IWSMT-12, 19-23 October 2014, Bregenz, Austria

Mechanical Properties of Fe-9Cr Steel by High Energy Proton Irradiation

Research Reactor Institute, Kyoto University
Q. Xu, Y. Ishi, Y. Kuriyama, Y. Mori, K. Sato, T. Uesugi, T. Yoshiie

Research Institute for Nuclear Engineering
University of Fukui
K. Fukumoto


Kansai International Airport
KUR
(Reactor (5MW))
KUCA
(Critical Assembly)

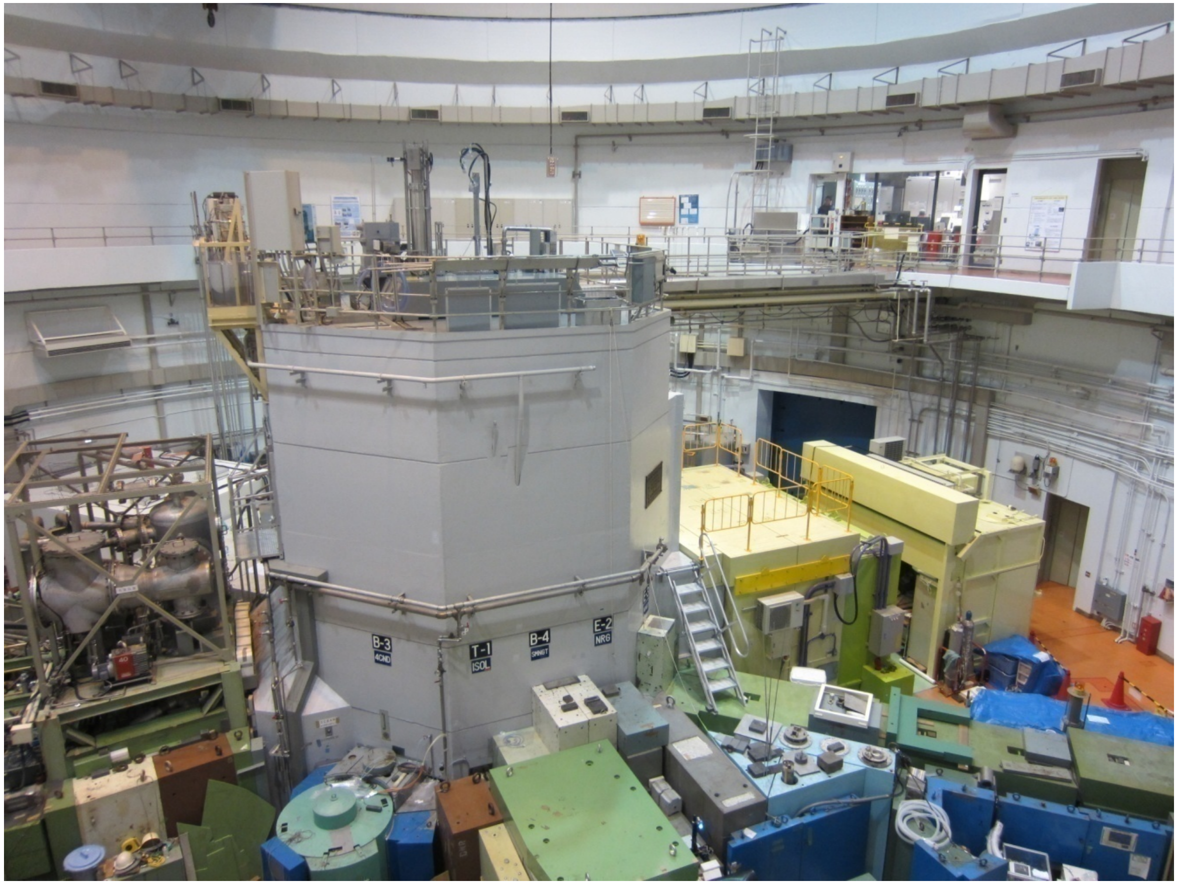
KUR

Type : Light-water moderated tank-type reactor

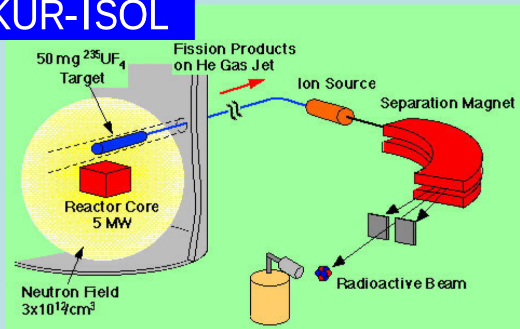
Power : Max 5MW

First critical : 1964

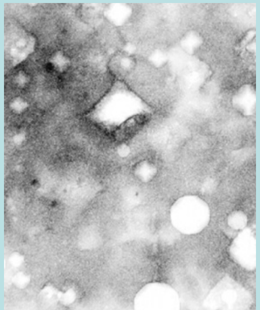
Fuel : 93% → 20% enriched uranium in 2009



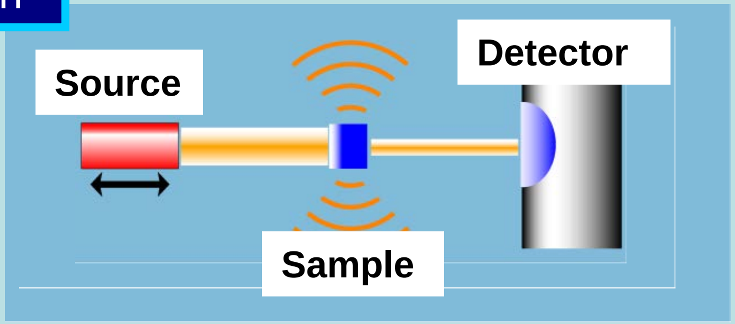
Material Research



Magnetic Moment; PAC



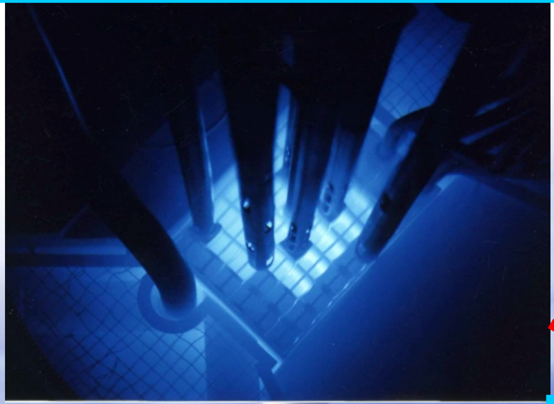
Radiation Effect



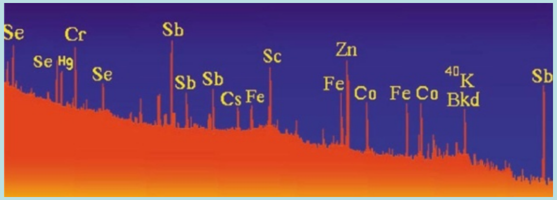
Electronic States
(Mössbauer Spectroscopy)

