RaDIATE Collaboration Meeting

NBI2017+RaDIATE

September 22, 2017

Session: Low Energy Ion Beam Facilities & PIE Activities in Japan

Ion Beam Facilities in Japan (TIARA/DuET/HIT)

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R a D I A T E

4th Collaboration Meeting in IVIL of Tokai-mura, Japan
during 20-22th Sep. 2017

JAEA

J-PARC

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2. Introduction of Ion Beam Facilities in Japan (TIARA/DuET/HIT)

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RaDIATE Collaboration Meeting

1. Research Background

■ **Merit of Low Energy Multiple-Ion Beam Experiment:**

(1) Higher dpa rate (about 5 dpa/h)

(2) No radioactivity

(3) Relatively low cost operation

(4) He/dpa and H/dpa can be controlled for the purpose

1. Research Background

■ **Irradiation hardening can be estimated from microstructural analysis.**

Tensile Properties

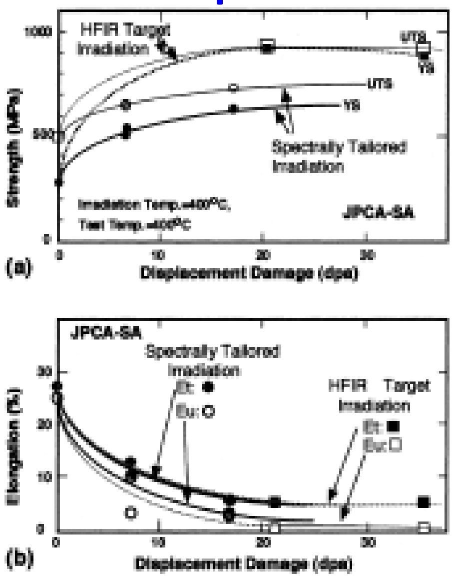


Fig. 1. (a) Yield and ultimate tensile strengths and (b) uniform and total elongations as a function of displacement damage for JPCA-SA steels irradiated at 400°C in the ST ORR/HFIR and the HFIR target capsules.

TEM images

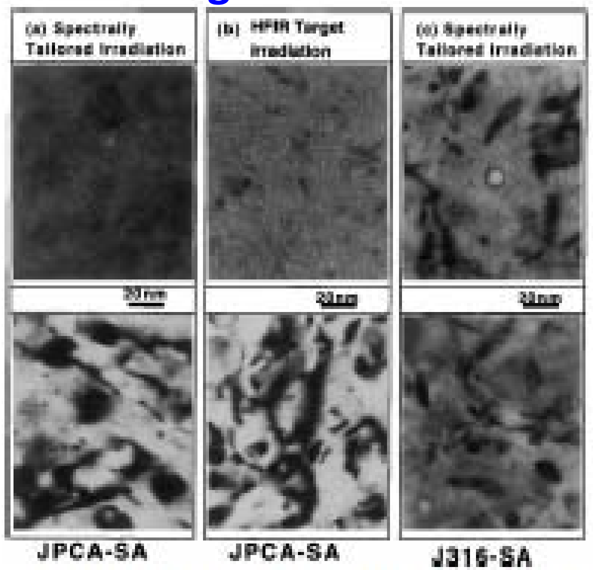


Fig. 2. Microstructures formed at 400°C in: (a) JPCA-SA, (b) J316-SA steels irradiated in the ST ORR/HFIR capsules, and (c) JPCA-SA steel irradiated in the HFIR target capsule.

Radiation hardening estimated from Microstructures

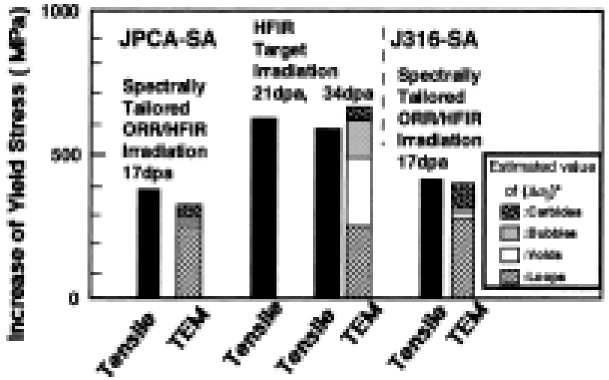


Fig. 3. Comparison of increase of yield strength obtained from tensile tests and the values evaluated from the microstructures in the JPCA-SA and J316-SA steels irradiated at 400°C in the ST ORR/HFIR and the HFIR target capsules.

$$\Delta\sigma_i = M\alpha\mu b(N_i d_i)^{1/2},$$

$$(\Delta\sigma_{loop})^* = (\Delta\sigma_{loop})^2/\Delta\sigma_{YS}.$$

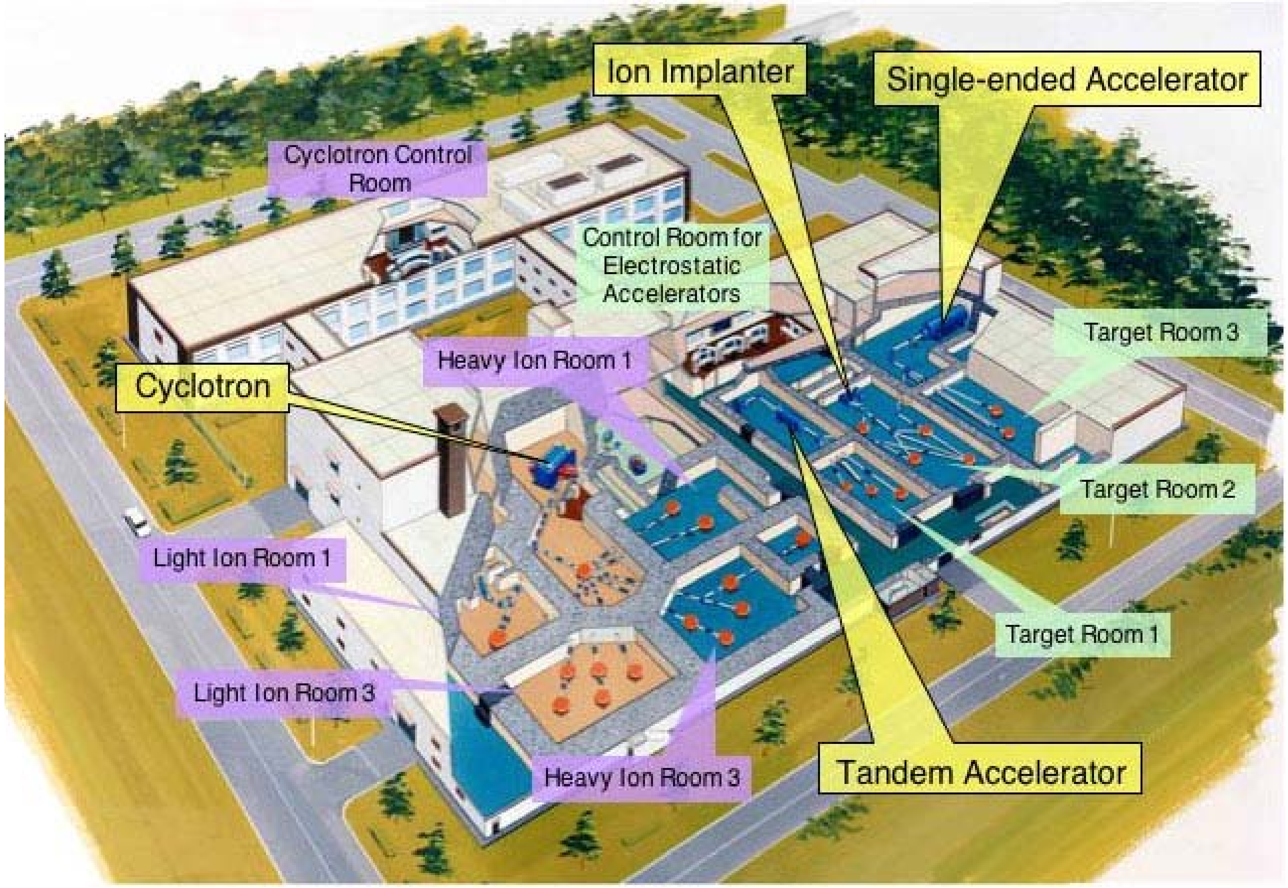
E. Wakai, et al.,

Journal of Nuclear Materials 283–287 (2000) 435–439

2. Introduction of Ion Beam Facilities in Japan(TIARA/DuET/HIT)

■ **Triple Ion Irradiation Facility of JAEA (QST at present)**

Takasaki city, Gunma-prefecture, Japan

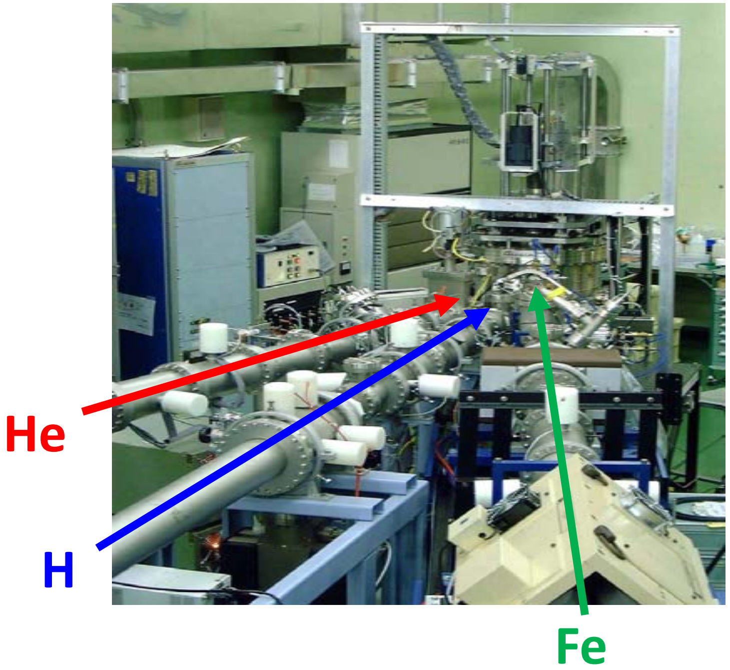


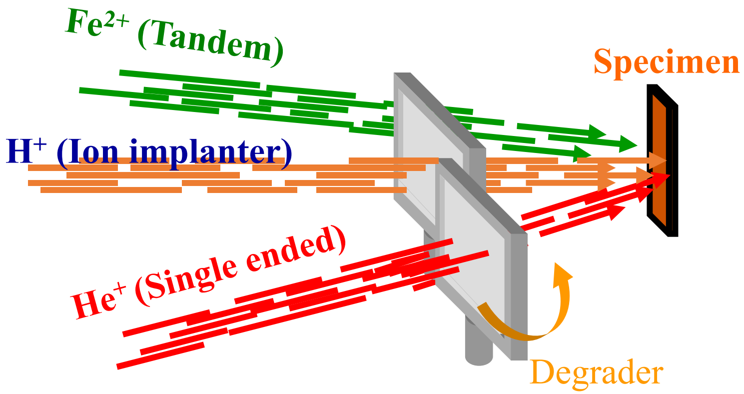
４種類の加速器で得られる主なビーム性能

加速器	加速粒子	エネルギー (MeV)	加速器の特徴
サイクロトロン	陽子	5～90	AVF型 (Azimuthaly Varying Field) K値110
	ヘリウム	10～110	
	アルゴン	94～990	
	クリプトン	200～1030	
	キセノン	300～930	
	金	440～460	
タンデム加速器	陽子	0.8～6	ターミナル電圧 0.4～3 MV
	炭素	0.8～18	
	ニッケル	0.8～18	
	金	0.8～21	
シングルエンド加速器	陽子	0.4～3	ターミナル電圧 0.4～3 MV
	重陽子	0.4～3	
	ヘリウム	0.4～3	
	電子	0.4～3	
イオン注入装置	陽子	0.02～0.4	ターミナル電圧 10～400 kV
	アルゴン	0.02～1.2	
	銀	0.02～1.2	

