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Deuterium trapping at irradiation-induced defects in tungsten studied by positron annihilation spectroscopy

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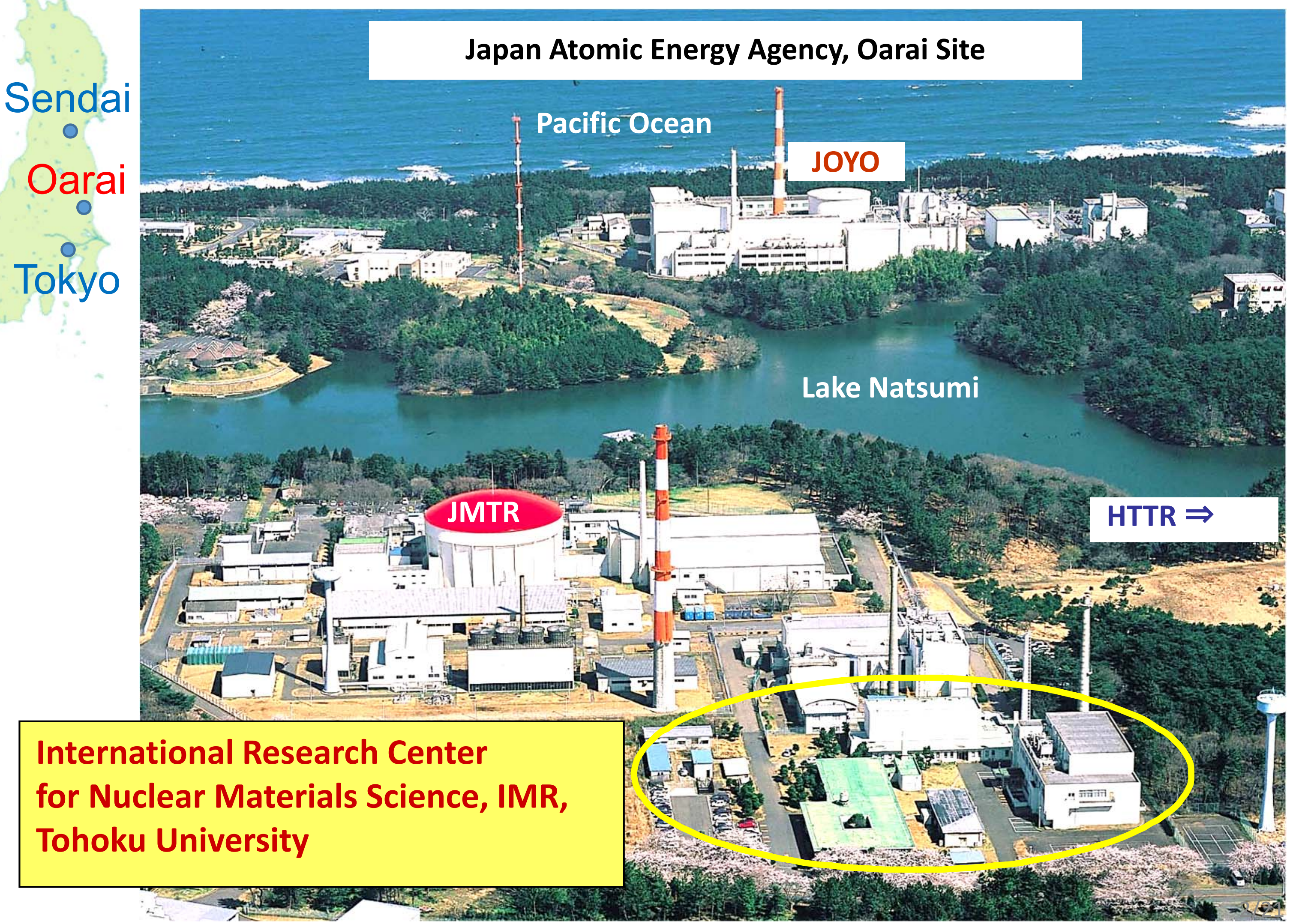
Japan Atomic Energy Agency, Oarai Site
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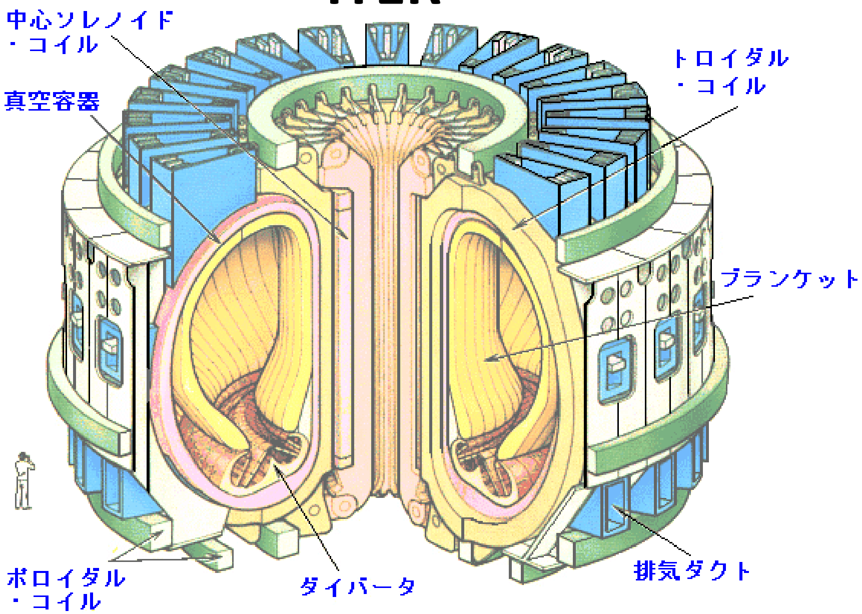
http://www.rist.or.jp/atomica/dic/dic_detail.php?Dic_Key=2543



Fusion reaction:

$^{2}H + {}^{3}H \rightarrow {}^{4}He + n$

Materials will be irradiated with plasma and neutron.

→ Severe condition for materials.

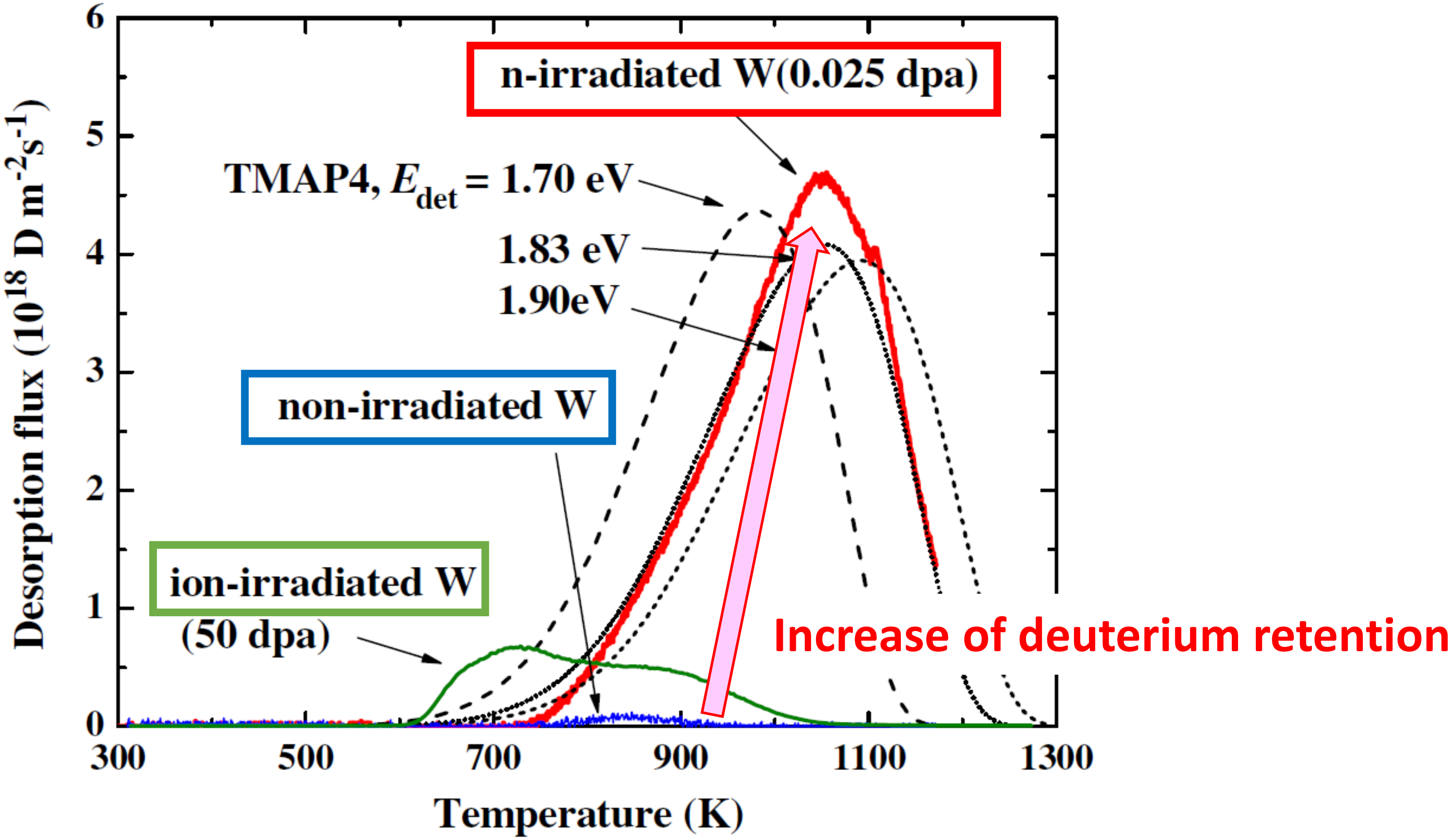
Tungsten : the first candidate as the plasma-facing material.