PAC: perturbed angular correlation

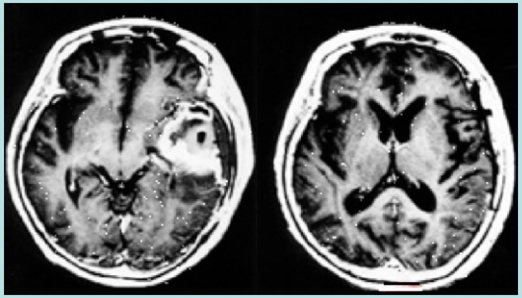
Research Using Neutron in KUR



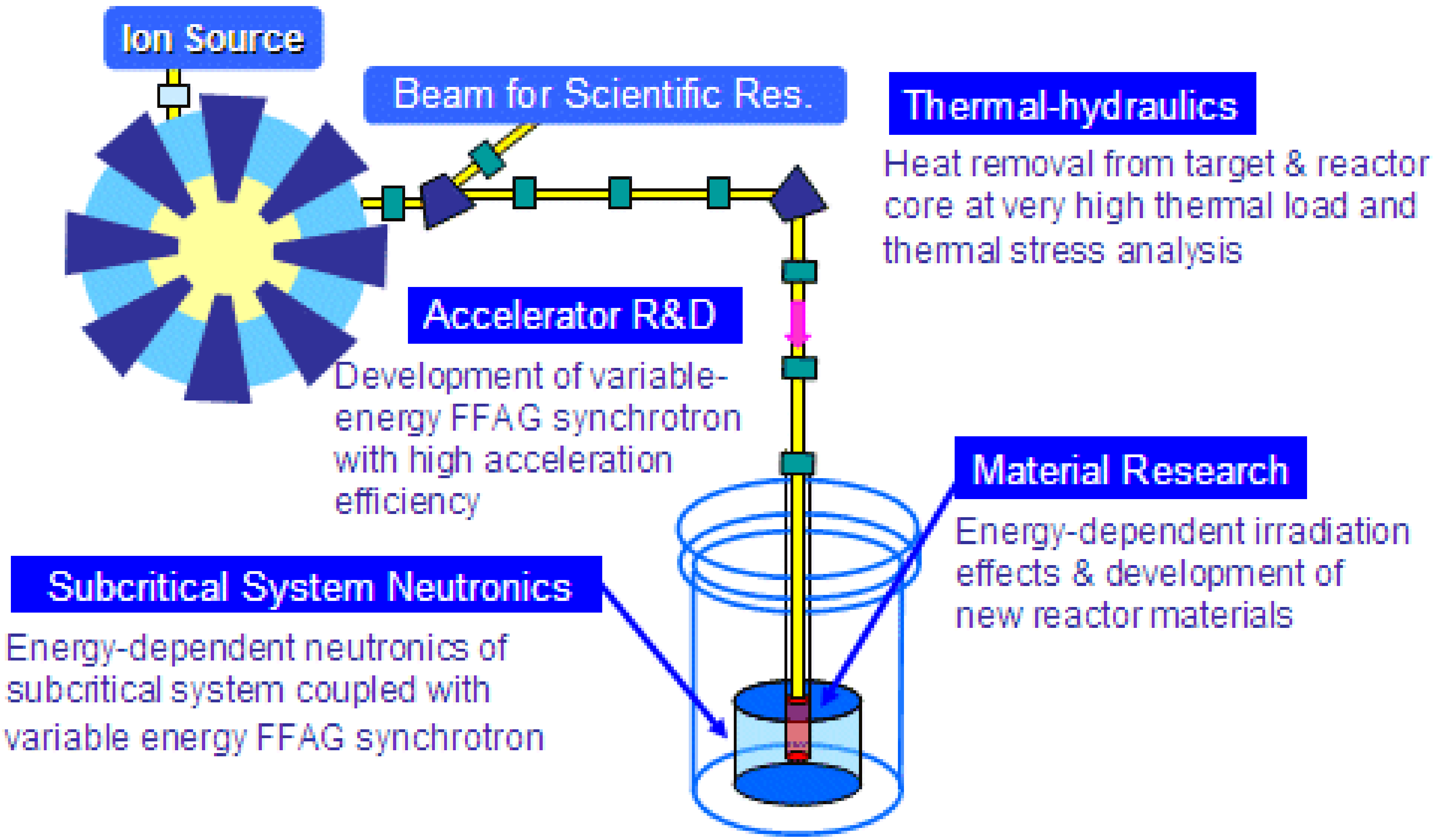
Radioactive Analysis



Cancer Treatment, Life Science

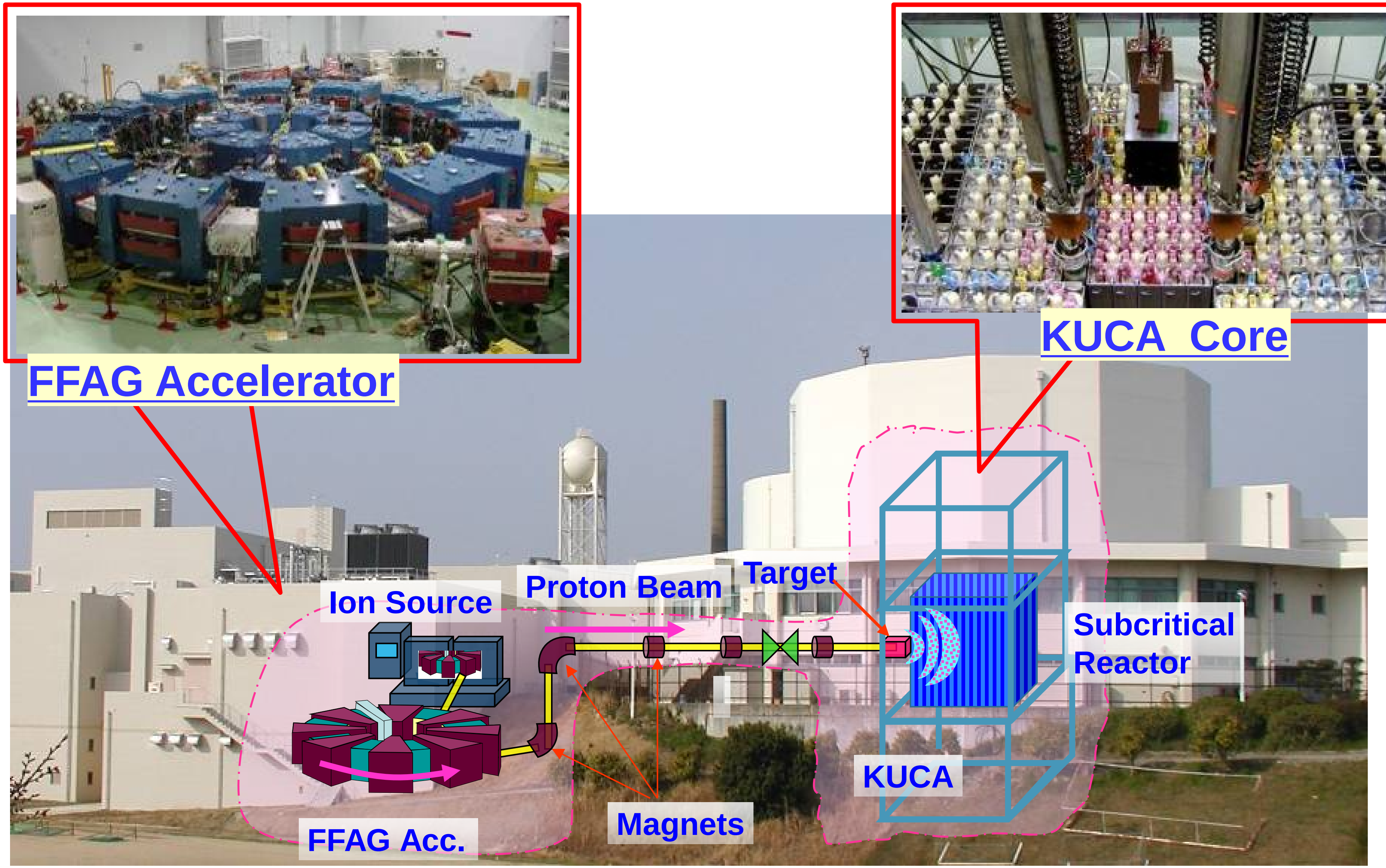


Accelerator Driven System (ADS)