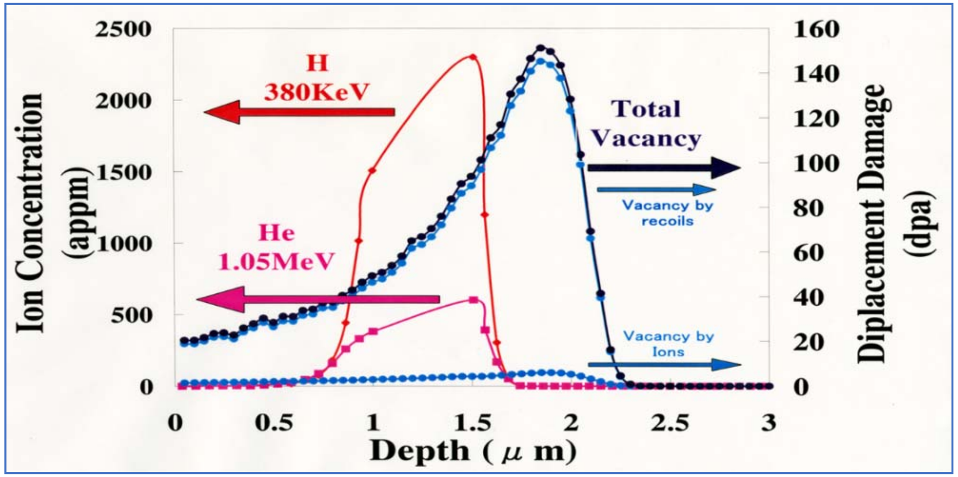
2. Introduction of Ion Beam Facilities in Japan(TIARA/DuET/HIT)

■ Triple Ion Irradiation Facility of JAEA (QST at present)



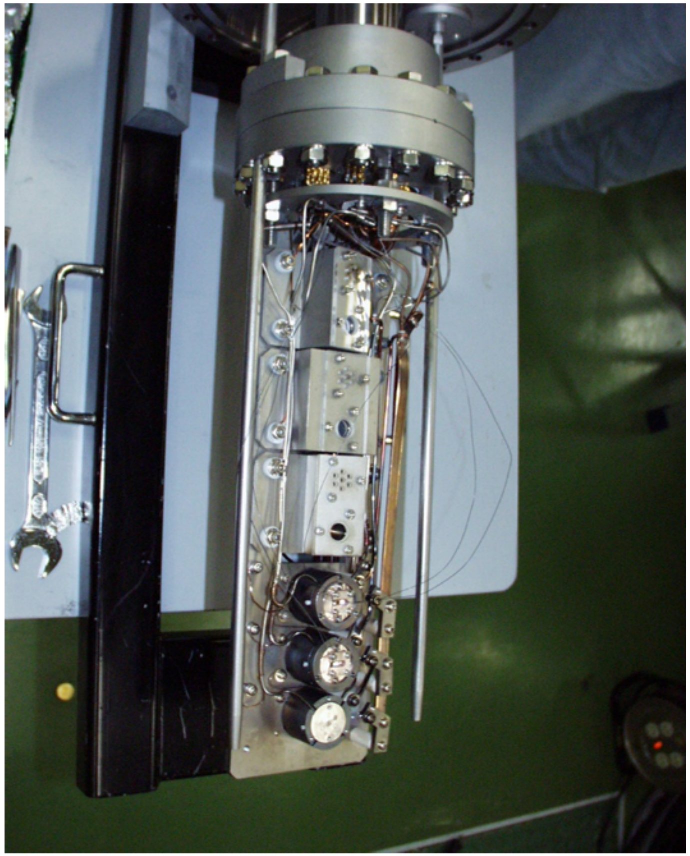


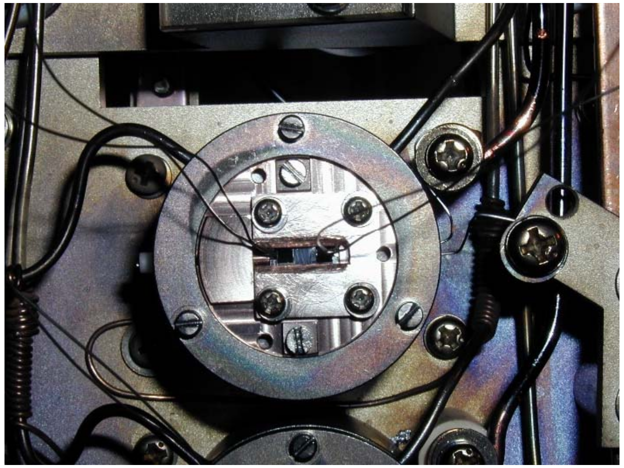
10.5 MeV Fe^{2+}, 1.05 MeV-He^{+}, 0.38 MeV-H^{+}

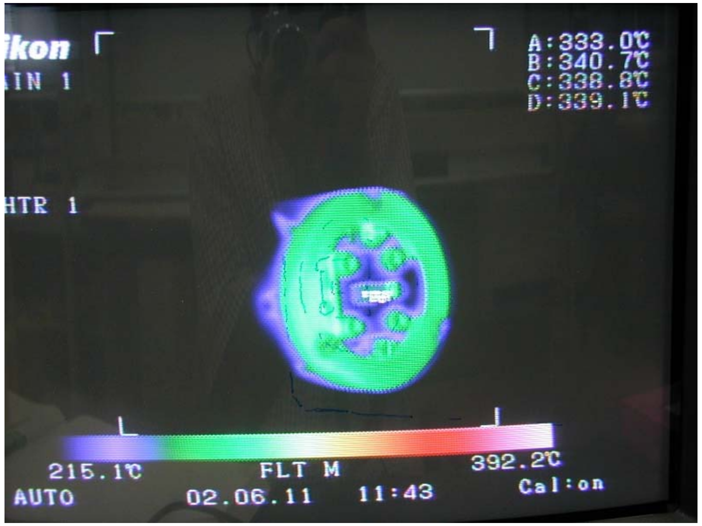


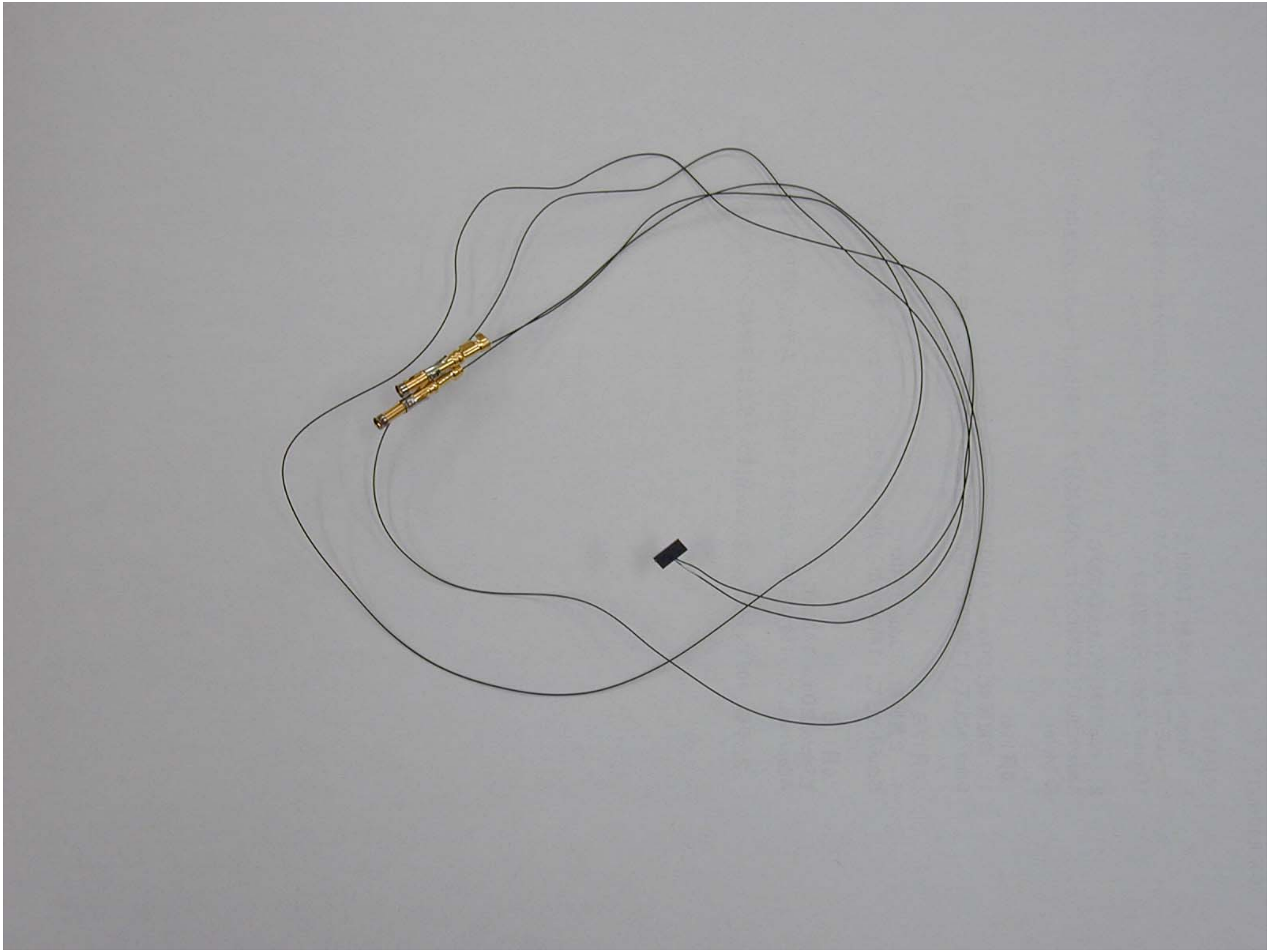
2. Introduction of Ion Beam Facilities in Japan(TIARA/DuET/HIT)