- ✓ *High melting point*
- ✓ *Low sputter rate*
- ✓ *Low activation*
- ✓ ***Low solubility of hydrogen isotopes**: important for reducing tritium retention*

Present issue :

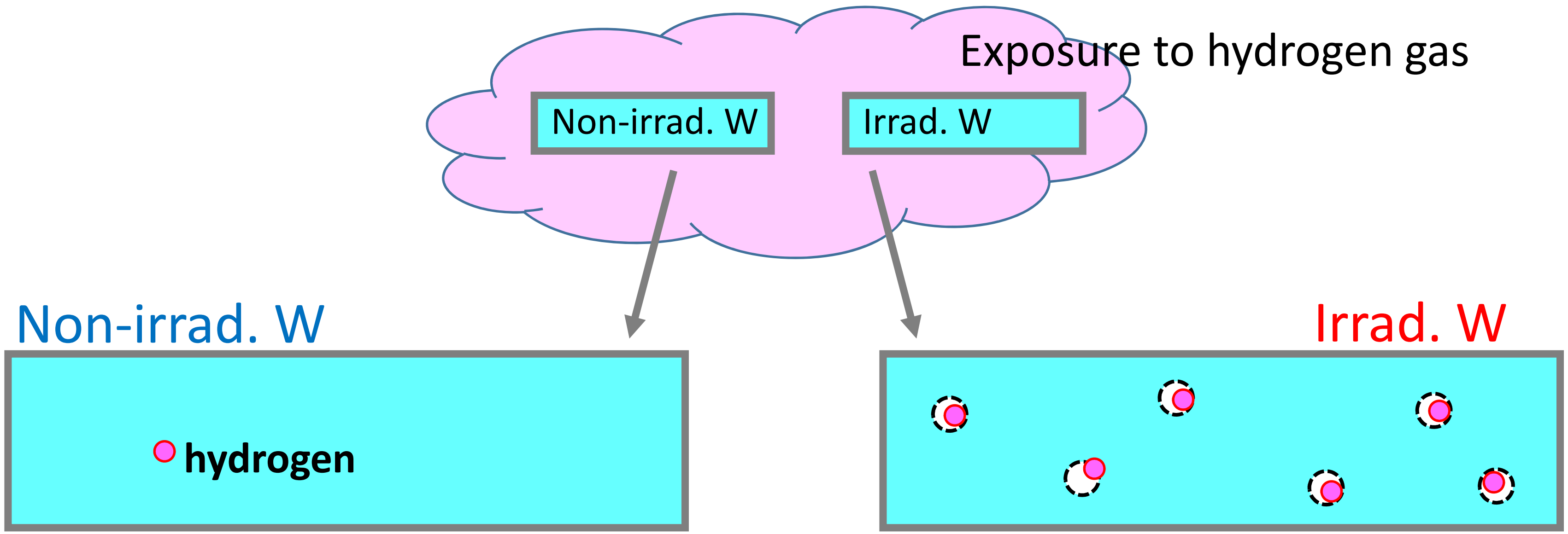
After irradiation, hydrogen retention in tungsten increases.

Thermal Desorption Spectrometry of Non-irradiated/Irradiated tungsten exposed to deuterium plasma



Y. Hatano et al., J. Nucl. Mater., **438** (2013) S114-S119.

Why does hydrogen retention increase after irradiation?



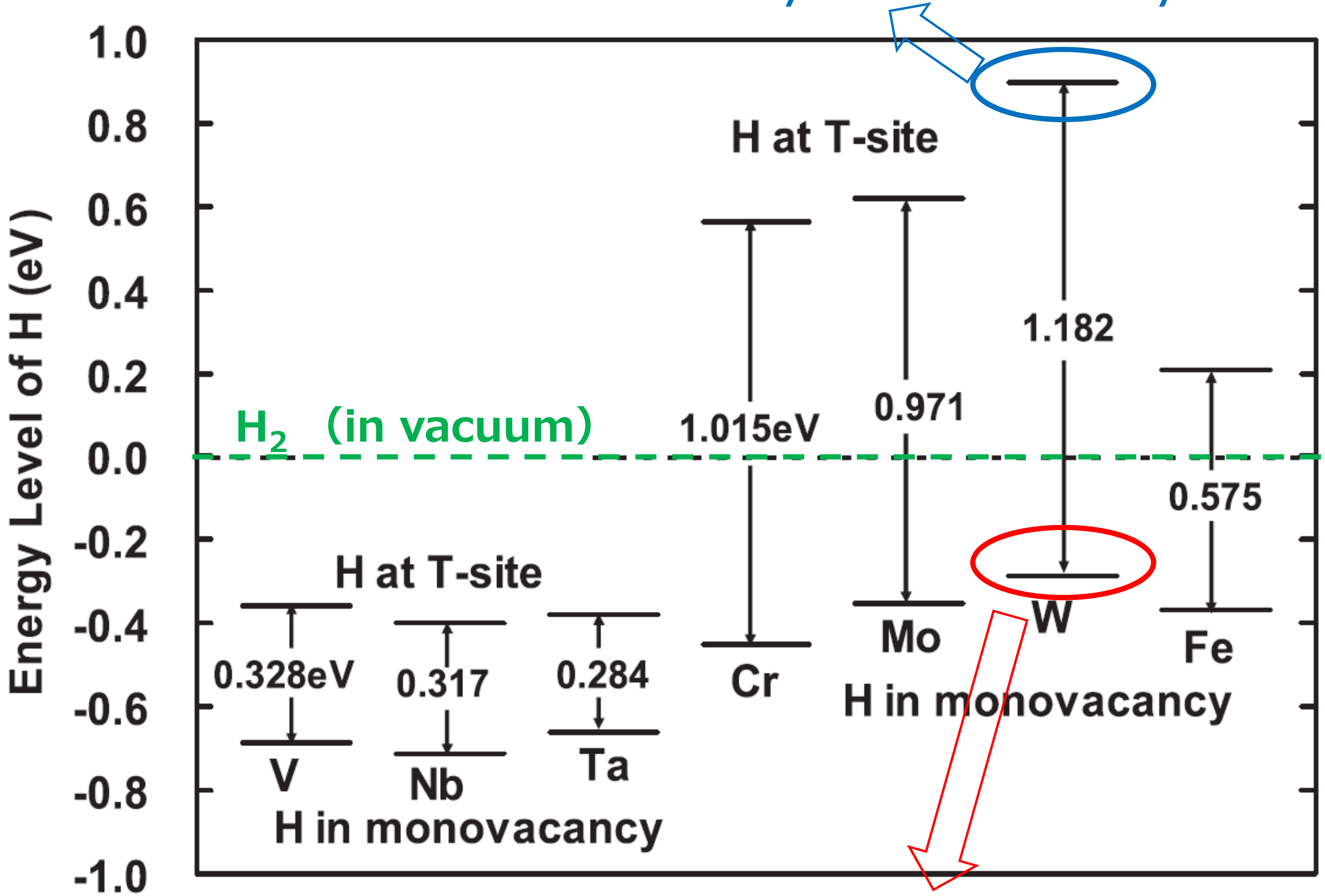
Hydrogen retention is almost zero due to the very low solubility of hydrogen in W ($D/W \sim 10^{-12}$ @300°C).

Hydrogen trapping at irradiation-induced defects is suggested.

In this study, we show hydrogen trapping at irradiation-induced defects by using positron annihilation spectroscopy.

Why does hydrogen retention increase after irradiation?

