

# **Behaviors of structural materials under high energy proton and spallation neutron mixed spectrum irradiation, an overview of STIP Results**

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# Introduction

For developing high power advanced spallation neutron targets, it is necessary to understand:

- (1) the synergistic radiation effects of displacement damage, He and H on the hardening and embrittlement, and
- (2) liquid metal corrosion and embrittlement effects of structural materials (under irradiation).

# Irradiation experiments at SINQ (STIP)

Materials	STIP-I	STIP-II	STIP-III	STIP-IV	STIP-V
Austenitic steels	≤ 12 dpa ≤ 400° C	≤ 20 dpa ≤ 400° C	≤ 20 dpa ≤ 400° C	≤ 20 dpa < 400° C(?)	20 dpa 400° C
FM steels (FMS)	≤ 12 dpa ≤ 360° C	≤ 20 dpa ≤ 400° C	≤ 20 dpa ≤ 800° C	≤ 25 dpa < 600° C(?)	20 dpa 400° C
FMS-ODS		≤ 20 dpa < 400° C	≤ 20 dpa ≤ 800° C	≤ 25 dpa < 600° C(?)	20 dpa 600° C
Ni-alloy	≤ 12 dpa ≤ 400° C	≤ 20 dpa ≤ 400° C			
Al-alloy	≤ 3 dpa ≤ 60° C	≤ 6 dpa ≤ 60° C			
Zr-alloy	≤ 22 dpa < 300° C	≤ 35 dpa < 300° C	≤ 35 dpa < 300° C		
Ta		≤ 30 dpa ≤ 350° C		Yes	
Mo, W, alloys	Yes (no results)	Yes (no results)		Yes	Yes
SiCf/SiC, CMC		Yes (to be tested soon)		Yes (to be tested soon)	Yes 800° C

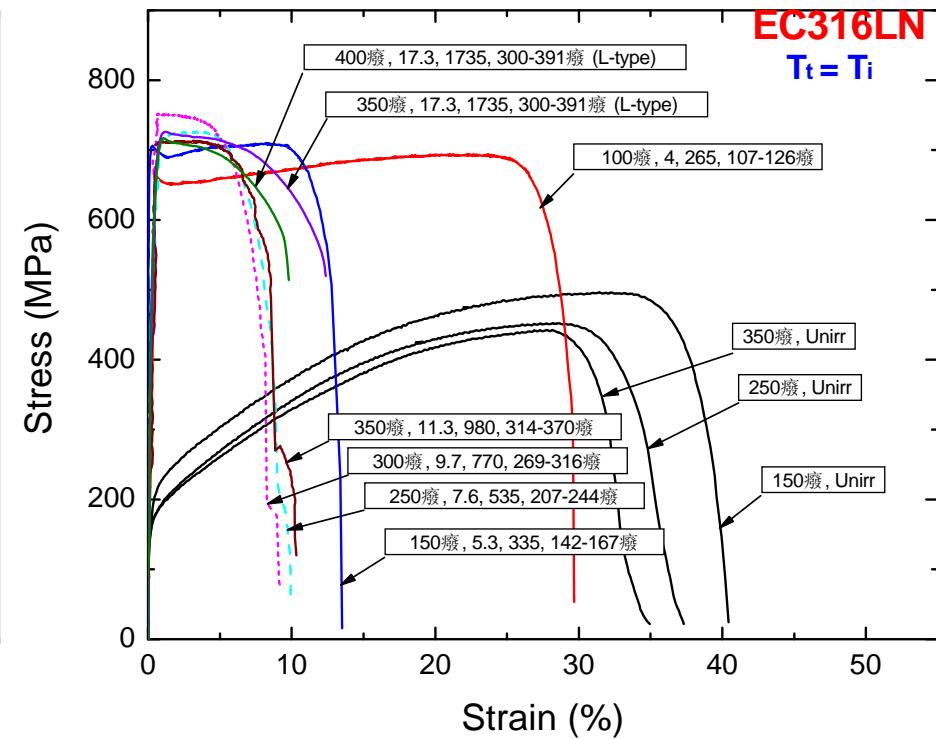
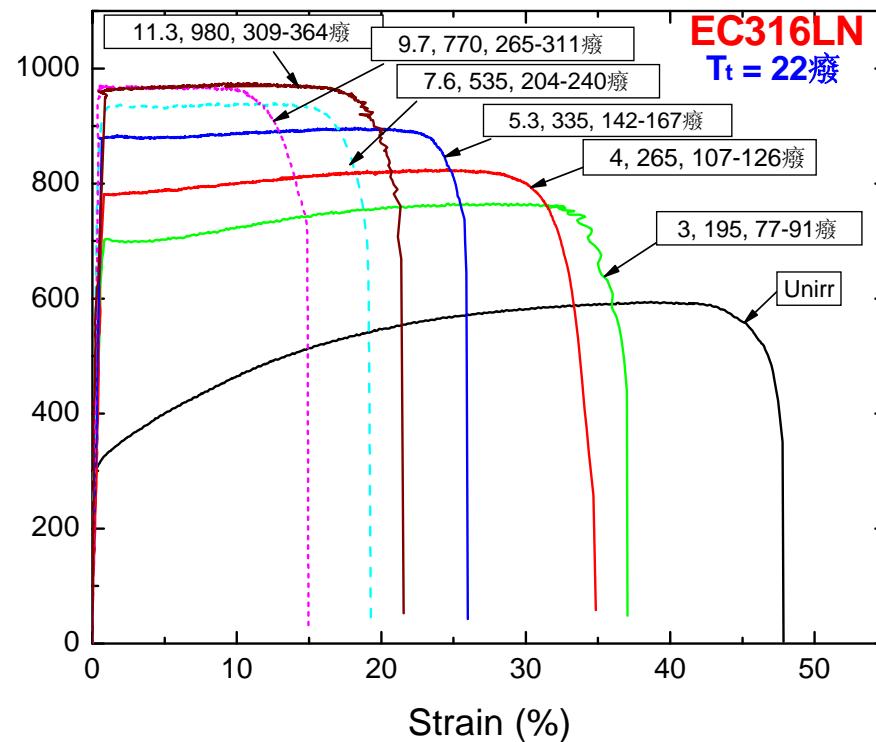
PIE has been performed on the specimens under irradiation conditions marked in red colour.

