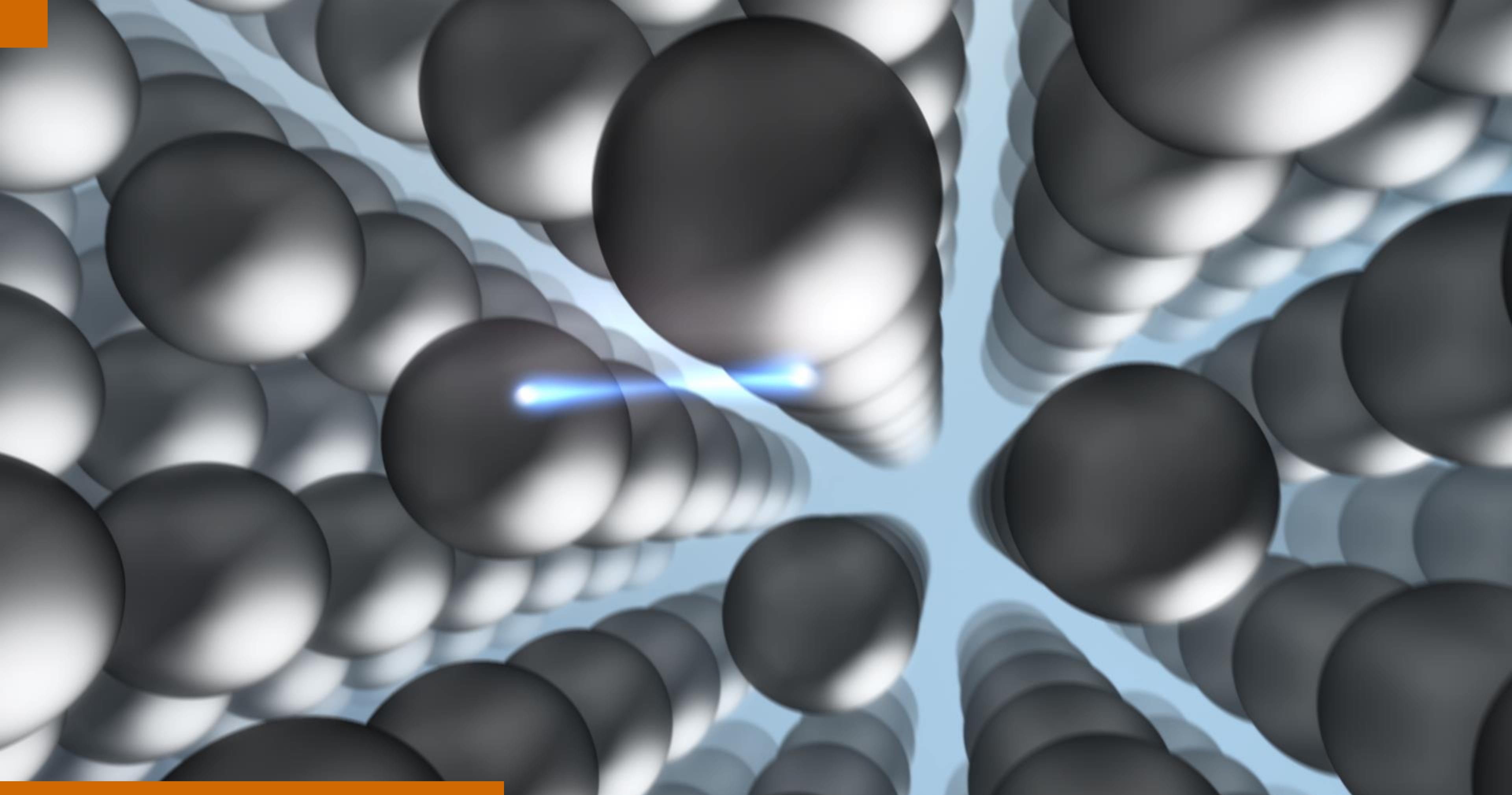

Long-term ageing effects in reactor pressure vessel steels investigated by positron annihilation spectroscopy

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Long-term ageing effects in reactor pressure vessel steels investigated by positron annihilation spectroscopy

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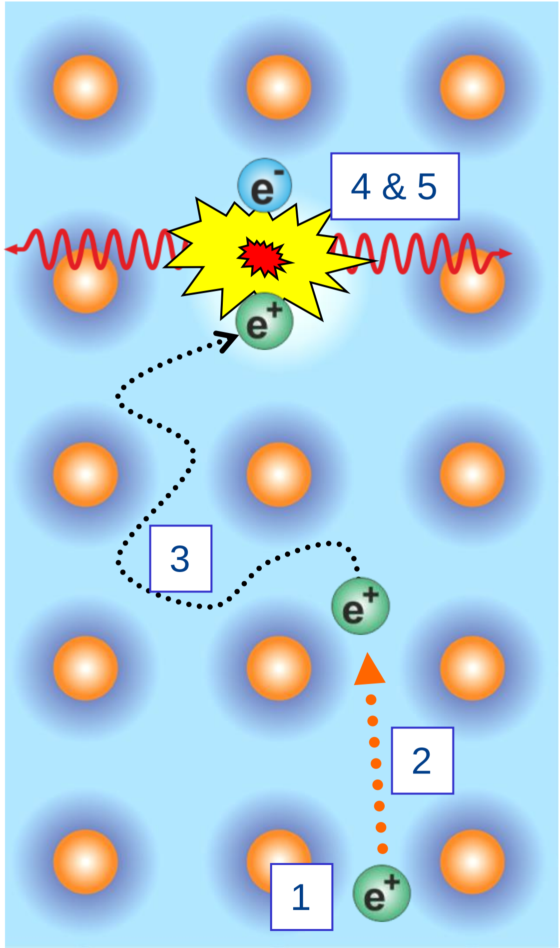
- Positrons for spectroscopy
- Setup for measurement
- Samples & Results