Very low solubility limit in bulk

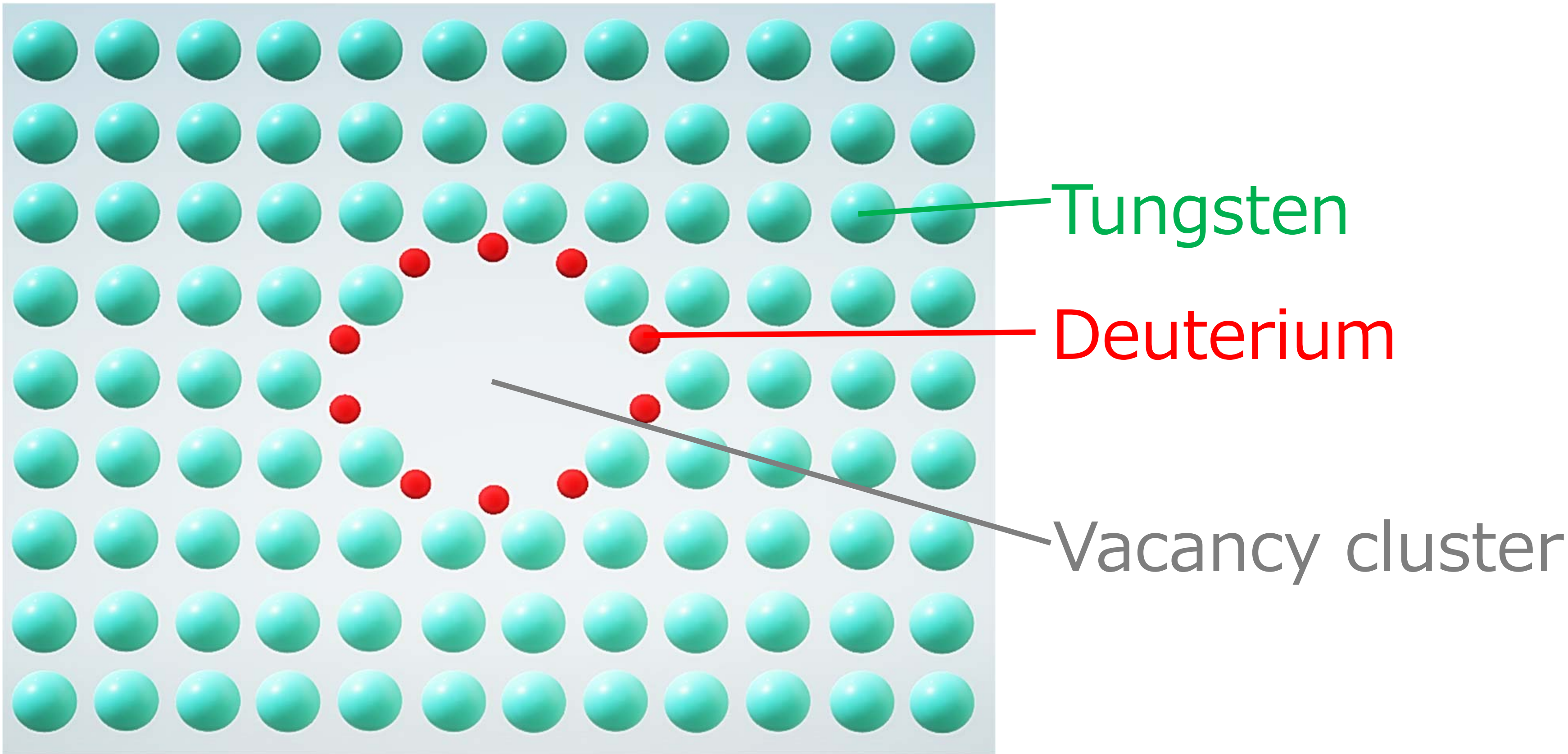


K. Ohsawa et al., Phys. Rev. B 85 (2012) 094102.

Strong trapping at vacancy is suggested.

Purpose of this study

To observe deuterium trapping at vacancy clusters by positron annihilation spectroscopy.



Pure tungsten (4N)
ϕ6×0.5 mm disk → 900 ℃×1h → 1300 ℃×0.5h (re-crystallization)

Neutron irradiation

HFIR @ORNL

$8x10^{20}$ n/cm^2 (~0.3 dpa)

~300 ℃ × 48 days

Heat treatment process

In D_2 gas atmosphere (~ 0.1 MPa)

or

In vacuum (~10^{-4} Pa)

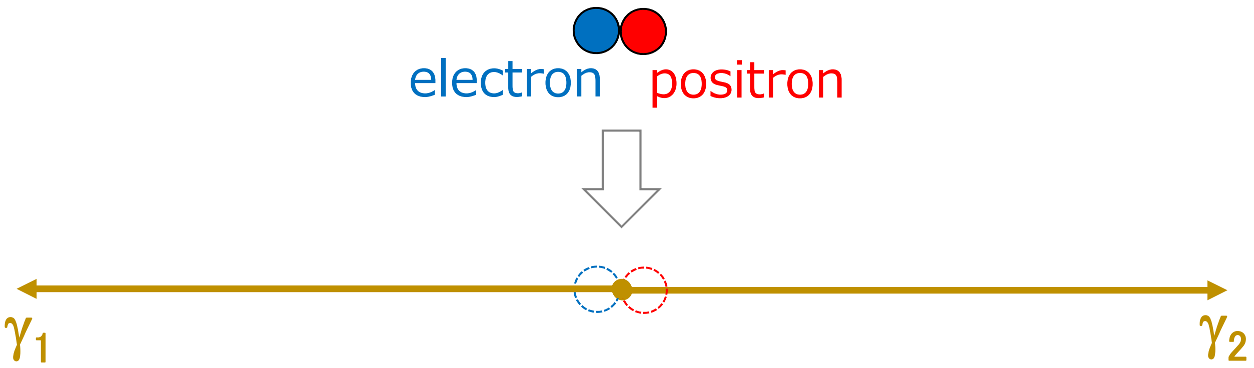
300 ℃ × 100 h

Diffusion length of deuterium in bulk : ~0.3 mm

5 Specimens

	Annealing in D_2	Neutron irradiation	Annealing in vacuum	Annealing in D_2
As-prepared	-	-	-	-
As-prepared → Annealed in D_2	✓	-	-	-
As-irrad.	-	✓	-	-
Irrad. → Annealed in vacuum		✓	✓	-
Irrad. → Annealed in D_2		✓	-	✓

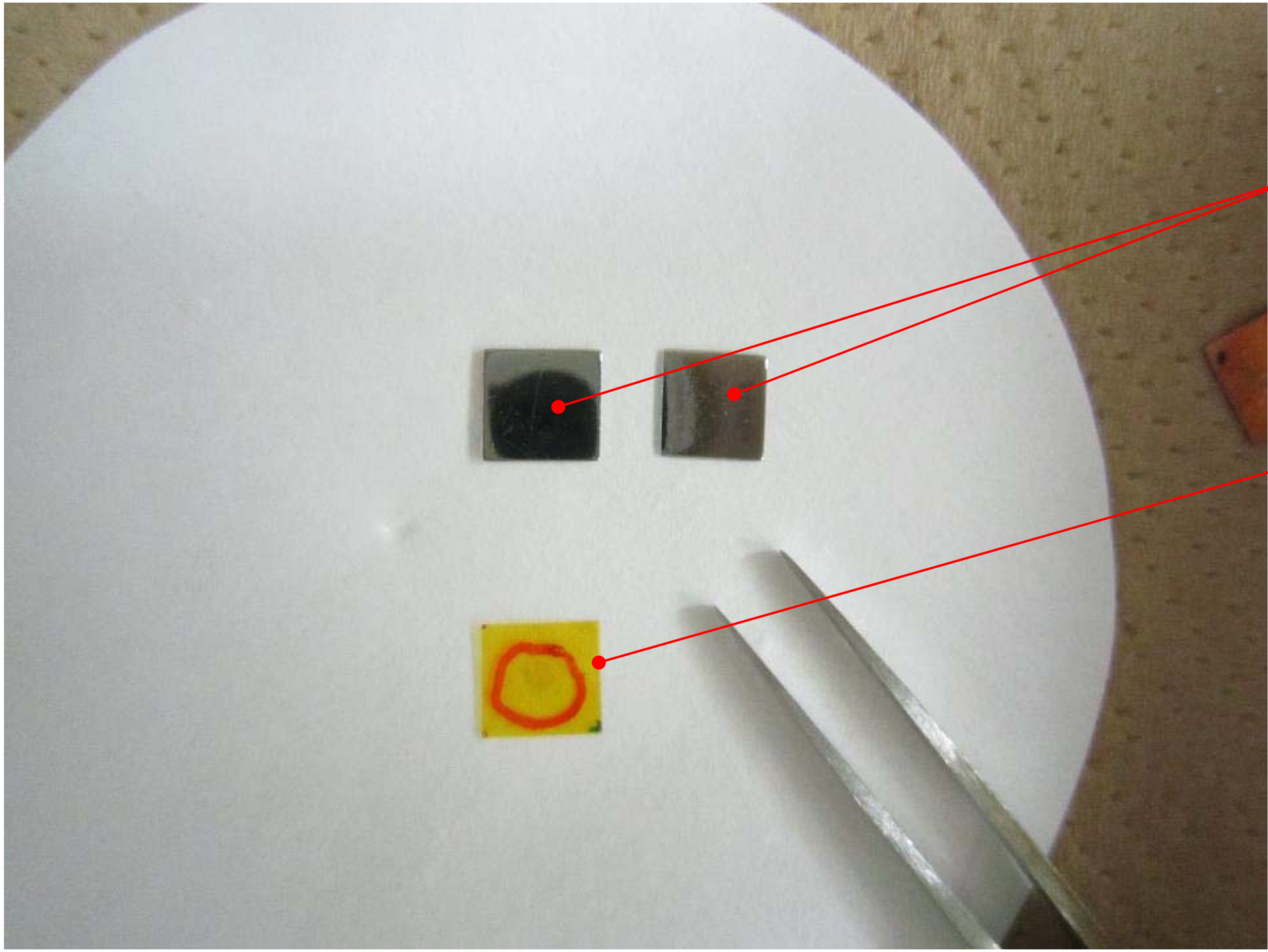
Positron annihilation spectroscopy



$E_1 = mc^2 = 511\ keV$

$E_2 = mc^2 = 511\ keV$

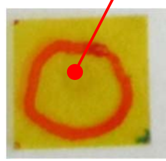
Positron annihilation spectroscopy; samples and source



Identical samples. ~10x10x0.5mm.