- **Triple Ion Irradiation Facility of JAEA (QST at present)**









2. Introduction of Ion Beam Facilities in Japan(TIARA/DuET/HIT)

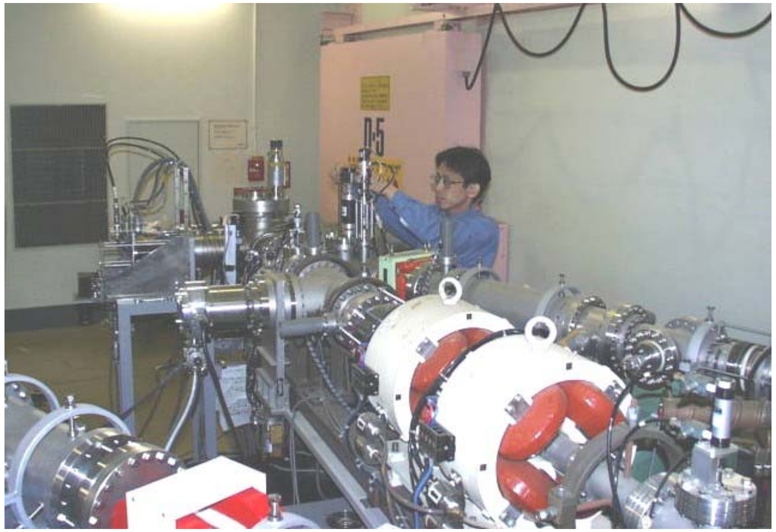
DuET Facility of Kyoto Univ.

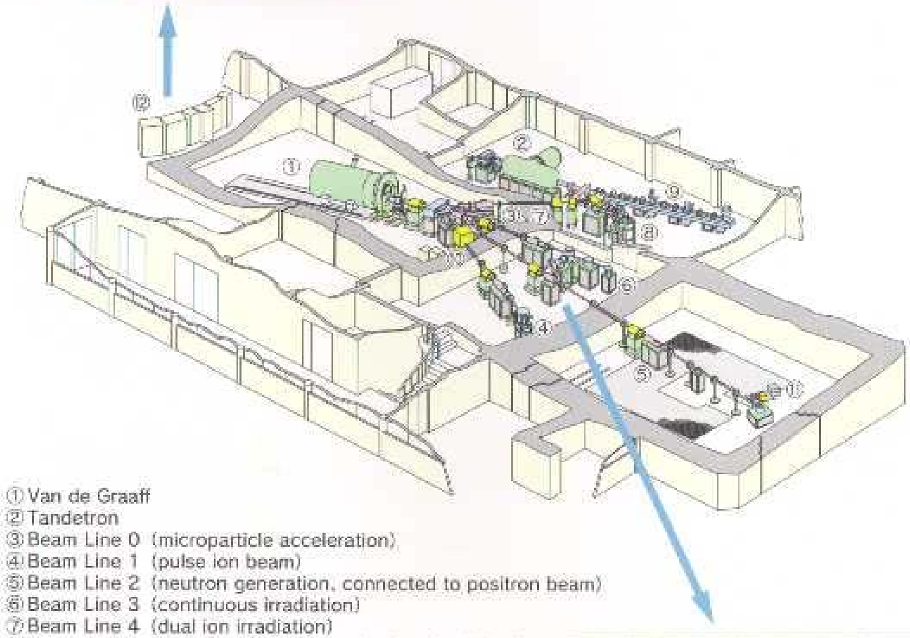
Two beam lines such as Fe ion beam and He ion beam

2. Introduction of Ion Beam Facilities in Japan(TIARA/DuET/HIT)

■ HIT Facility of Univ. of Tokyo (Tokai-mura, Ibaraki)

Features of HIT
1. Dual ion beam irradiation using two accelerators
2. Spatially leveled high flux irradiation by beam scanner
3. Pulse ion beam
4. Heavy ion microbeam of ~1 μ m in diameter
5. Microparticle acceleration to hypervelocity

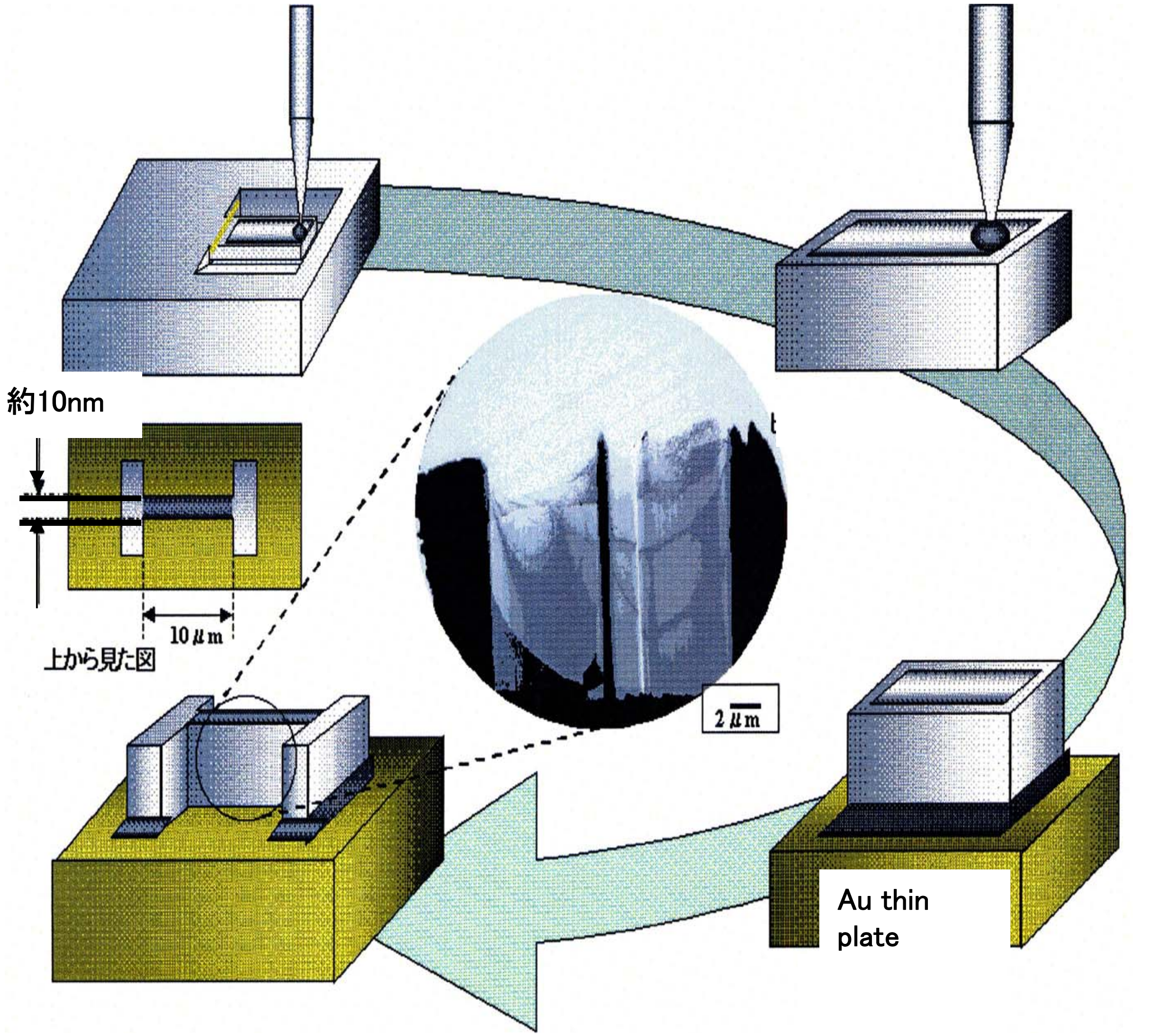




① Van de Graaff
② Tandetron
③ Beam Line 0 (microparticle acceleration)
④ Beam Line 1 (pulse ion beam)
⑤ Beam Line 2 (neutron generation, connected to positron beam)
⑥ Beam Line 3 (continuous irradiation)
⑦ Beam Line 4 (dual ion irradiation)
⑧ Beam Line 5 (heavy ion irradiation, dual ion irradiation)
⑨ Beam Line 6 (microbeam)
⑩ Pulse beam generator
⑪ Positron beam connected to Beam Line 2
⑫ Control room

3. Some Results

TEM Specimen prepared by Focused Ion Beam



3. Some Results

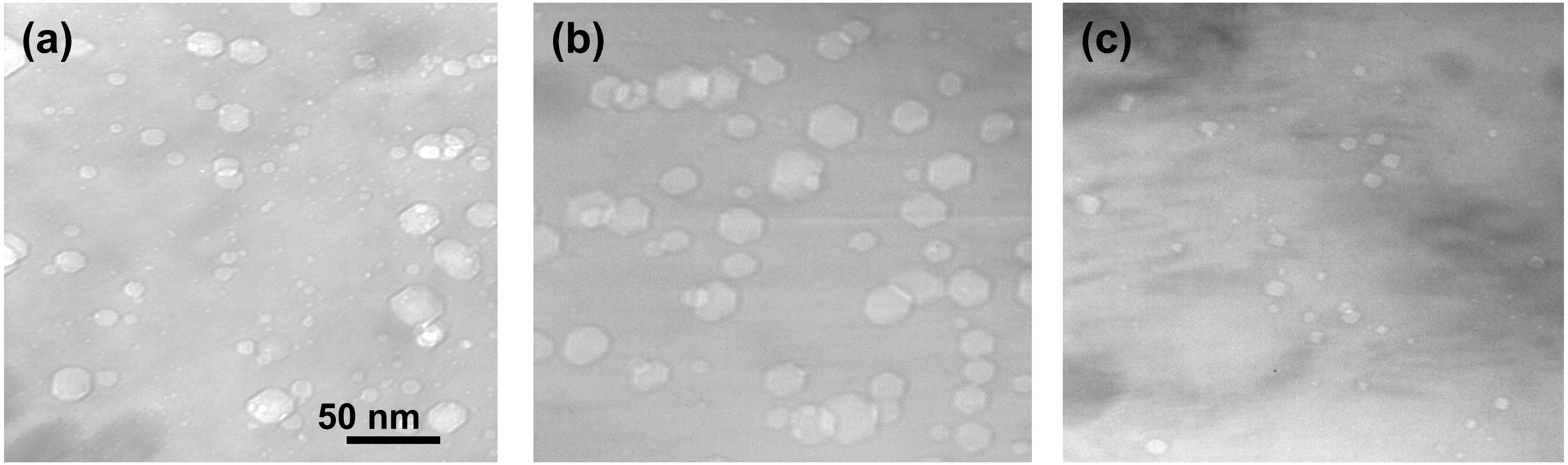
Swelling of F82H under Dual or Triple Ion Irradiation

(10.5 MeV Fe2+, 1.05 MeV-He+, 0.38 MeV-H+)

Triple beams (100 appm-He/dpa, 500 appmH/dpa)

Triple beams (10 appm-He/dpa, 40 appm-H/dpa)

Dual beams (10 appm-He/dpa)



1.2%	3.2%	0.08%

Cavities formed in F82H irradiated at **470°C to 50dpa** at the depth of around 1 μm.