Summary – Fate of positrons in solid matter



lattice of a solid with a single vacancy

1) Positron generation & implantation in the solid
   - β^+ decay of ^{22}Na
   - pair production

2) Thermalization – reducing energy

3) Diffusion through the lattice
   - ~ 100 nm

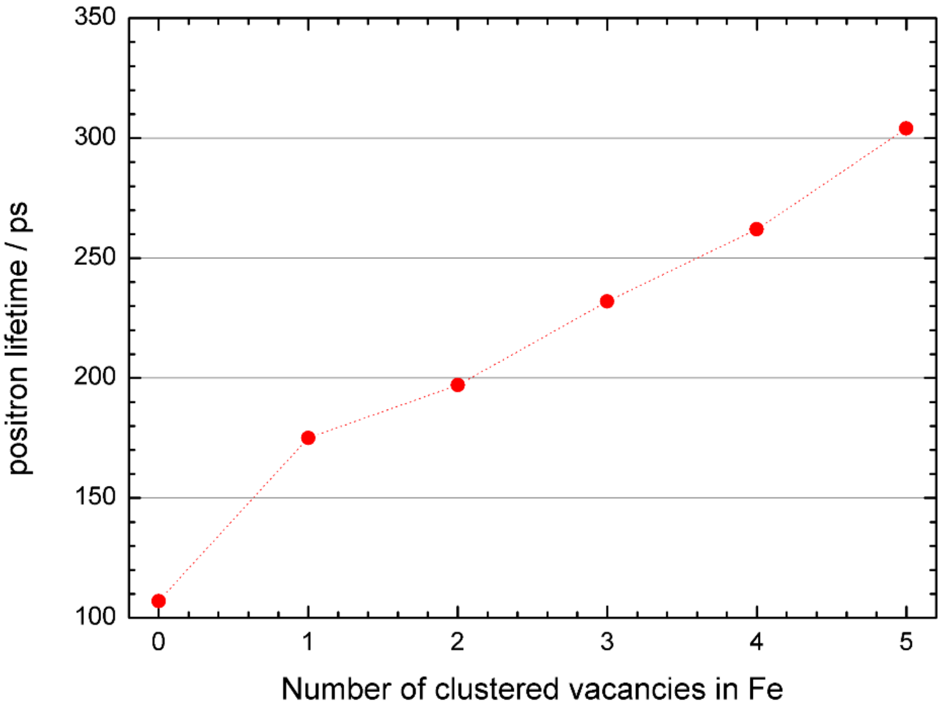
4) Trapping in defects

5) Annihilation with an electron
   - emission of two photons in metals/ semiconductors

Positron annihilation lifetime spectroscopy - PALS

positron trapping in open-volume defects (dislocations, vacancies)

→ lower electron density
→ lower annihilation probability
→ longer positron lifetime