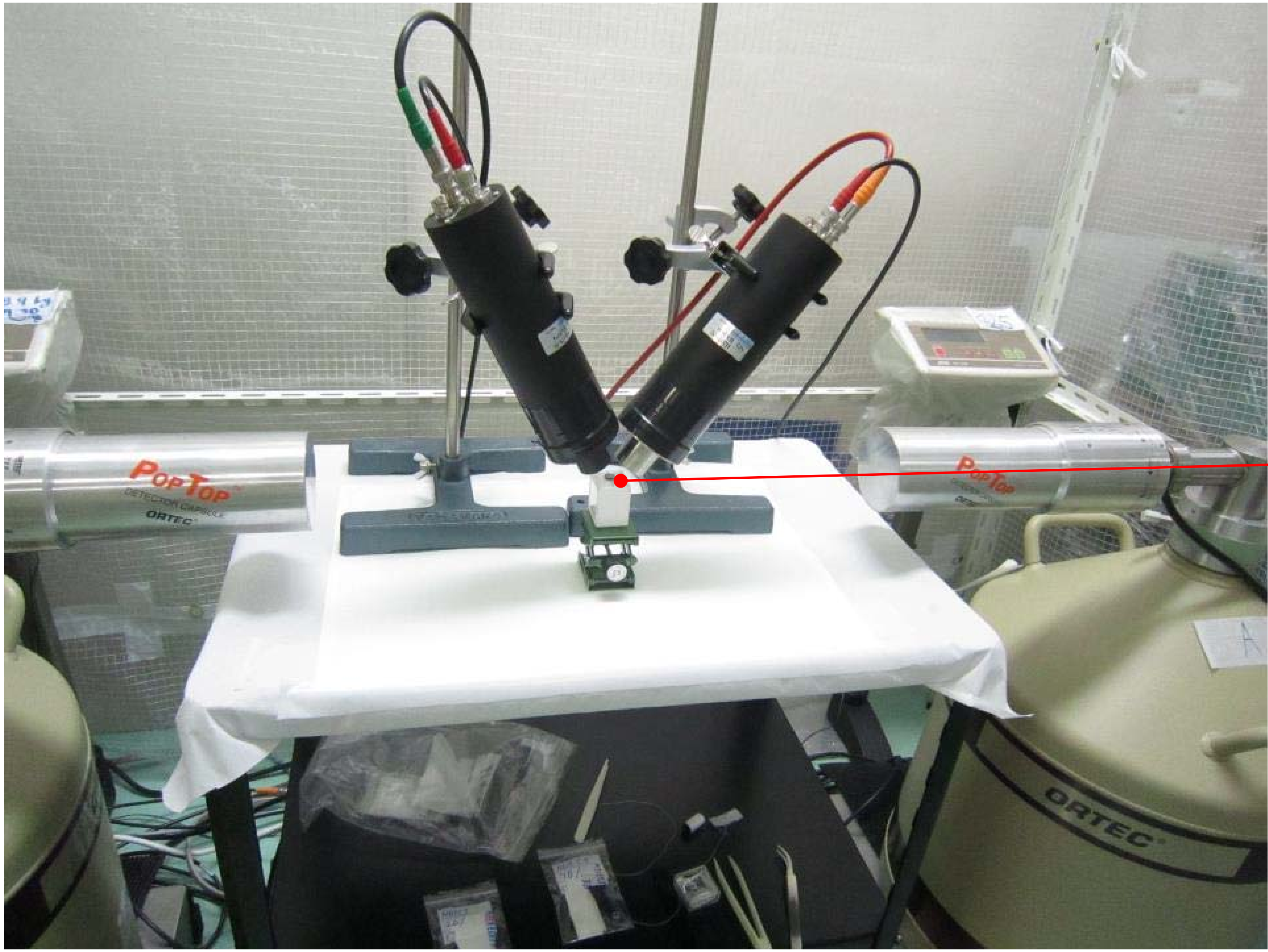
Positron source. $^{22}NaCl$ are sealed by Kapton film.

$^{22}NaCl$ (2-3mm in diameter)



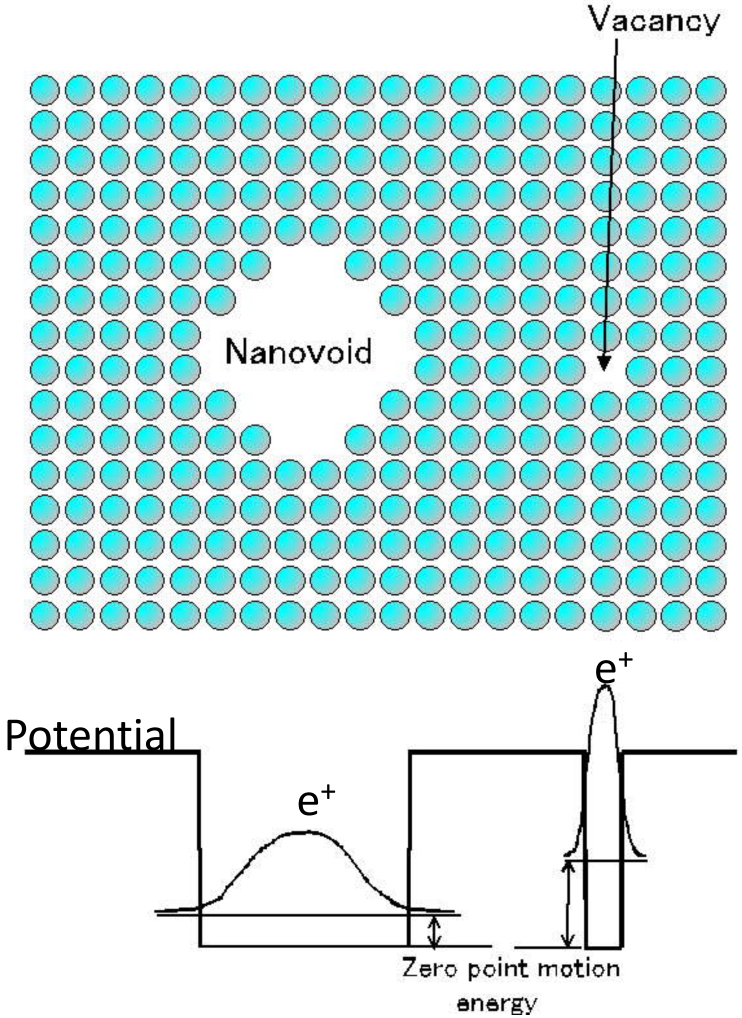
~ 10mm

Positron annihilation spectroscopy; detectors

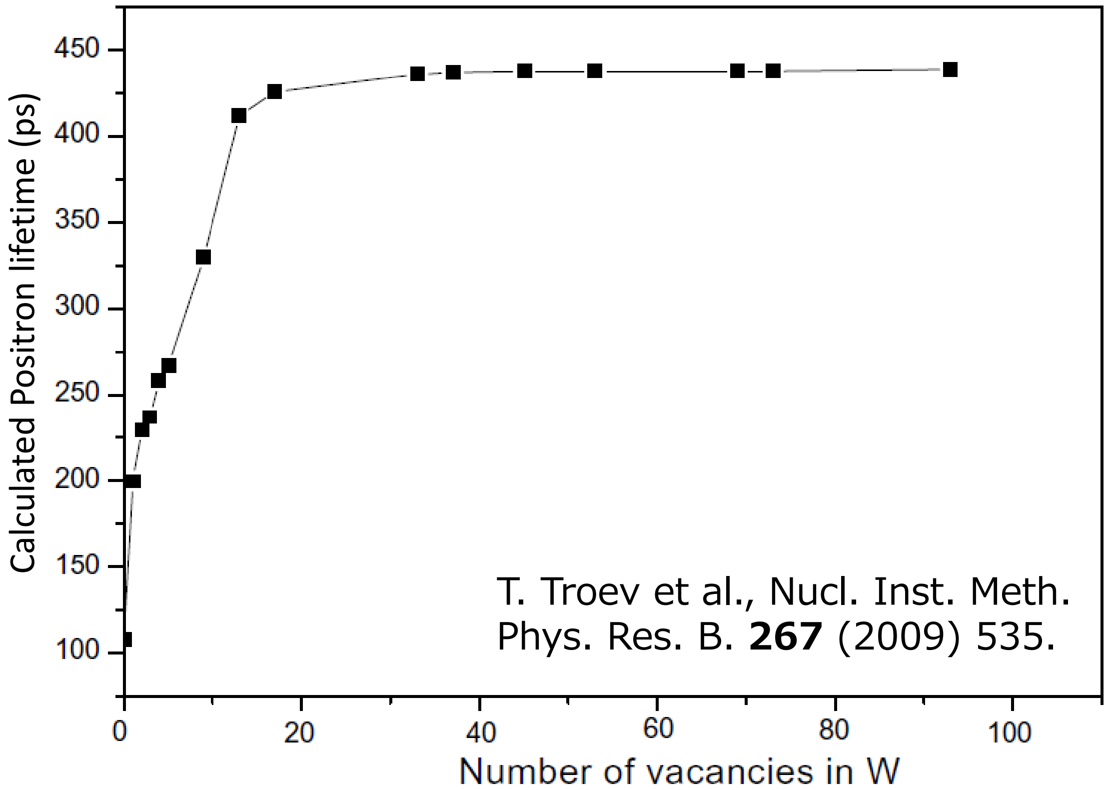


Positron source sandwiched by 2 samples.

