Yong Dai :: Laboratory for Nuclear Materials :: Paul Scherrer Institut

Irradiation studies for spallation target applications

BRIDGE 2023, October 18, 2023, PSI

PAUL SCHERRER INSTITUT

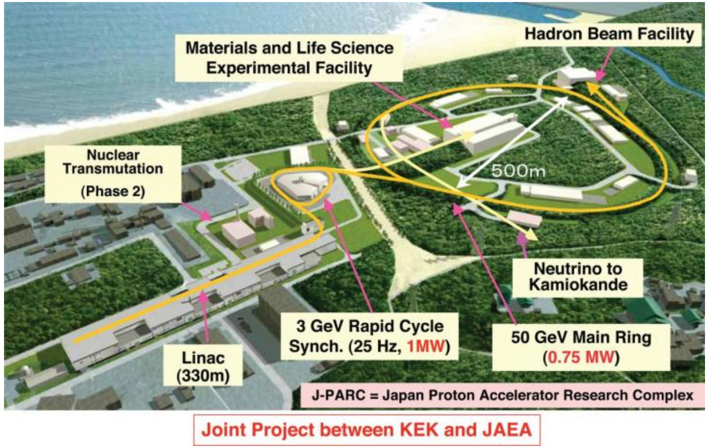
Table of content

- Introduction of STIP - SINQ Target Irradiation Program
- Characteristics of STIP
- STIP for spallation target applications

Introduction of STIP

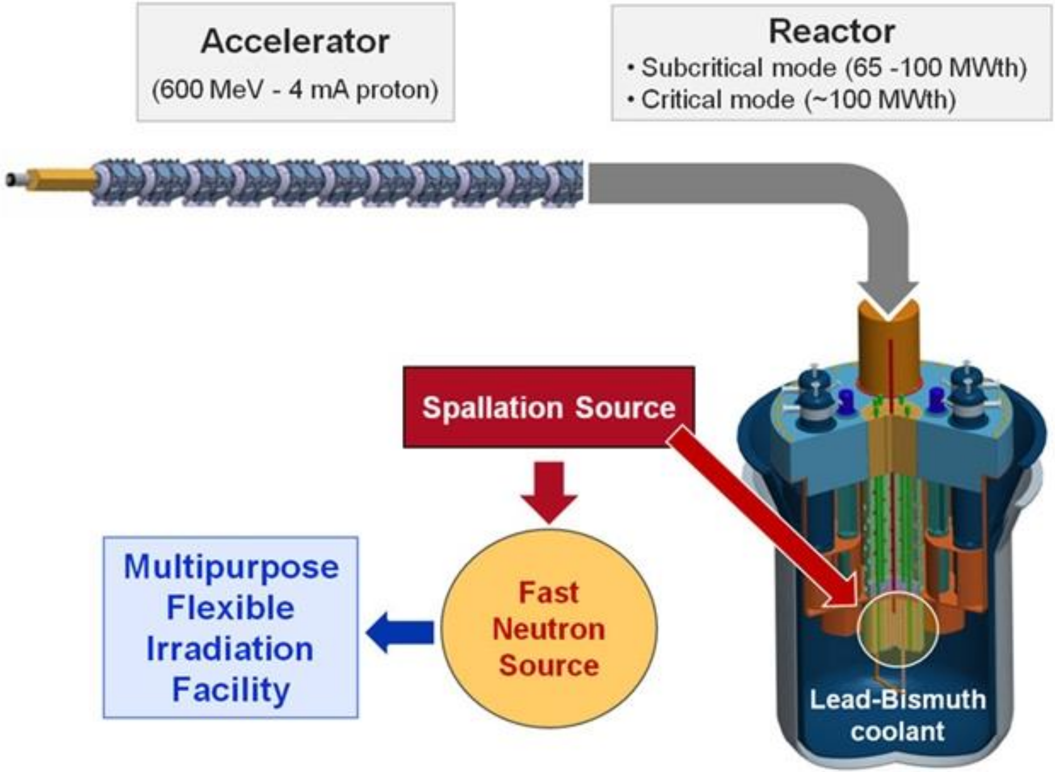
Introduction of STIP

MW Class Spallation source projects in the 1990s



Introduction of STIP

ADS – Accelerator Driven System for nuclear waste transmutation



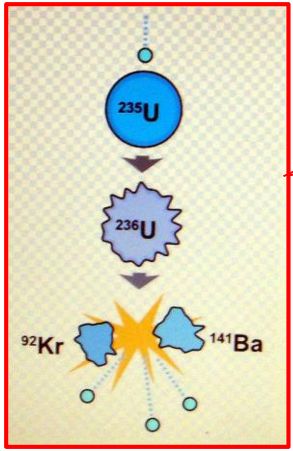
MYRRHA

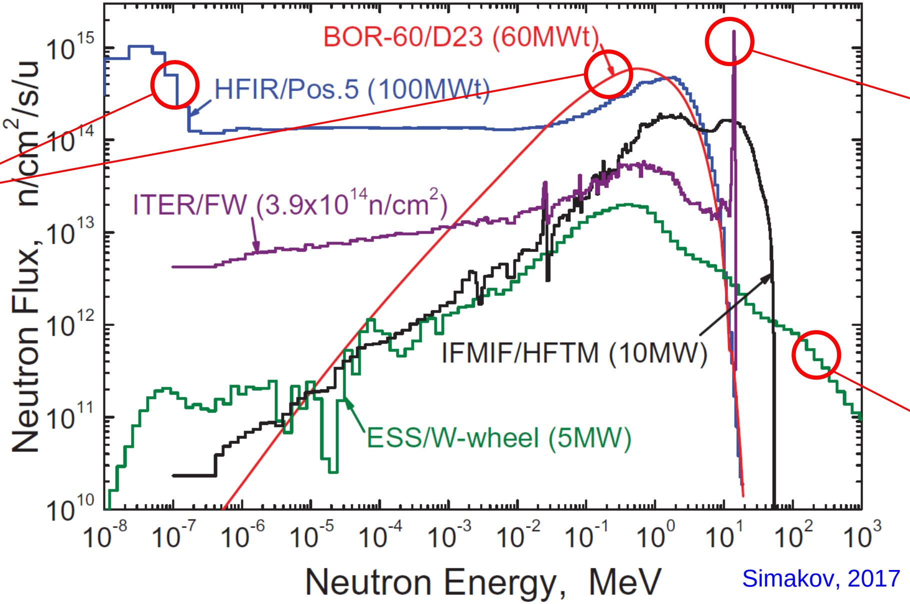
Multipurpose
h**Y**brid
Research
Reactor for
High-tech
Applications

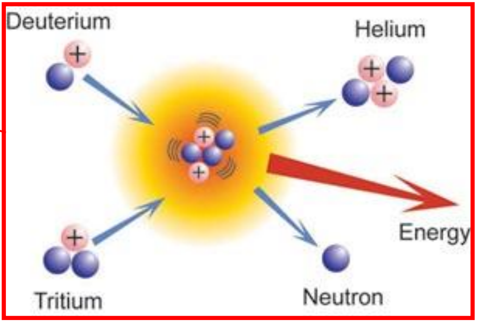
@ SCK-CEN

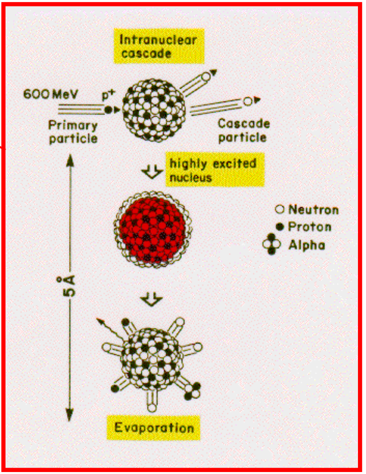
Introduction of STIP

Fission, fusion and spallation





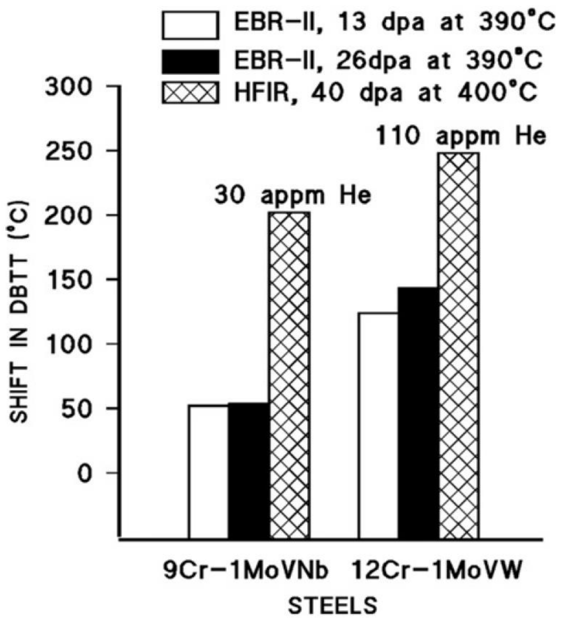




	Fission reactors	Fusion reactors	Spallation targets
Energy	0.1 - 3MeV n	14MeV n	0.1MeV- 3 GeV n 0.6 - 3GeV p
He/dpa (in Fe)	< 1	11	< 100
H/dpa (in Fe)	< 1	41	< 500