E. Wakai, et al., "Effect of triple ion beams in ferritic/martensitic steel on swelling behavior", Journal of Nuclear Materials 307-311 (2002), pp.278-282.

3. Some Results

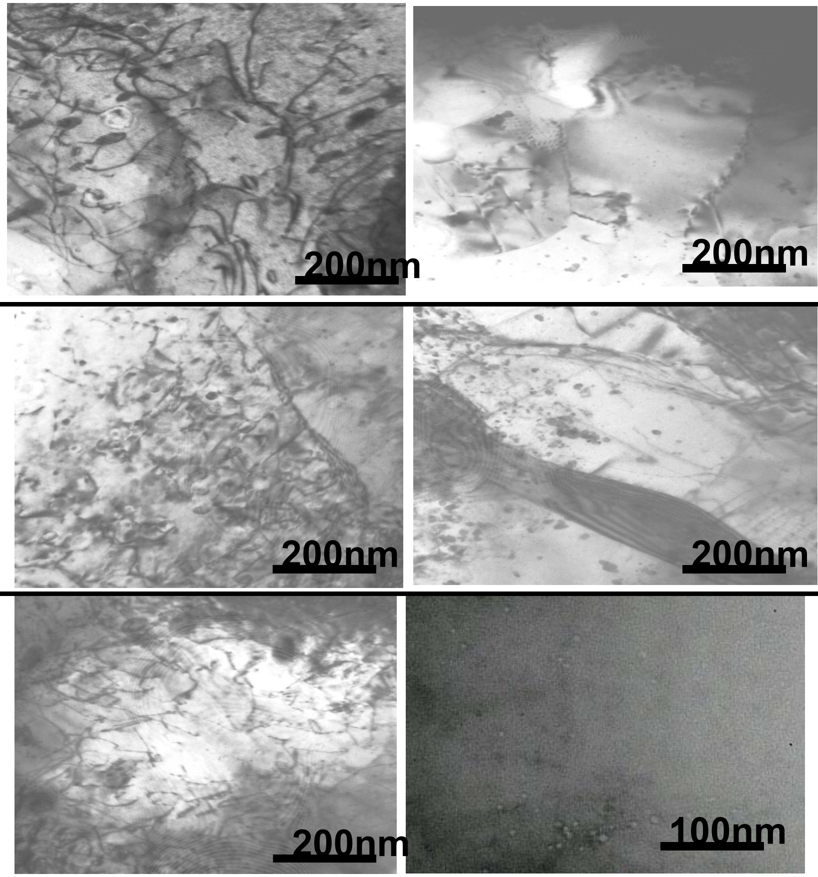
50 dpa

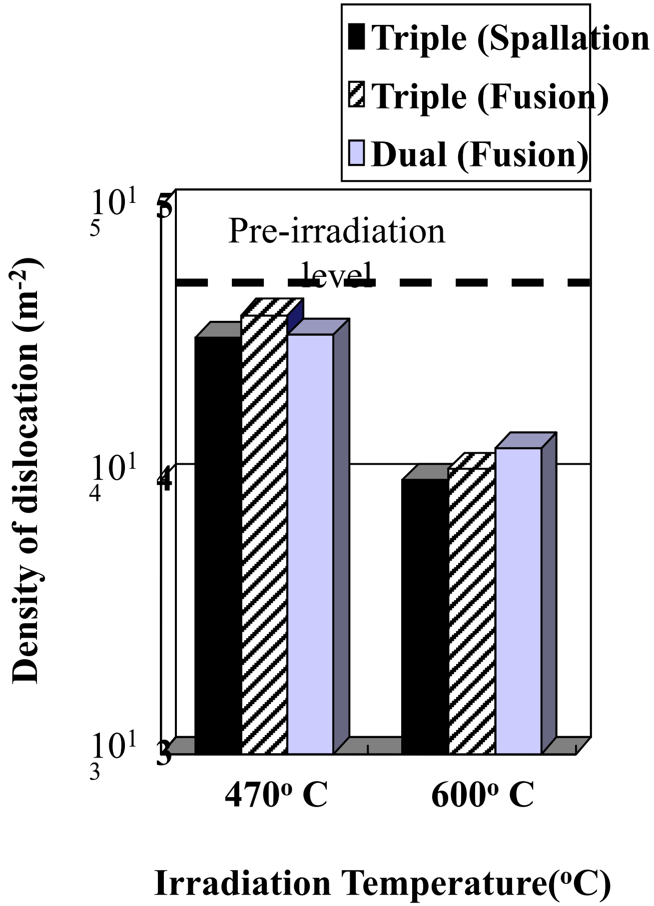
470°C 600°C

Spallation (triple)

Fusion (triple)

Fusion (dual)





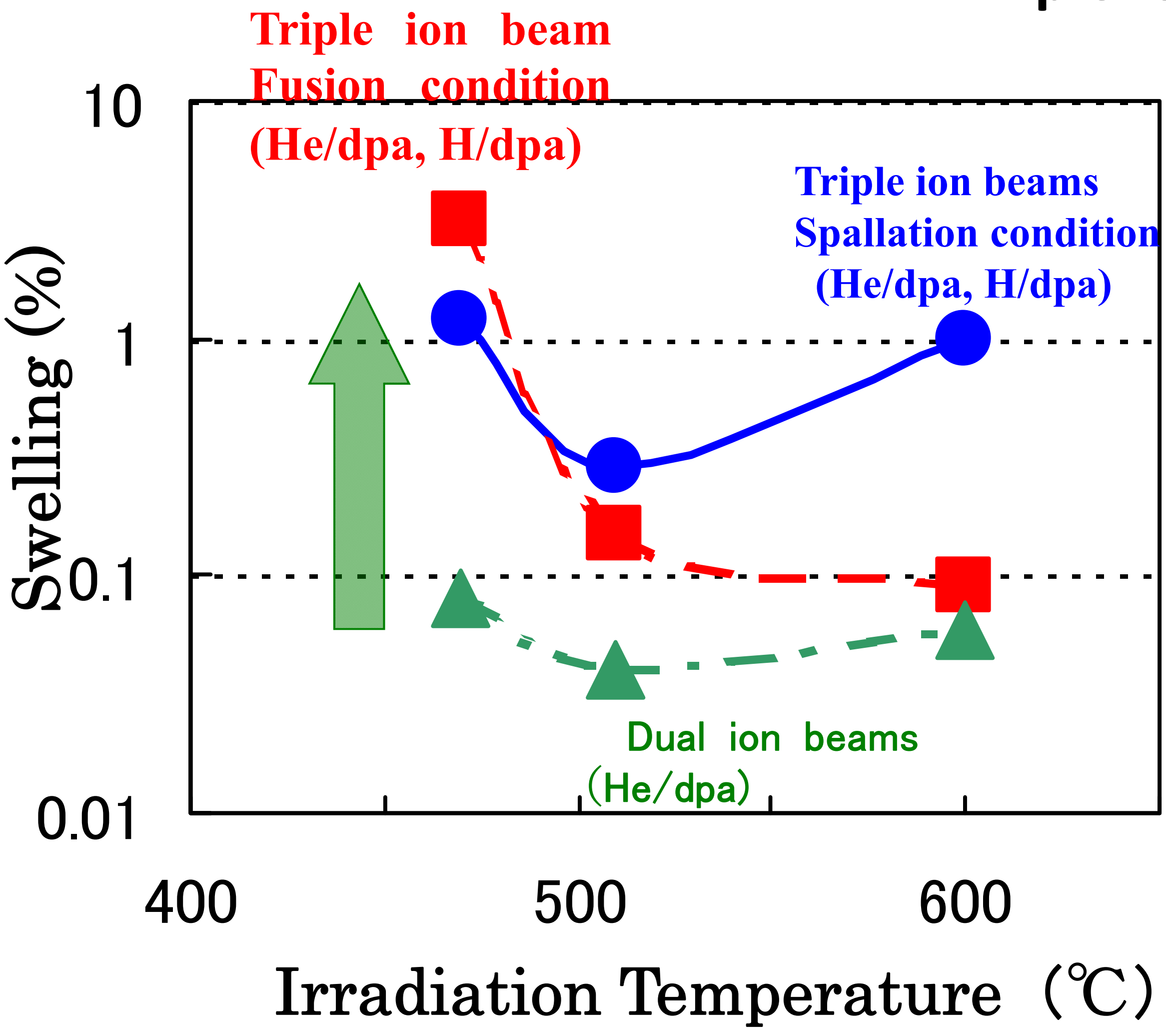
Dislocation of F82H under Dual or Triple Ion Irradiation

E. Wakai, et al., "Effect of triple ion beams in ferritic/martensitic steel on swelling behavior", Journal of Nuclear Materials 307-311 (2002), pp.278-282.