# Irradiation induced effects in austenitic steels

**SS 316L, SS316LN, SS 316F, JPCA  
in SA, CW and weld conditions**

# Austenitic steels

## SS316LN

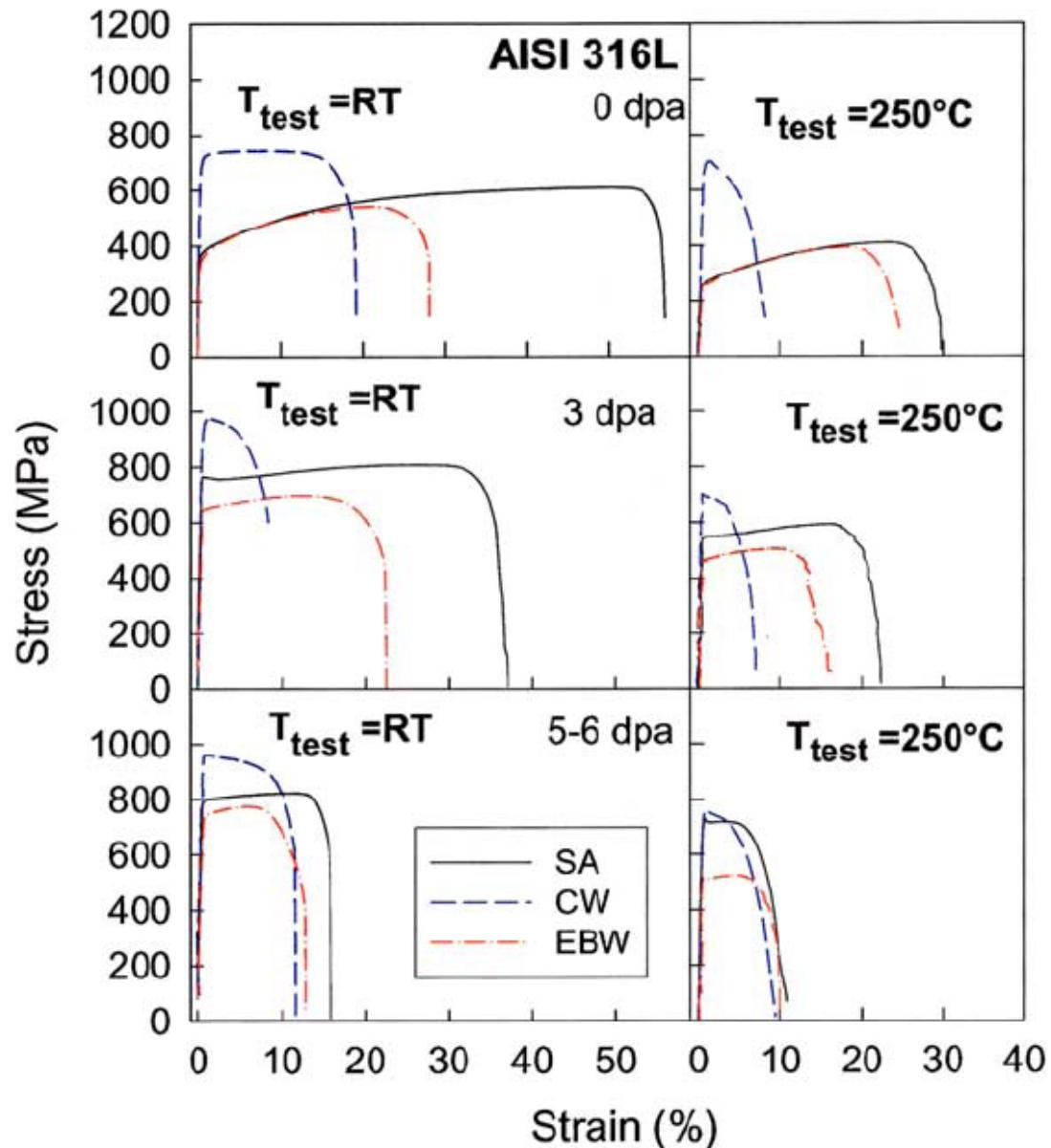


Y. Dai et al. / JNM, 377 (2008) 109

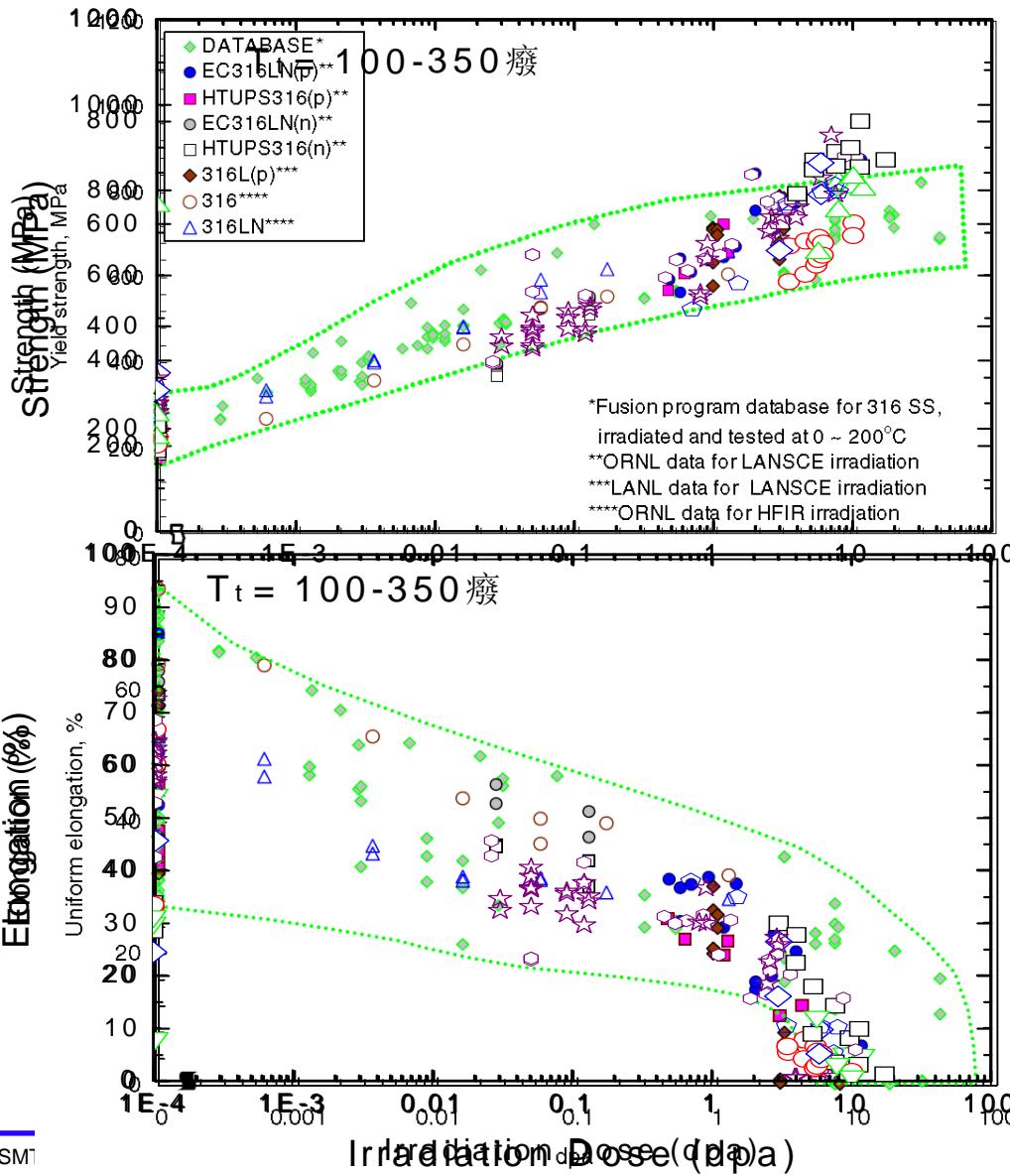
# Austenitic steels

SS 316L

J. Chen et al. / JNM,  
343 (2005) 236



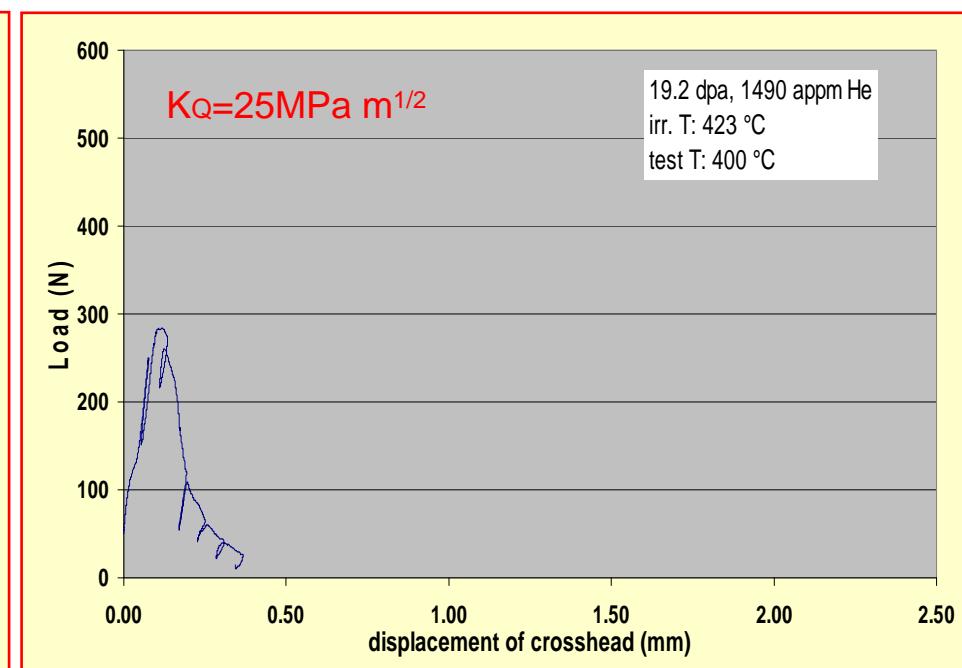
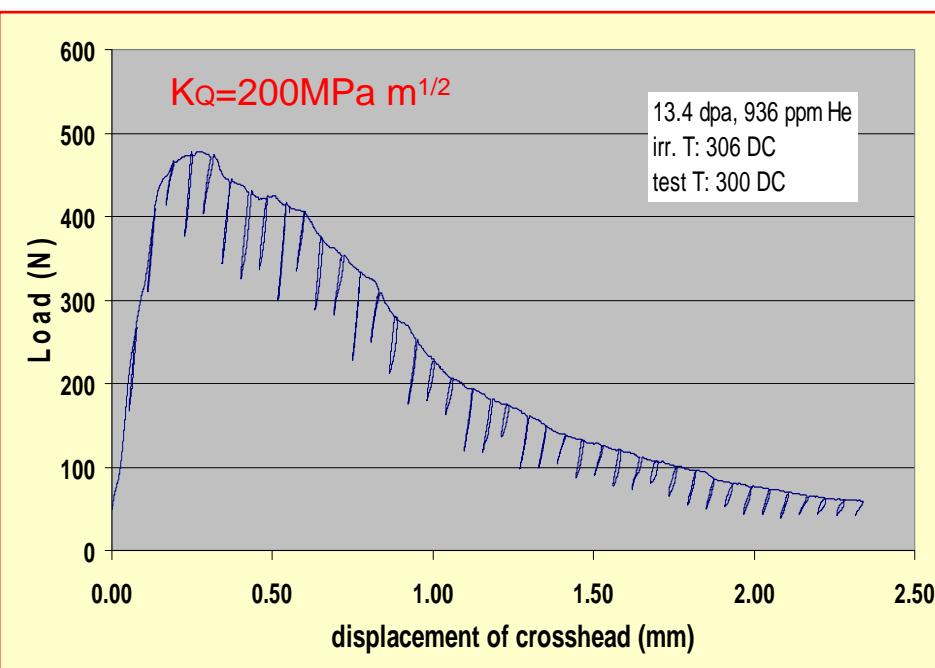
# Austenitic steels



Austenitic steels irradiated in spallation targets show greater hardening and embrittlement effects, particularly at higher doses ( $>\sim 10$ dpa)

Mansur, JNM, 356 (2006) 1.