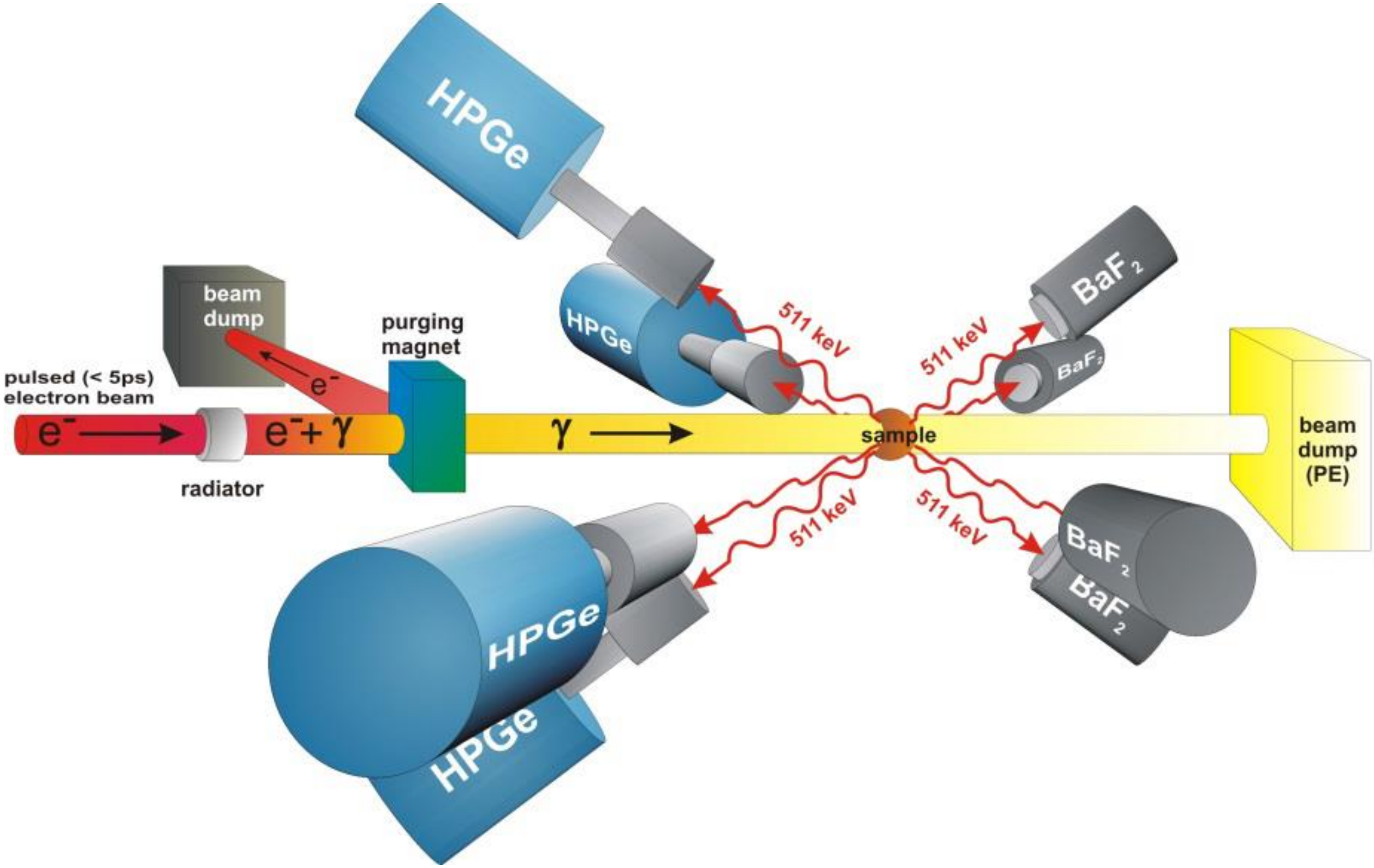
identification and concentration of open-volume defects

Positrons for spectroscopy

Setup for measurement

Samples & Results

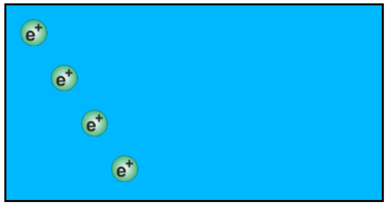
Gamma-induced Positron Annihilation Spectroscopy



Accelerator-based PALS

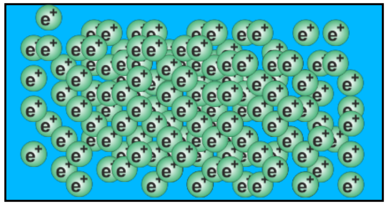
Implantation of positrons

- **+** adjustable energy → adjustable implantation depth
- **–** limited implantation depth of a few µm



Pair production inside sample

- **–** no depth information
- **+** information from the entire sample volume
  (oxide layer on surface has neglible influence)