Introduction of STIP

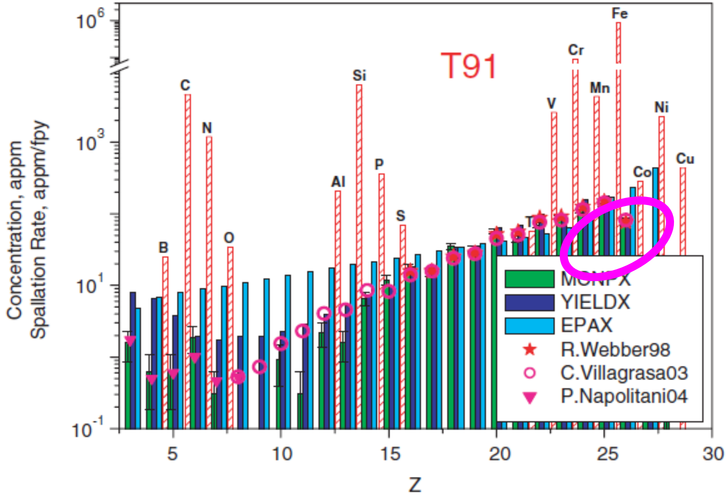
A key issue of fusion materials: Helium embrittlement effect



W.R. Corwin, J.M. Vitek, R.L. Klueh,
J. Nucl. Mater. 149 (1987) 312.

Introduction of STIP

Difference in other transmutation element production



Impurity production

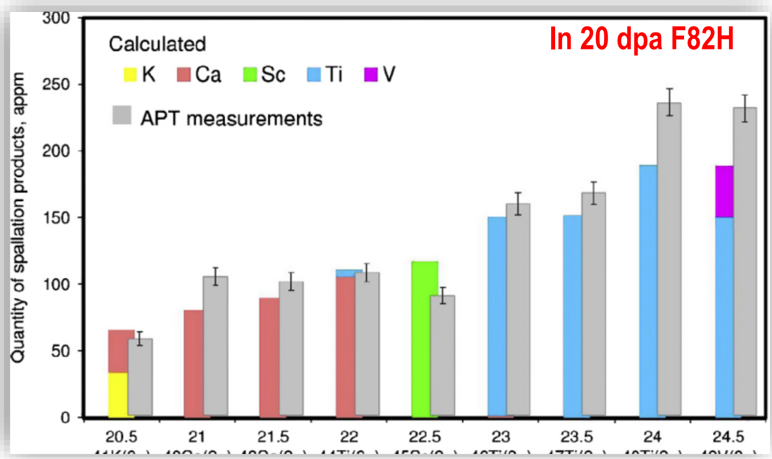
P: < 0.4 appm/dpa
S: < 0.5 appm/dpa

B: < 0.03 appm/dpa

@ 32 dpa, in d spallation target of

ADS with 600 MeV proton beam

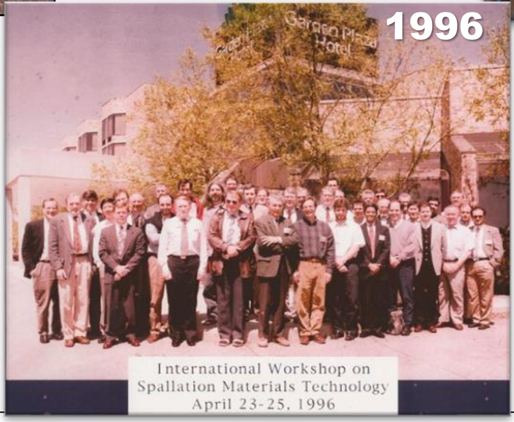
P. Vladimirov, A. Möslang, JNM, 356 (2006) 287.



V. Kuksenko et al. JNM 447 (2014) 189–196

Introduction of STIP

Inter. Workshop of Spallation Materials Technology – IWSMT



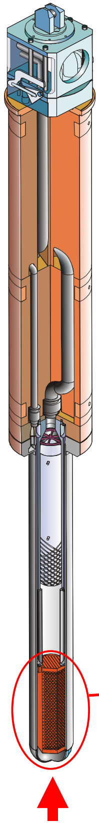
Introduction of STIP

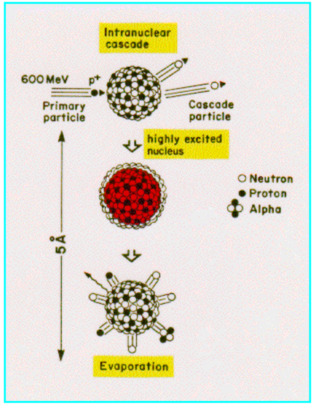
- Main purposes:
  1) to provide necessary materials data for developing advanced high power spallation targets;
  2) to understand radiation, He and H effects in different structural materials;
  3) to study liquid metal effects on structural materials in spallation irradiation environments.
- STIP was initiated in 1996 at IWSMT-1, joined by CEA, FZJ, JAEA, LANL and ORNL. Since then, 20+ international institutions joined/contributed to the 8 STIP irradiation experiments.
- Specimens irradiated inside the spallation target with high energy protons and spallation neutrons, 3-15 dpa/yr with 20–90 appm He/dpa in steels.
- In total, ~ 9000 samples from 70+ different materials were irradiated in up to 32 dpa / 3000 appm He / 12500 appm H (in Fe).

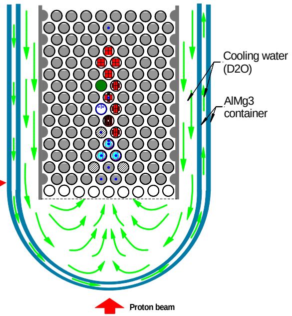
Characteristics of STIP

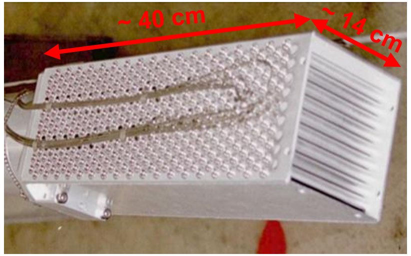
Characteristics of STIP

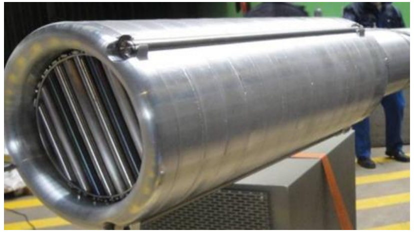
SINQ targets







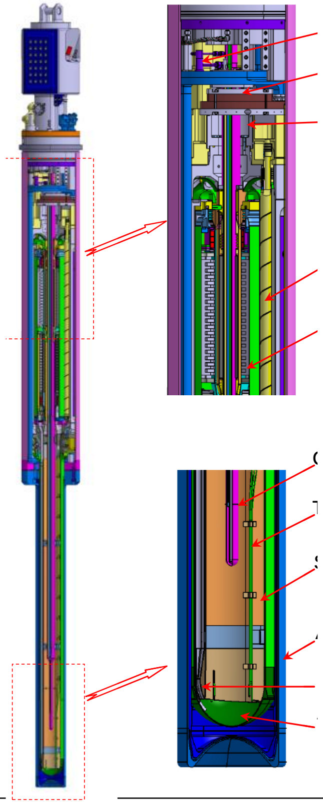




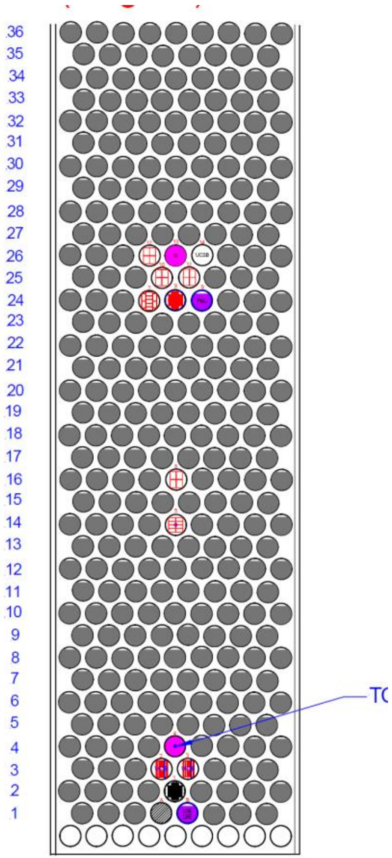
Target materials: Pb, zircaloy-2

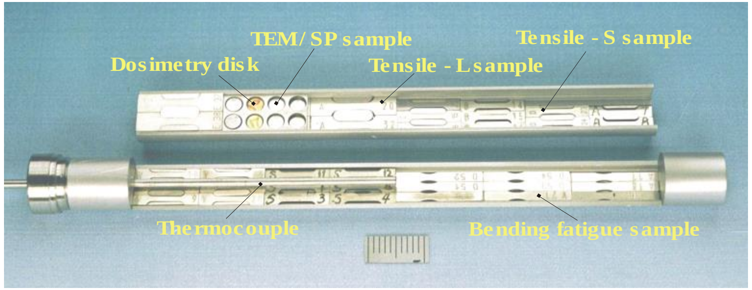
Structural materials: AlMg3, zircaloy-2, SS316L