Concept of FFAG-KUCA Experiment on ADS

FFAG (Fixed Field Alternating Gradient)



Study of Materials Irradiation Effects by Proton Beam

New Materials irradiation chamber for FFAG

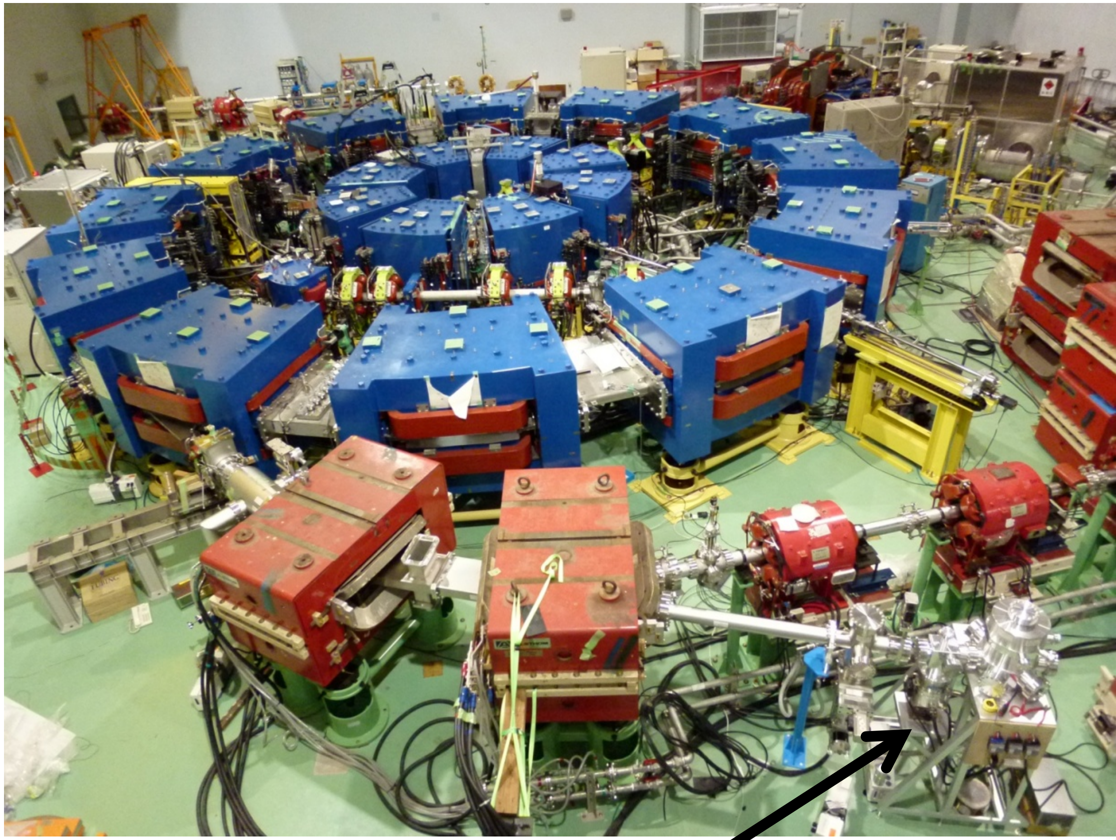
Irradiation temperatures:
 6K – 700 K

In-situ fatigue test

Post irradiation test

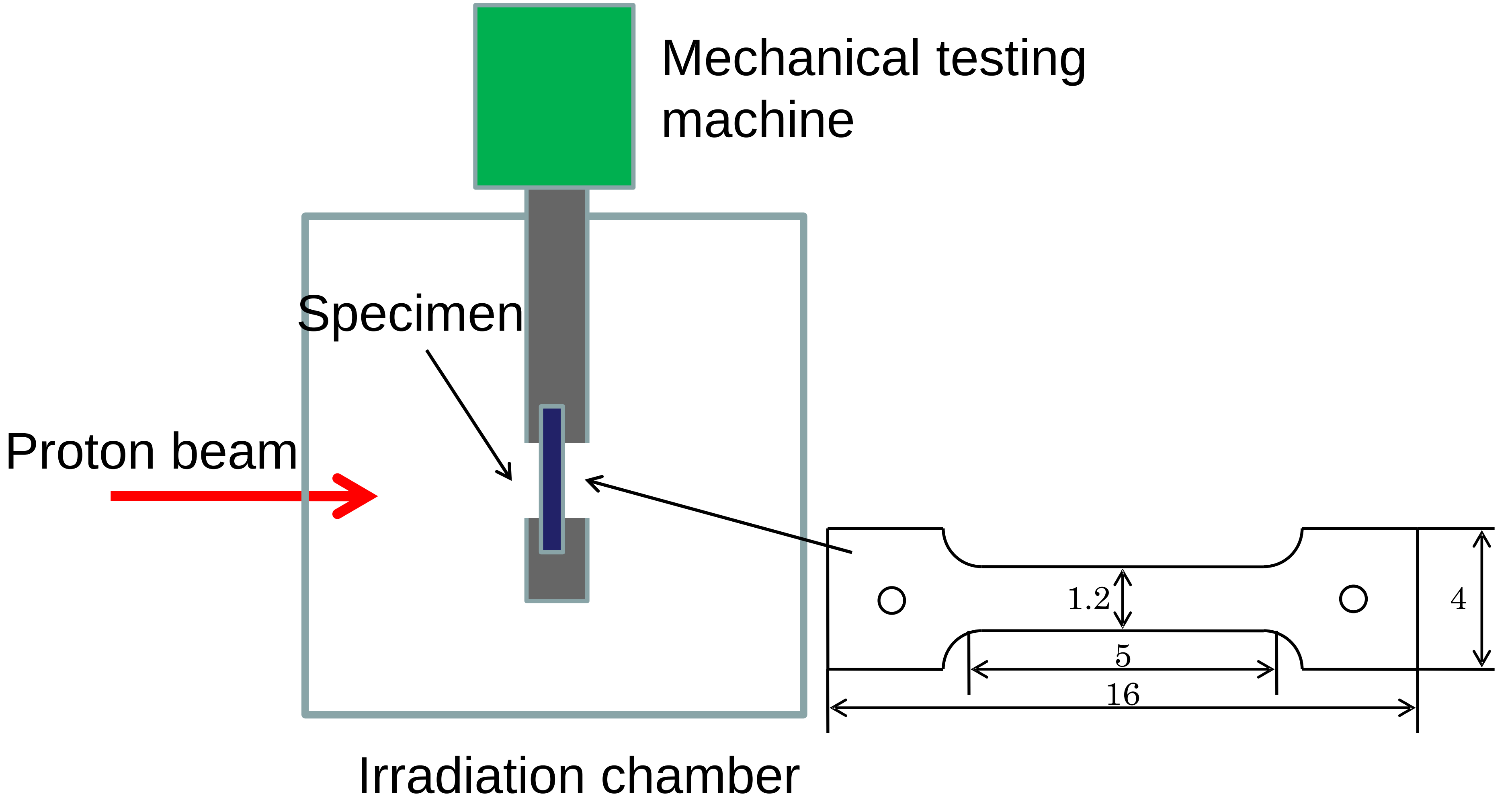
 Positron annihilation
 lifetime measurements