Positron annihilation spectroscopy; lifetime

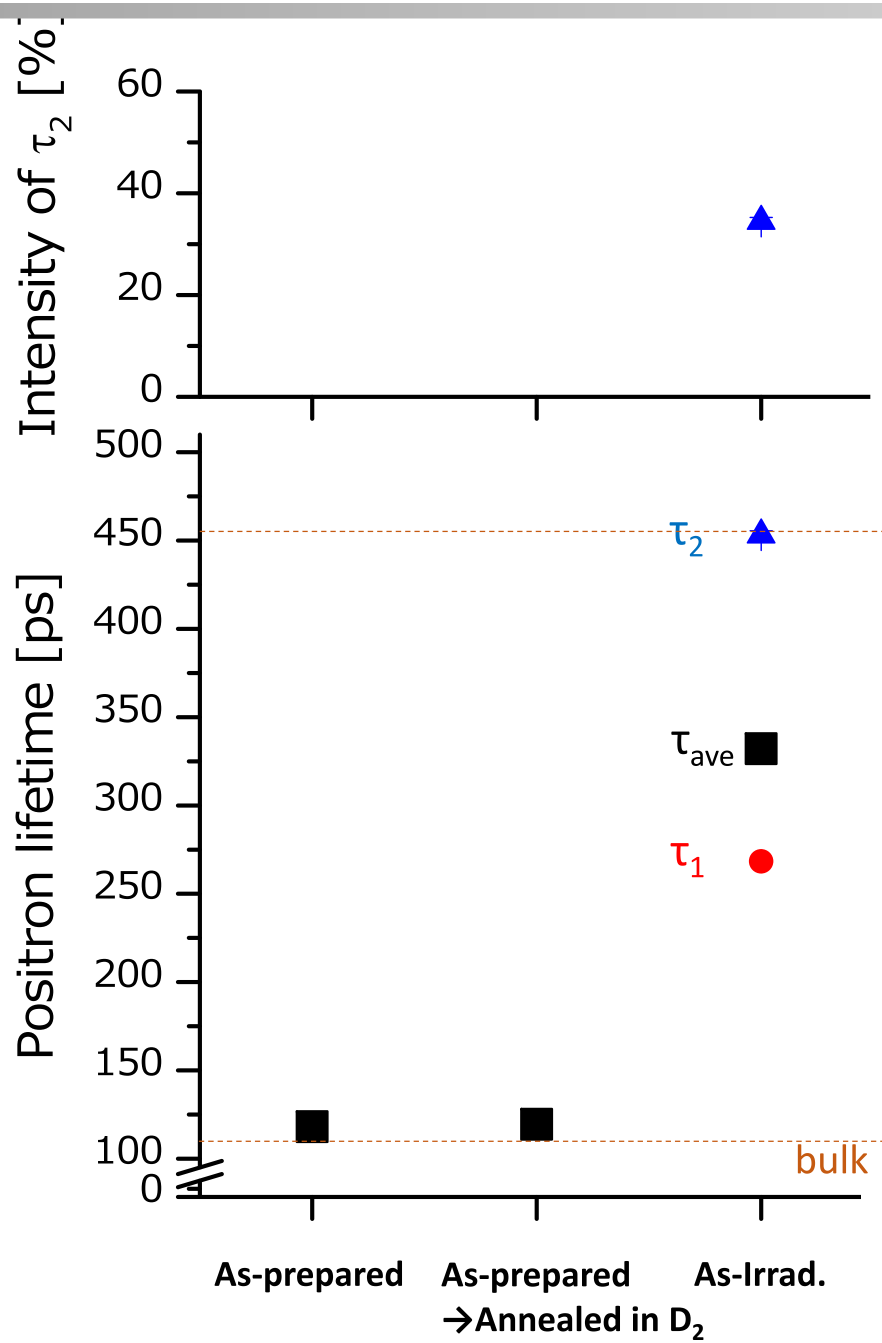


Calculated positron lifetime in Tungsten



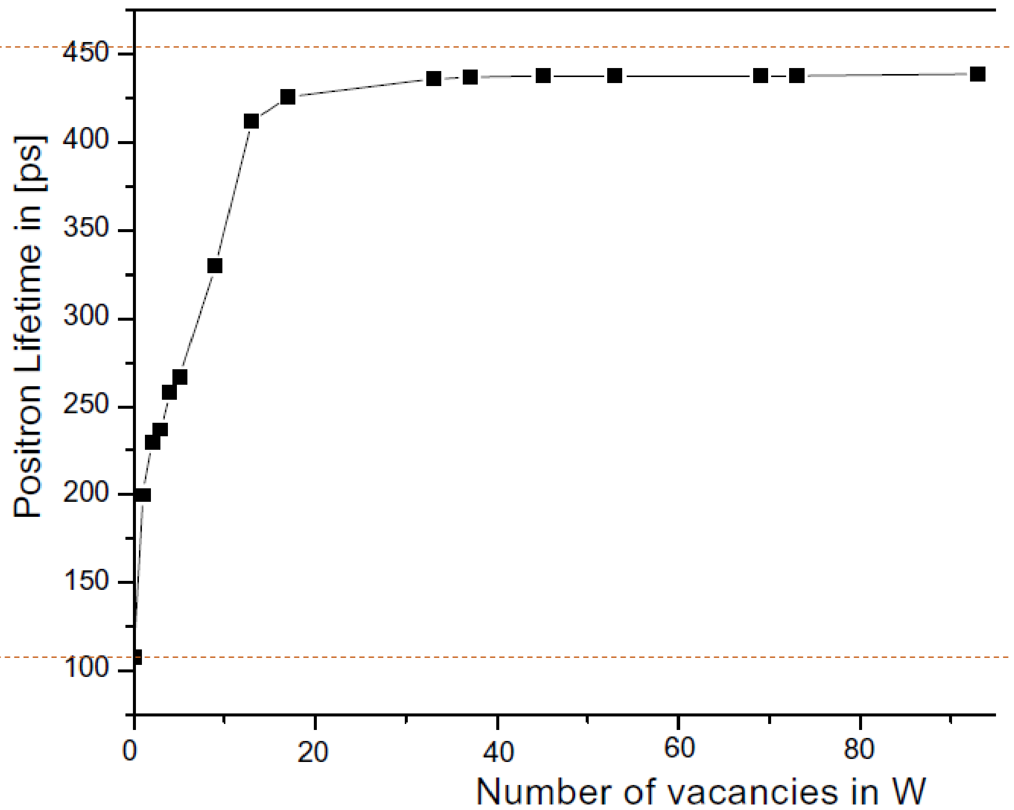
Positron lifetime, $\tau = \left[\int dr\, n_{electron}(r) n_{positron}(r) g(r) \right]^{-1}$