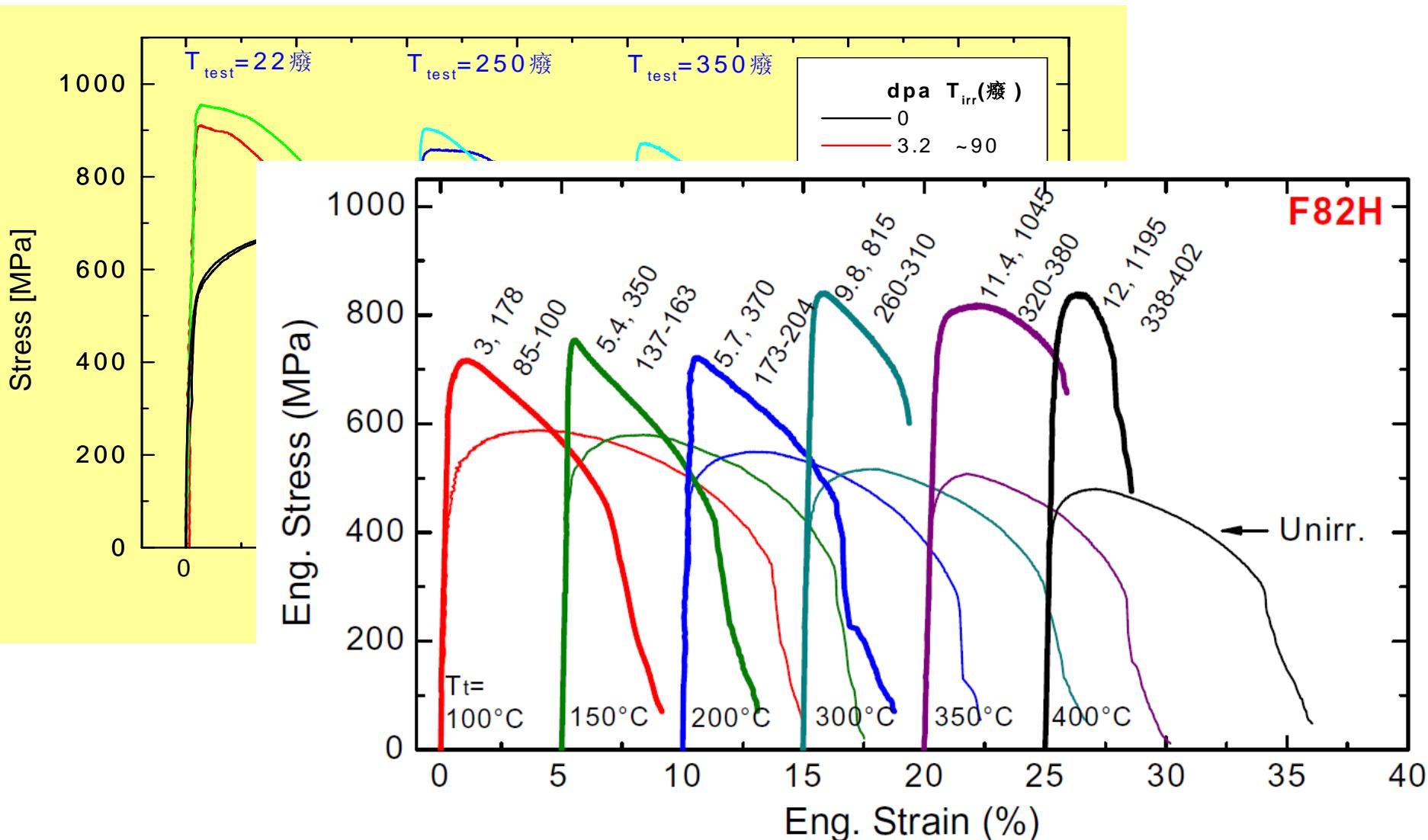
# Austenitic steels



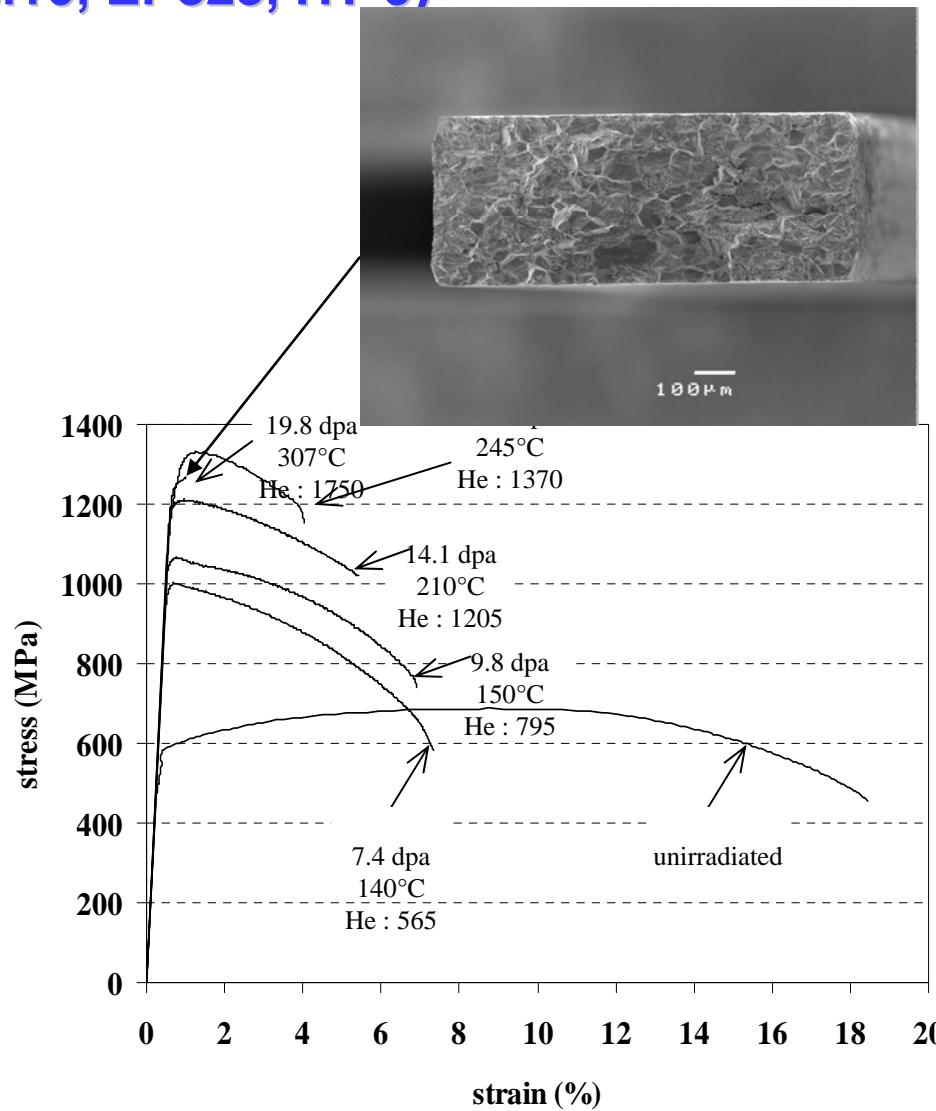
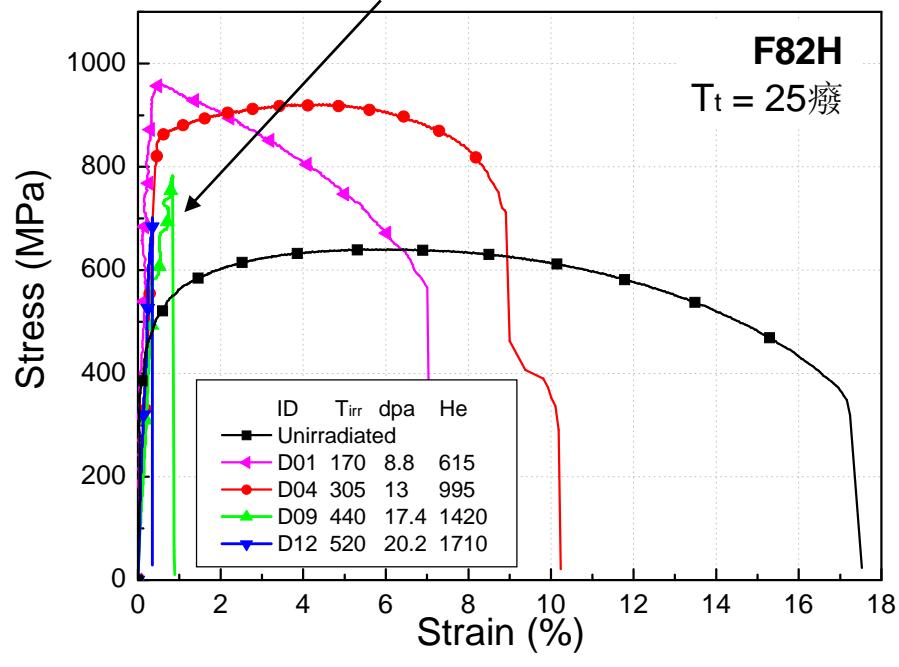
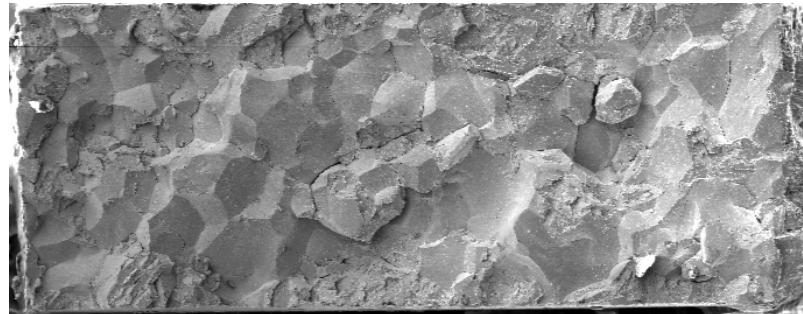
# Irradiation induced effects in ferritic/martensitic steels

**T91, T92, EM10, HT-9, EP823, MANET, F82H, Optimax –A & -C,  
Optifer-V & -IX, Eurofer-97....  
in N&T, EBW, TIG-W conditions**

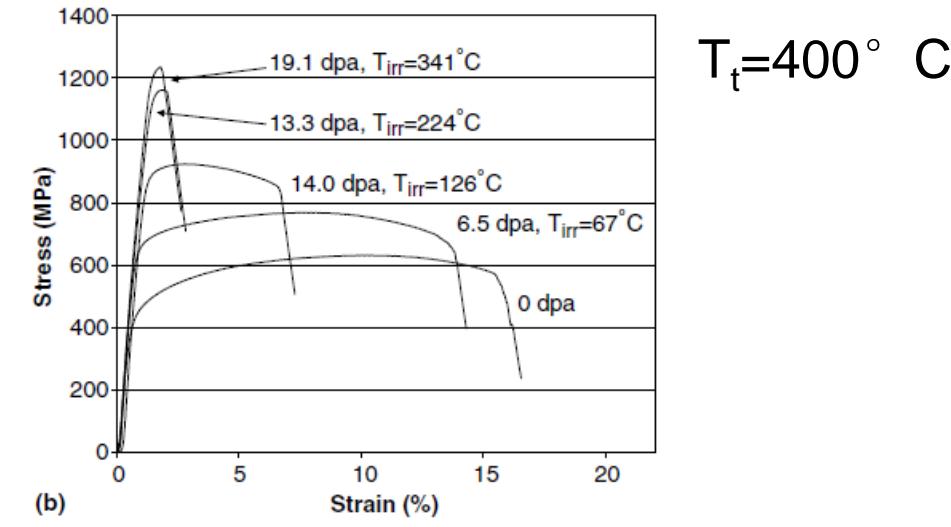
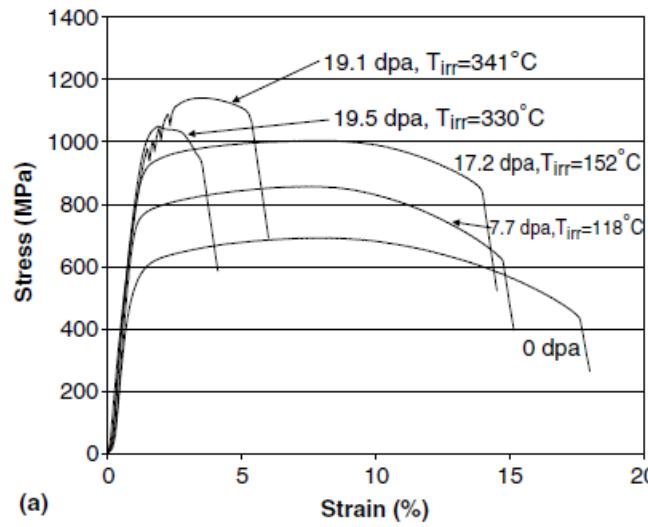
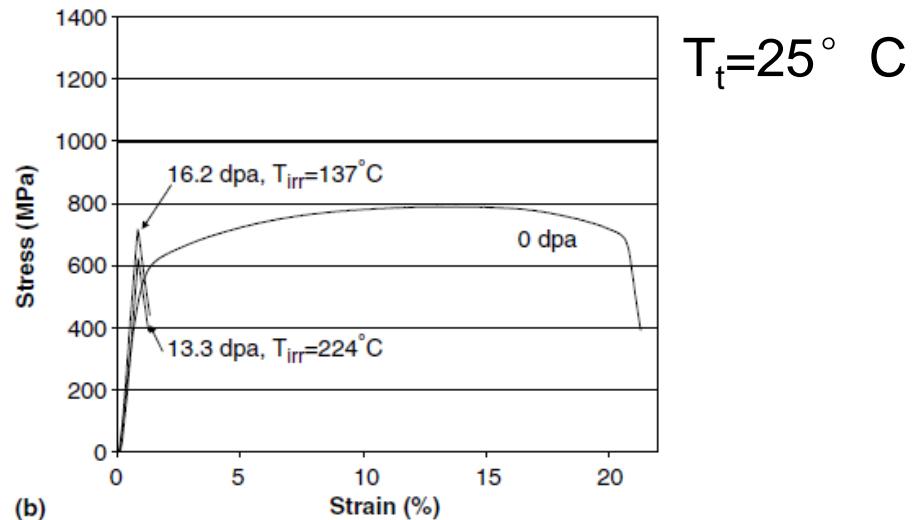
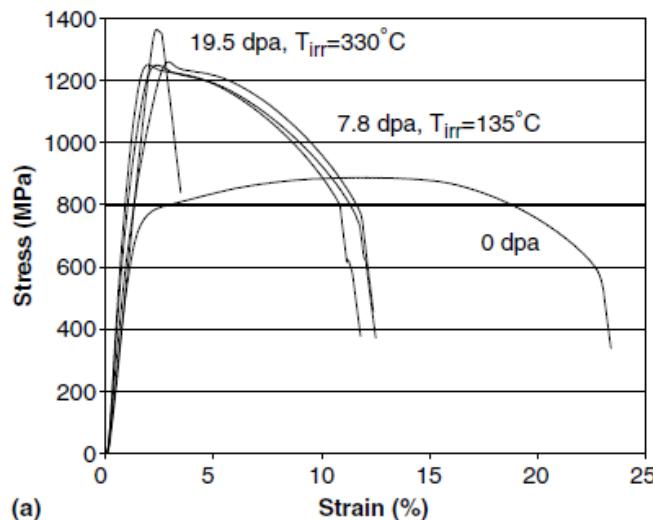
# Tensile properties of FMS after irradiation



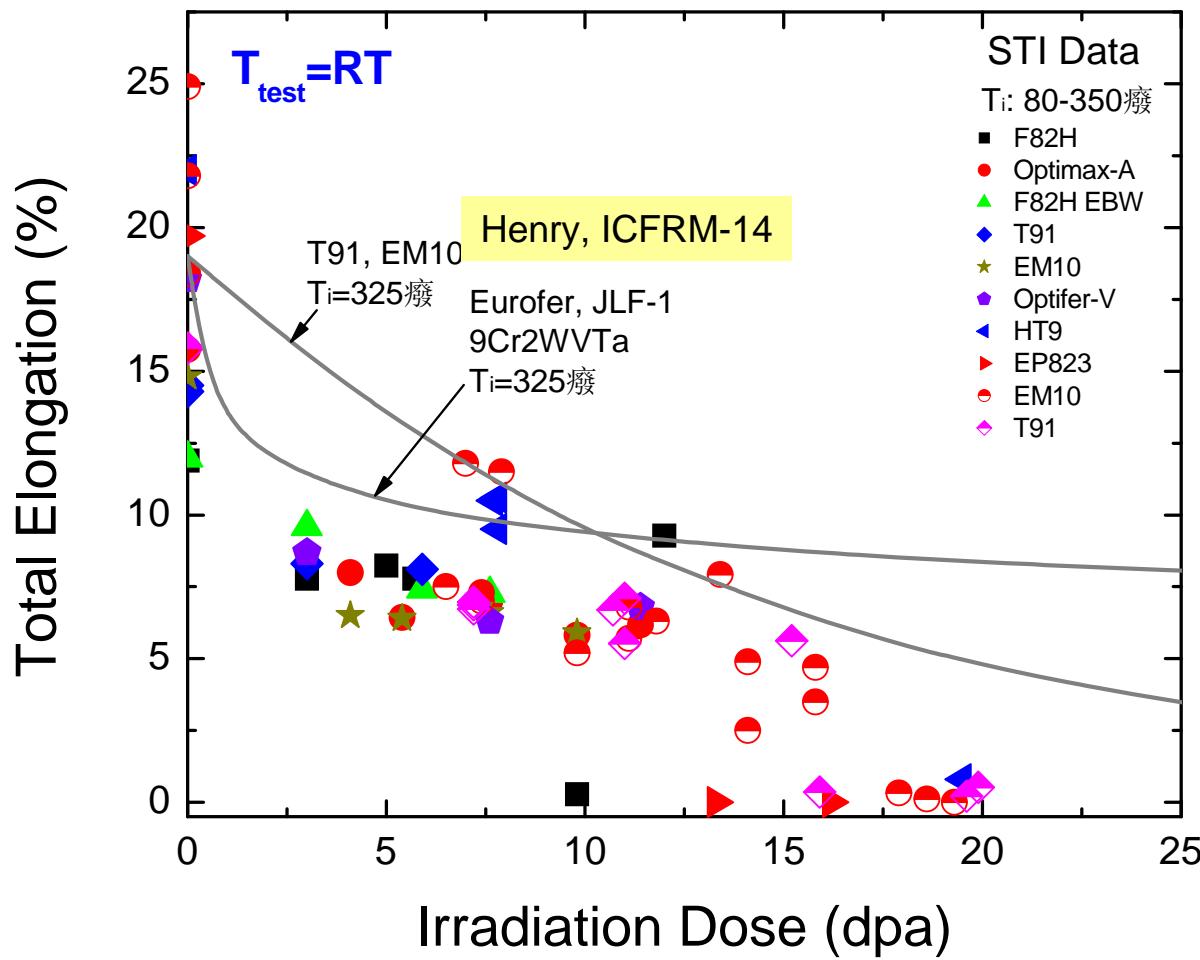
- ☐ Brittle fracture observed at doses  $\sim 10$  dpa (800 appm He) in different FM steels (F82H, EM10, EP823, HT-9)