Positrons for spectroscopy

Setup for measurement

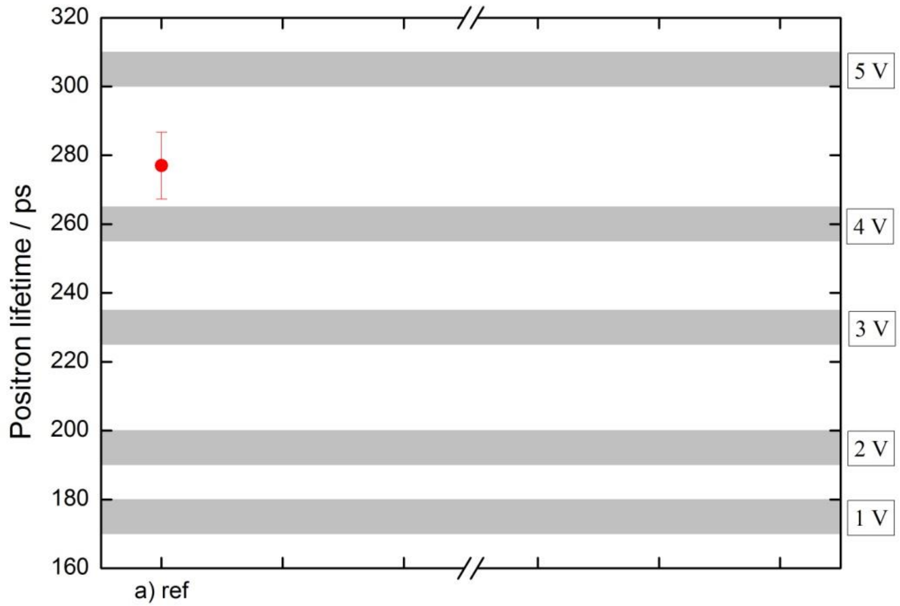
Samples & Results

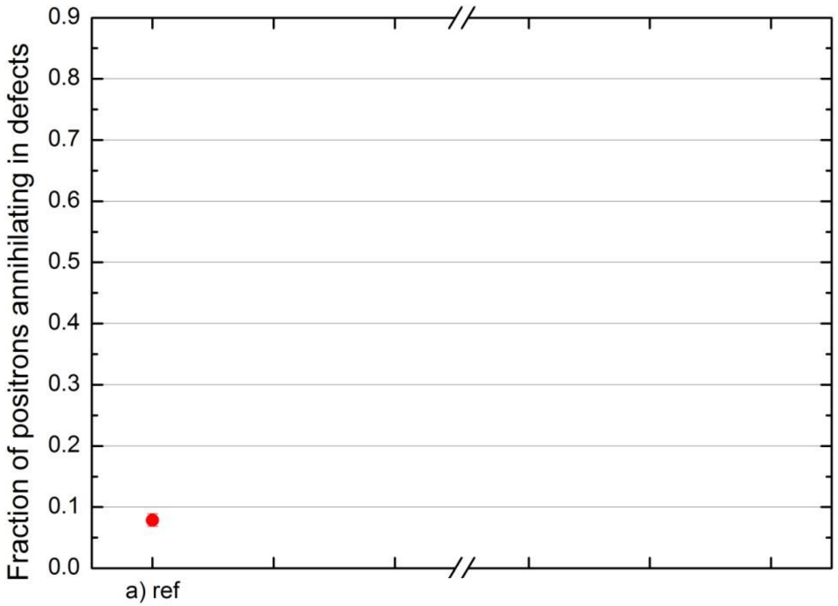
Sample list

Type	Name	Neutron fluence (10^{19} n/cm²)
German base metal	20MnMoNi5-5	unirradiated
German base metal	20MnMoNi5-5	4.3
German weld	S3NiMo1	unirradiated
German weld	S3NiMo1	4.7
Japanese base metal	JPB	unirradiated
Japanese base metal	JPB	8.9
Japanese base metal	JPB	8.9 + annealed