Positron lifetime

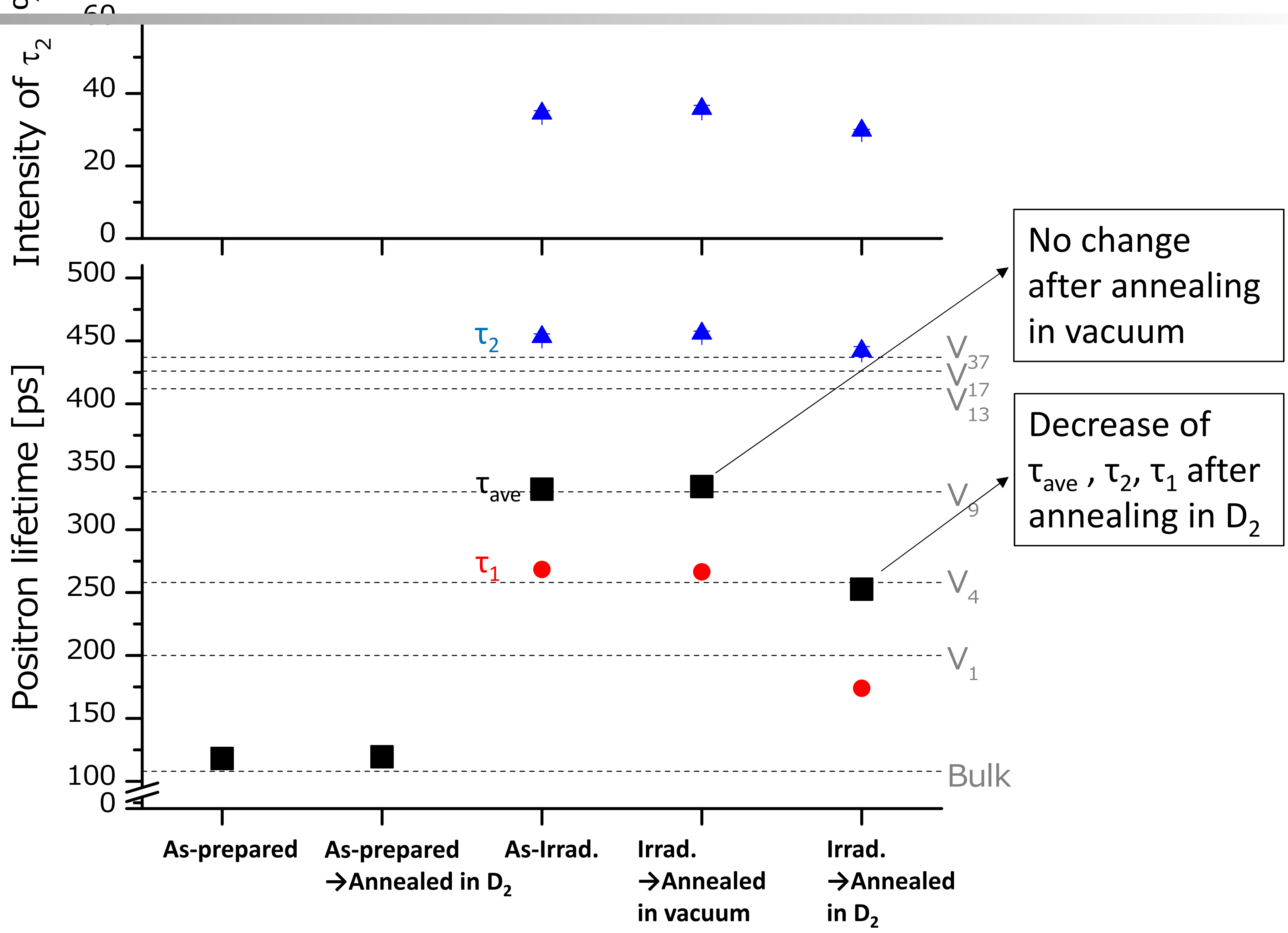


Calculated positron lifetime value in vacancy cluster in tungsten

T. Troev et al.,
Nucl. Inst. Meth. Phys. Res. B. **267** (2009) 535.

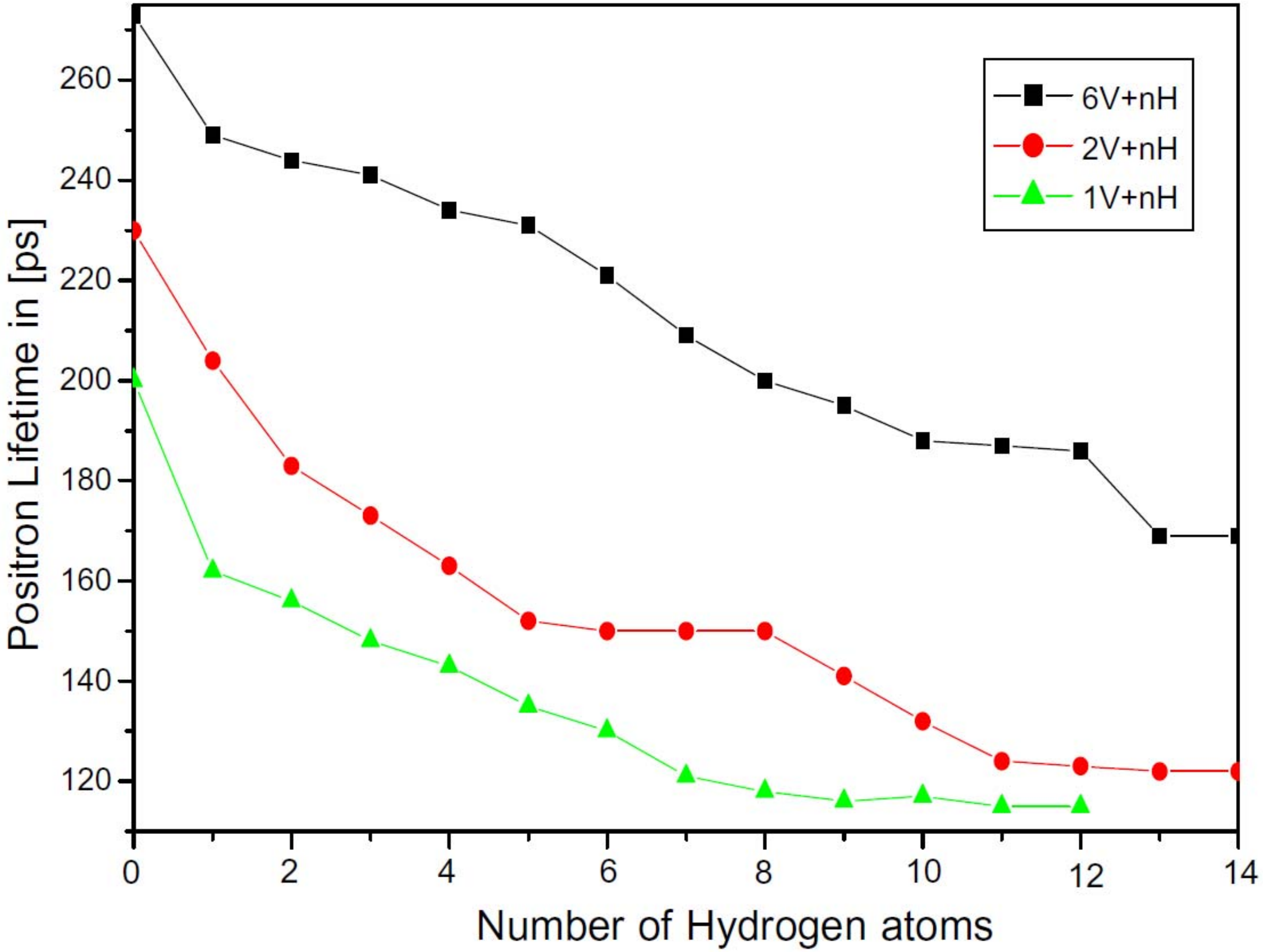


Positron lifetime



Decrease of positron lifetime : due to deuterium trapping at vacancy clusters?

Hydrogen trapping effect on positron lifetime in vacancy clusters in tungsten



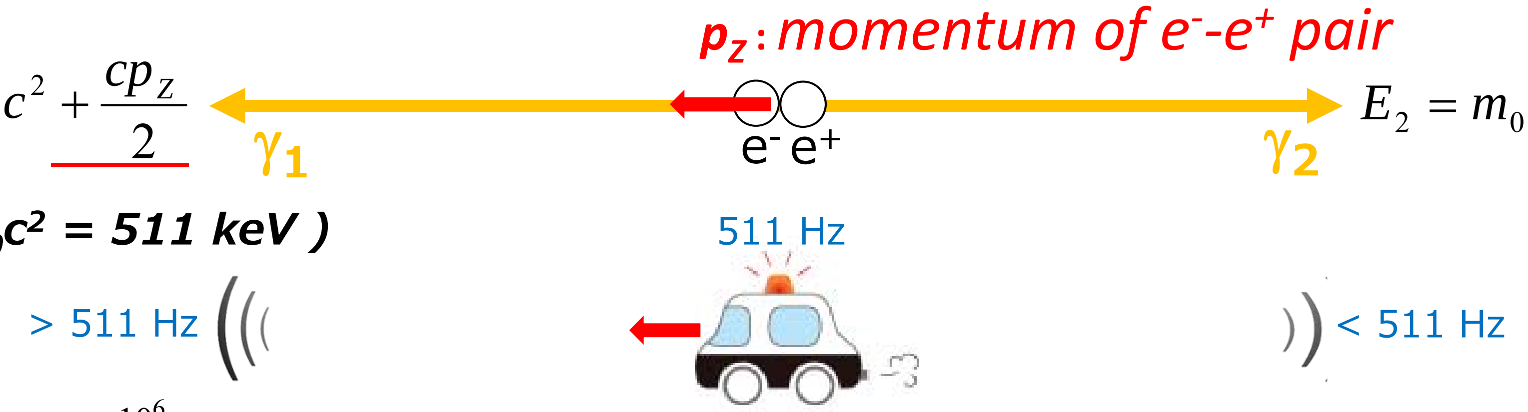
T. Troev et al., Nucl. Inst. Meth. Phys. Res. B. **267** (2009) 535.