Electrical resistivity
 measurement

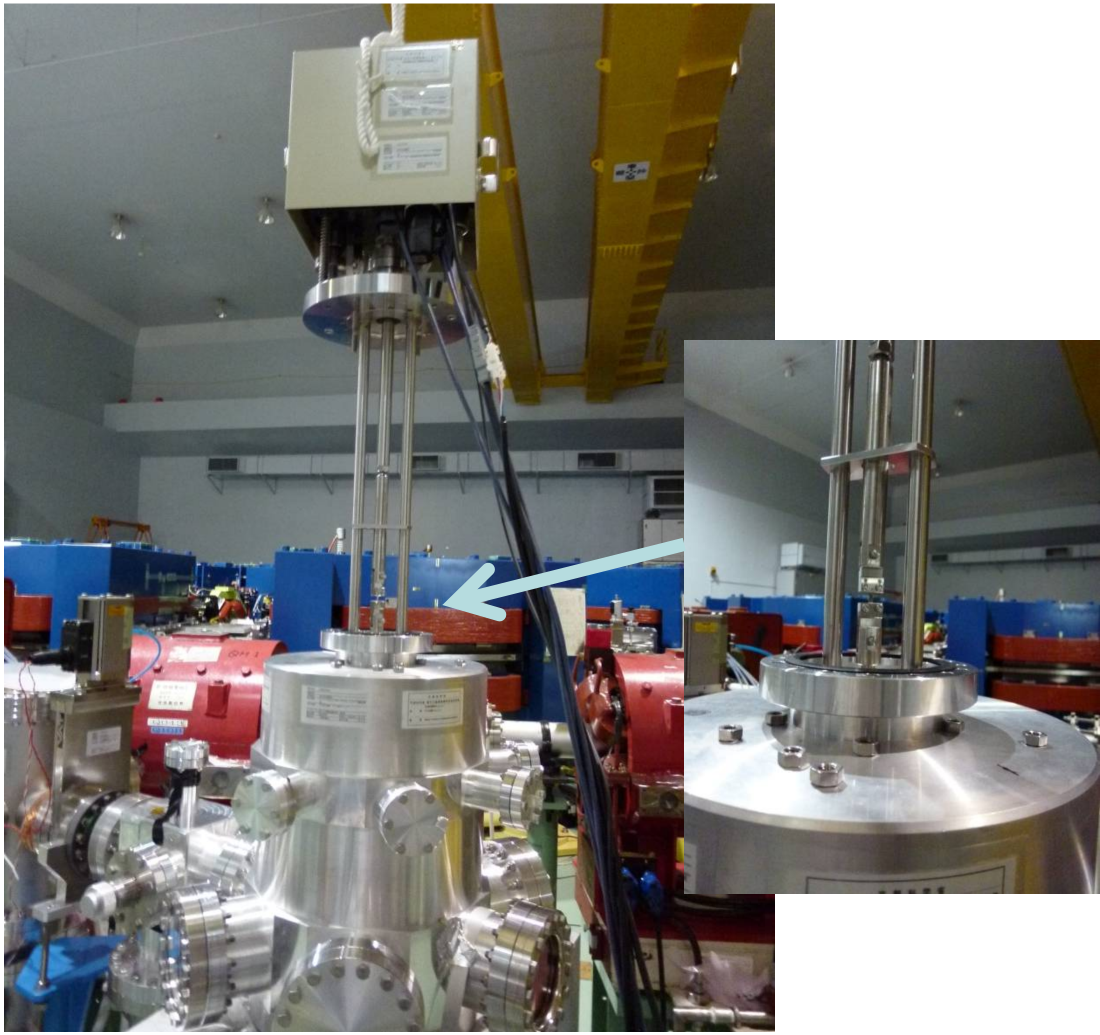


Materials Irradiation Chamber

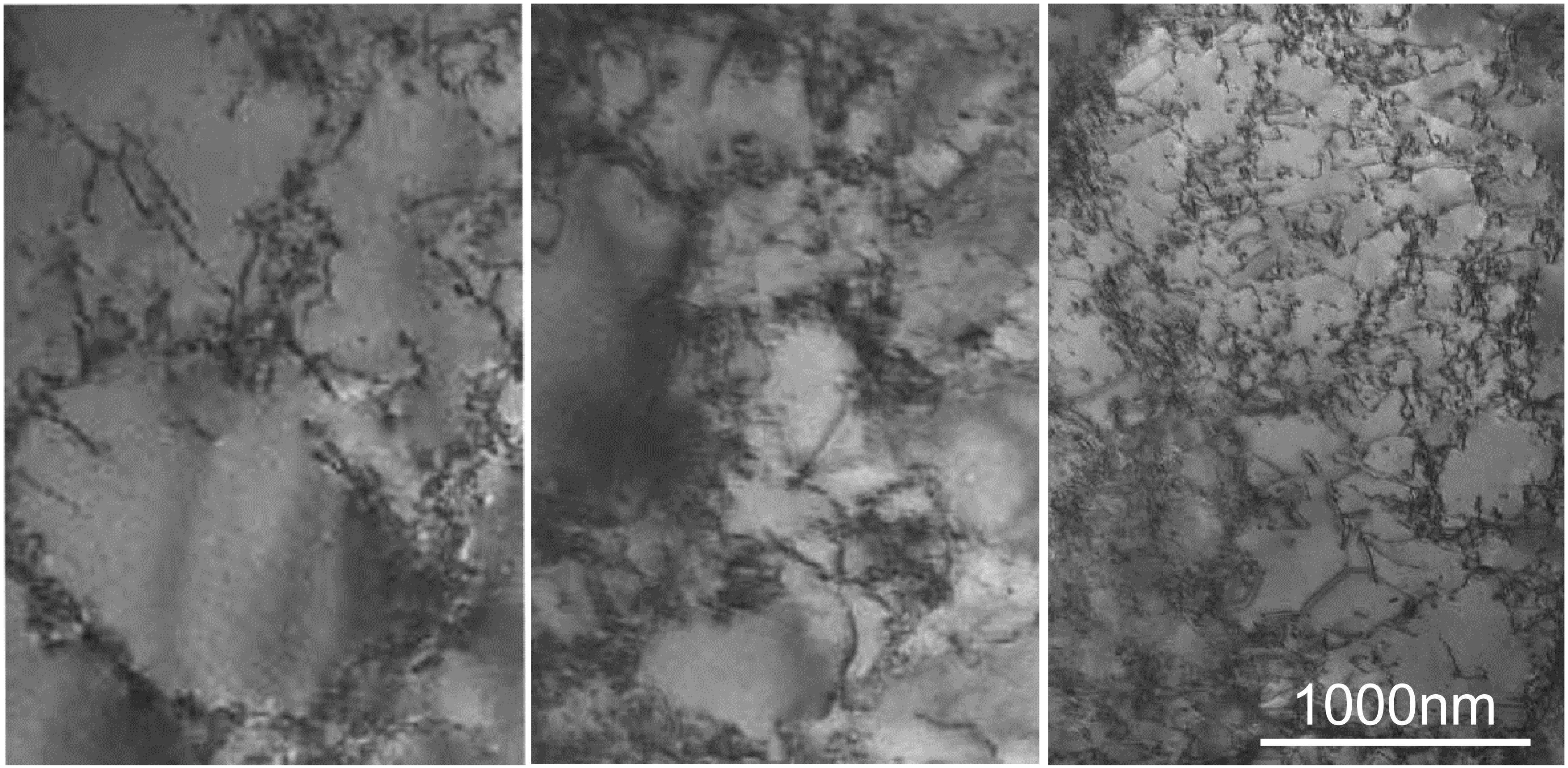
Mechanical Property Test during Irradiation