Reference sample a) - Japanese material

- a) reference as-received

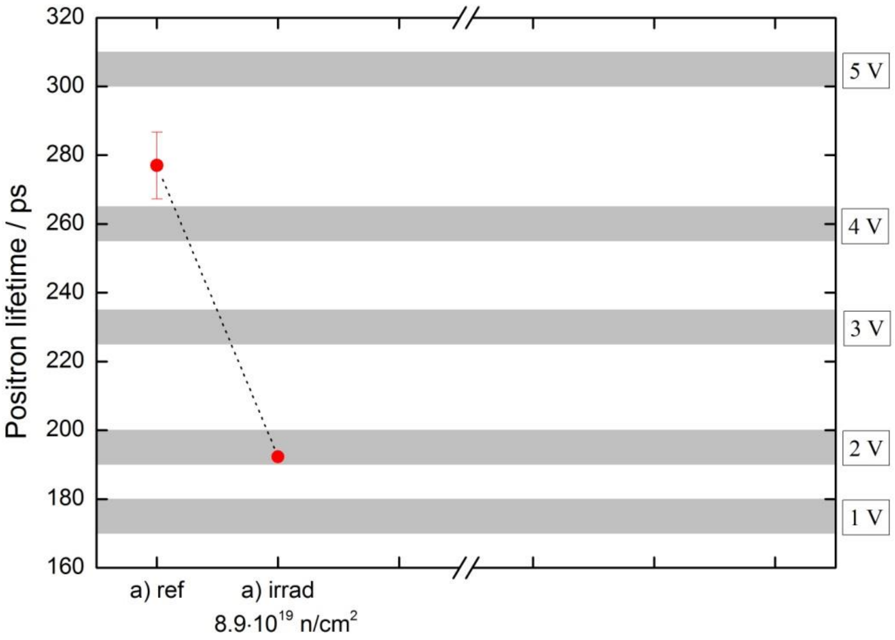


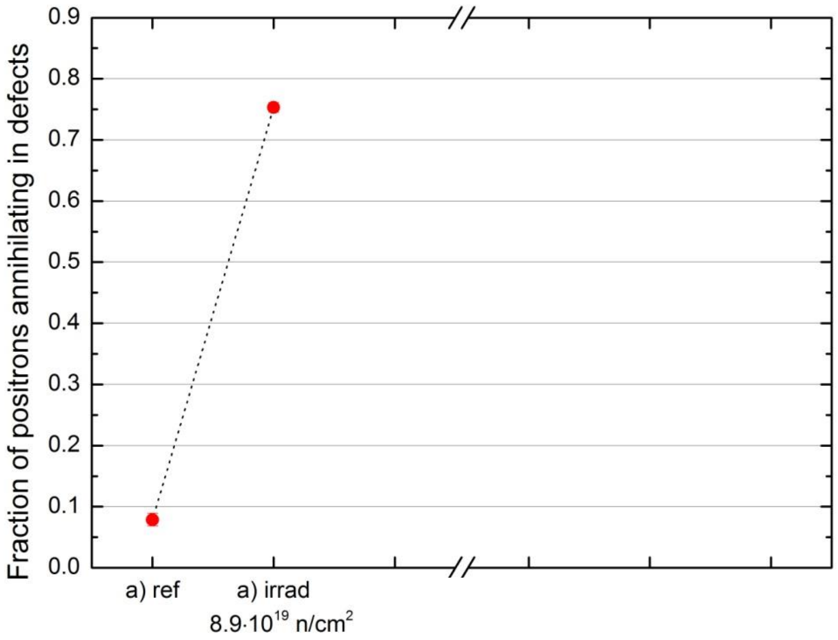


- low fraction of vacancy clusters having ~ 4-5 vacancies (for values from Fe)
- main part: defect-free bulk (135 ps in steel)

Irradiation of sample a)

- a) reference as-received
- a) $8.9 \cdot 10^{19}$ n/cm²

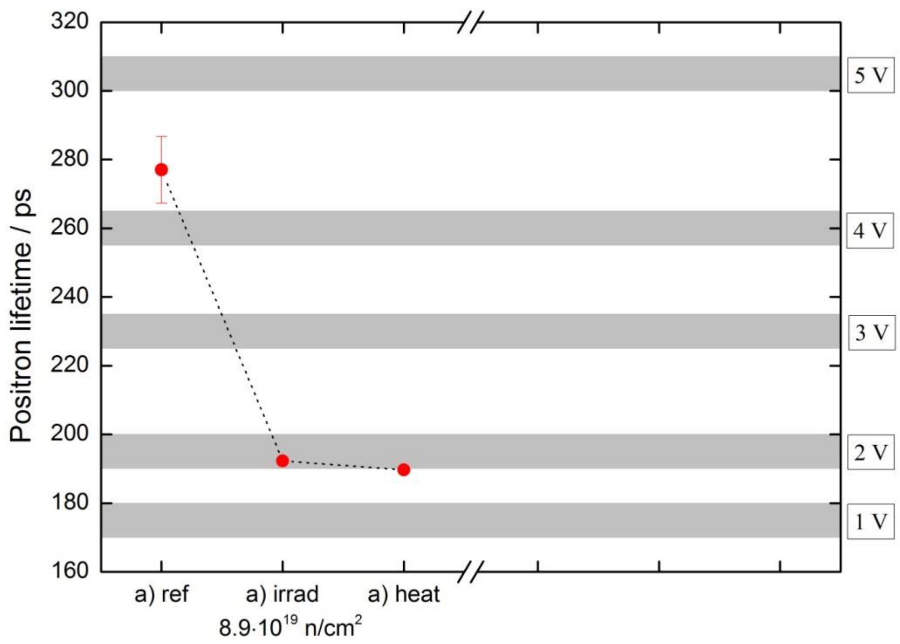


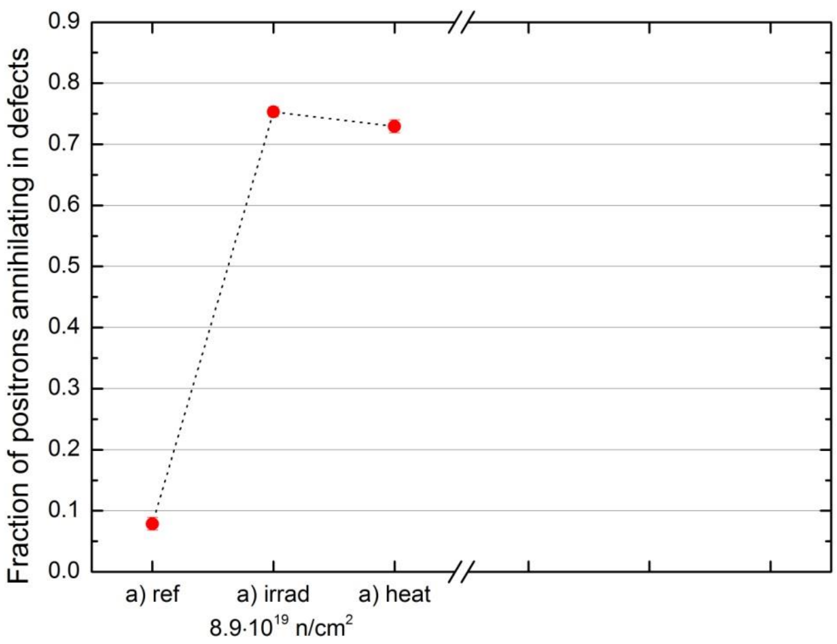


- huge fraction of di-vacancies compared to reference
- irradiation generates a lot of defects
- no positron saturation

Temperature treatment of irradiated sampe a)

- a) reference as-received
- a) $8.9 \cdot 10^{19}$ n/cm²
- a) $8.9 \cdot 10^{19}$ n/cm² + T = 290 °C