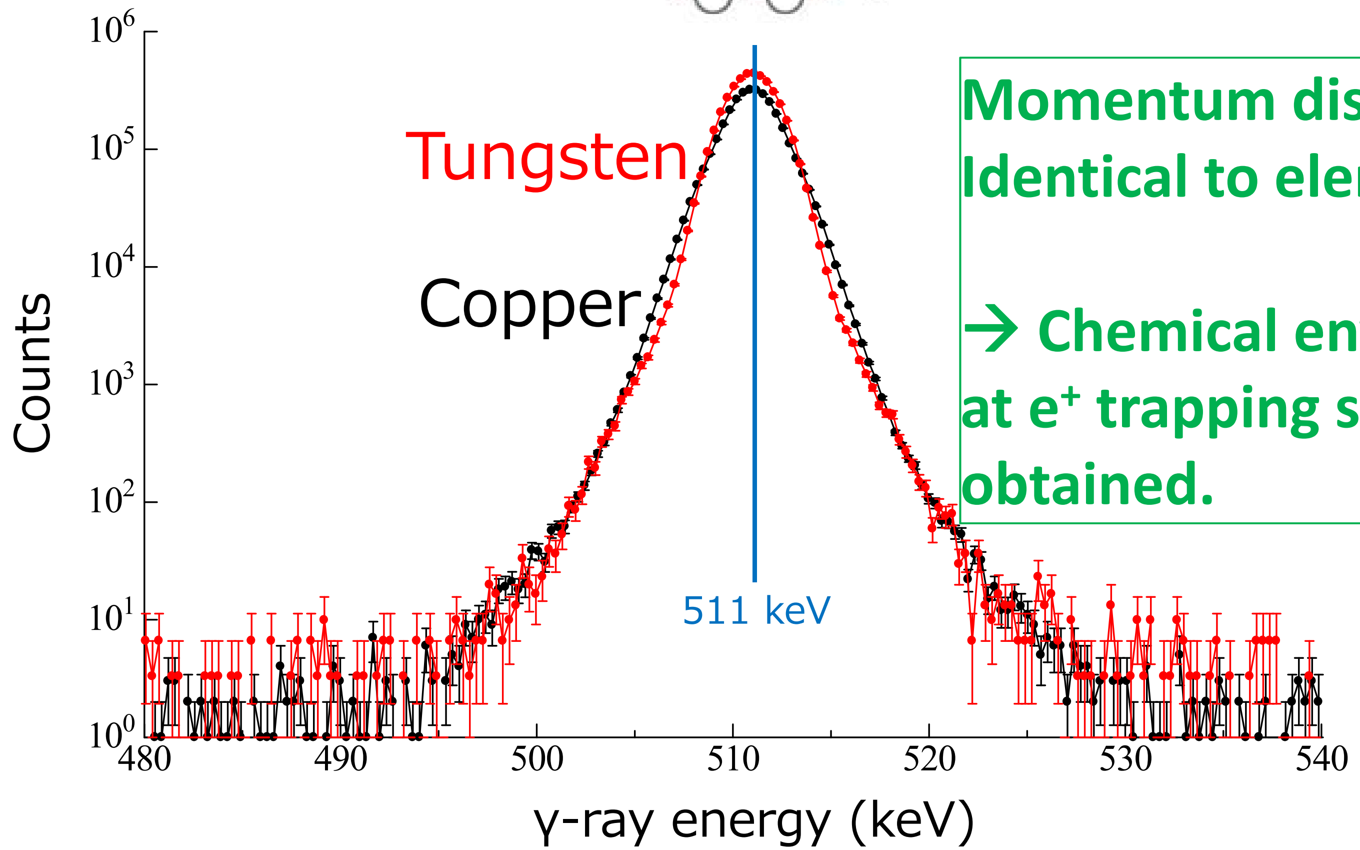
Measurement of *momentum of e^--e^+ pair* by Doppler effect

$$E_1 = m_0c^2 + \frac{cp_Z}{2}$$

$$E_2 = m_0c^2 - \frac{cp_Z}{2}$$

(m_0c^2 = 511 keV)

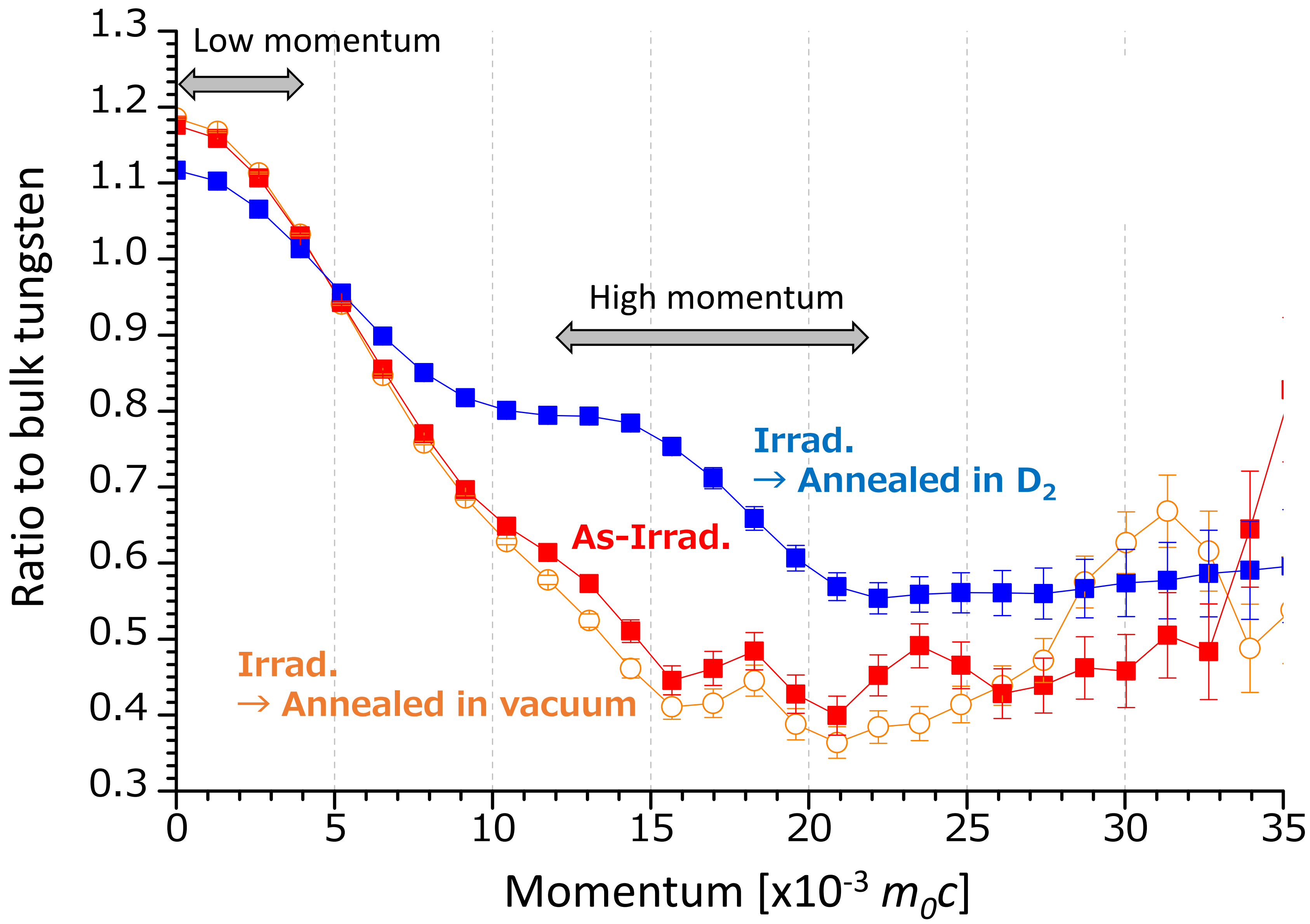




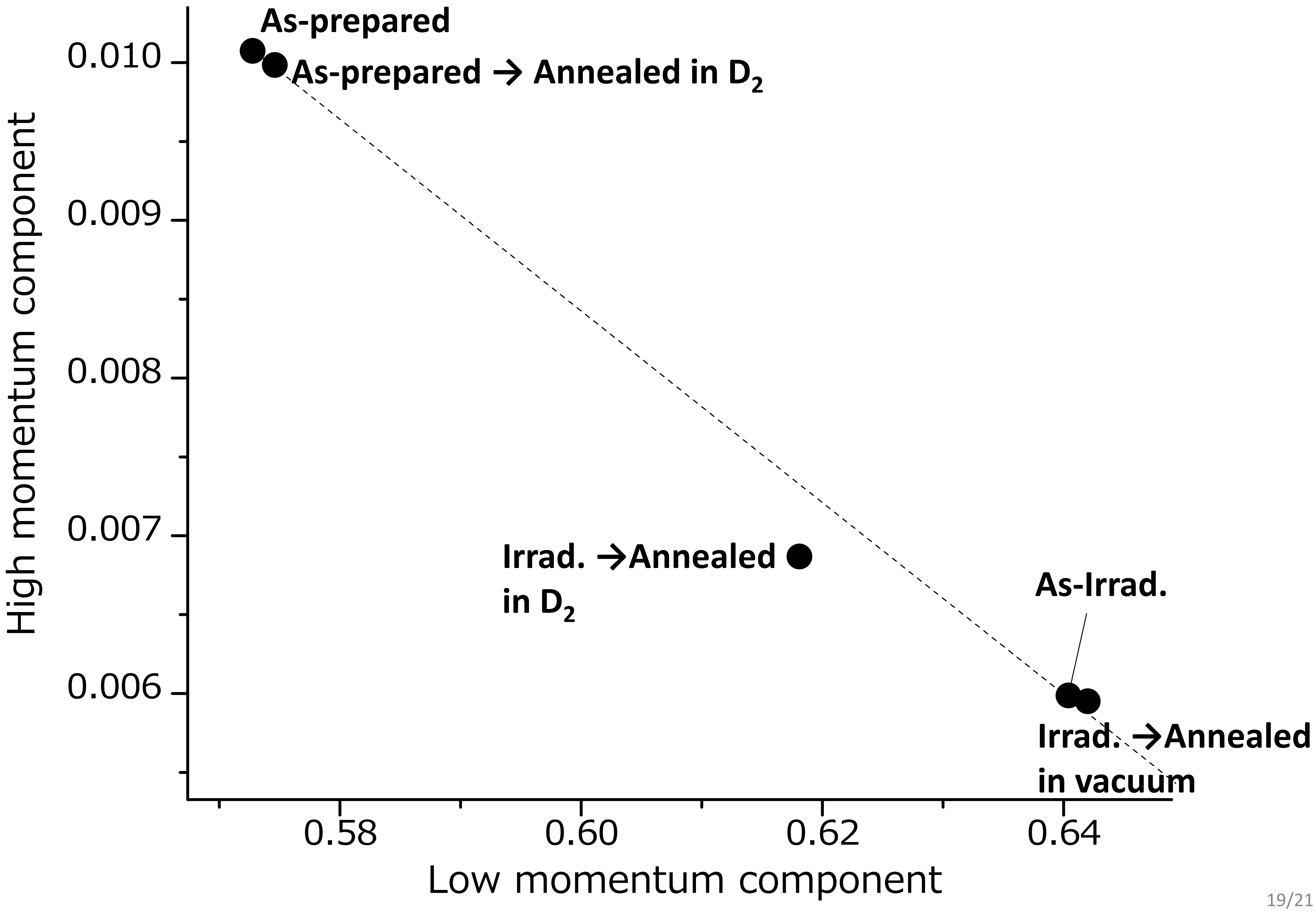
Momentum distribution : Identical to element.