Mechanical Property Testing Machine



Fatigued Structures of Ni
Deformation Period:30s Total 300 cycles



No irradiation

After 150MeV proton irradiation to $5x10^{-7}$dpa

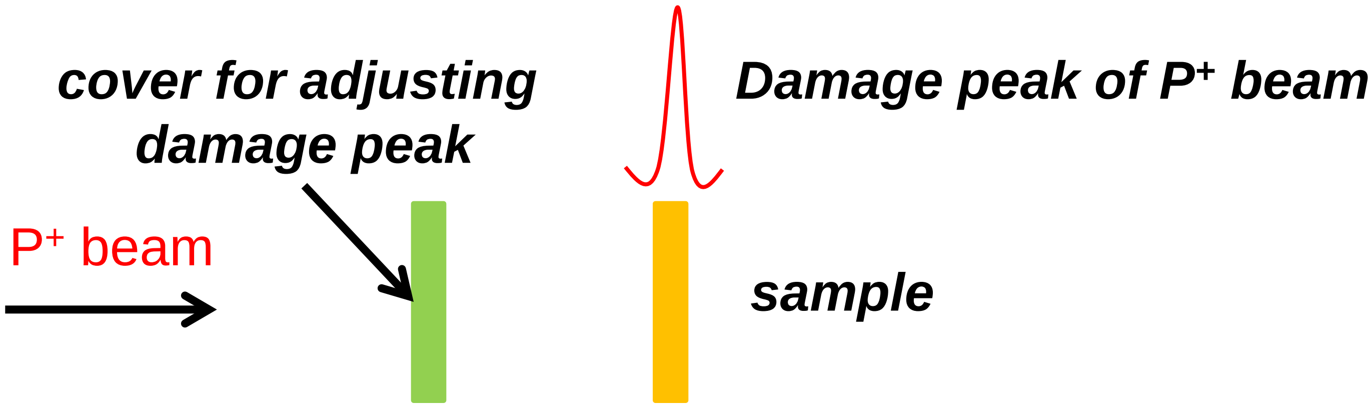
During 150 MeV proton irradiation $5.2x10^{-11}$ dpa/s $5x10^{-7}$dpa

Experimental Procedure

Materials : Fe-9Cr ferritic steel with 0.25 mm thickness
Fe-8.5Cr-0.88Mo-0.44Mn-0.28Si-0.2V-0.096C-0.076Nb-0.05Ni-0.05N-0.005Al-0.002S(mass%)

Irradiation :

(1) 6.4×10^{-6} dpa by 150 MeV protons at RT (range: 24 mm)
(2) 9.0×10^{-4} dpa by 11 MeV protons at 573 K (range: 0.305mm)



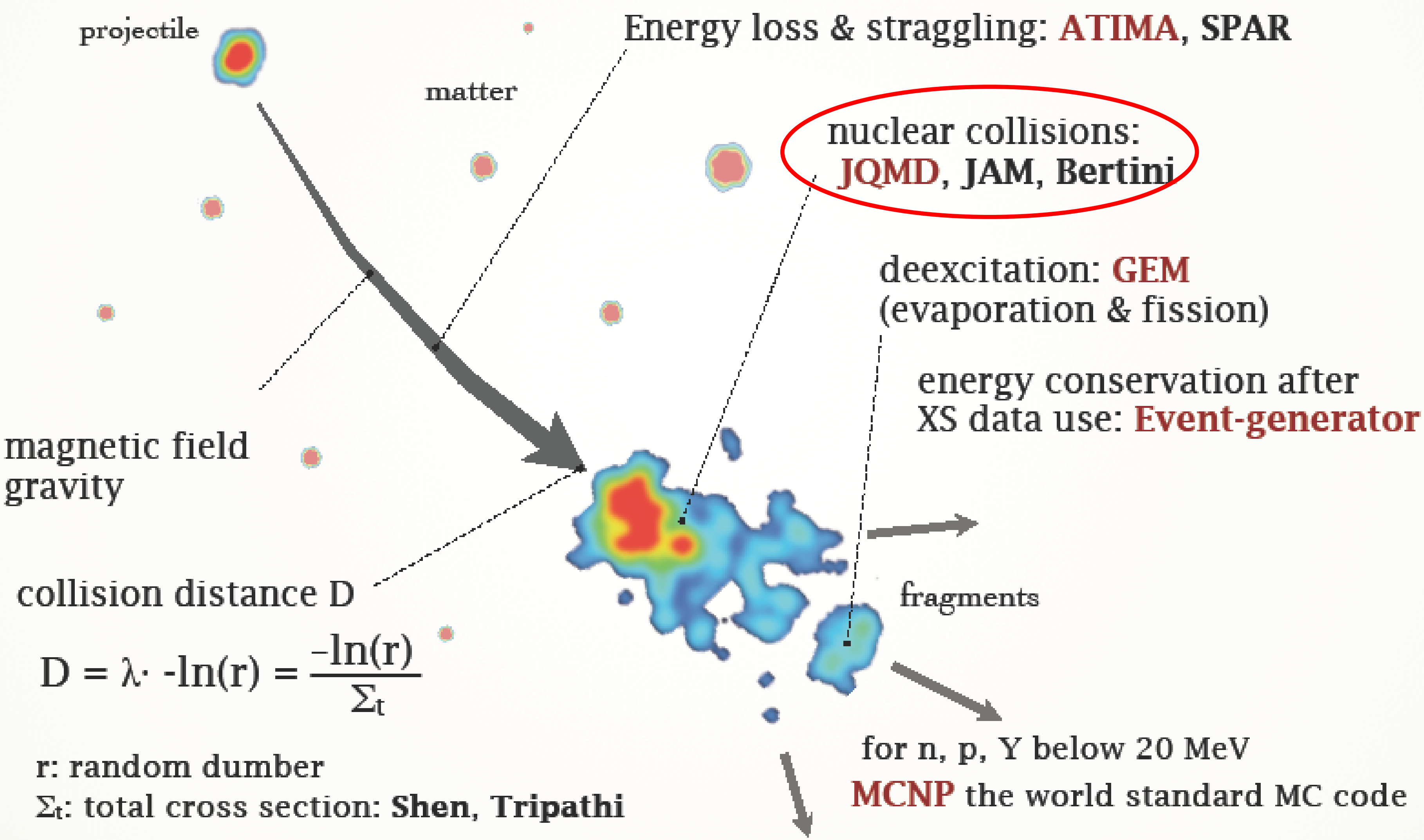
Post Irradiation Experiments :

- Positron annihilation lifetime measurements
- Tensile test

  Tension rate: 2×10^{-3} /s

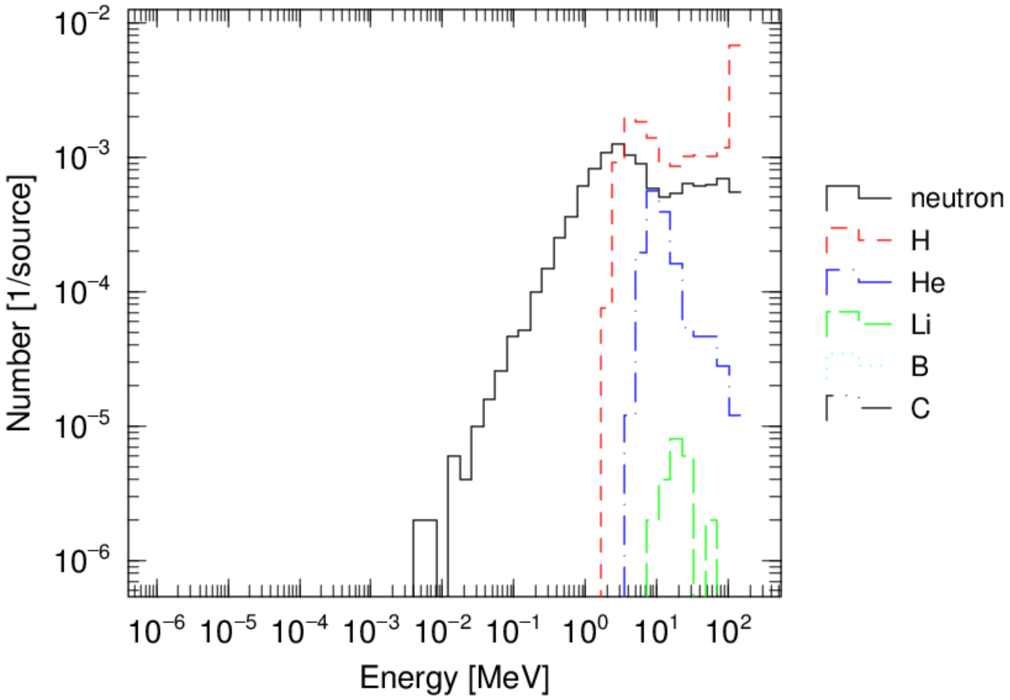
  Temperature: RT

PHITS (particle and heavy ion transport code system)