JAEA J-PARC

3. Some Results

TIARA Triple Ion Beam Experiment

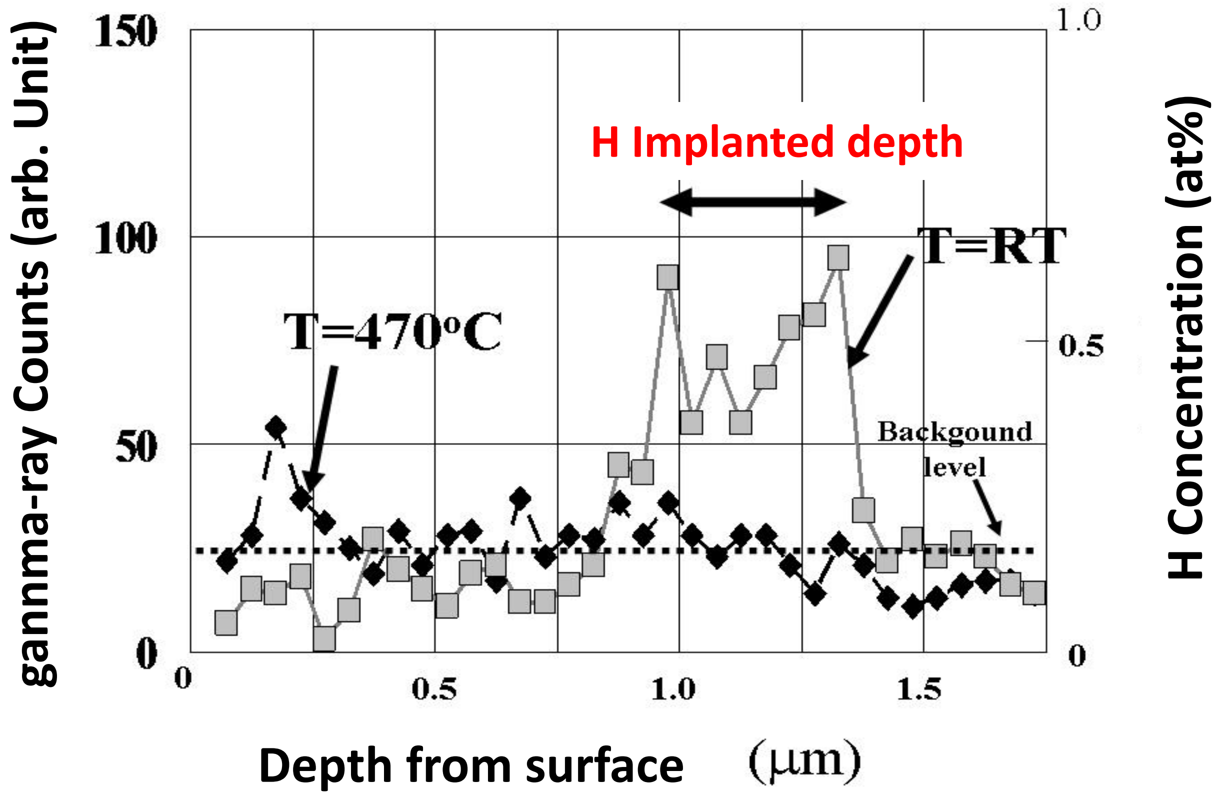


Material: F82H steel

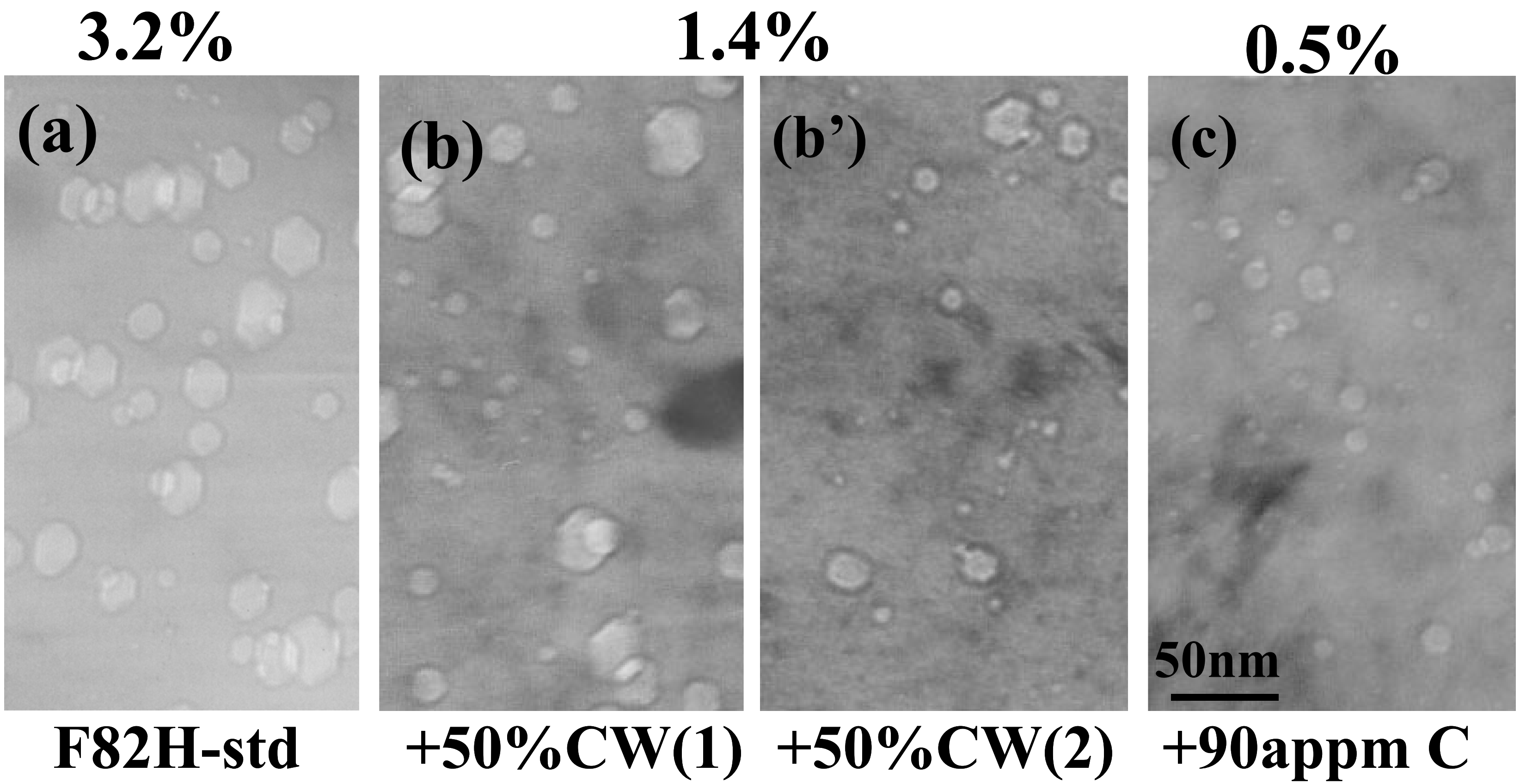
(Fe-8Cr-2W-0.1C-0.04Ta ferritc/martenstic steel) for fusion structure material,

50 dpa

H measurement in nuclear resonance method (from $^{15}N(H, \alpha\gamma)^{12}C$)

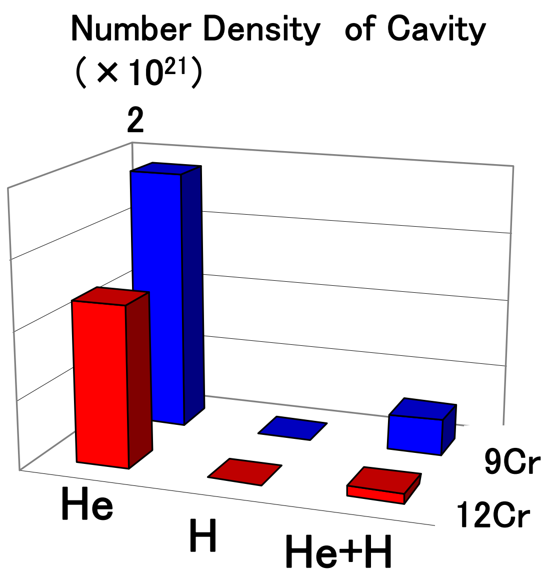


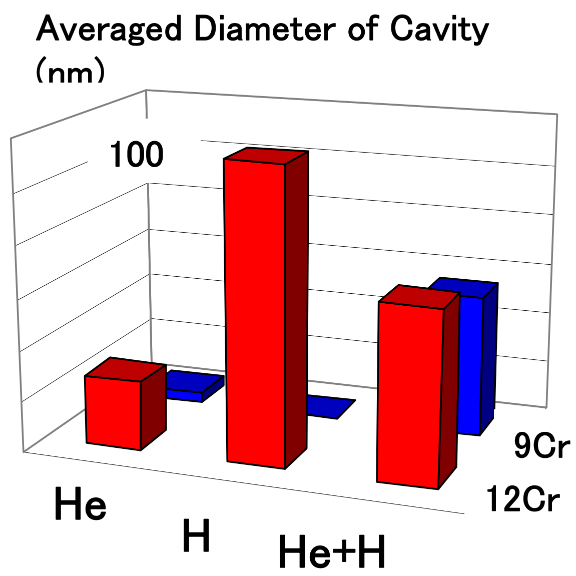
Swelling Reduction for F82H steel

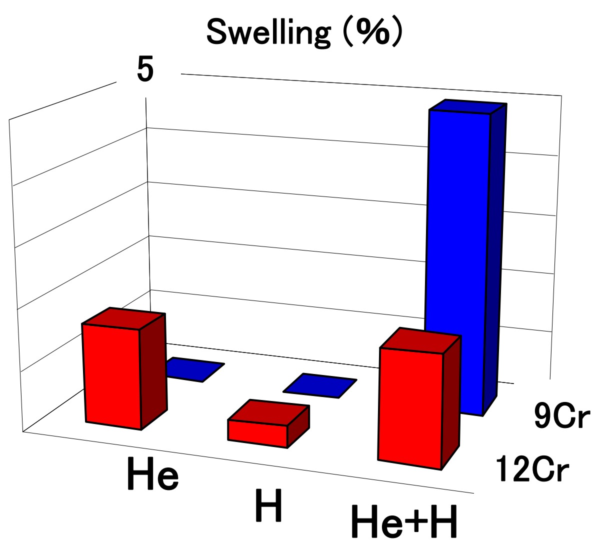


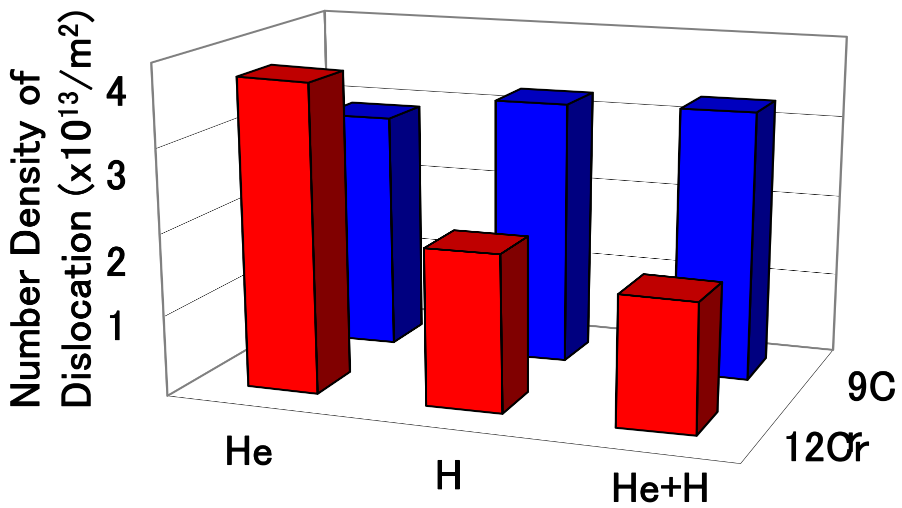
Swelling can be reduced by CW and carbon concentration