→ Chemical environment at e^+ trapping sites is obtained.

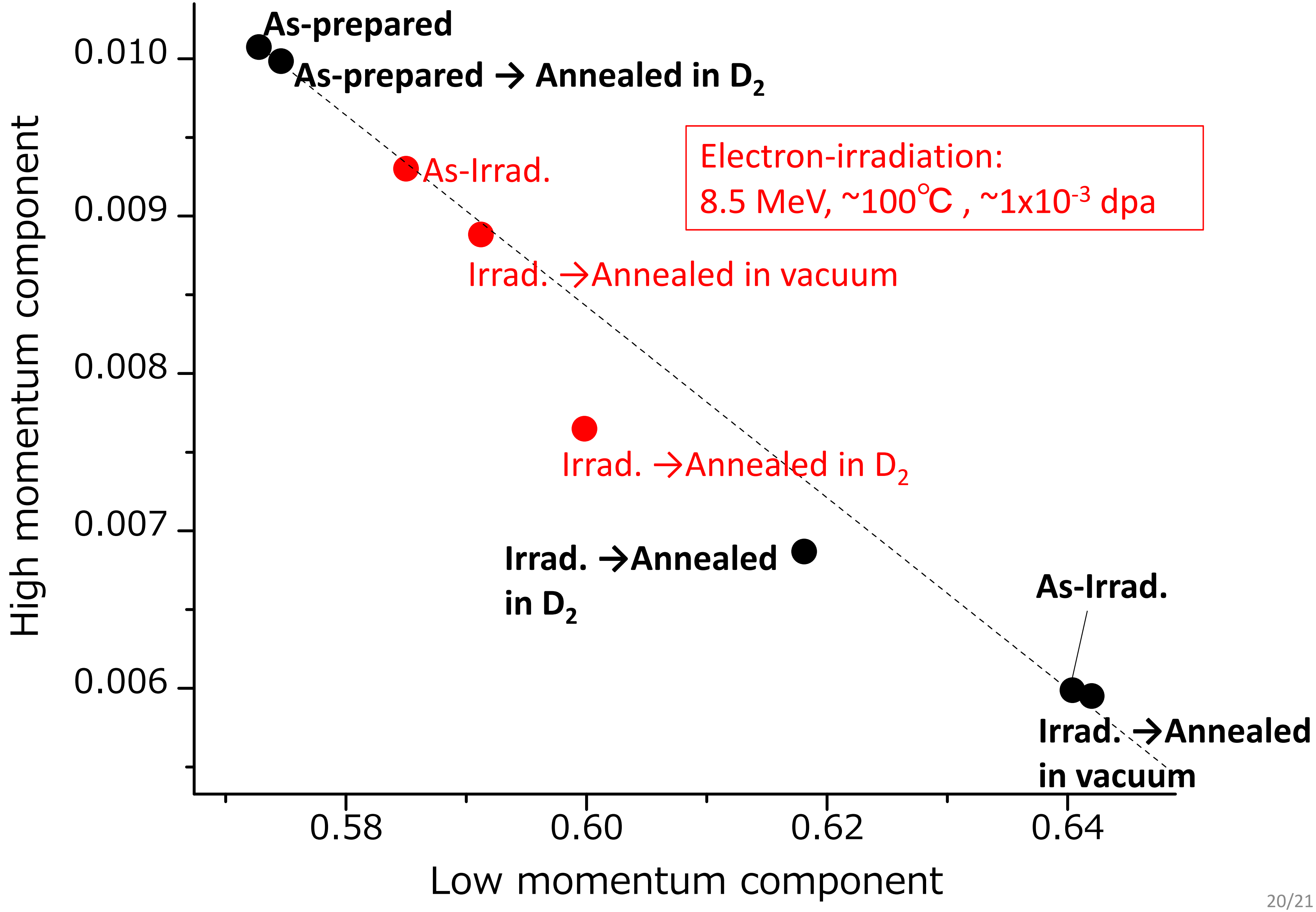
Coincidence Doppler broadening measurement



Correlation of Low- & High- momentum



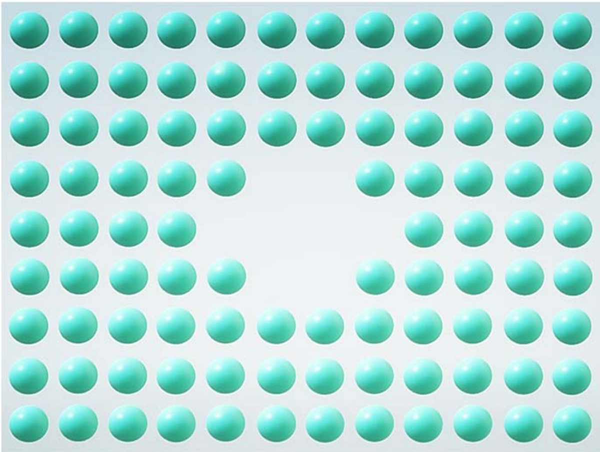
Correlation of Low- & High- momentum



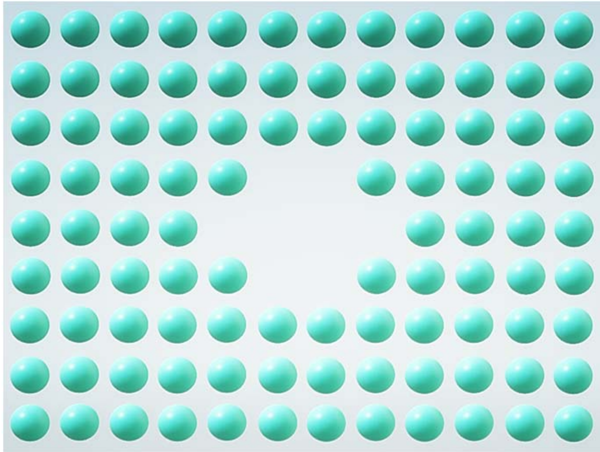
Summary

Pure tungsten was neutron-irradiated (~300 ℃ × 48 days), then annealed in vacuum or deuterium gas (300 ℃ × 100 h)

As-Irrad.

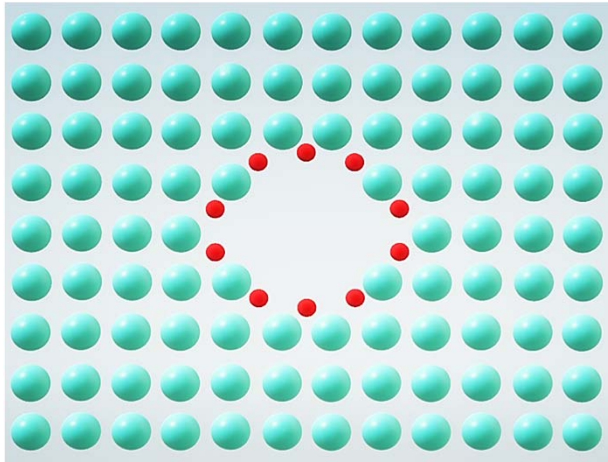


Annealed in *vacuum*



No change of vacancy cluster

Annealed in D_2 *gas*



Deuterium is inside vacancy cluster

Deuterium trapping at irradiation-induced defects was successfully observed.

T. Toyama et al., J. Nucl. Mater., 499 (2018) 464.