+100 keV 5E15 cm^{-2} **He^+**

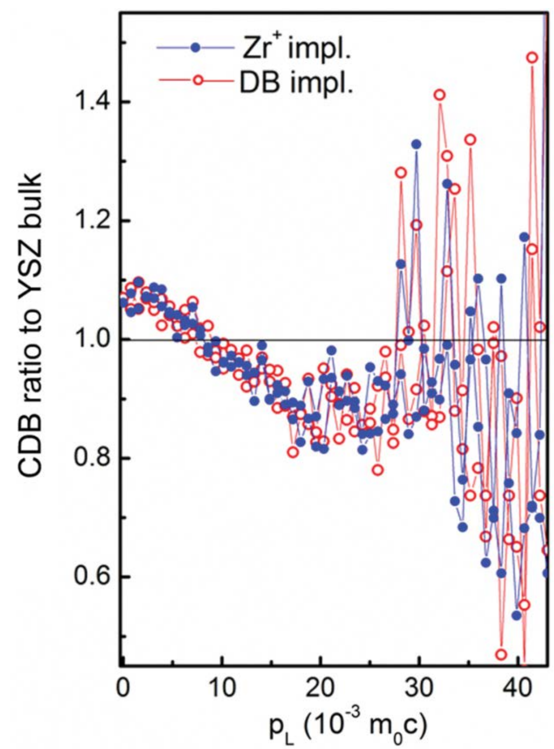


max. damage: 21 dpa

Positron annihilation spectroscopy
Results: Zr^+ & He^+ implantation

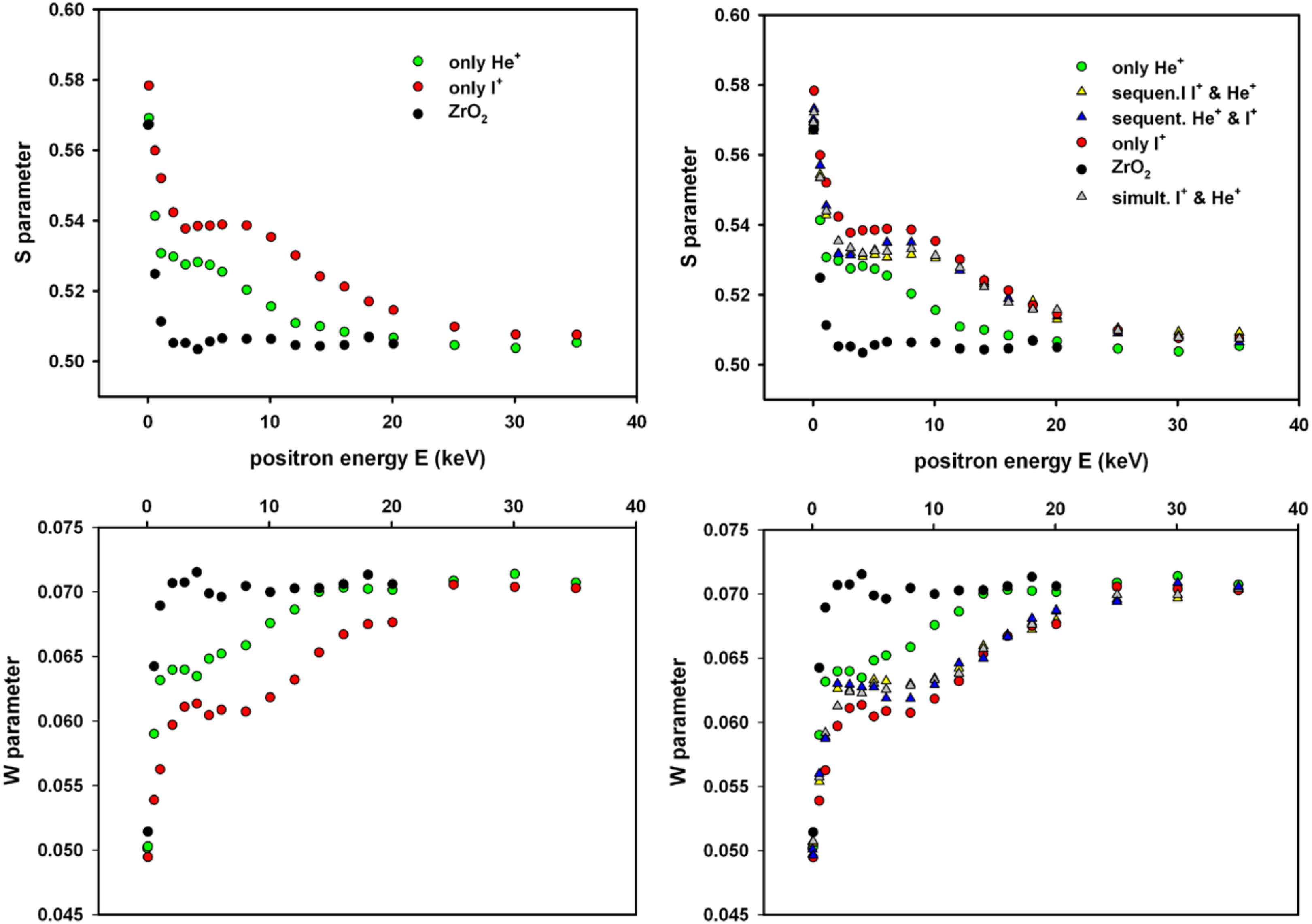


S-W parameter

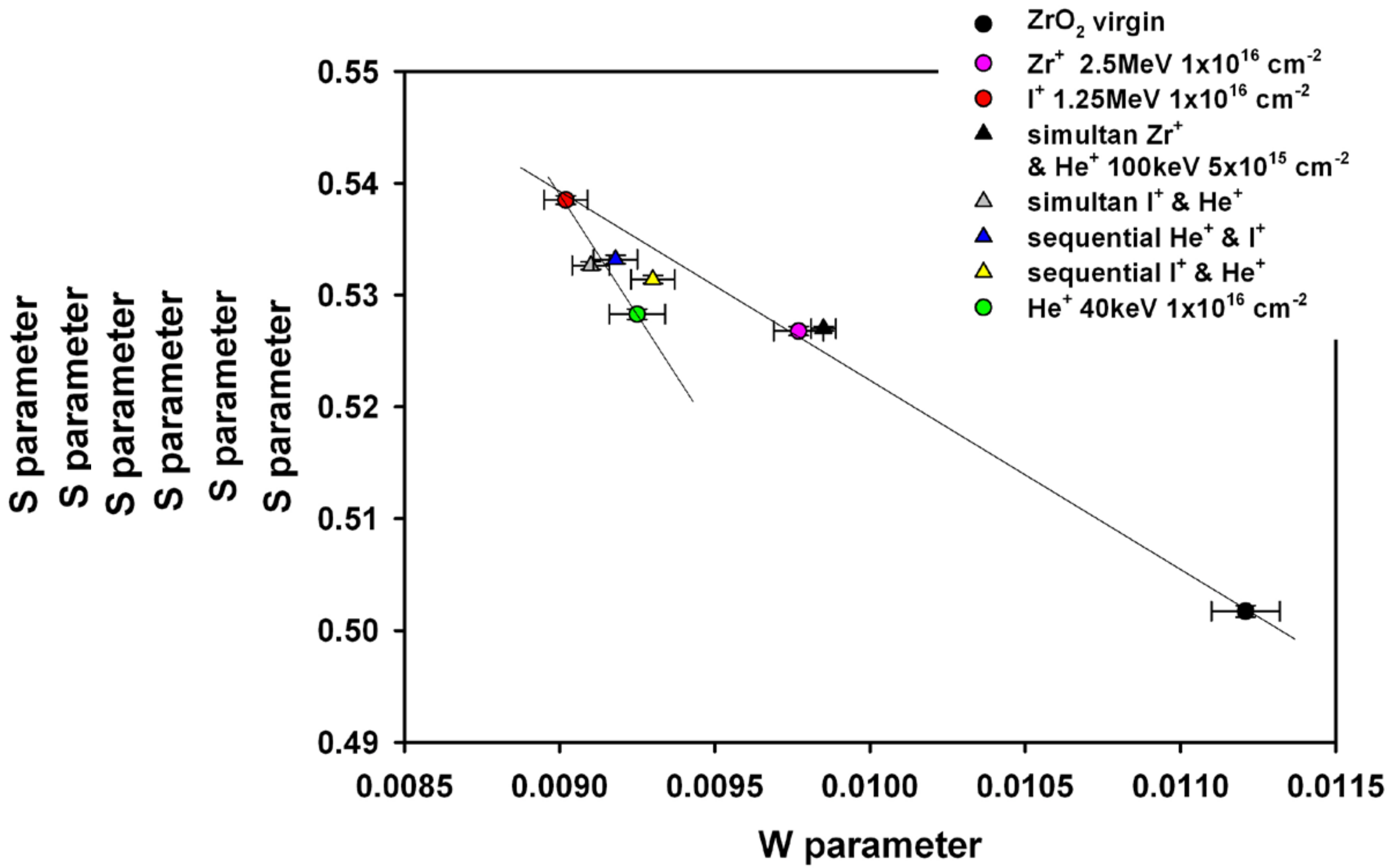


Coincidence Doppler Broadening

Positron annihilation spectroscopy
Results 1: I^+ & He^+ implantation



Positron annihilation spectroscopy
Results: I^+, Zr^+ & He^+ implantation



Summary

- DB and cDB positron spectroscopy is a suitable tool to characterise vacancy-type defects and delivers information about the He release in ZrO_2 :

- Zr^+ or I^+ implantation creates the same vacancy-type defects (straight line between virgin YSZ and the SW pairs of Zr and I in S-W-plot)
- only higher damage by I^+ implantation could be detected in comparison to Zr^+ implantation (atomic numbers: Zr:40 and I:53; different implantation energy), chemical surrounding of defects unchanged
- He is released after simultaneous Zr^+ and He^+ implantation, empty vacancies remain, vacancy-supported He diffusion
- no significant difference of damage between simultaneous and sequential I^+ and He^+ implantation
- He is embedded into open volume created by simultaneous or sequential I^+ and He+ implantation, in contrast to Zr^+ & He^+ implantation, model of vacancy-supported diffusion process not working ?

Thanks!