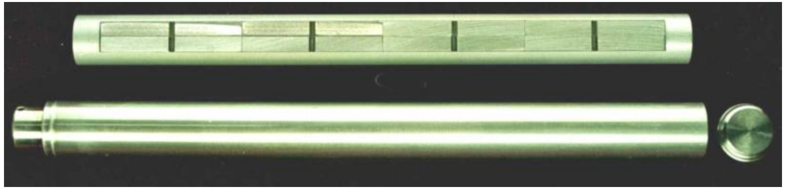
MEGAPIE – LBE target



Characteristics of STIP

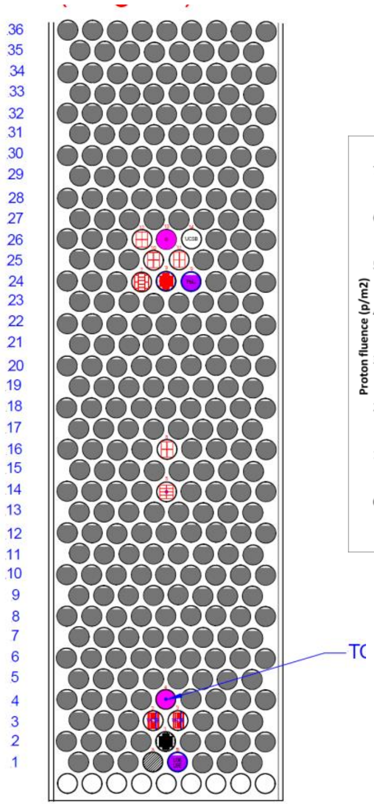


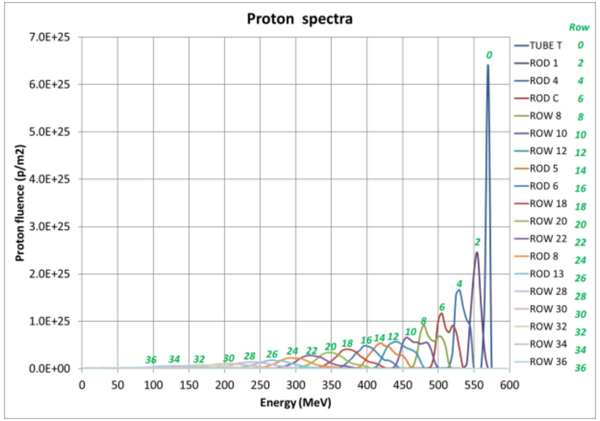


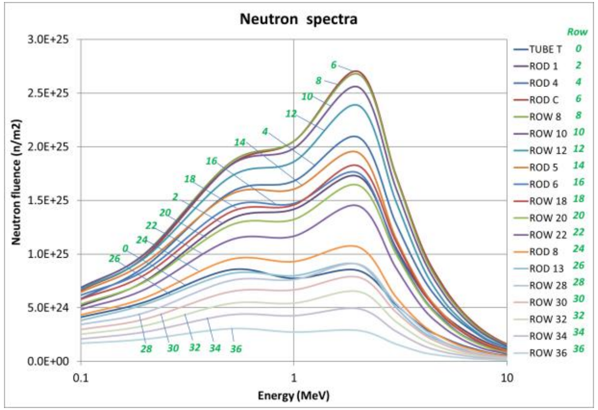


Characteristics of STIP

p & n spectra in SINQ Target-9 (STIP-VI)

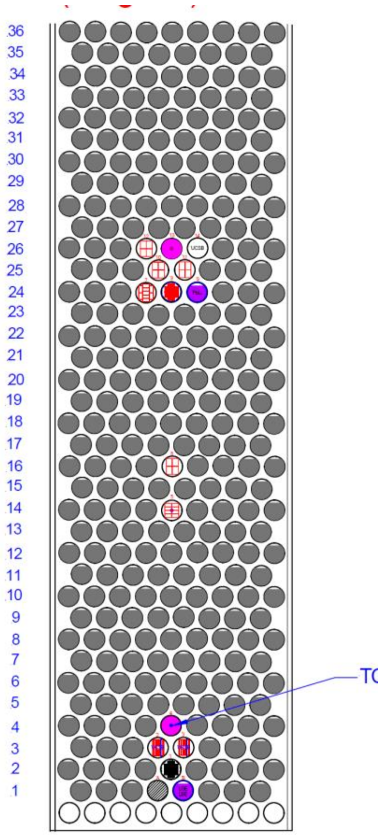


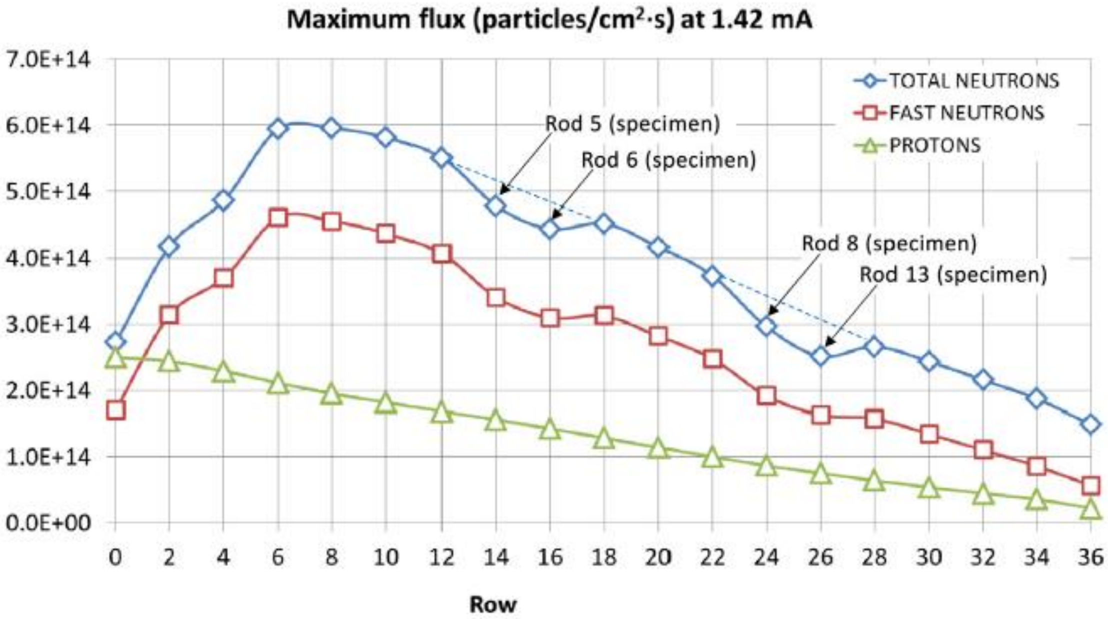




Characteristics of STIP

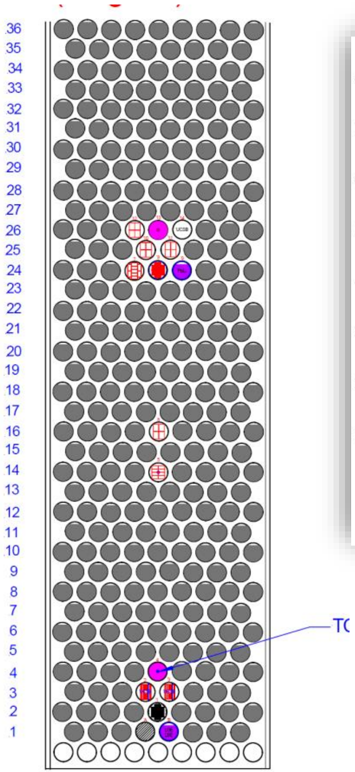
p & n fluxes in SINQ Target-9 (STIP-VI)