Spallation Products Estimated by PHITS Code

PHITS: Particle and Heavy Ion Transport Code System

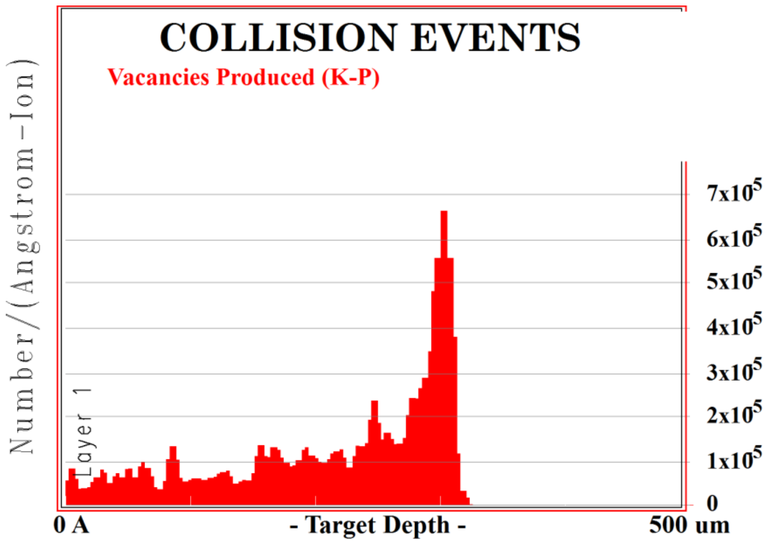


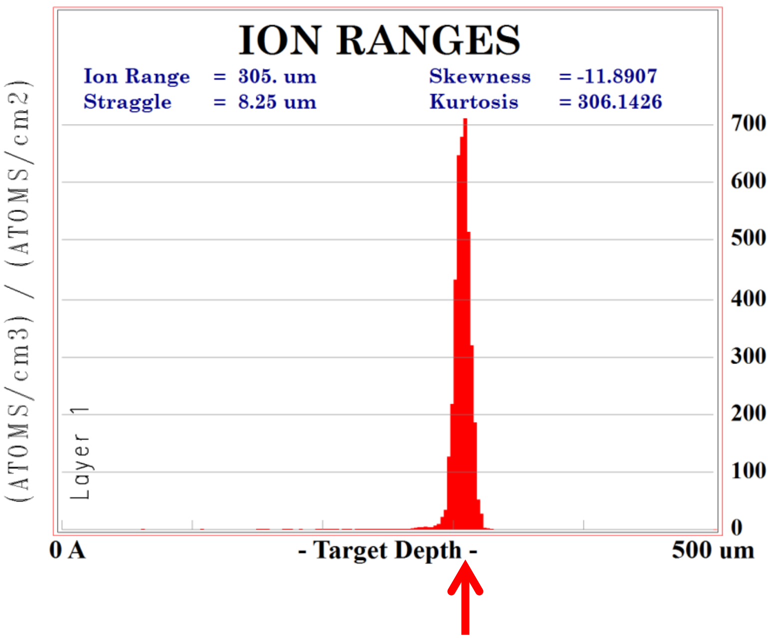
Secondary Particles, 150MeV proton to Fe

Light particles: higher energy, not contribute to damage formation
Heavy particles: lower energy, contribute to damage formation

Damage of 11MeV P^+ Beam Estimated by SRIM

Dose: 6.01×10^{16} p/cm^2
Average damage: 9×10^{-4}dpa
Concentration of H: 2.8×10^{-5}





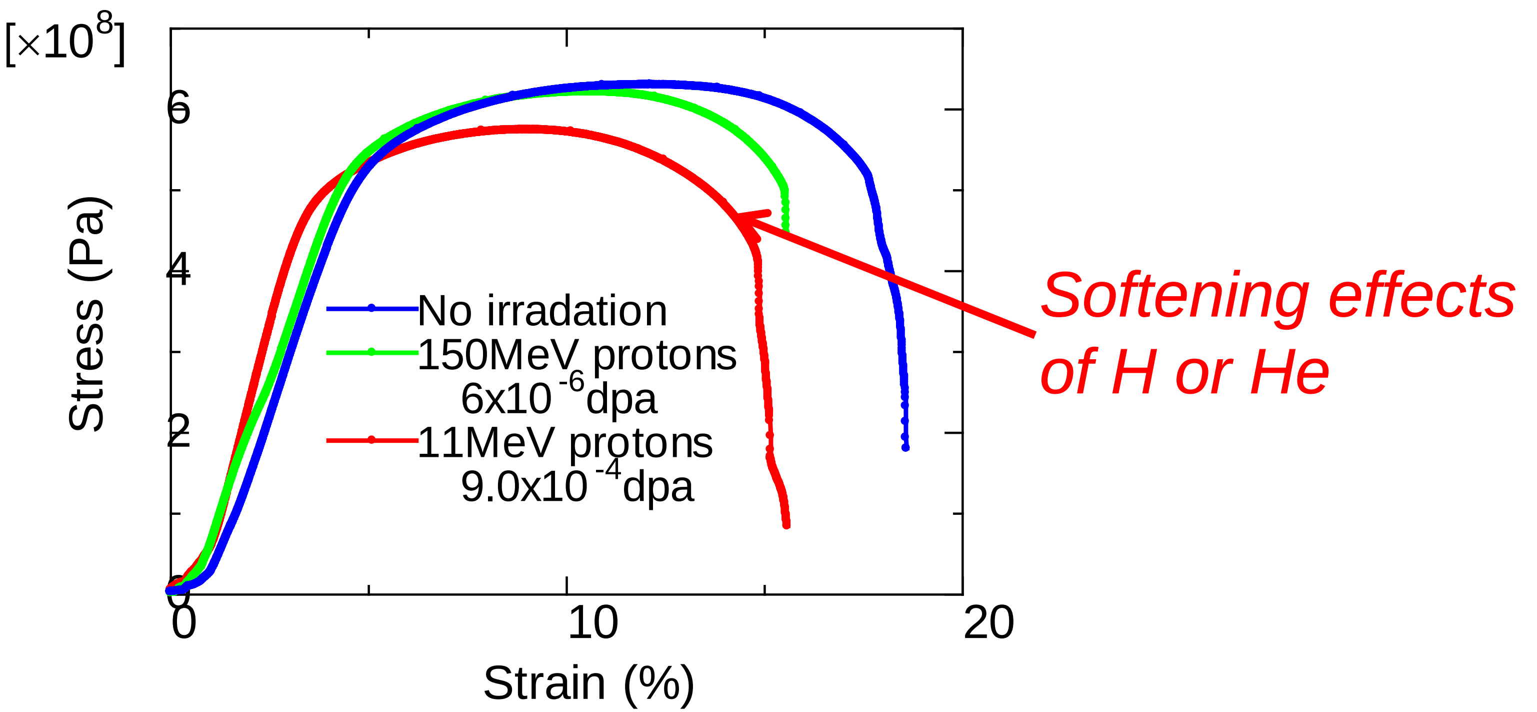
0.305 mm

Results of Positron Annihilation Lifetime

Sample	Mean lifetime τ_m	Short lifetime τ_1	Long lifetime τ_2	Intensity of τ_2 I_2
Unirr.	132.8±03	35.4±6.5	137.7±0.7	91.3±0.7
150MeV	128.1±0.2	11.8±6.5	131.3±0.4	90.0±1.6
11MeV	133.4±0.6	26.8±5.0	132.0±0.6	90.2±0.5

Lifetime for positron annihilation with *dislocations* in Fe is 117 ps.
Lifetime for positron annihilation with *mono-vacancy* in Fe is 175 ps.
Lifetime for positron annihilation with *a vacancy on an edge dislocation line* in Fe is 140 ps.
Comput. Mater. Sci. 14 (1999) 28.

