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PSI

Status and prospective of STIP Irradiation Experiments and Ti-, Mo-,W-alloys irradiated in STIP

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RaDIATE 2018, CERN, 18.12.2018

Outline

- SINQ Target Irradiation Program (STIP)
- Ti, Mo and W-alloys and pure Ta irradiated in STIP
- The PIE capabilities at PSI

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SINQ Target Irradiation Program

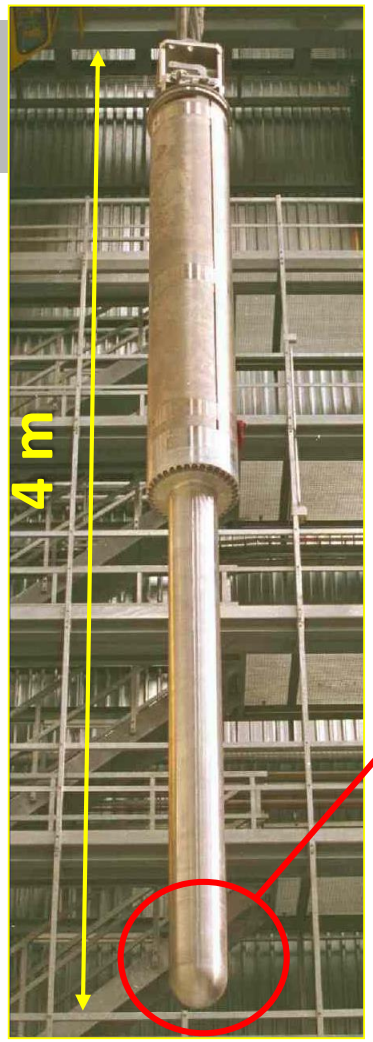
STIP

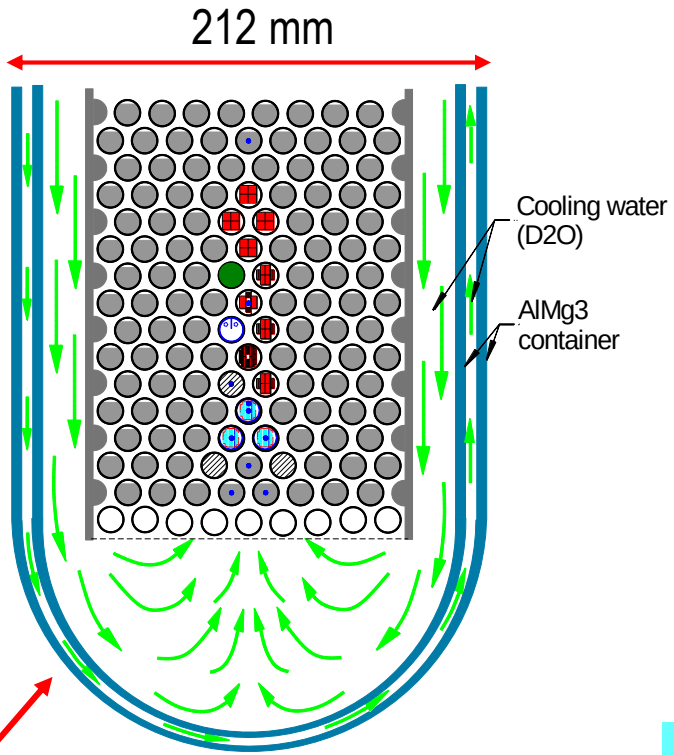
SINQ Target Irradiation Program- STIP

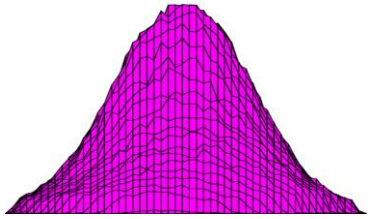
- Main purposes:
  1) to provide necessary materials data for developing advanced spallation targets;
  2) to understand radiation, He and H effects in different structural materials;
  3) to study liquid metal effects on structural materials in spallation irradiation environments.
- The program was initiated in 1996 and joined by PSI, CEA, FZJ, JAEA, ORNL, with about 15 partners in Europe, Asia and USA.
- 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.
- Each irradiation lasts 2 years. Seven irradiation experiments were conducted during 1998 and 2014.
- More then 8000 samples from materials such as SS 316, FM steels T91, F82H, Optifer, Eurofer, ODS-FM steels, Al-, Ti- Ni-, Mo-, W-alloys, C/SiC, SiC/SiC….. were irradiated in STIP-1 to -6 up to 25 dpa / 1800 appm He (in steels) at temperatures up to ~800°C.
- STIP-8 is being conducted.