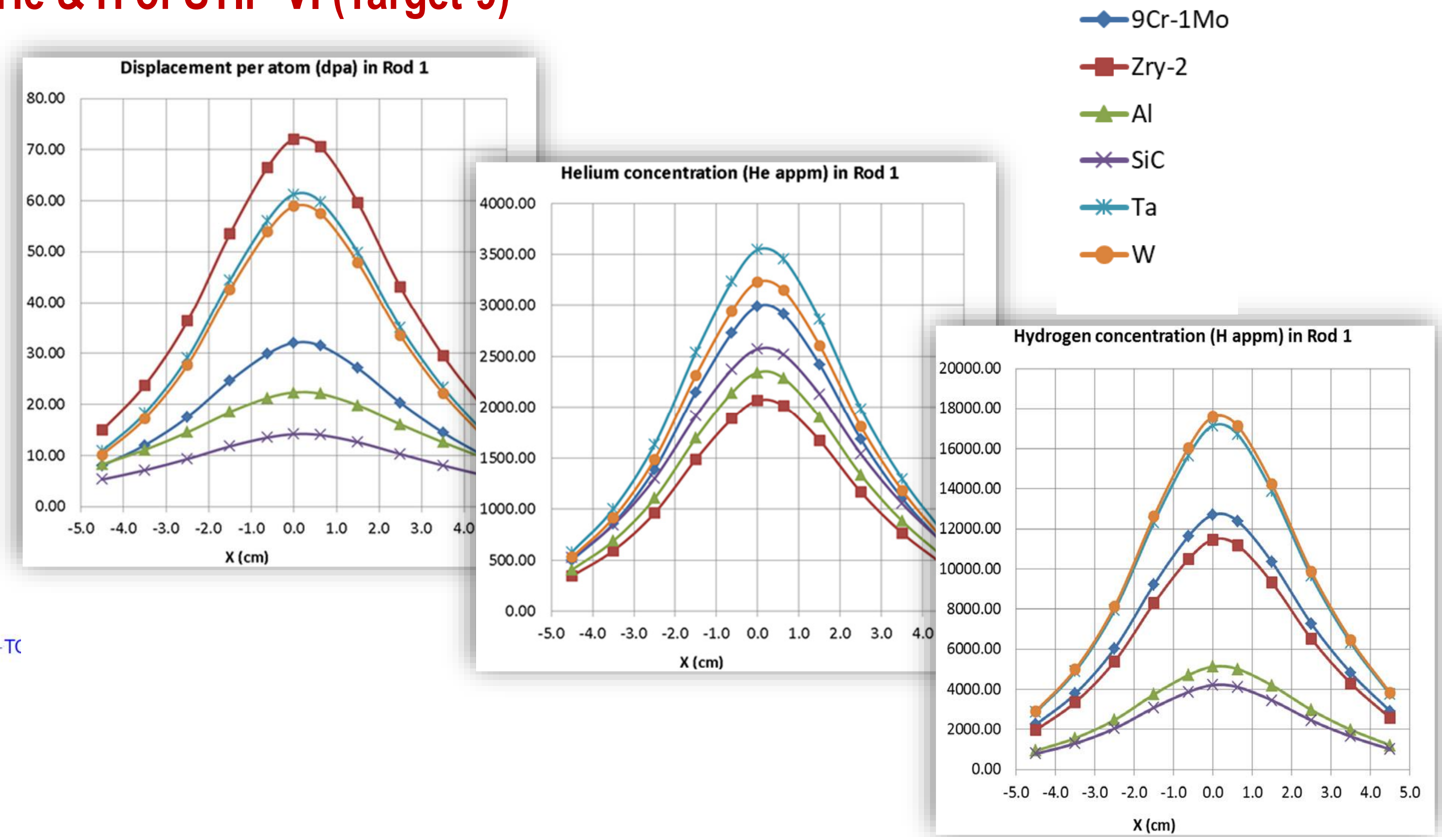




Characteristics of STIP

Dpa, He & H of STIP-VI (Target-9)





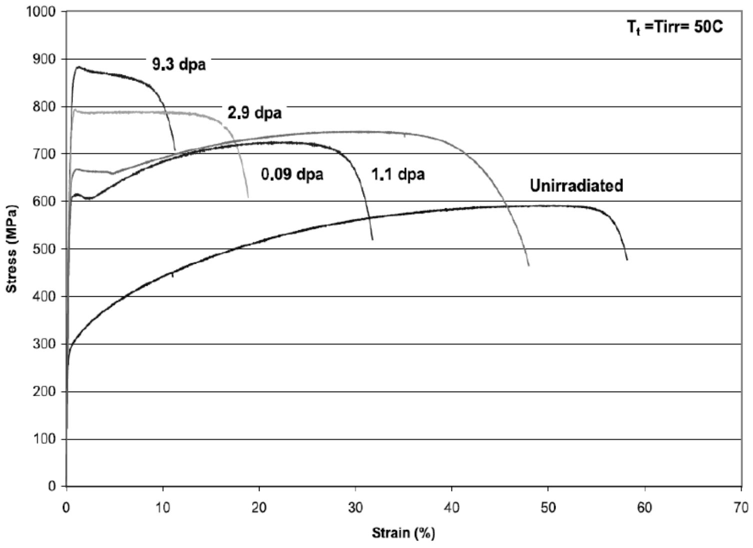
STIP for spallation materials application

STIP for spallation target applications

Austenitic steels

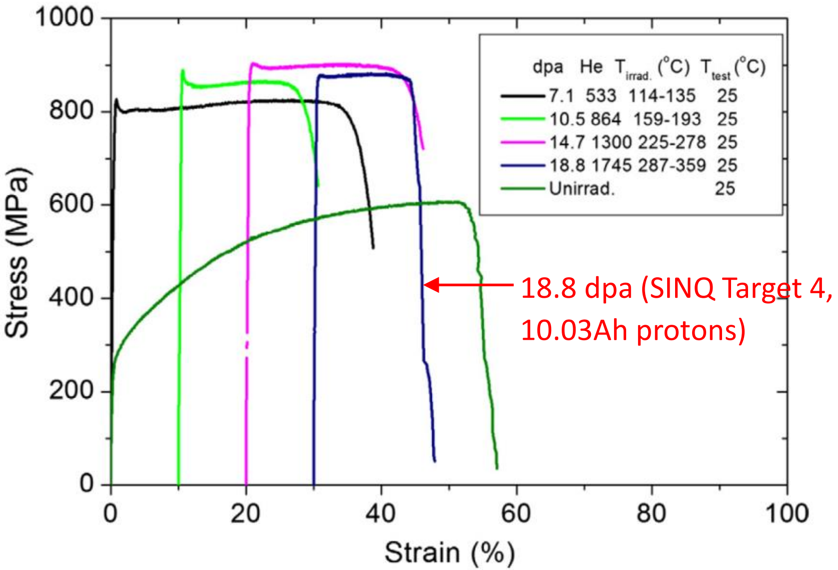
Applications:
- Pb-cladding tubes in SINQ Target-4 – Target-6
- Containers of SNS and JSNS Hg targets