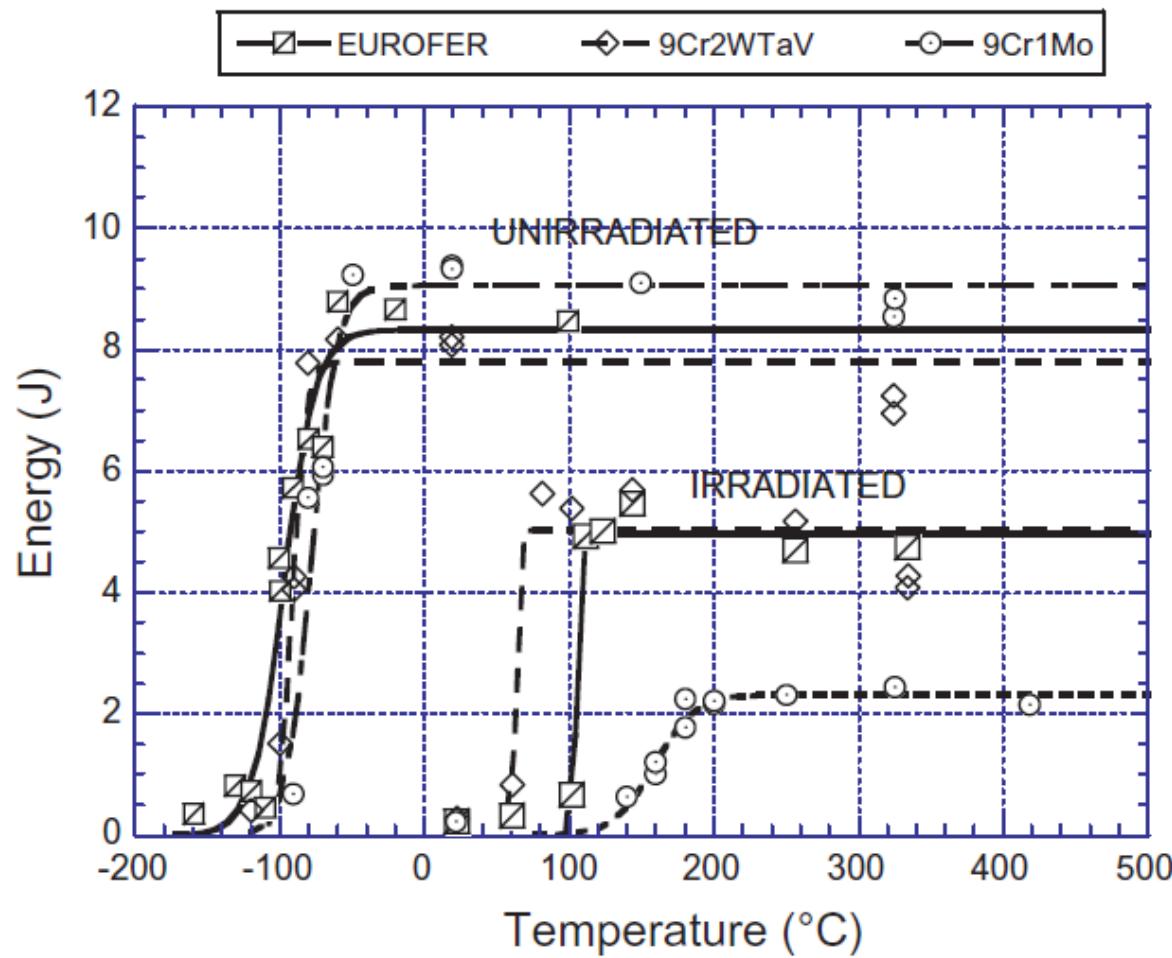
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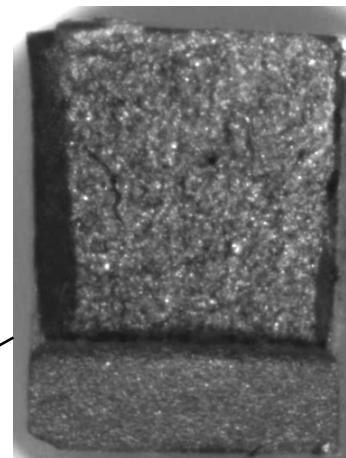
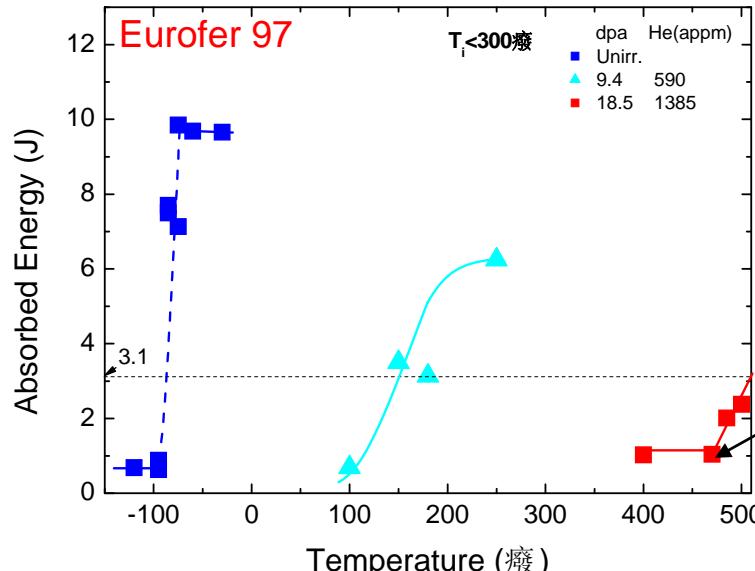
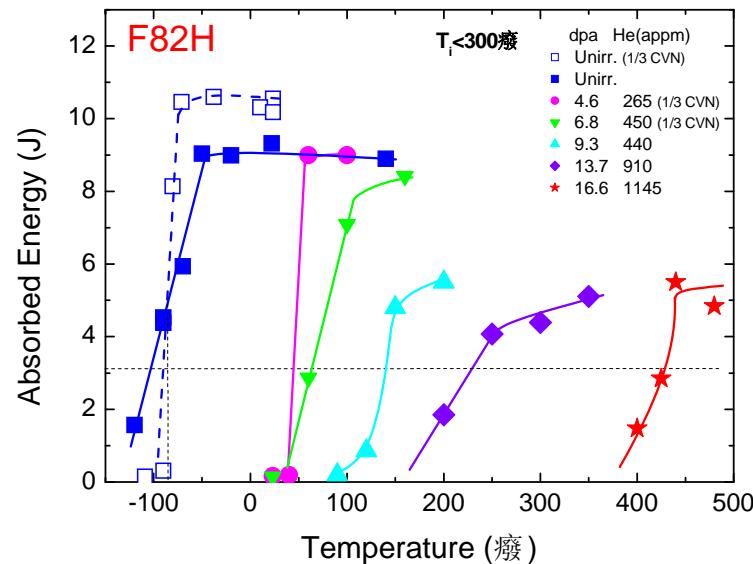
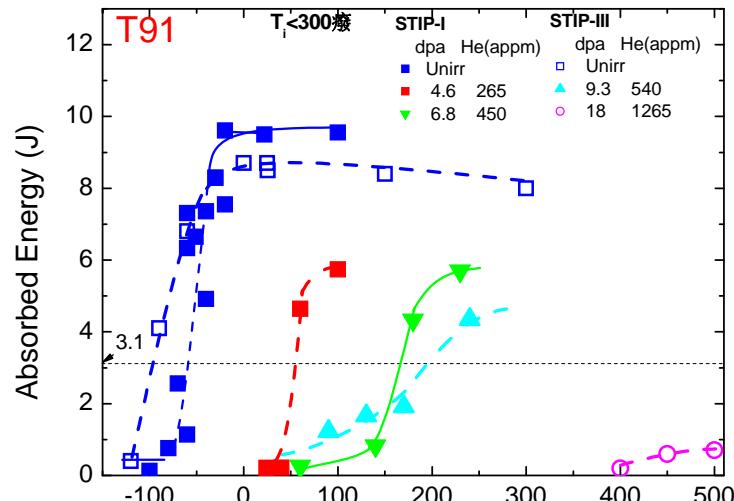
# DBTT shift after N-irradiation



Alamo et al.  
JNM 367–370  
(2007) 54

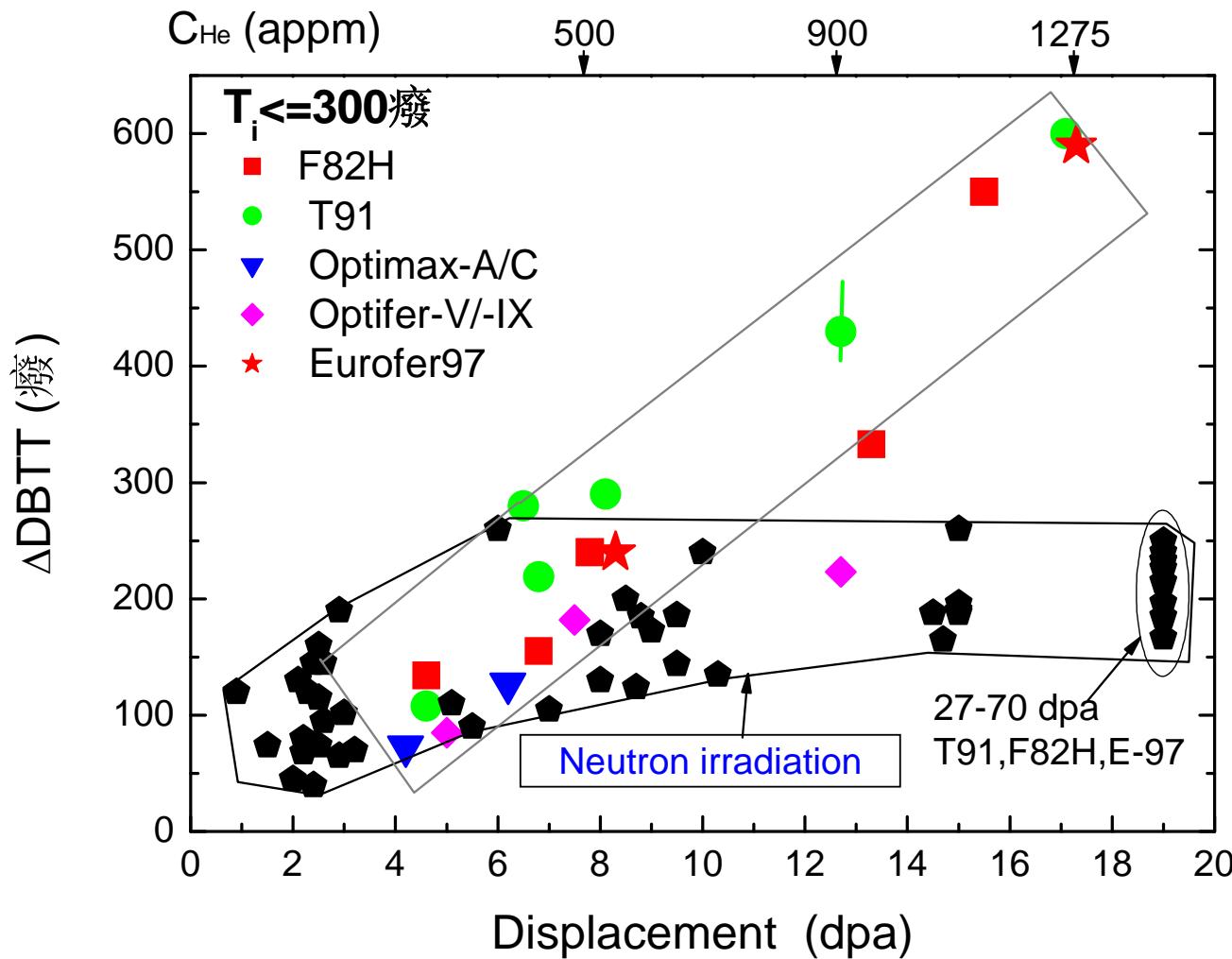
Fig. 3. Comparison of impact properties of EUROFER, 9Cr2WTaV and 9Cr1Mo steels in the unirradiated condition and after irradiation in BOR60 reactor at 325 °C for 32–42 dpa.