Model Fe-Cr Alloy: Swelling Behavior by Ion Irradiation (TIARA of JAEA)









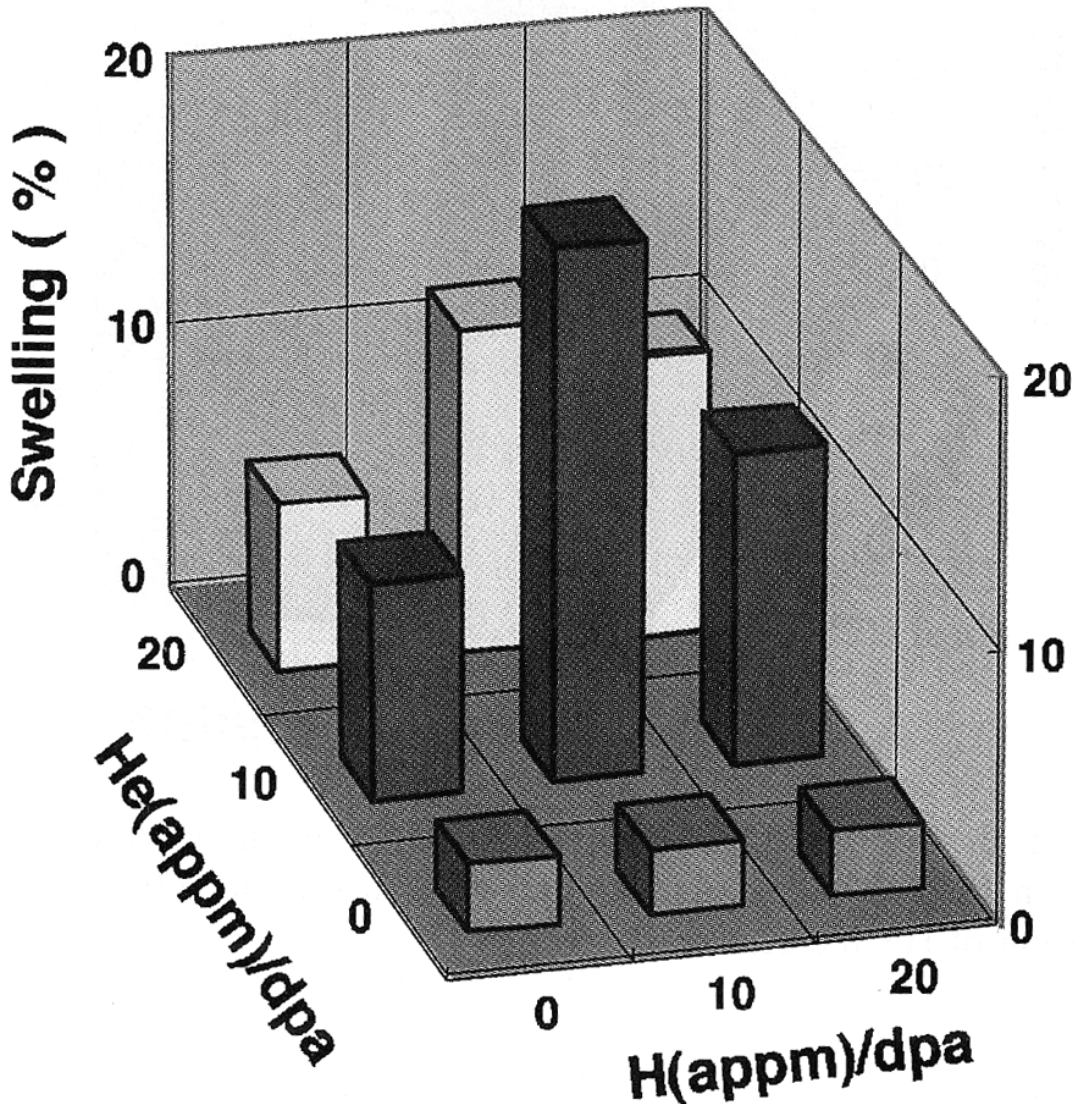
Swelling depending on Temp., Dual & Triple

By Tanaka

Synergistic effect of He, H, and Dpa in V

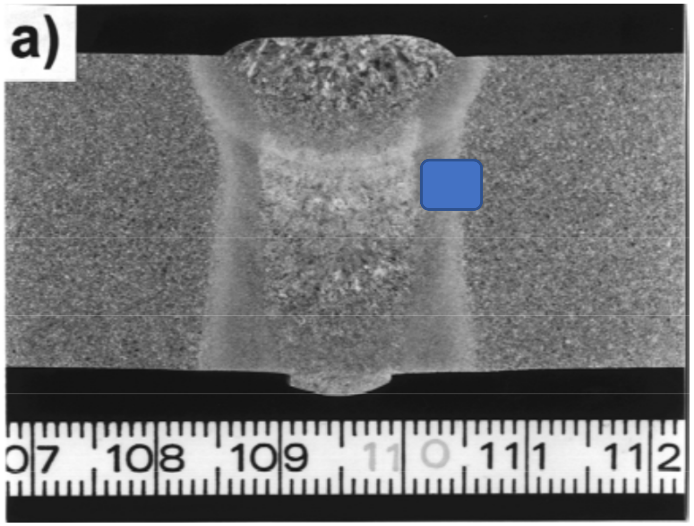
Materials: V

TIARA
Multi-ion beam
experiment

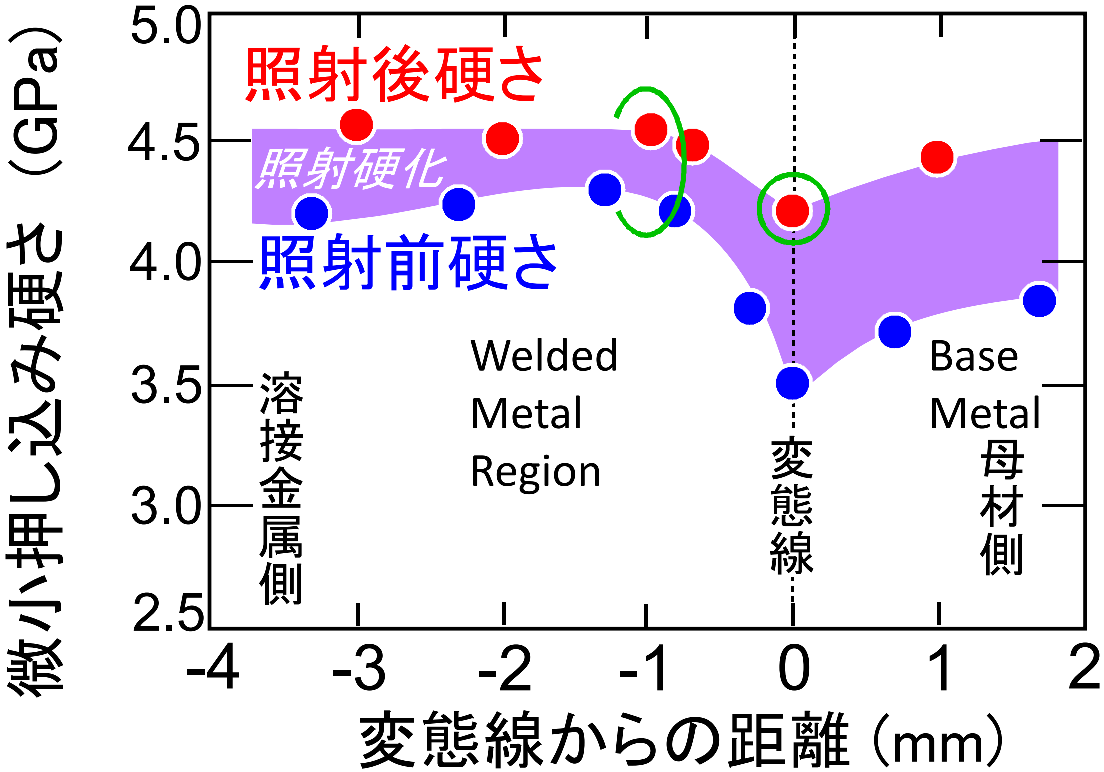


N.Sekimura et al.
Journal of Nuclear Materials 283–287(2000)