APT results



Maloy, JNM 296 (2001) 119

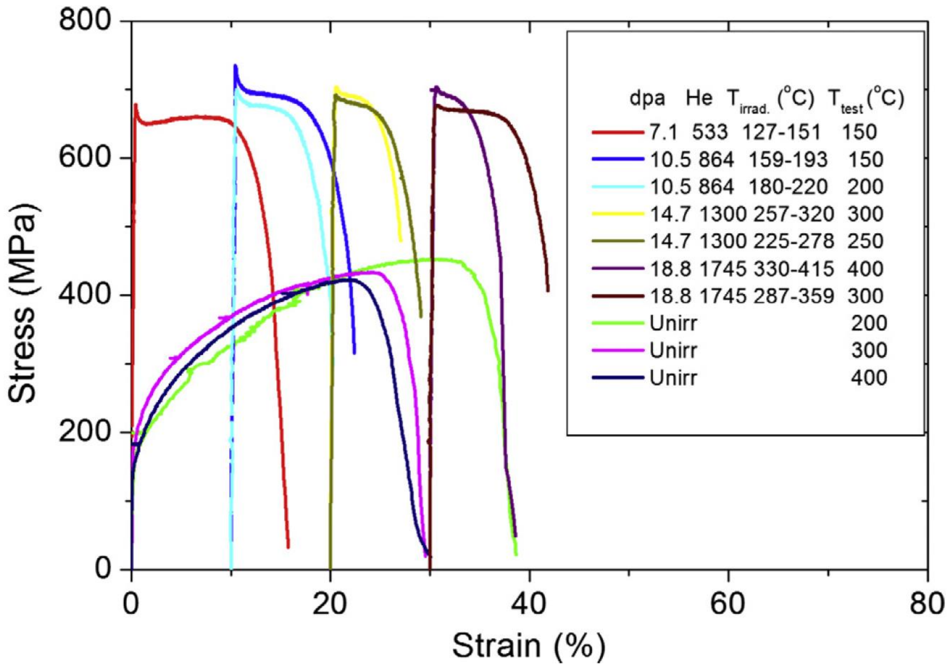
STIP results

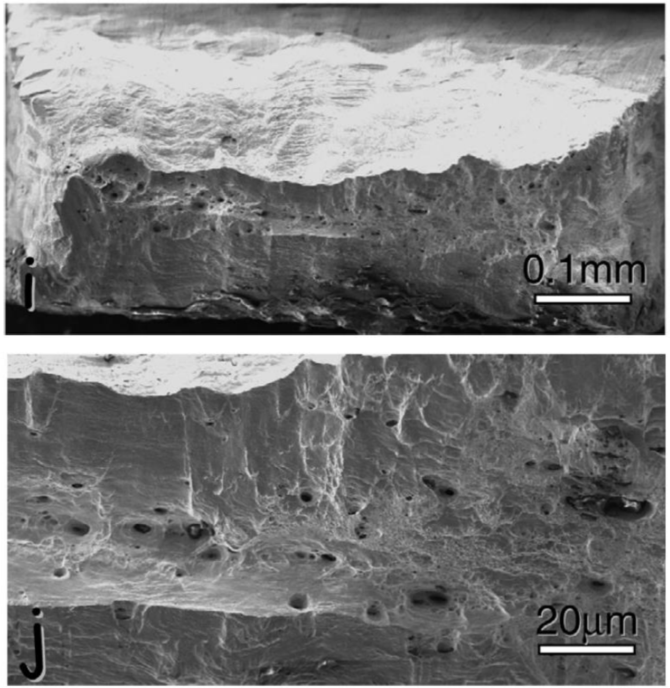


Li, JNM 450 (2014) 42

STIP for spallation target applications

Austenitic steels





18.8 dpa tested at 300°C

Li, JNM 450 (2014) 42

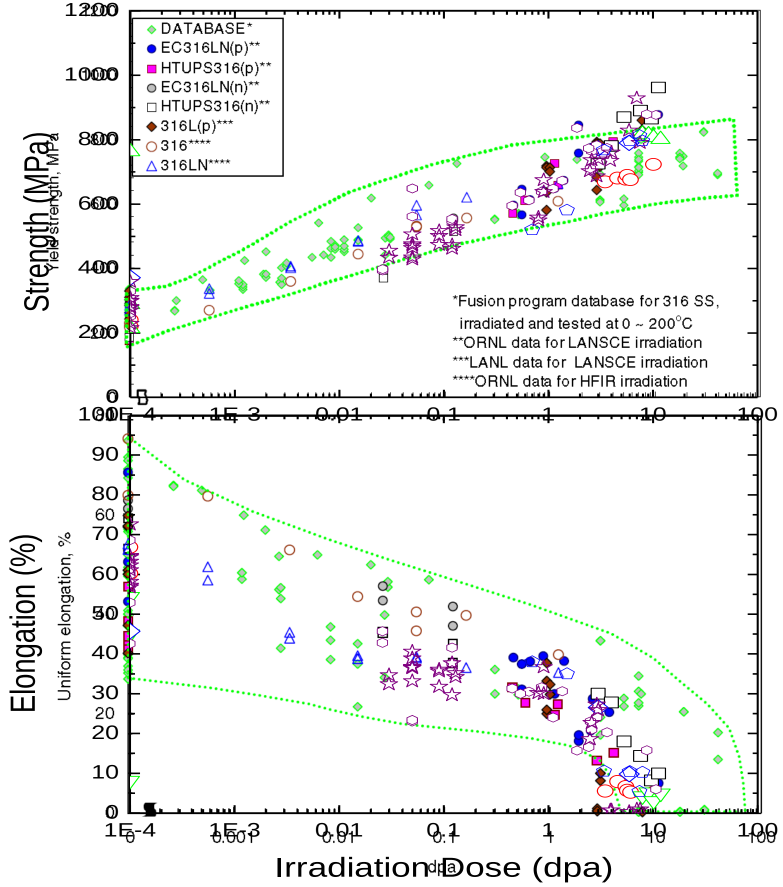
STIP for spallation target applications

Austenitic steels

Fission: irradiated & tested 0-200°C
Spallation: irradiated at <400°C and tested at RT

⇒ Deviate at >~10 dpa, due to high He content, however sample size effect may exist.

Mansur, JNM, 356 (2006) 1.



STIP for spallation target applications

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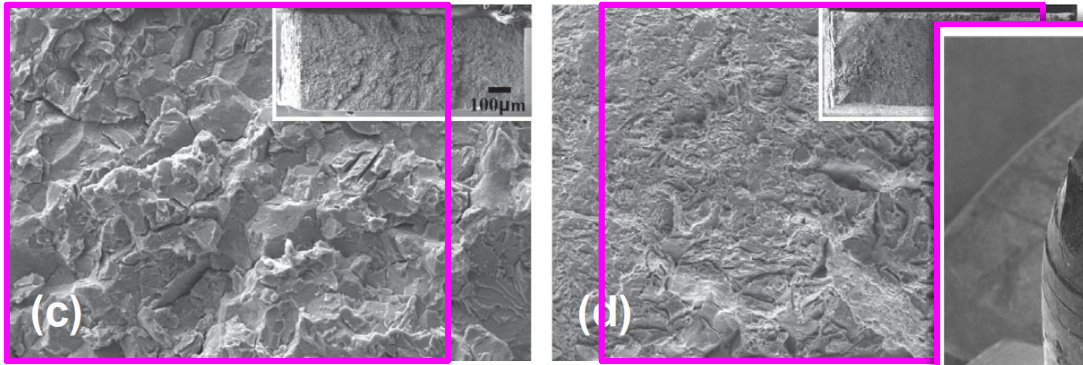
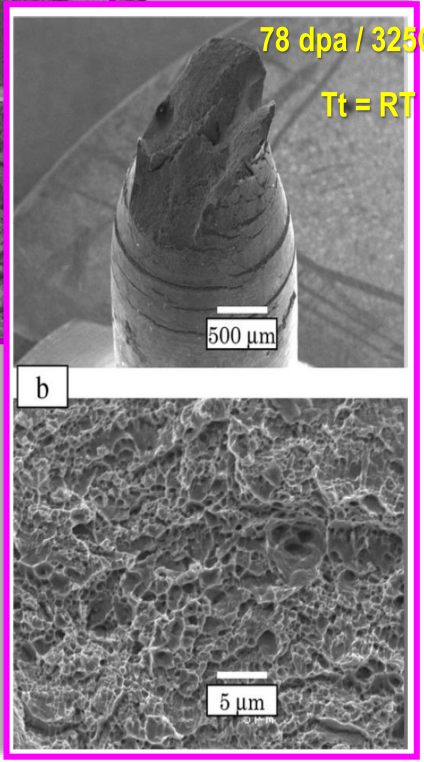
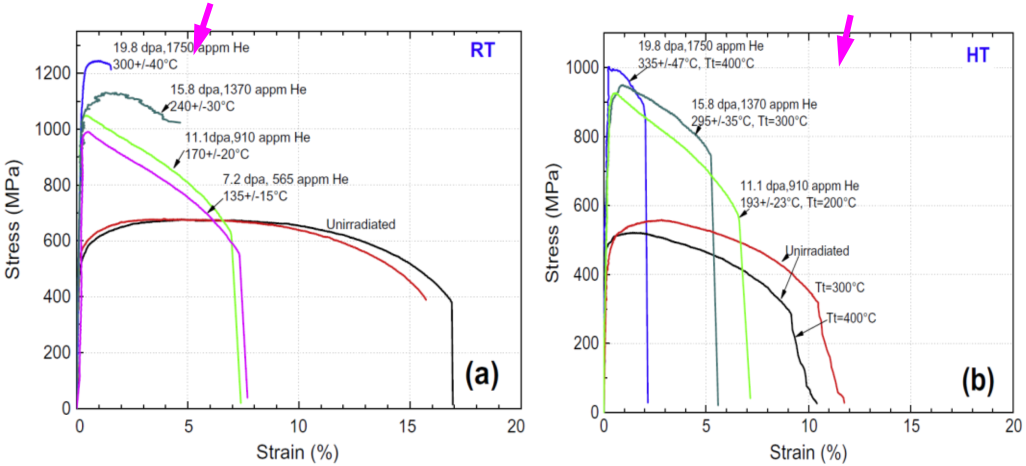