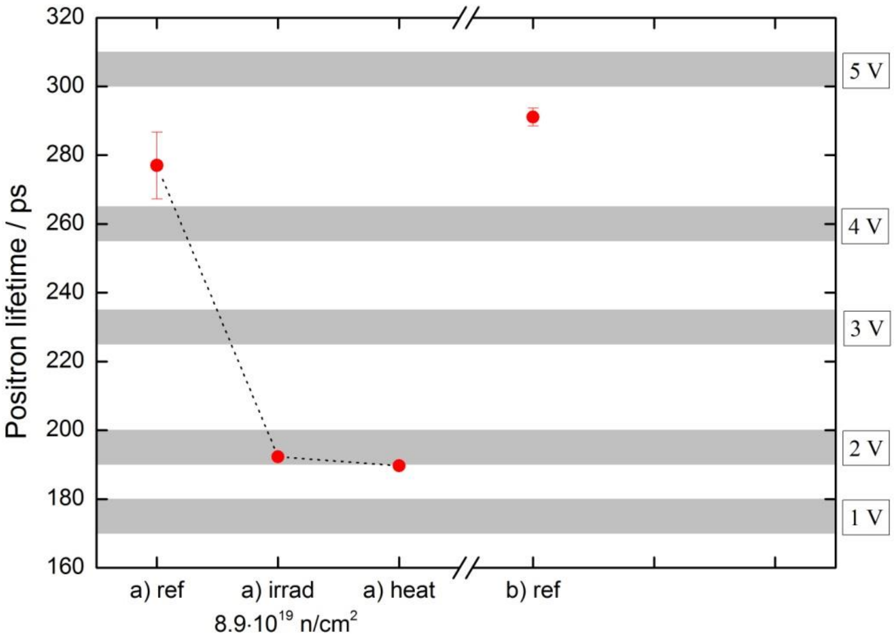


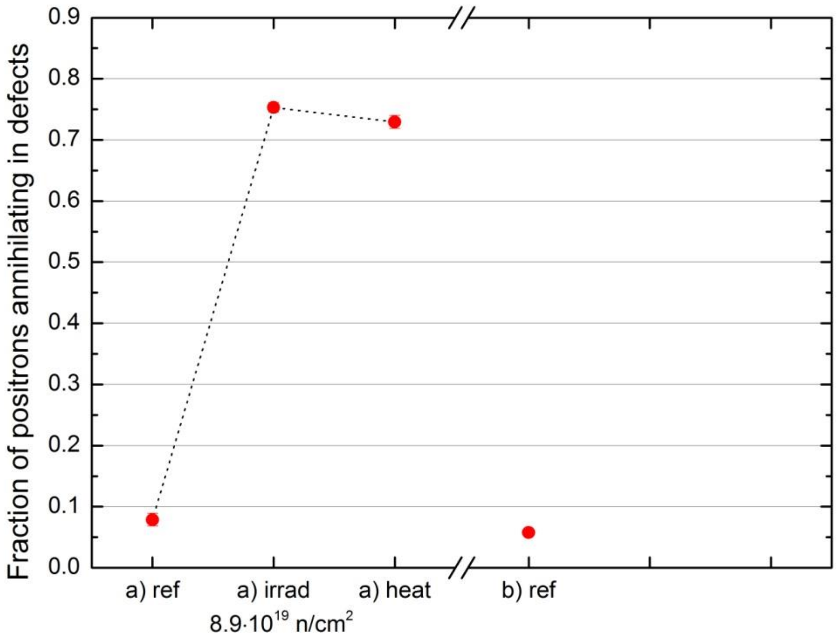
- defect type is the same, just small decrease in intensity
- temperature too low for significant defect annealing

Reference sample b) - German material

- a) reference as-received
- a) $8.9 \cdot 10^{19}$ n/cm²
- a) $8.9 \cdot 10^{19}$ n/cm² + T = 290 °C