Results of Tension Testing

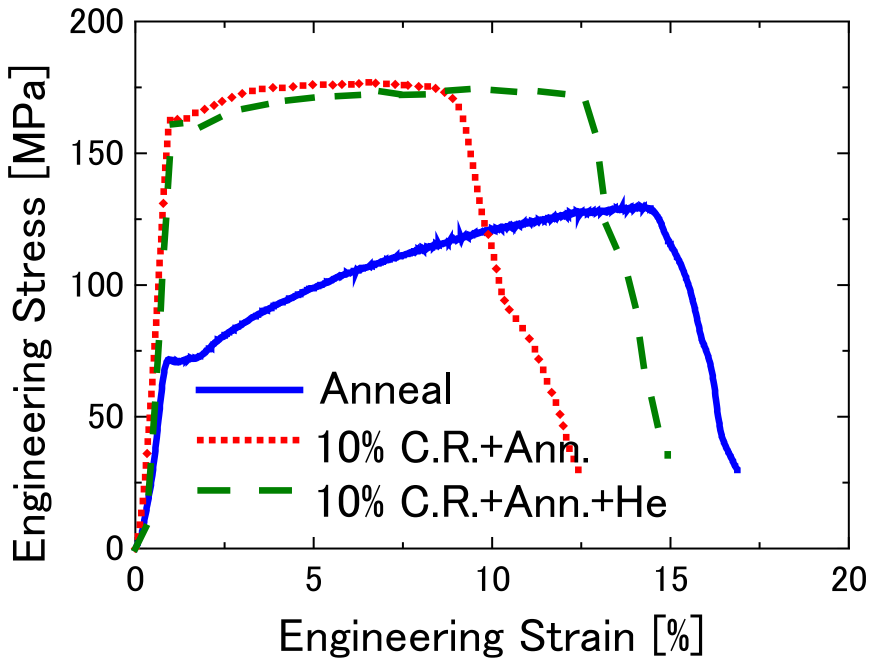


In general, tensile strength increases and elongation decreases after irradiation.

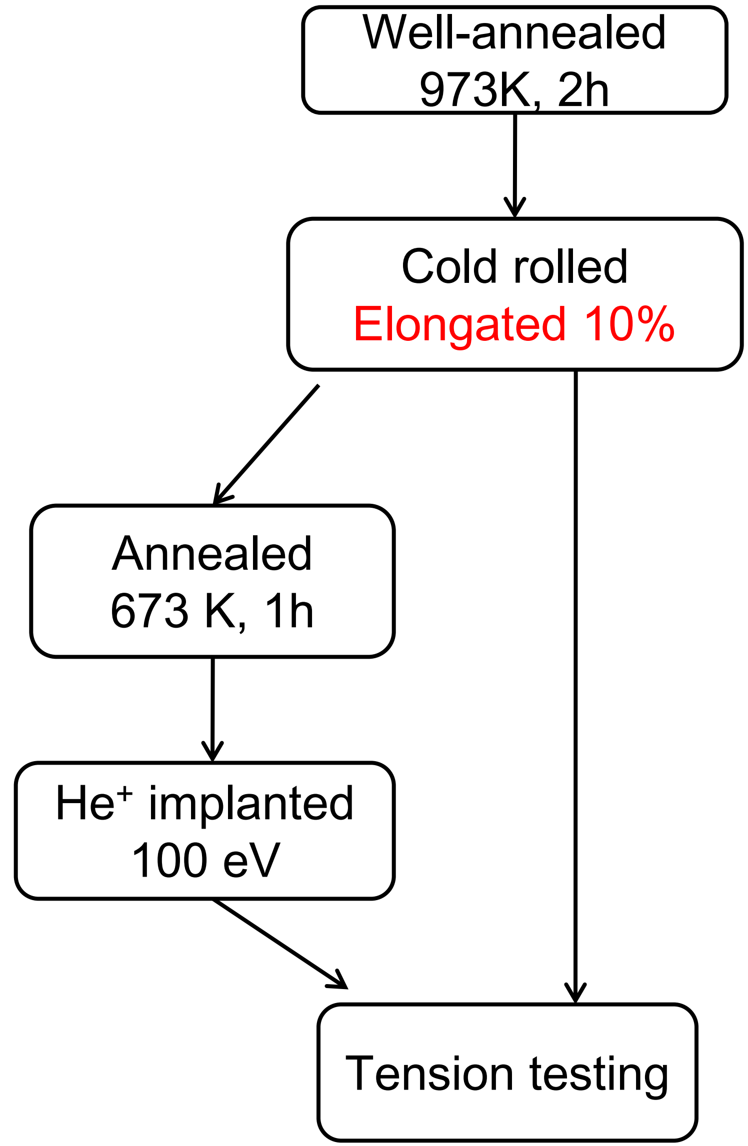
In the present study, the yield stress or tensile strength decreased after irradiation with proton.

Effect of He on the Tensile Strength of Fe Contained Only Dislocations

10% Deformation

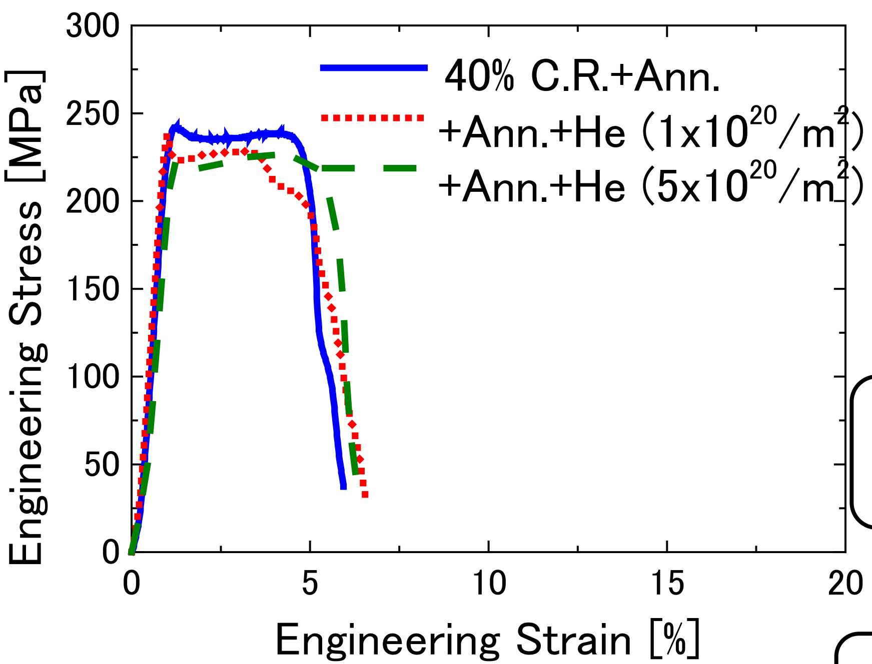


Mater. Sci. & Eng. A 612 (2014) 41-45.