Henry et al. JNM 417 (2011) 99

Zhang et al. JNM 450 (2014) 48

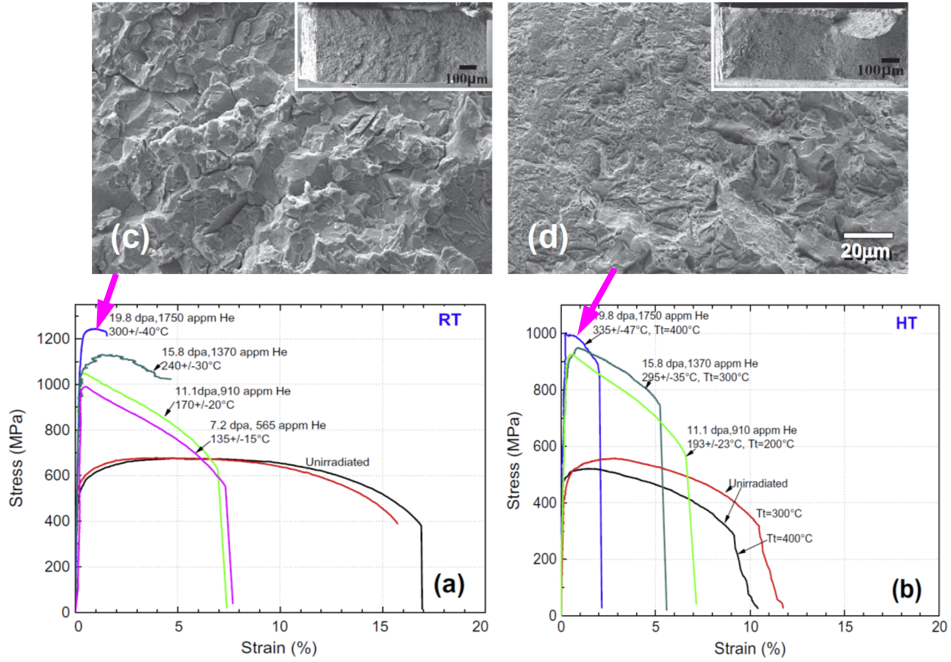
STIP for spallation target applications

Ferritic / martensitic steels

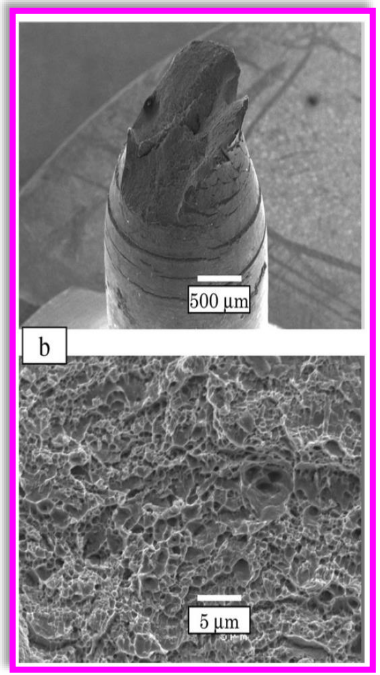
Applications:

- Liquid Pb-Bi containers of Megapie, ADS targets
- *Fusion reactors*

Eurofer 97



Zhang et al. JNM 450 (2014) 48

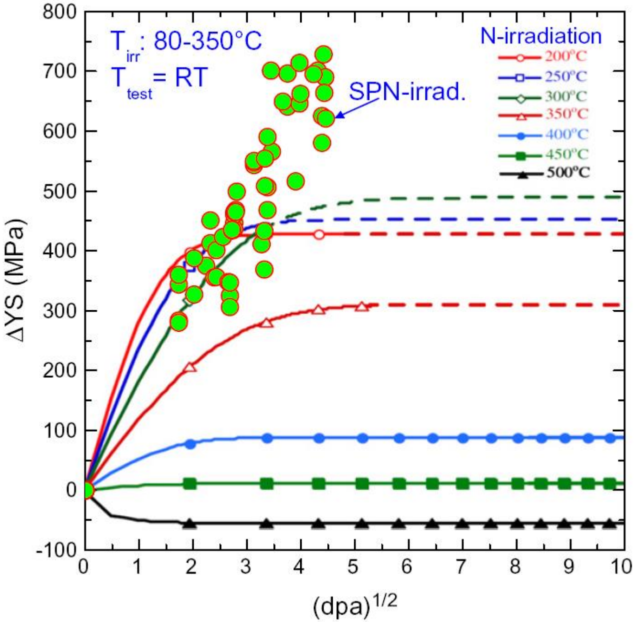


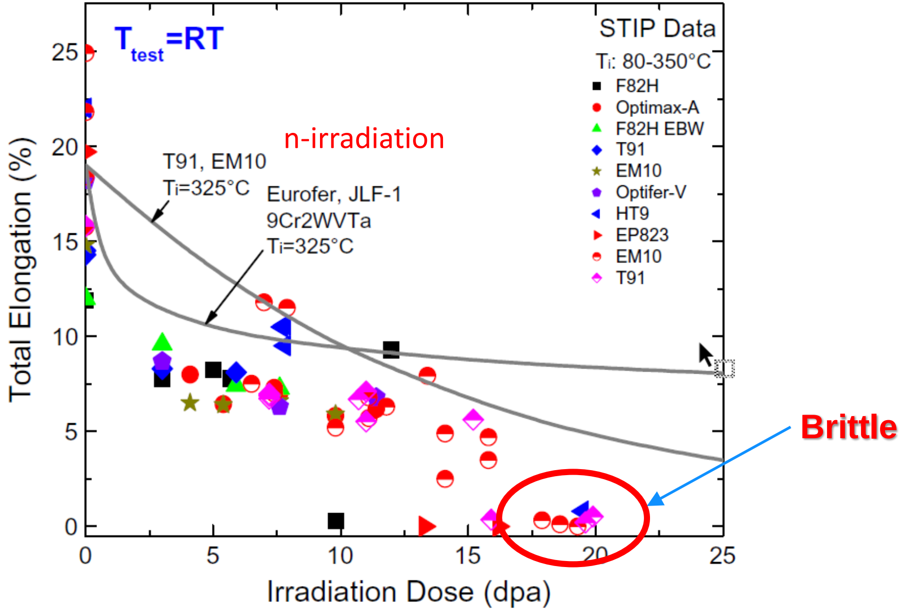
Neutron irradiation:
78 dpa / 325C
Tt = RT

Henry et al. JNM 417(2011) 99

STIP for spallation target applications

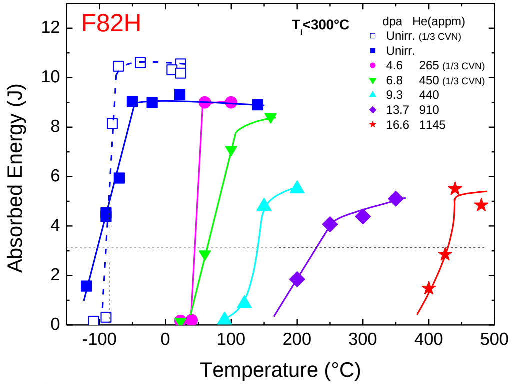
Ferritic / martensitic steels

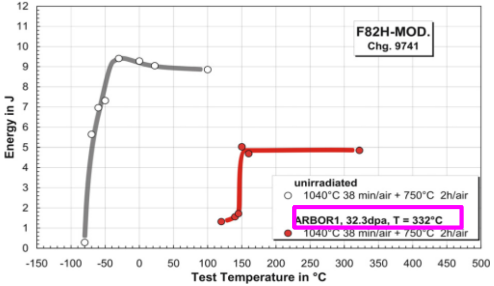




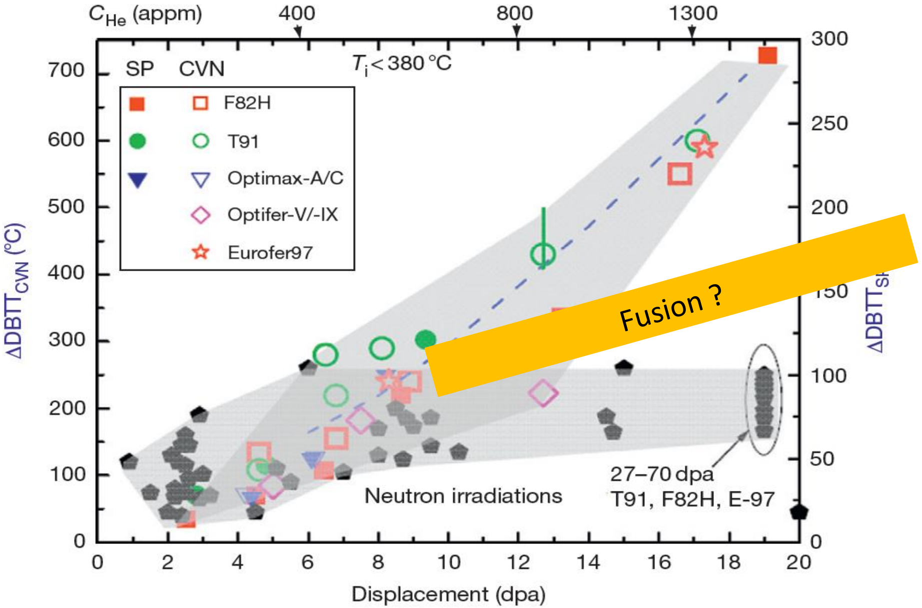
STIP for spallation target applications

Ferritic / martensitic steels





Petersen, JNM 367–370 (2007) 544



Dai, et al, in <Comprehensive nuclear materials> (2012), vol 1, 141-193.