# DBTT shift of T91 after P-N irradiation



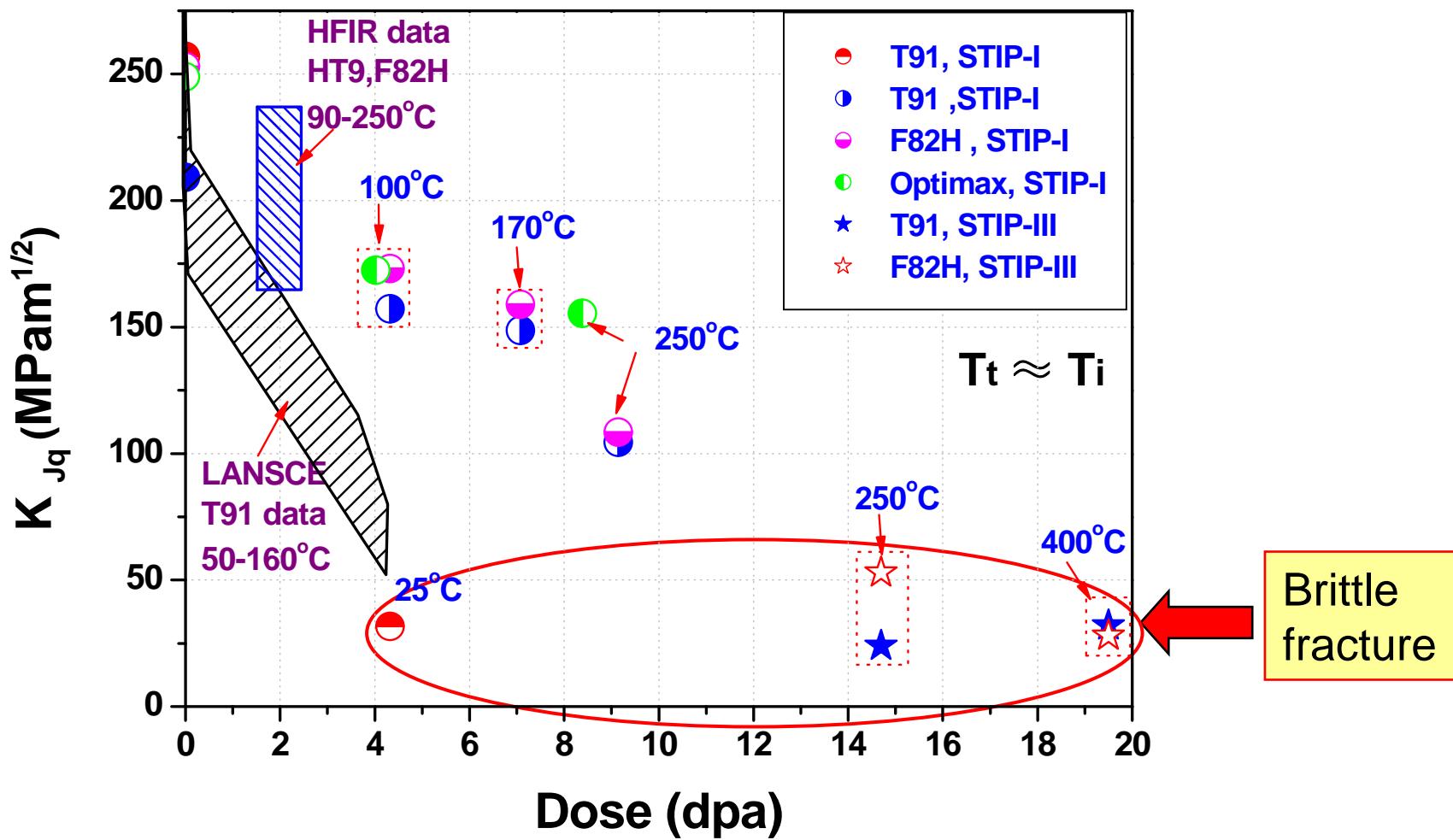
SEM to be  
done soon.

# FM steels – DBTT shift



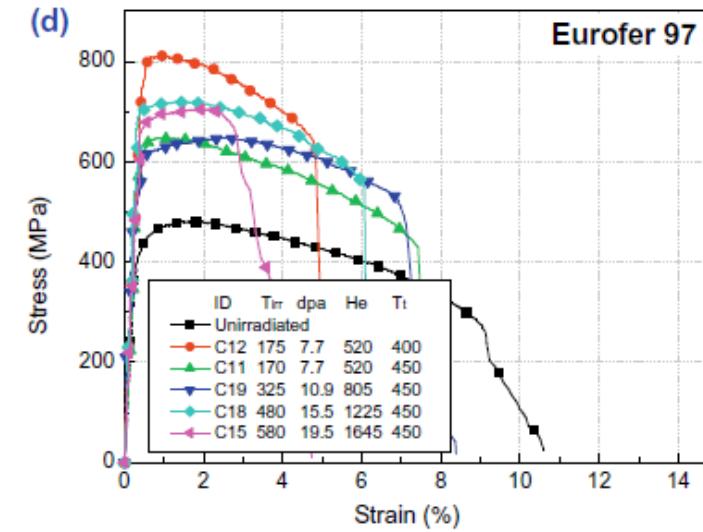
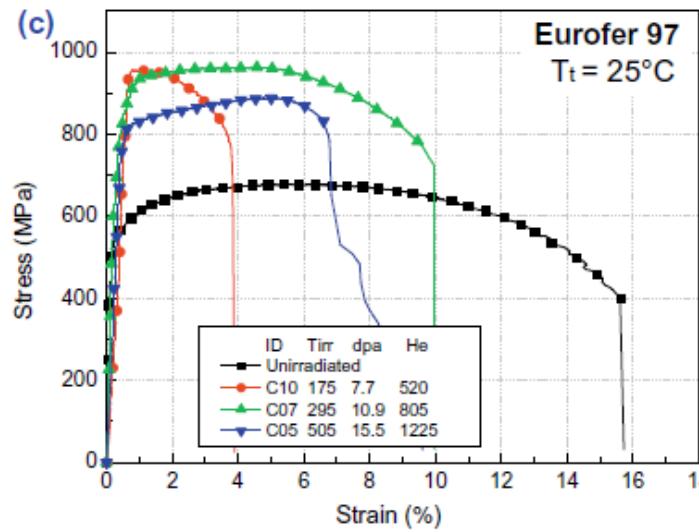
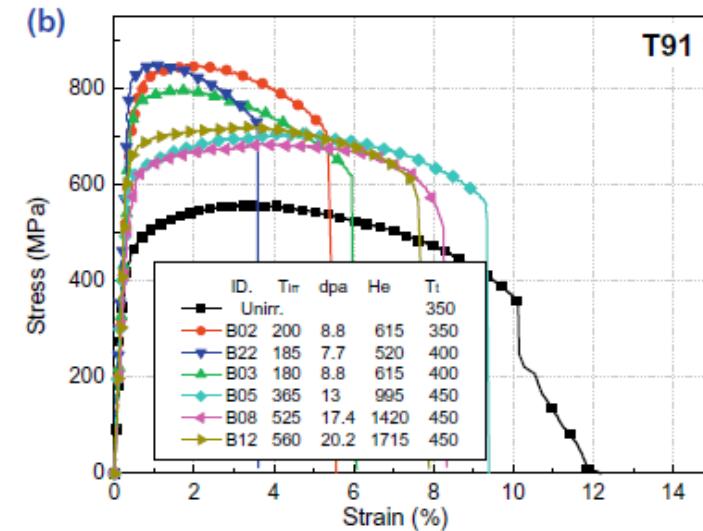
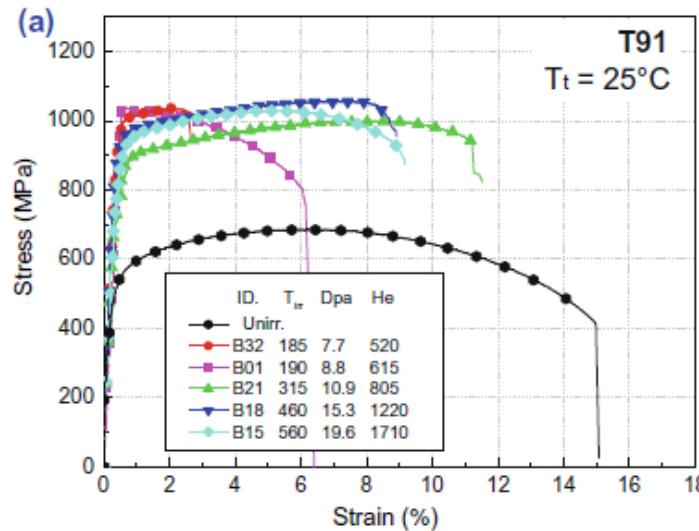
Neutron irradiation data from Klueh, Hu, Alamo, Gaganidze, van der Schaaf, Rensman, Lucon .....