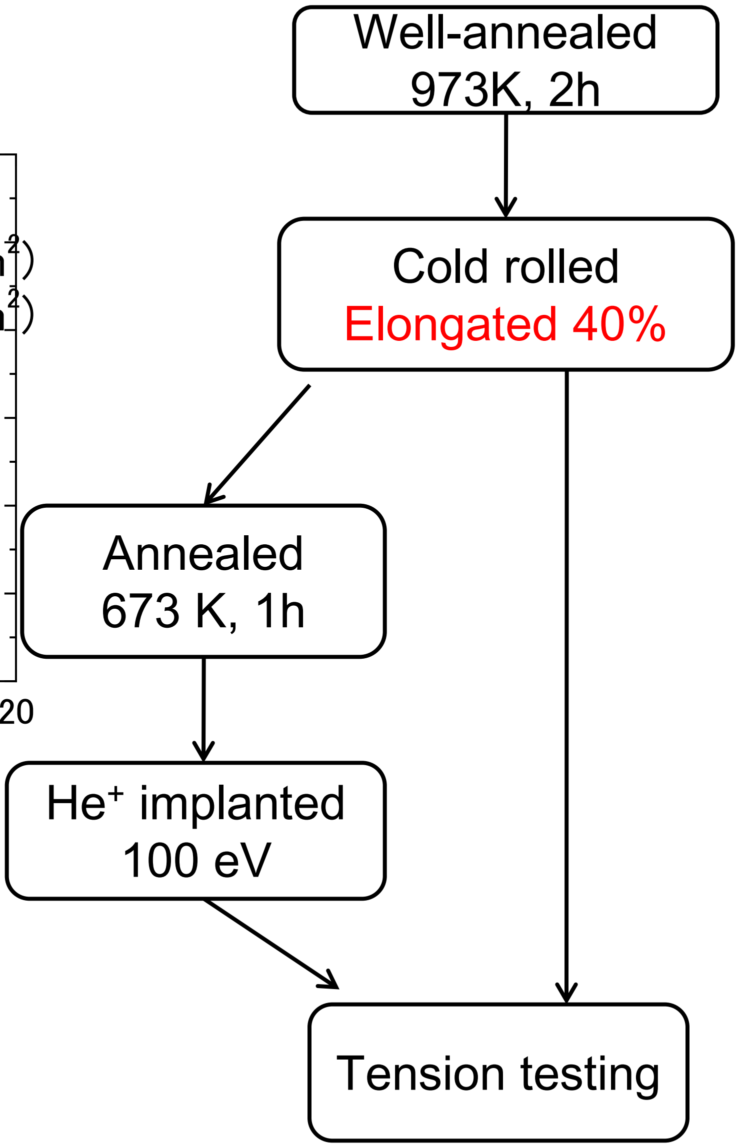


Effect of He on the Tensile Strength of Fe Contained Only Dislocations

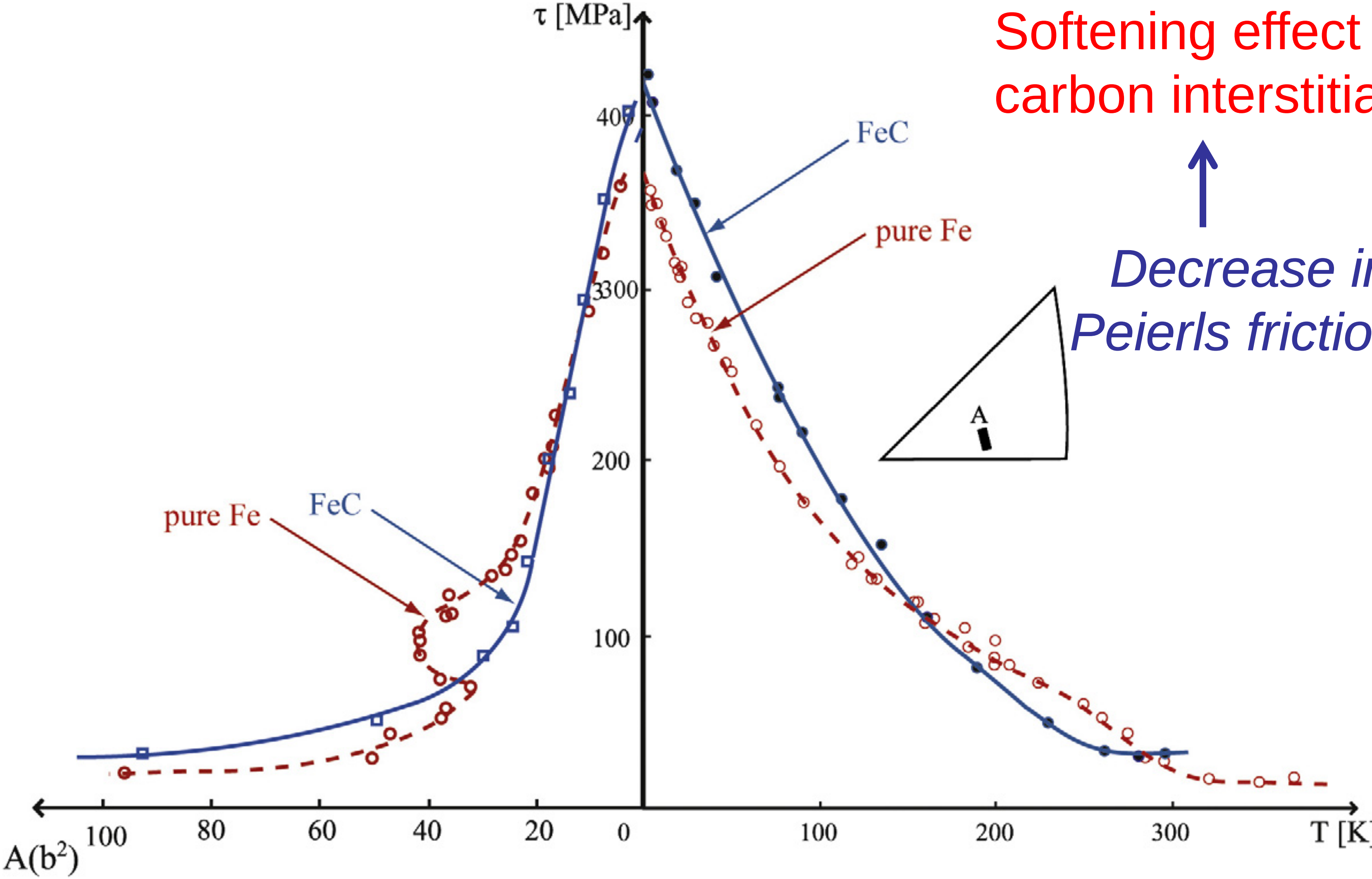
40% Deformation



Mater. Sci. & Eng. A 612 (2014) 41-45.



Yield Stress as Function of Temperature in Fe and FeC Alloy



Softening effect of carbon interstitials

Decrease in the Peierls friction force

E. Kuramoto et al. Scripta Metall, 1979

Conclusions

Mechanical properties of Fe-9Cr alloy, a candidate material for the beam window or the target, have been investigated by high energy proton irradiation.

- Tensile stress decreased after proton irradiation with 11 and 150 MeV, although the irradiation dose was low.
- Interstitial He and H atoms are key factor of softening in Fe-Cr alloy.