STIP for spallation target applications

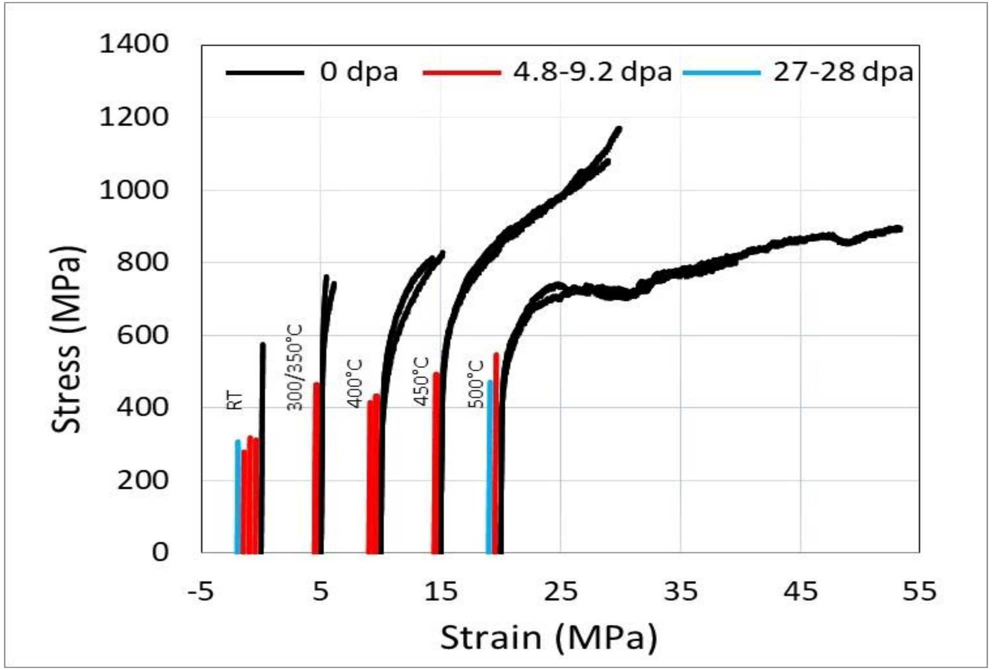
Pure tungsten

Applications:
- Target material for ISIS, CSNS, ESS, SNS Target-2
- *Fusion reactors*

Bending test

Ti: 80-550°C

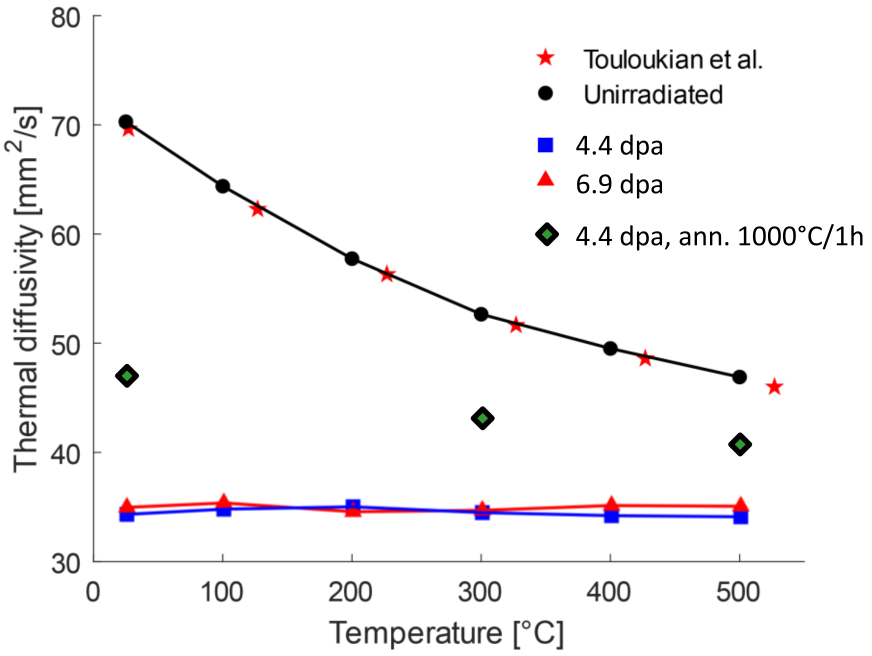
Tt: RT-500°C



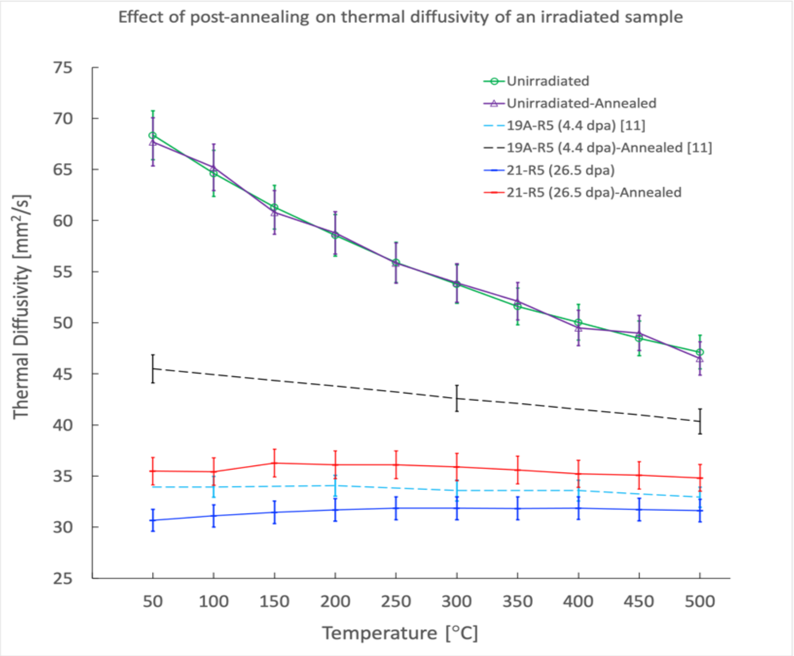
STIP for spallation target applications

Pure tungsten

Thermal diffusivity



Habainy et al. JNM 509 (2018) 152

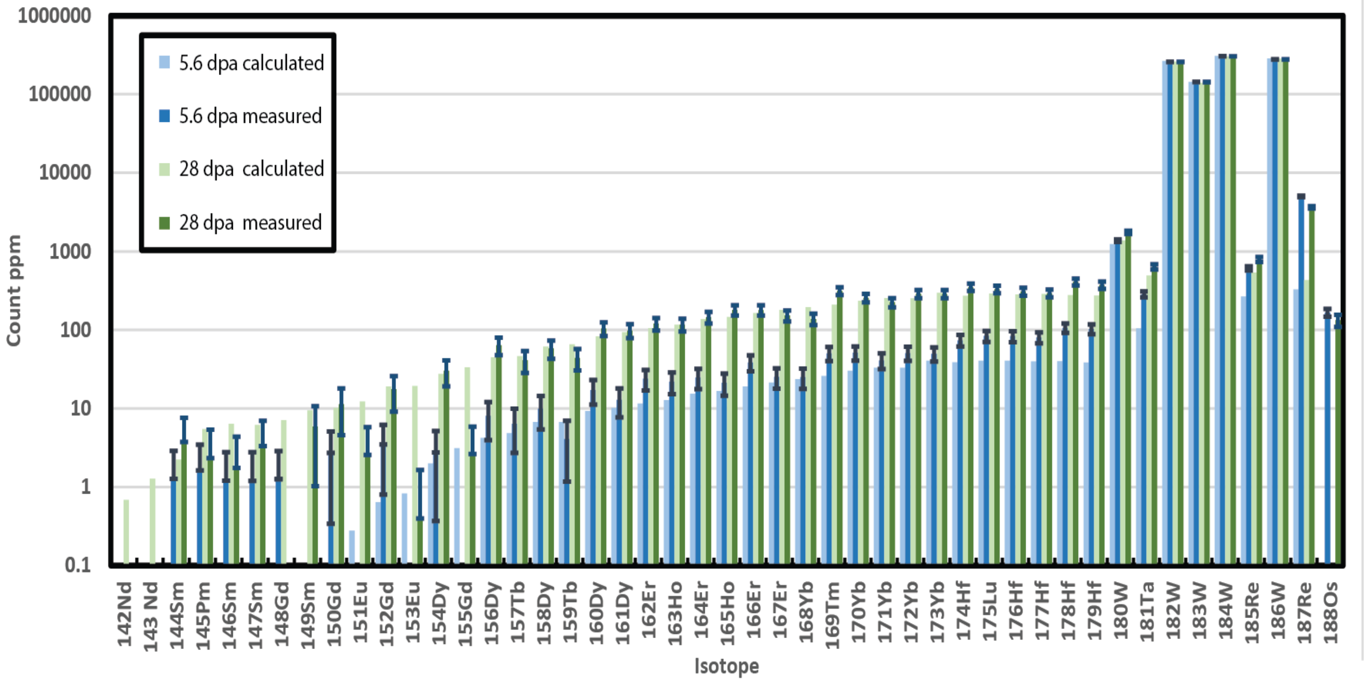


H. Sina et al. to be published

STIP for spallation target applications

Pure tungsten

Transmutation element production in W (STIP-V)