# FM Steels



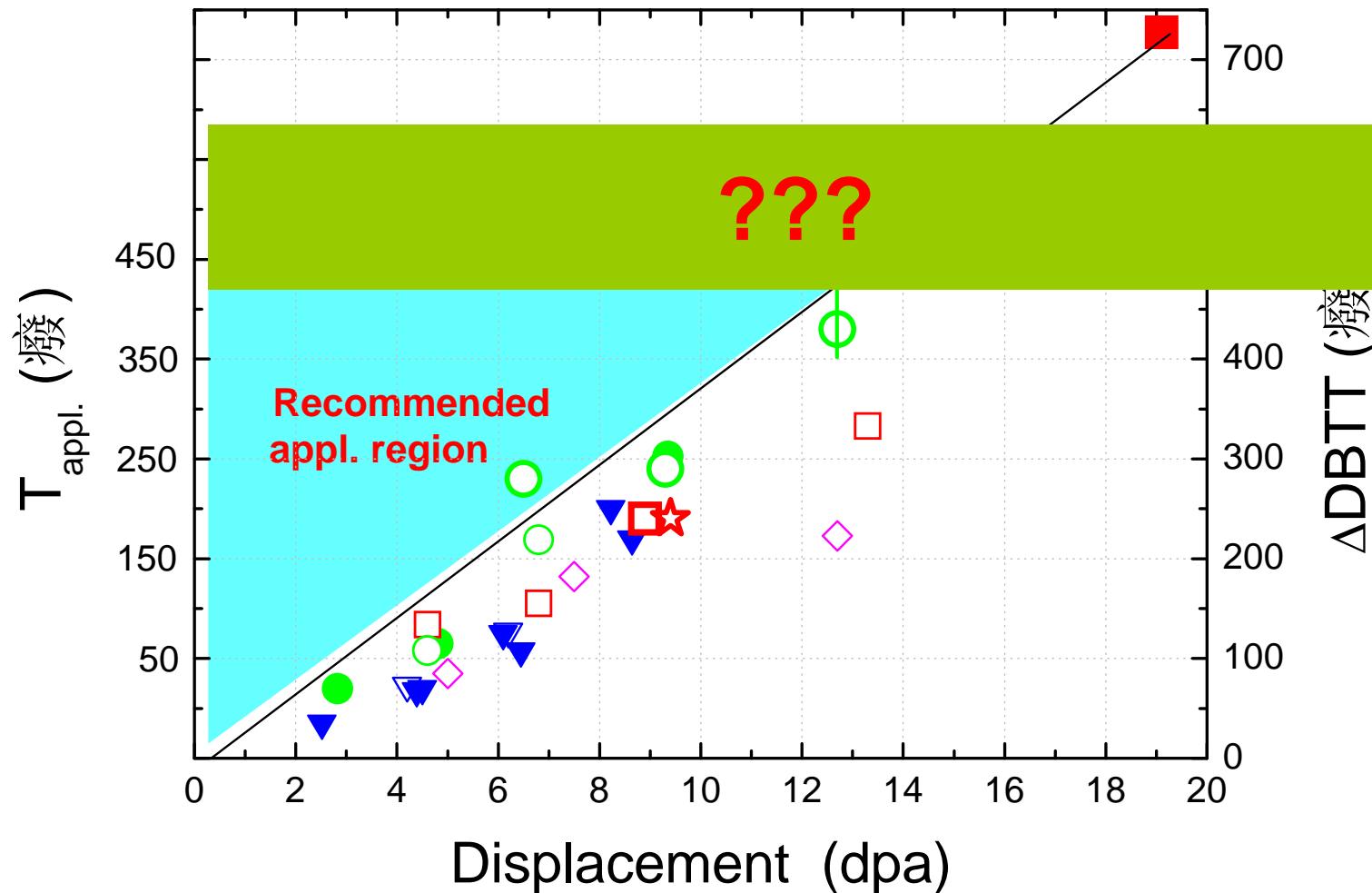
LANSCE data: Maloy et al. JNM 296 (2001)

HFIR data: A. F. Rowcliffe, et al. JNM 258-263 (1998) 1275

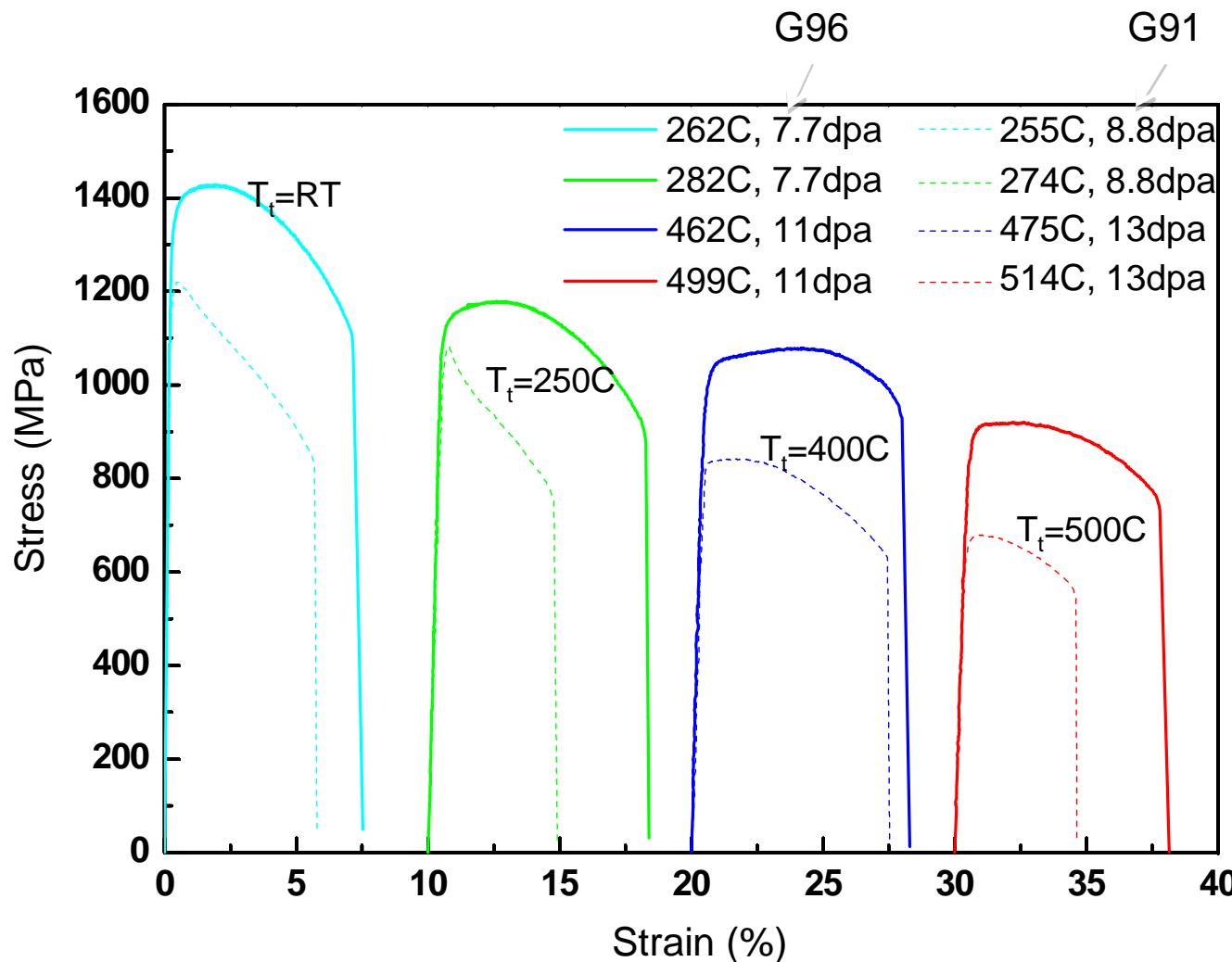
Less embrittlement at higher irradiation temperatures ( $>400^{\circ}\text{ C}$ )