- b) reference as-received



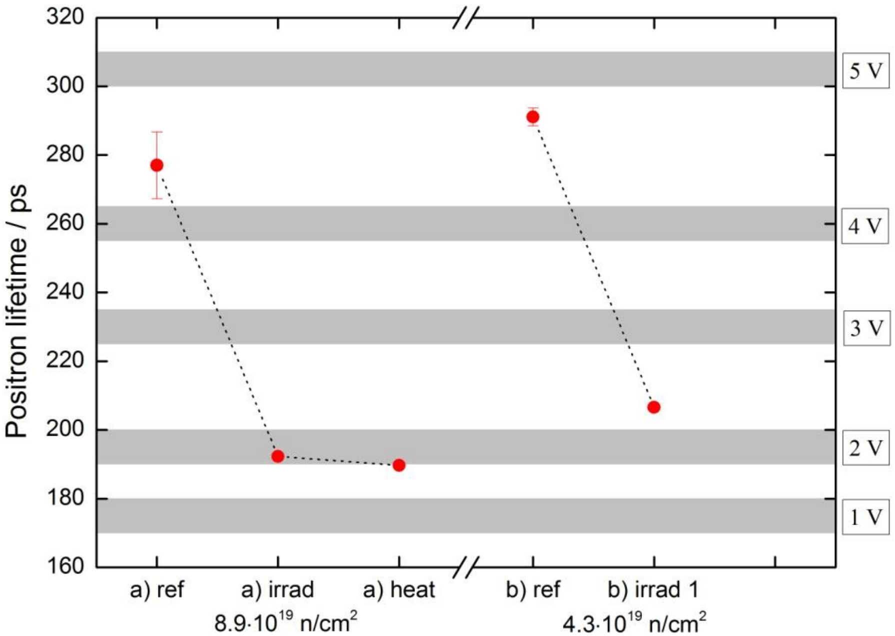


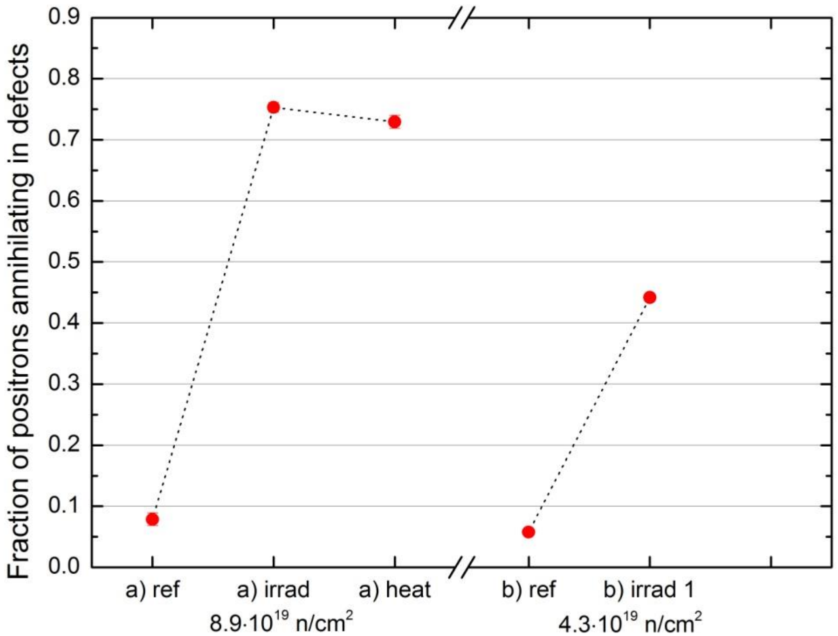
- situation equal to reference a), low fraction of vacancy clusters with ~ 4-5 vacancies
- lifetimes and intensities of both references comparable

Irradiation of sample b)

- a) reference as-received
- a) $8.9 \cdot 10^{19}$ n/cm²
- a) $8.9 \cdot 10^{19}$ n/cm² + T = 290 °C