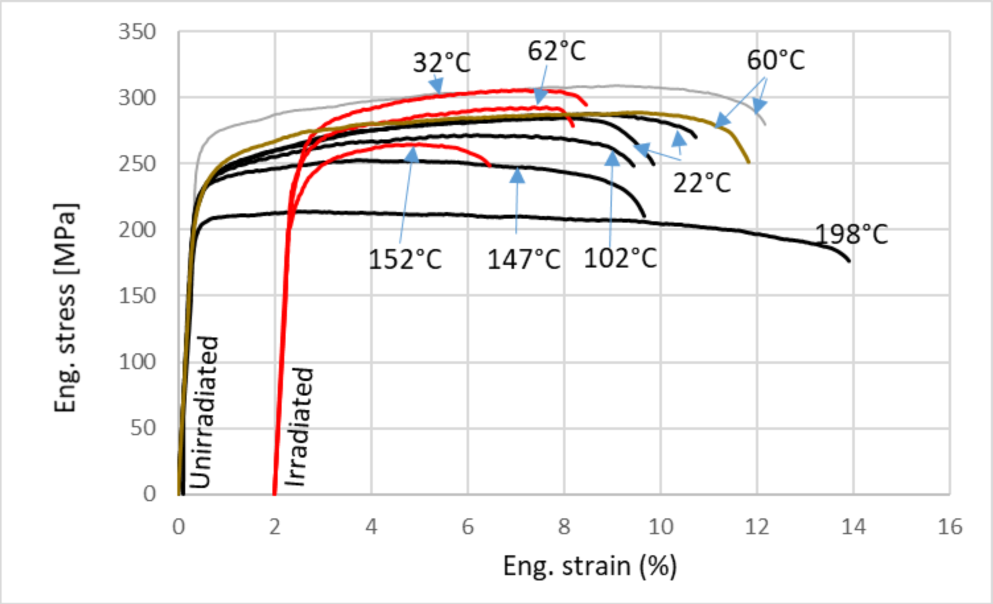
In neutron irradiation: mainly Re and Os (can be much higher! 1% at / dpa)

V. Araullo et al. to be published

STIP for spallation target applications

Al-alloy: Al 6061-T6

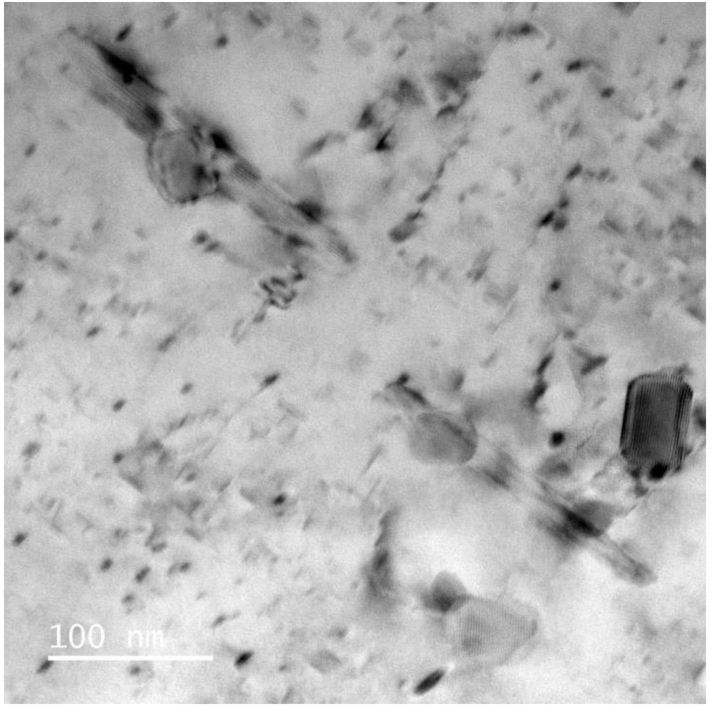
Applications:
- Proton beam windows of SNS, JSNS, CSNS

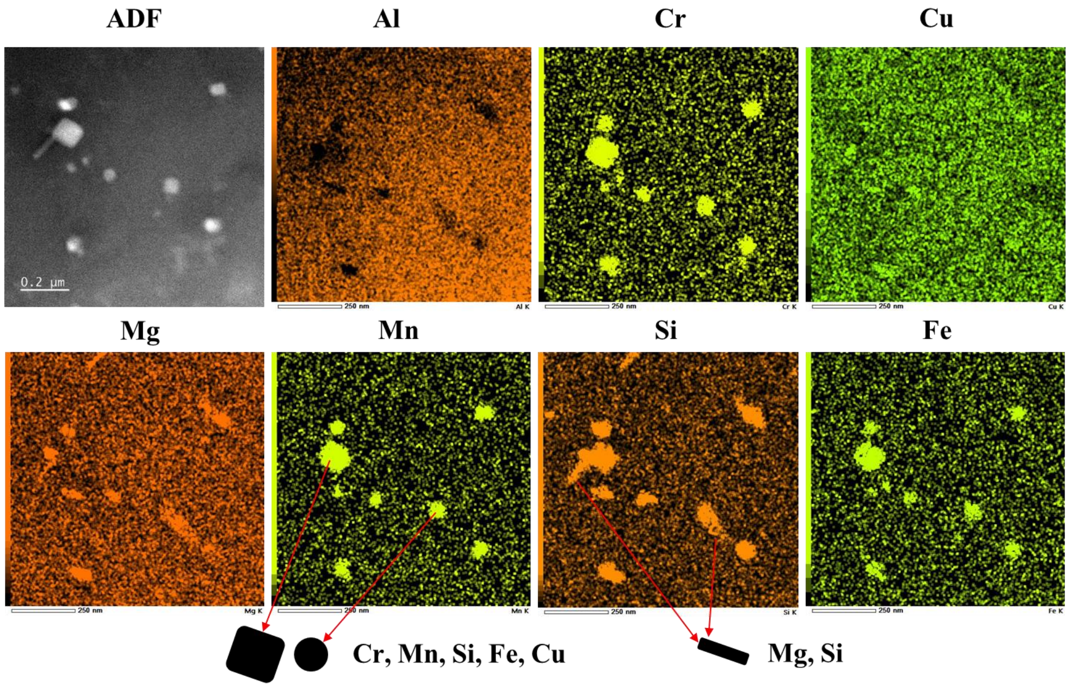


Dai, IWSMT-15, to be published

STIP for spallation target applications

Al-alloy: Al 6061-T6





Song, to be published

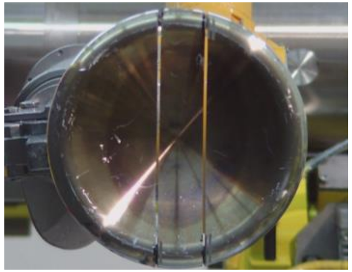
Studies for spallation target applications

Al-alloy: $AlMg_3$

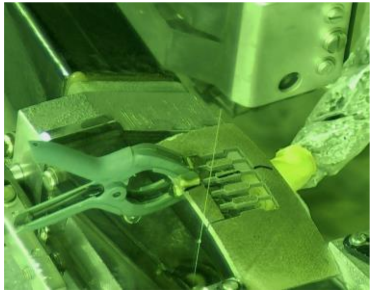
Applications:

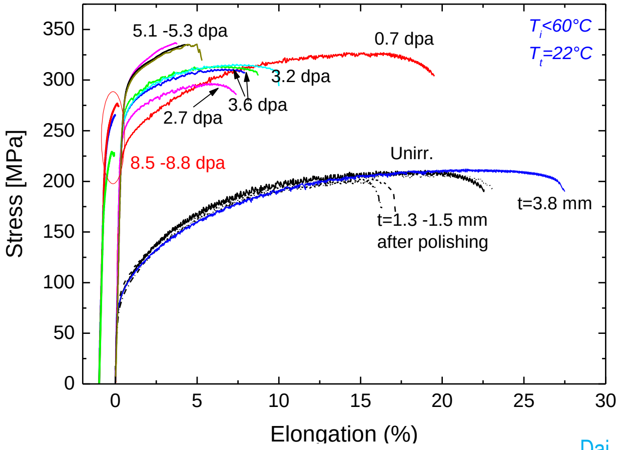
- Safety container of SINQ targets
- Proton beam windows of SNS, JSNS, CSNS

SINQ Target-3 (1998-99), 6.8 Ah P$^+$

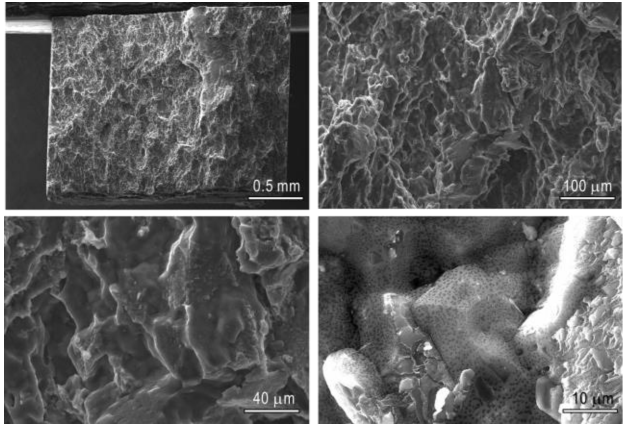


SINQ Target-9 (2011-12), 13.2Ah P$^+$





8.8 dpa /2400 appm He / 4800 appm H



Dai, IWSMT-13

Thank you!