Tong's presentation

## Dose and T range for FM steels for spallation target applications

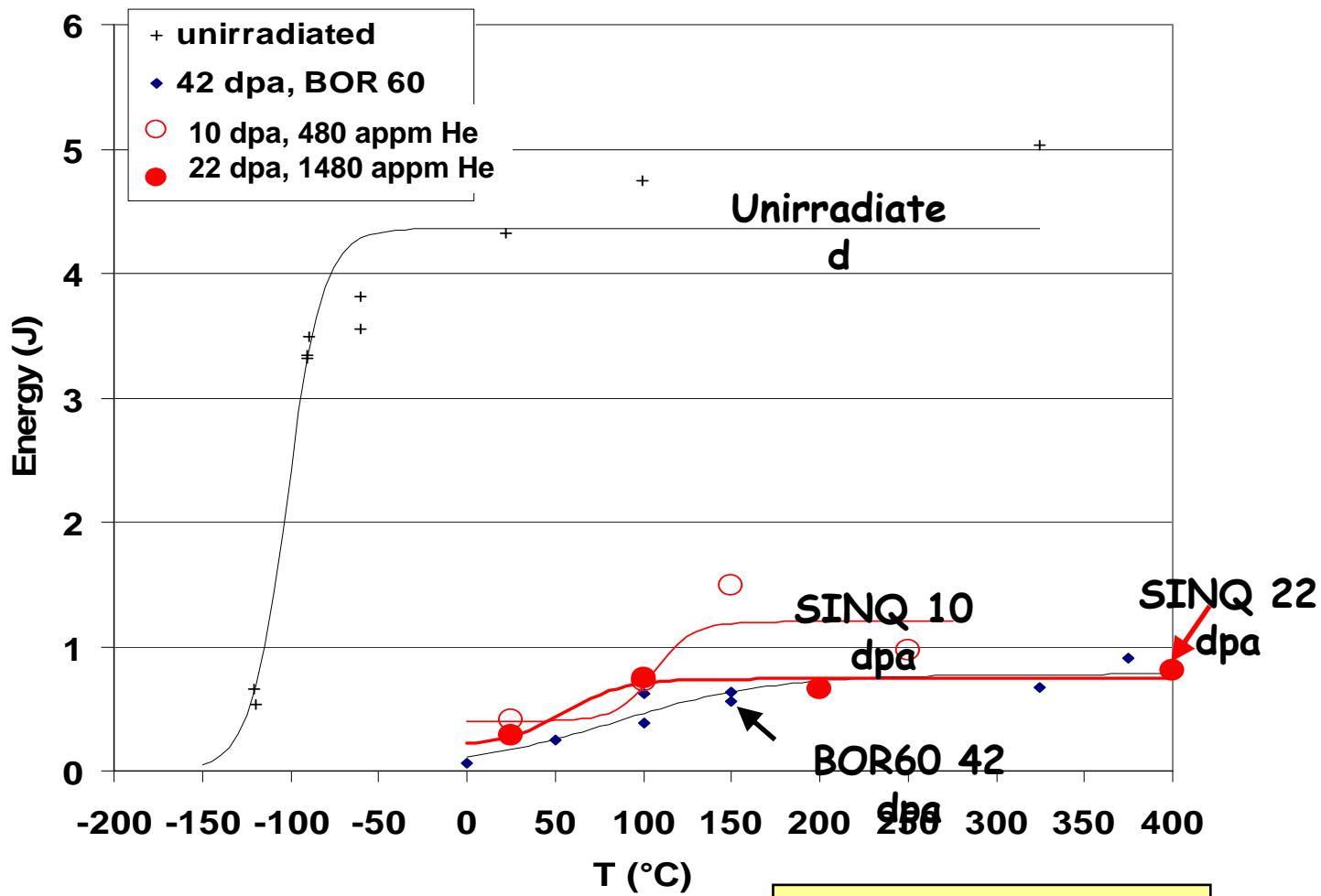


# Results of ODS steels



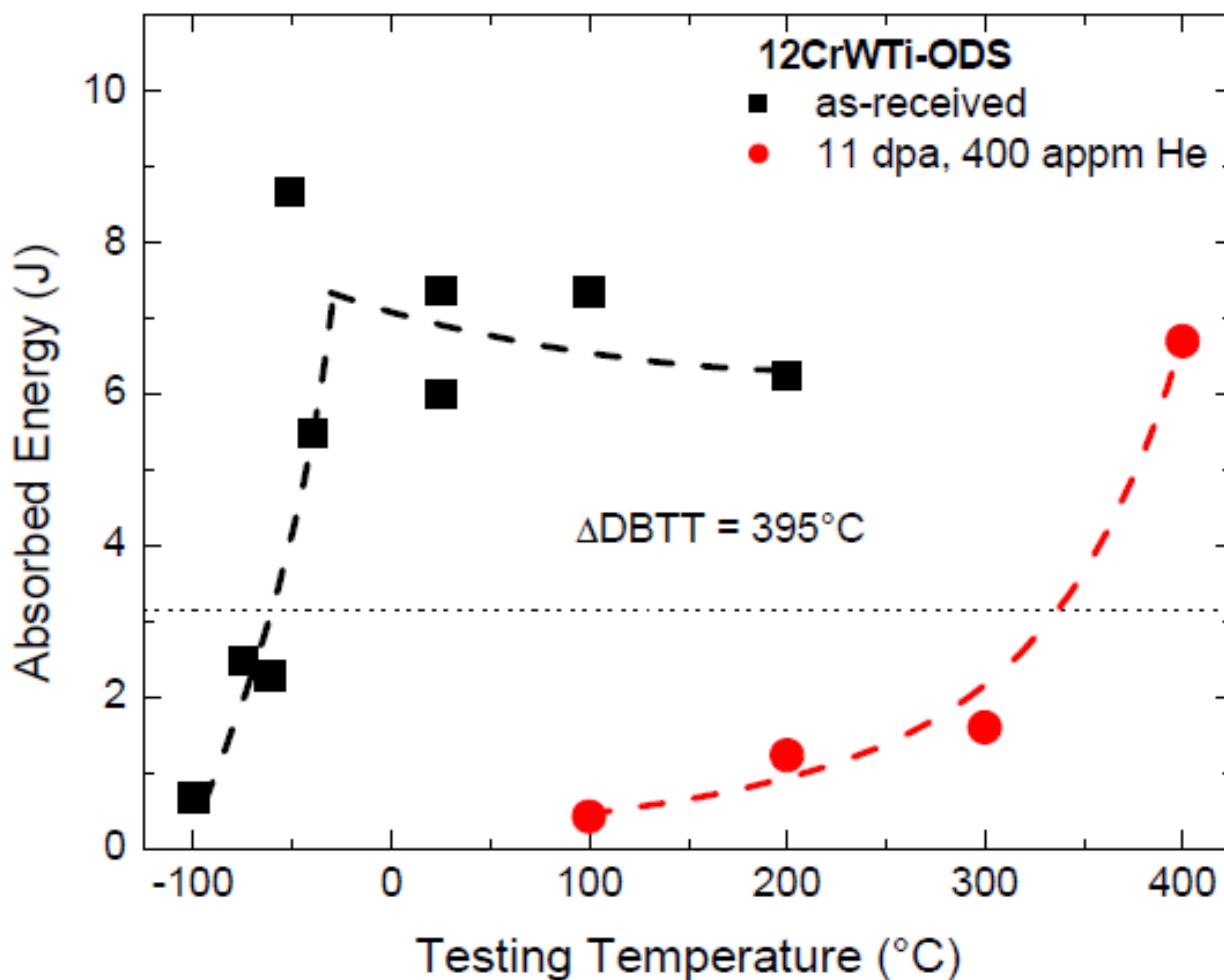
# Results of ODS steels

## MA957: Impact Properties



Henry's presentation

# Results of ODS steels



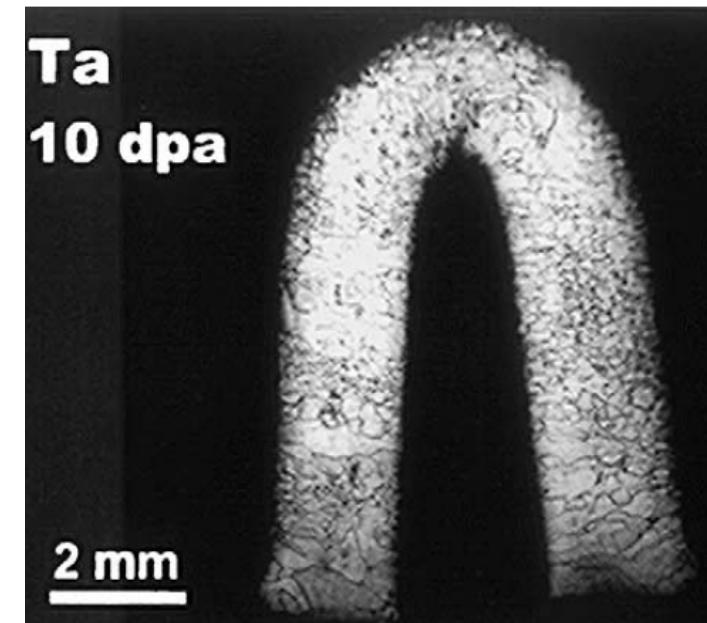
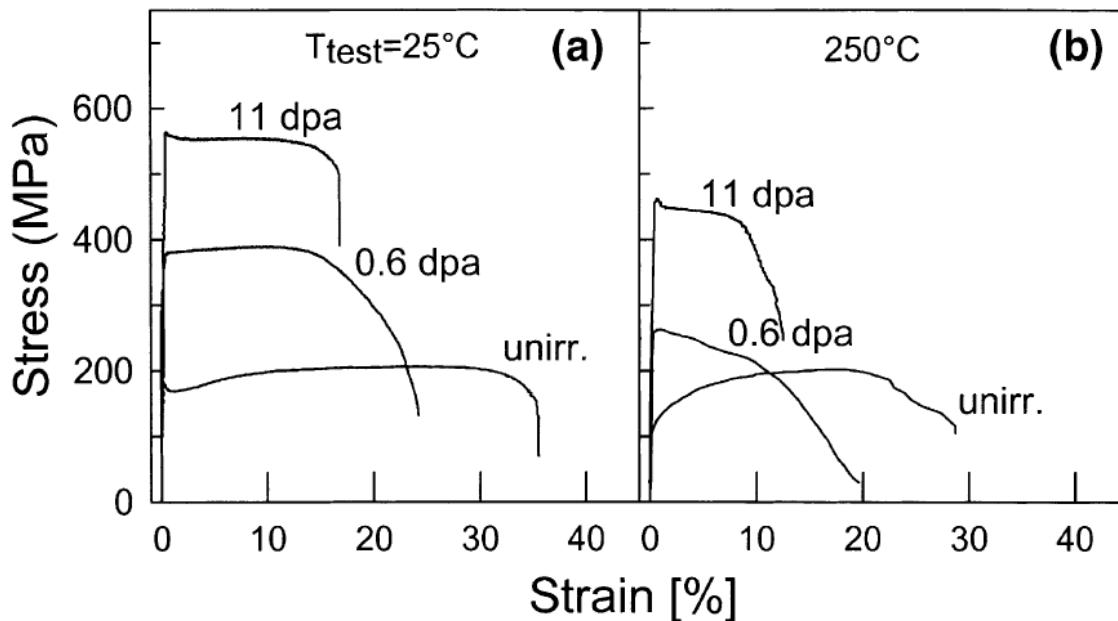
Xu's presentation

# Irradiation induced effects in pure Ta

# Pure Tantalum (Ta)

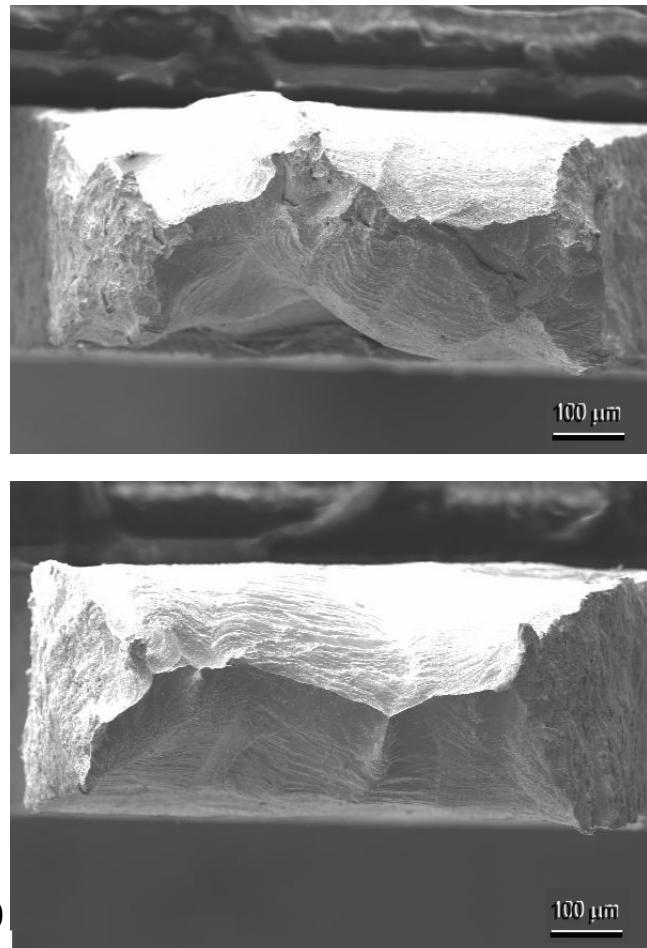
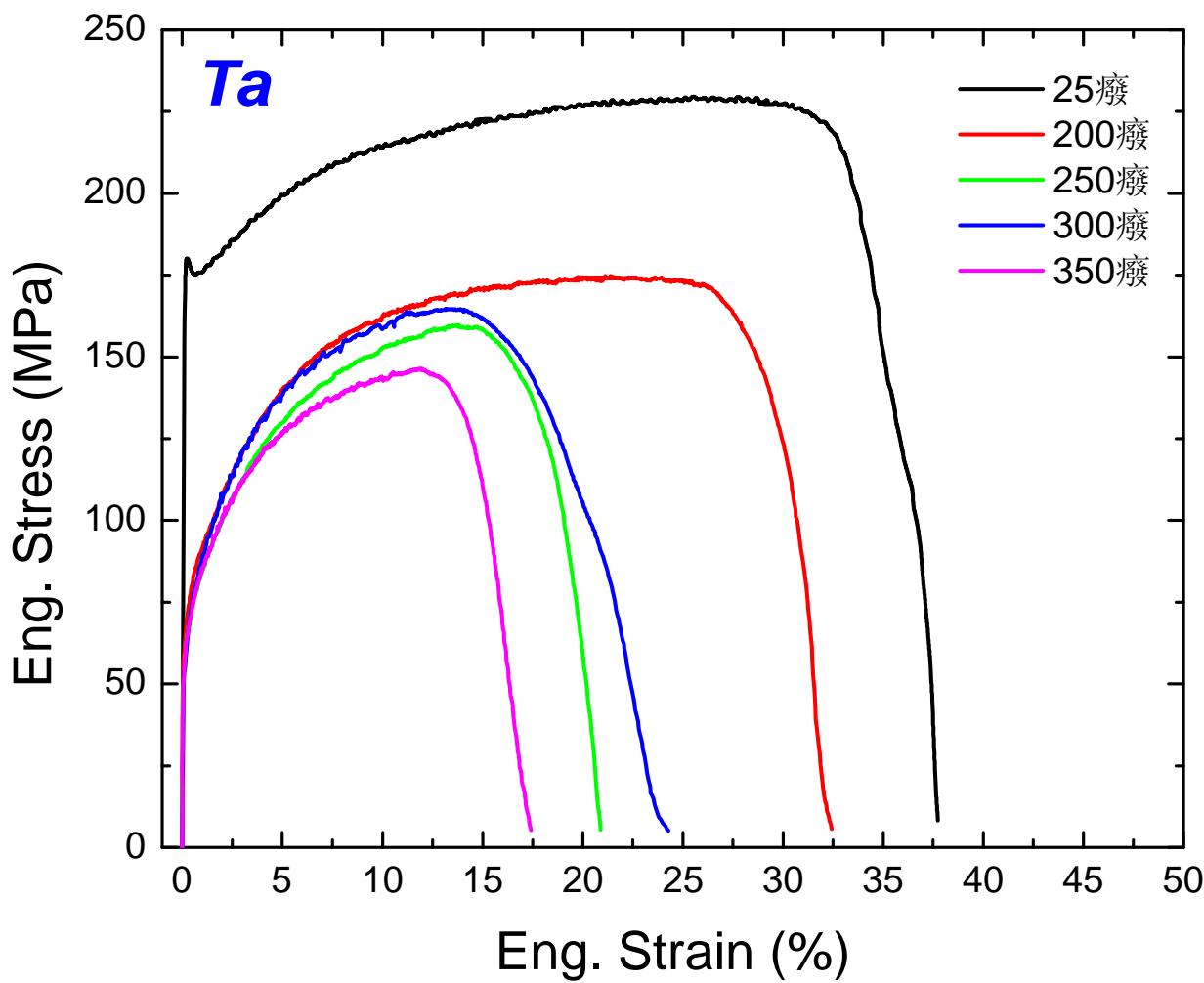
Ta from ISIS target

Chen et al, JNM 318(2003)56.