- b) reference as-received
- $4.3 \cdot 10^{19}$ n/cm²



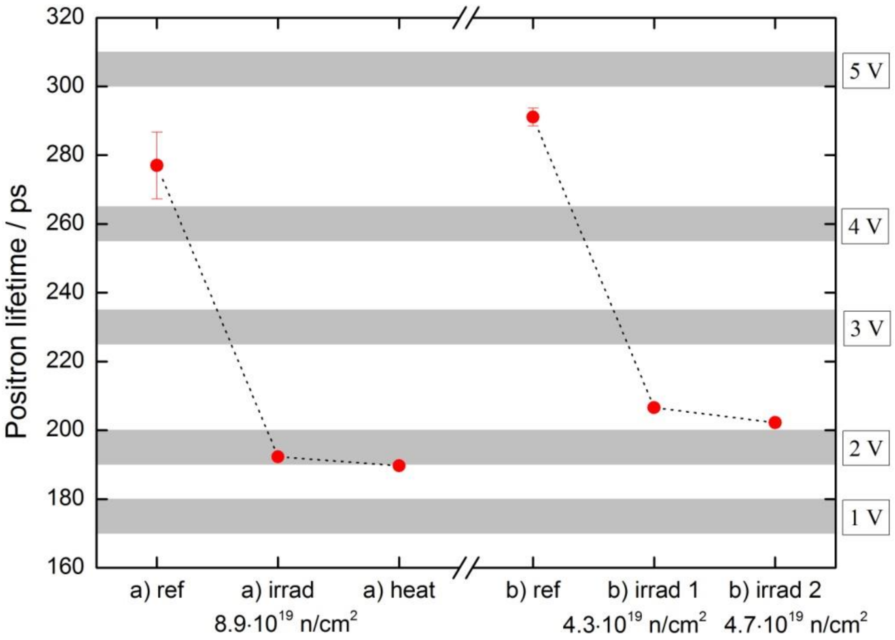


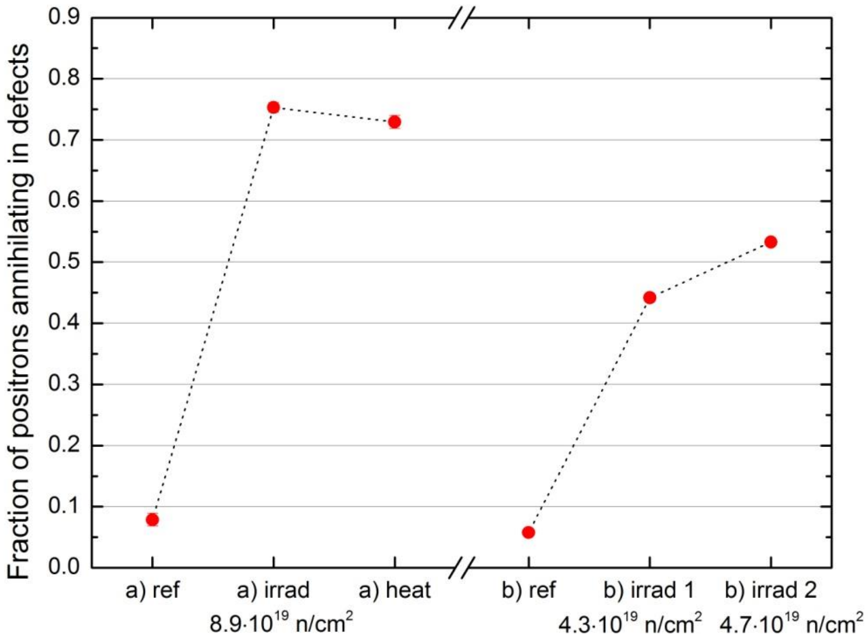
- di-vacancies (like for irradiated a) but lower intensity
- reason: irradiation was not as strong as for irradiated sample a)

Irradiation of sample b)

- a) reference as-received
- a) $8.9 \cdot 10^{19}$ n/cm²
- a) $8.9 \cdot 10^{19}$ n/cm² + T = 290 °C

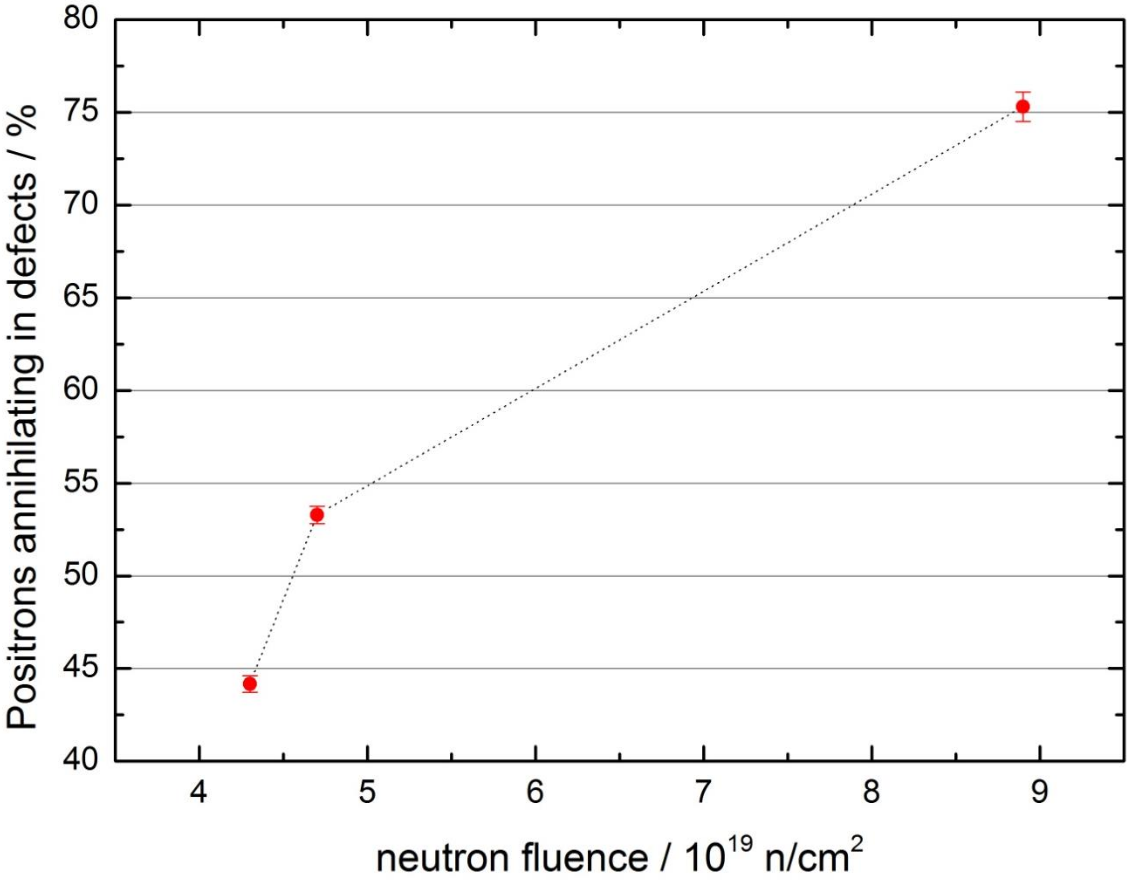
- b) reference as-received
- $4.3 \cdot 10^{19}$ n/cm²
- $4.7 \cdot 10^{19}$ n/cm²





- di-vacancies with slightly higher intensity

Influence of neutron fluence



Summary

- Non-irradiated reference samples from Germany & Japan similar
- Fluence-depending defect concentration
- Defect-annealing requires larget temperature than 290 °C

Thank you for your attention