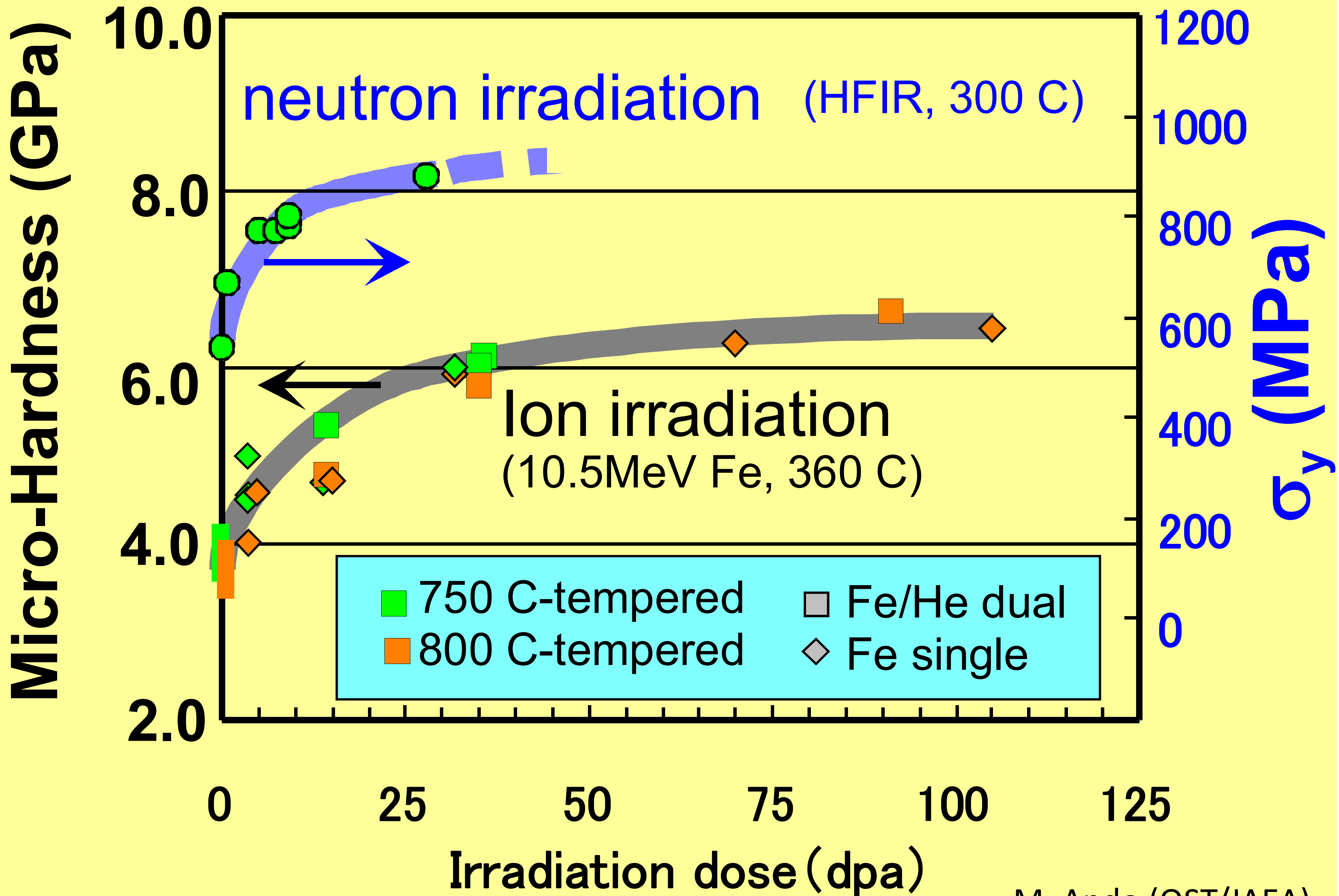
Nano-Indentation Measurement



TIG Welded F82H irradiated
to 5 dpa at 300C in tiara



Hardening Behavior,   F82H, 100dpa, 360°C



M. Ando (QST/JAEA)

HIT Ion Irradiation (SUS316) (N. Okubo)

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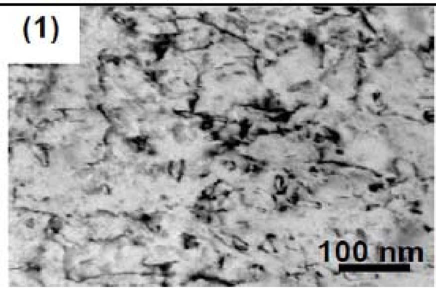
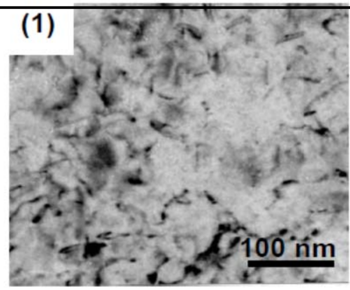
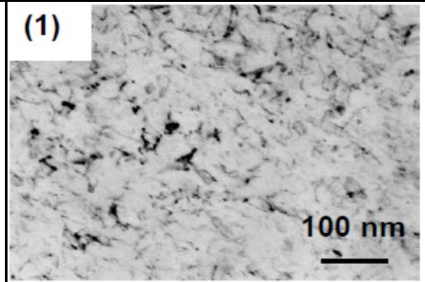
<tr><td></td><td></td><td>1 dpa</td><td colspan="2">10 dpa</td></tr>
<tr><td></td><td></td><td>Dislocation(No Cavity)</td><td>Cavity</td><td>Dislocation</td></tr>
<tr><td rowspan="3">He-appm/dpa</td><td>0</td><td>
</td><td>
</td><td>
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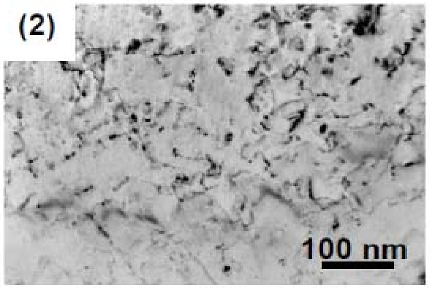
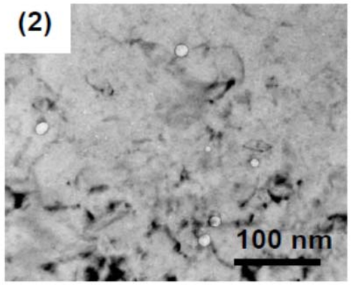
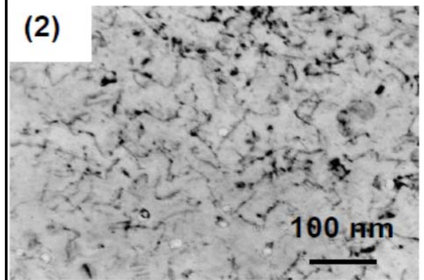
<tr><td>1</td><td>
</td><td>
</td><td>
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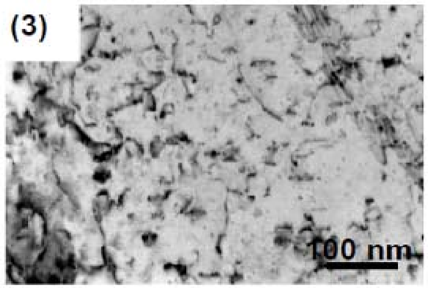
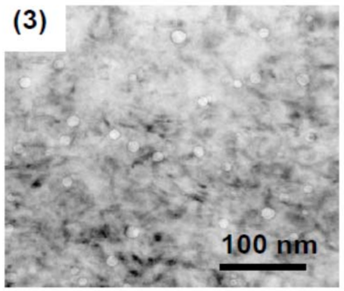
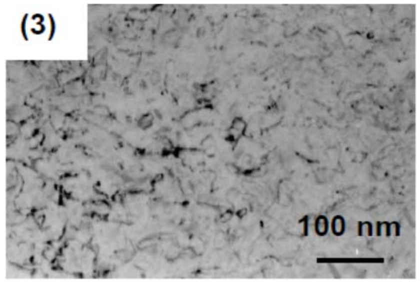
<tr><td>10</td><td>
</td><td>
</td><td>
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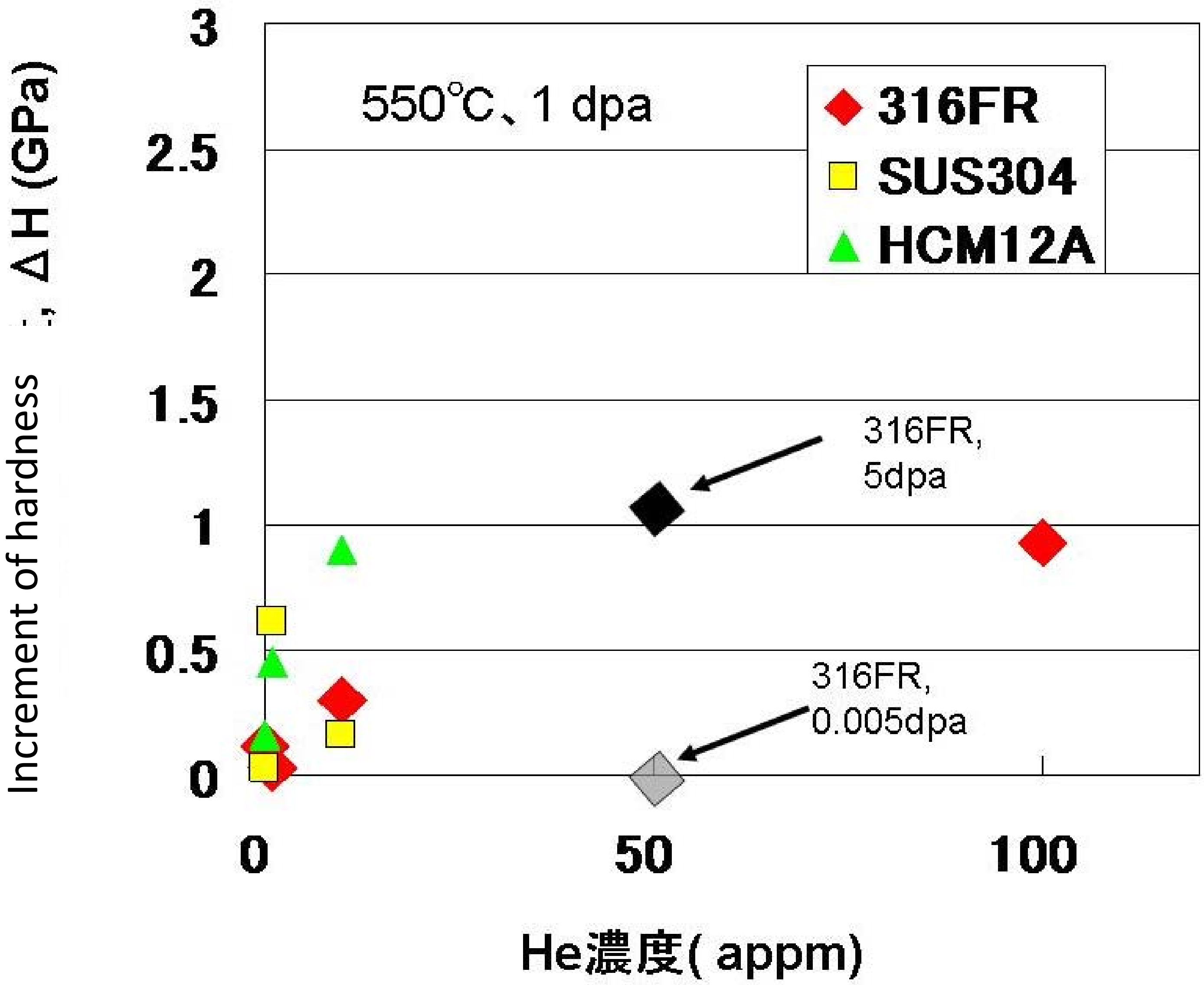
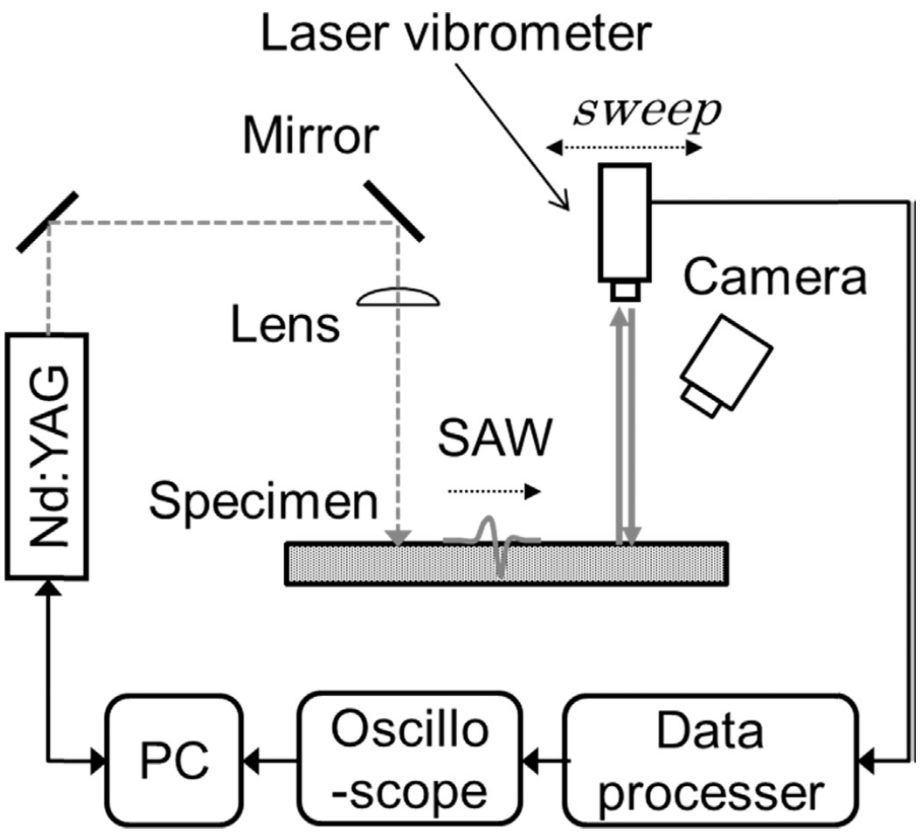
HIT Ion Irradiation (SUS316) (N. Okubo)