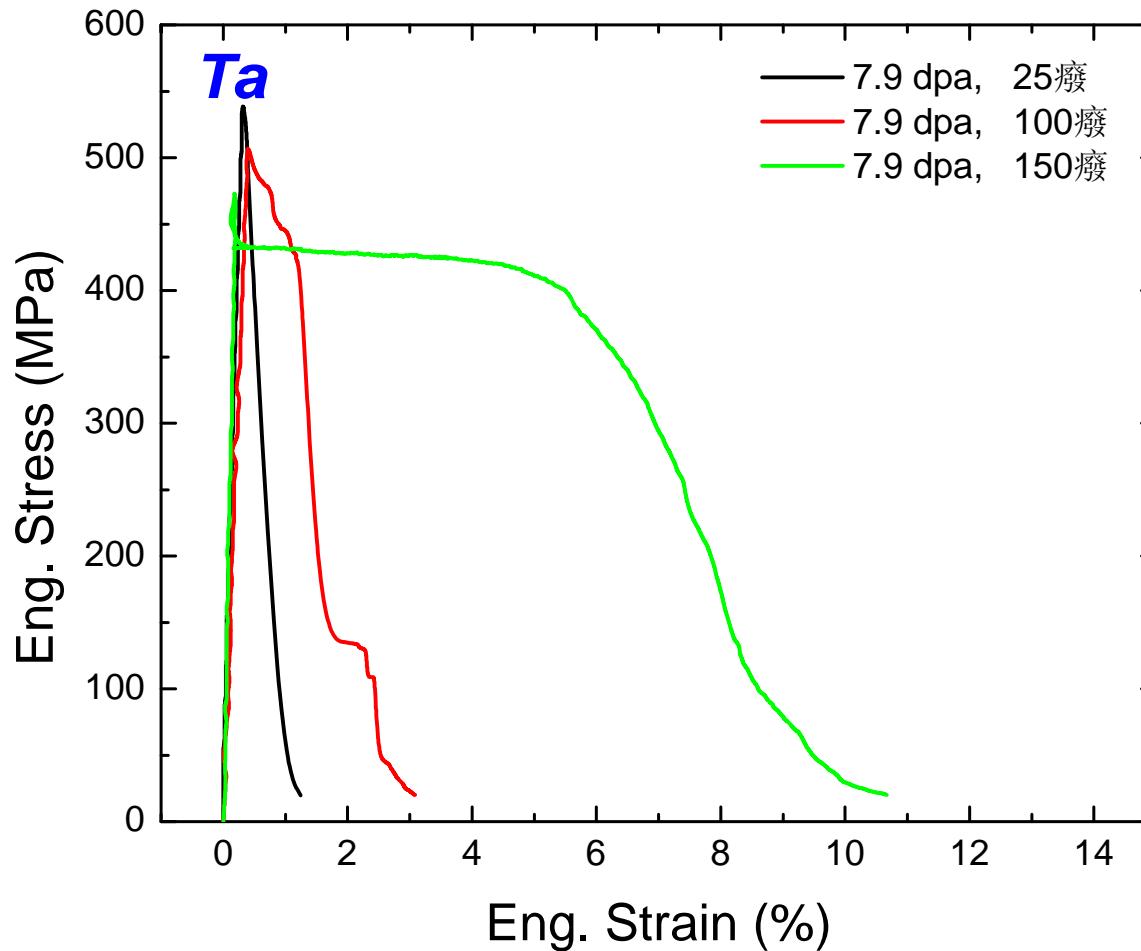
# Pure Tantalum (Ta)

Tensile stress-strain curves of unirradiated Ta specimens



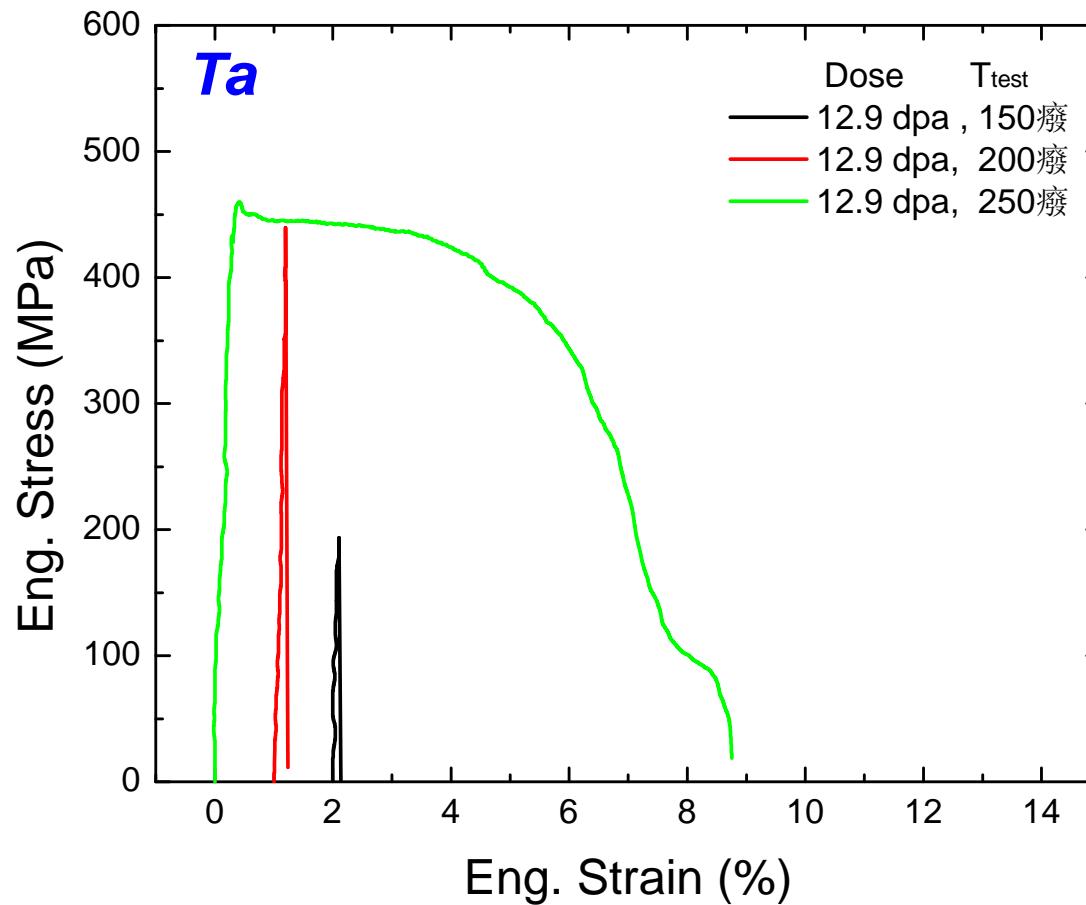
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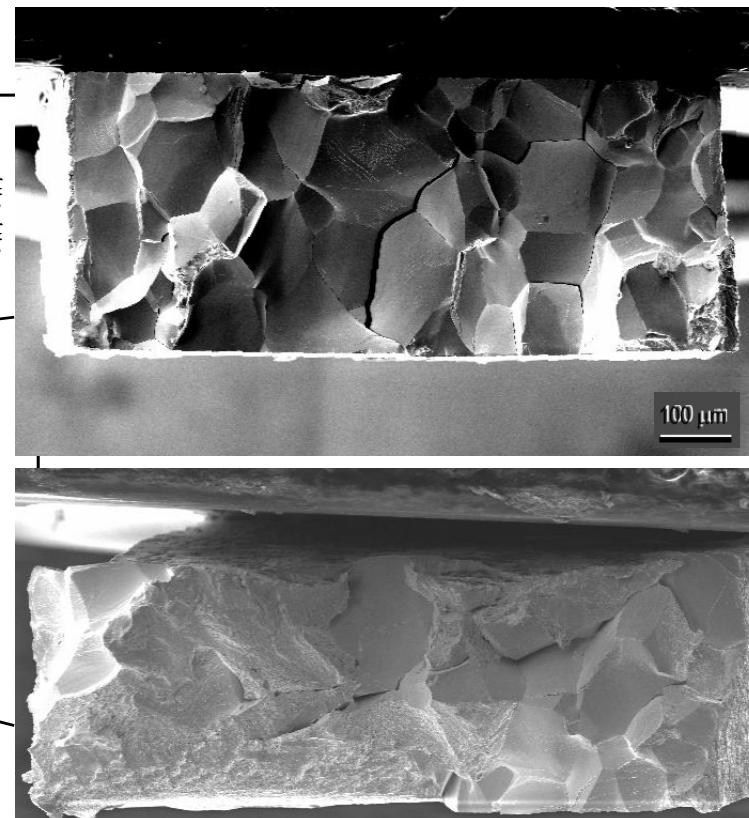
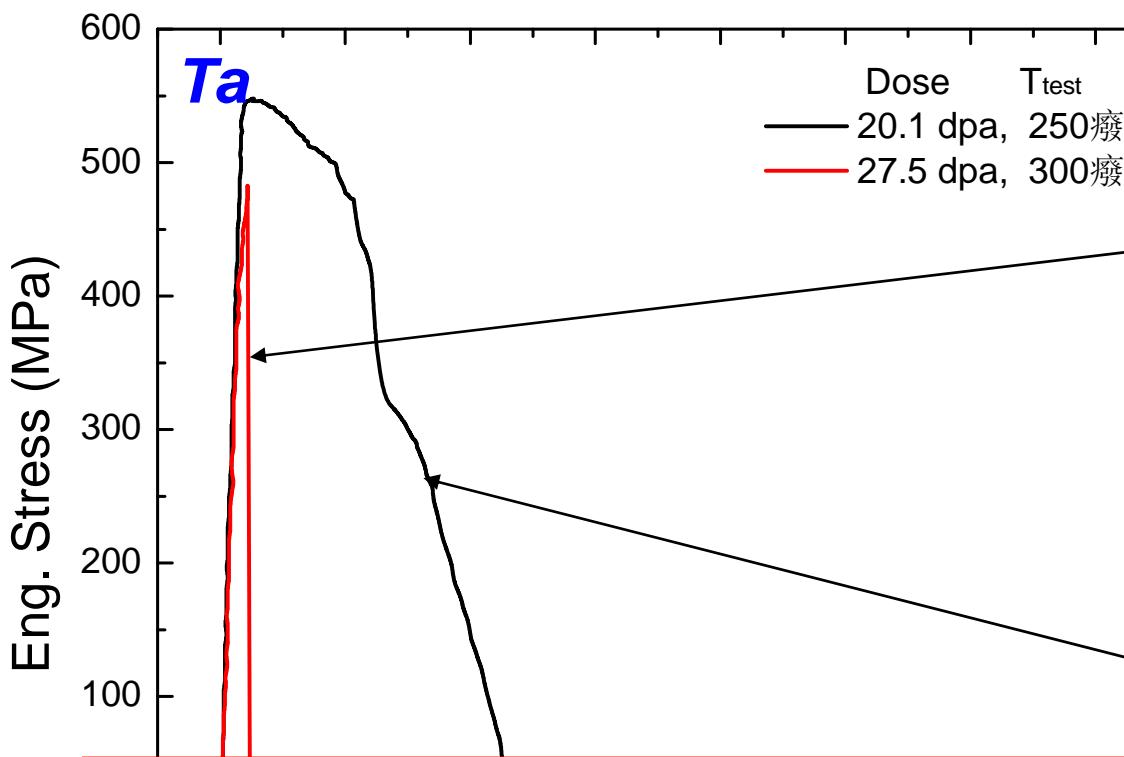
# Pure Tantalum (Ta)

Tensile stress-strain curves of unirradiated Ta specimens



# Pure Tantalum (Ta)

Tensile stress-strain curves of unirradiated Ta specimens



The main difference between STIP and ISIS samples might be the H content. The STIP Ta samples showed very high H content (35000 appm H @ 17 dpa).

# Summary

-  A rather comprehensive materials database for spallation target applications has been established by conducting irradiation experiments in SINQ targets and PIE.
-  In the low temperature regime (<350° C, temperature range for all existing spallation targets), at high concentrations (>~500 appm), He can induce significant hardening and embrittlement effects. Fracture toughness may decrease to below the lower shelf value. DBTT of FM steels may easily increase to the operation temperature of a target.
-  Irradiation effects on Ta needs further studied in order to understand He and H effects.

# Thank You !