SAW (Surface Acoustic Wave) Measurement Technique for detection of radiation hardening



S.-i. Kitazawa et al. Radiation Physics and Chemistry, 127(2016)264-268

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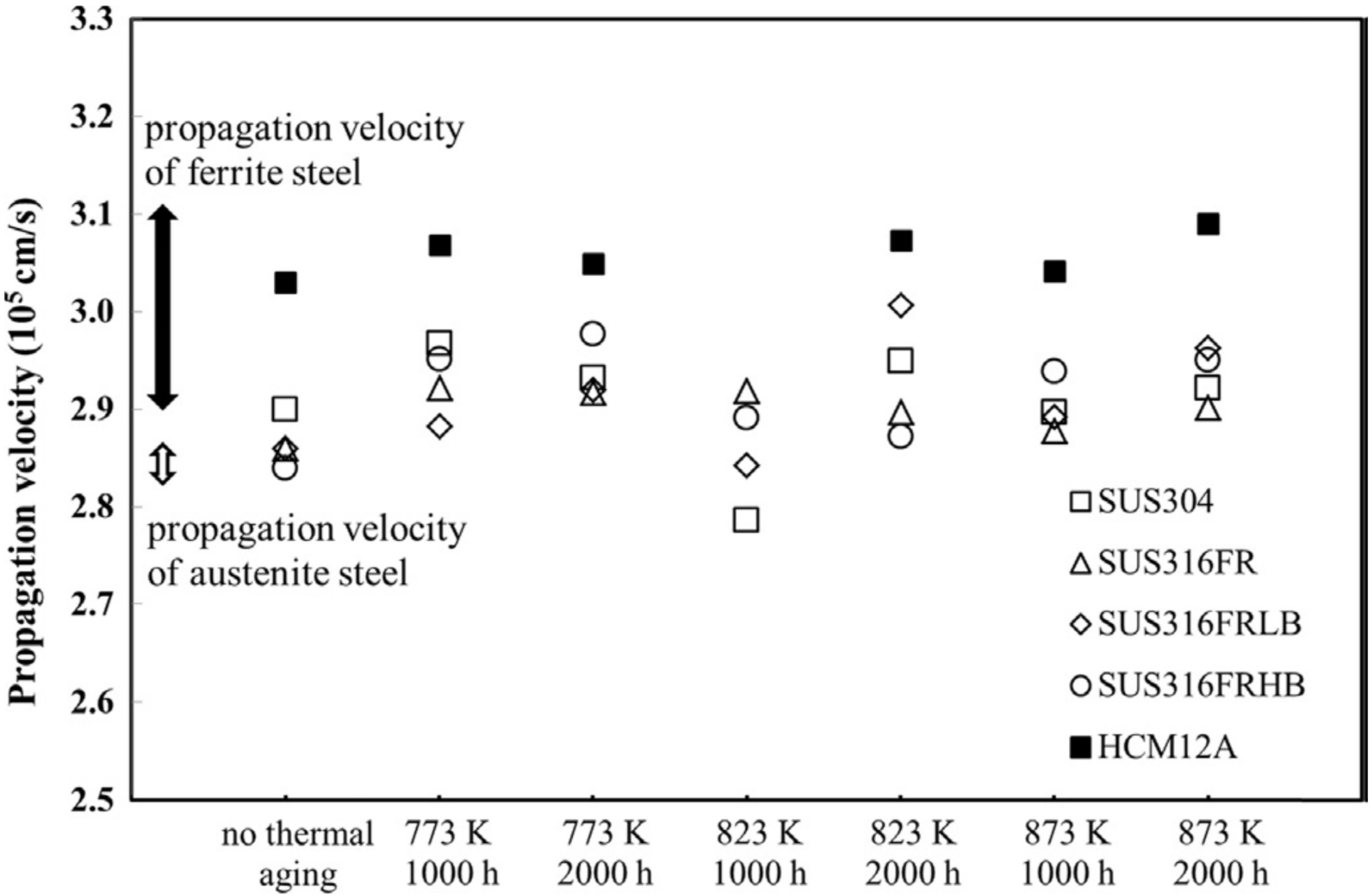

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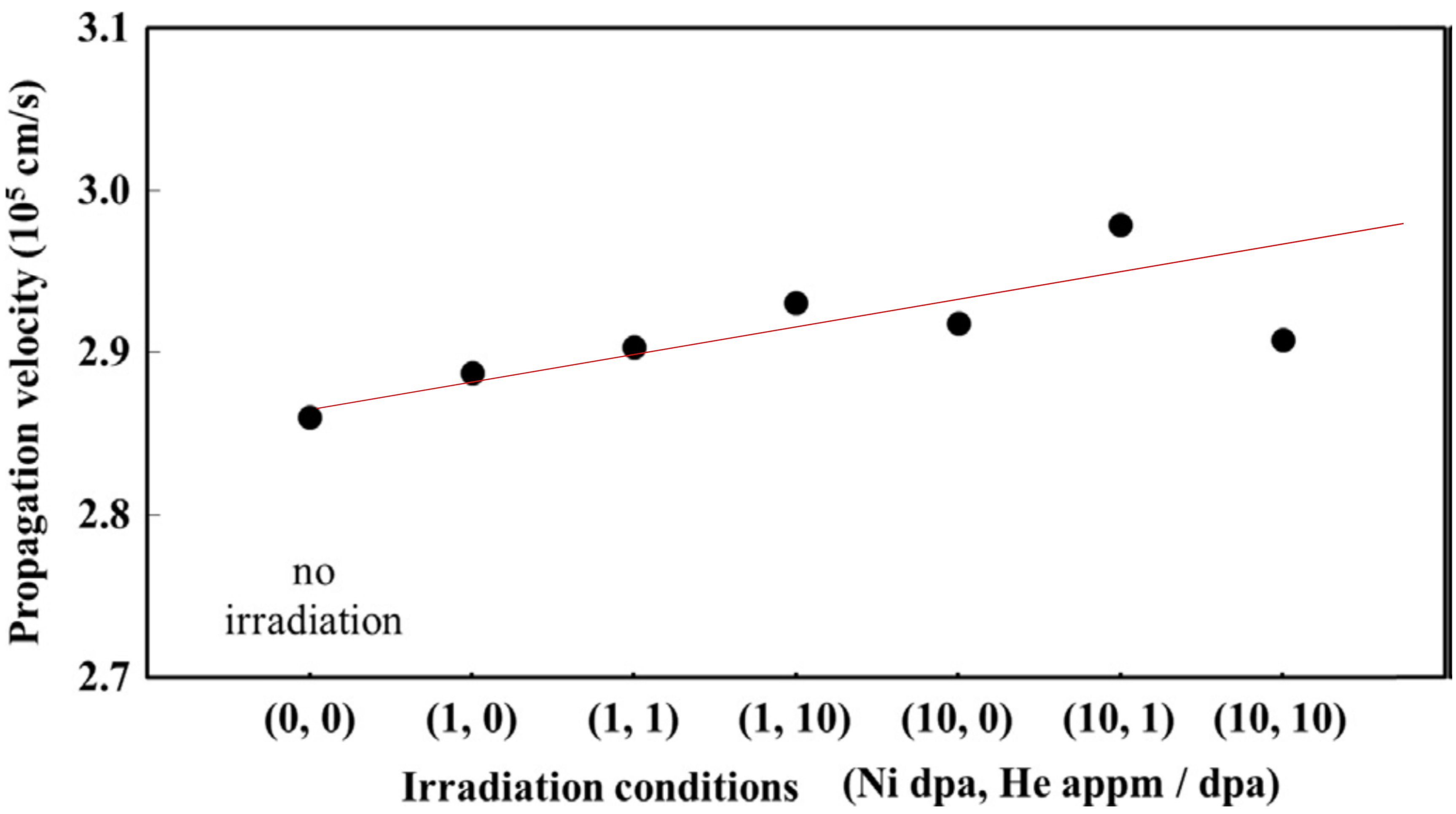

RaDIATE Collaboration Meeting

4. SUMMARY

- As low energy ion beam facilities with multiple ion beams in Japan, TIARA of JAEA (QST), DuET of Kyoto Univ., and HIT of Univ. of Tokyo were shown.
- The merits of low energy multiple-Ion beam experiment are given as below;

(1) Higher dpa rate (about 5 dpa/h), (2) No radioactivity,
(3) Relatively low cost operation,
(4) He/dpa and H/dpa can be controlled for the purpose

- The synergistic effect of He, H, dpa on swelling behavior were mainly shown in F82H, model alloy Fe-Cr, and V.
- Some analysis techniques were introduced such as SAW technique, nano indentation, H measurement in nuclear resonance method (from $^{15}N(H, \alpha\gamma)^{12}C$) for radiation damage.

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