SINQ Target

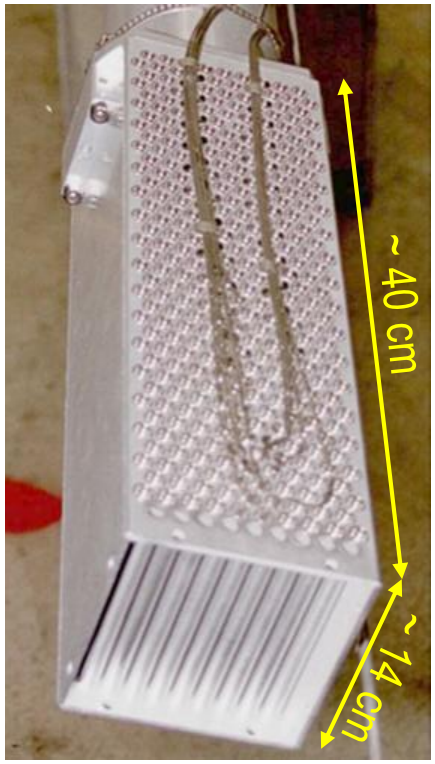
A previous version



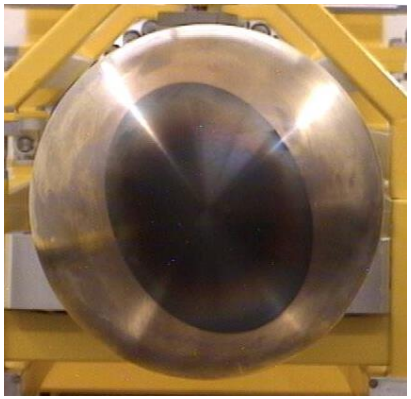




σ_x~3.5cm, σ_y~2cm



~360 Pb rods with SS / Zy-2 tubes

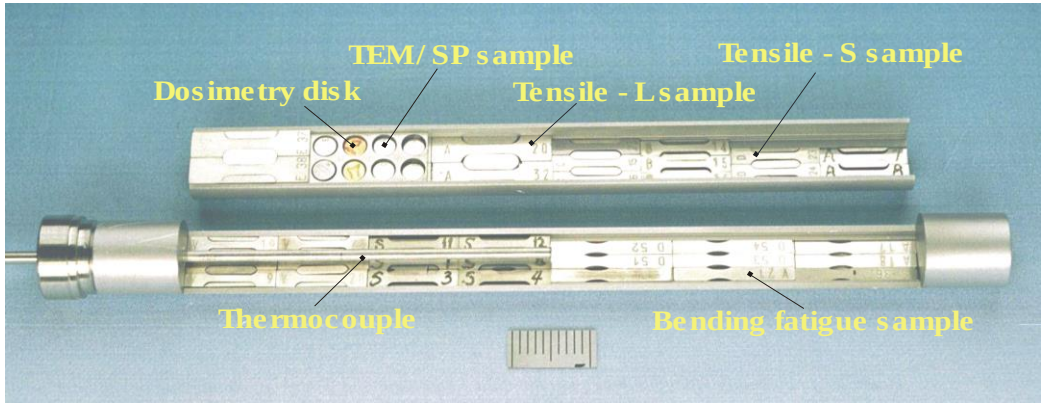


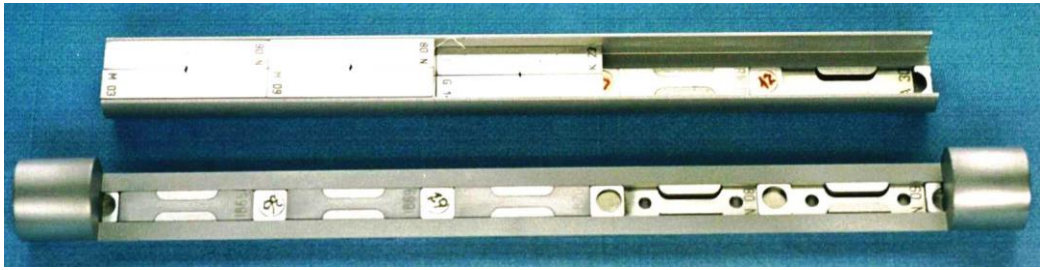
Proton beam:

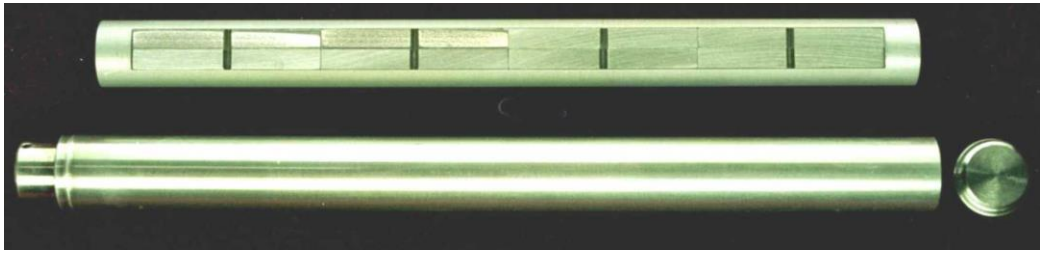
570 MeV, 1.5 mA

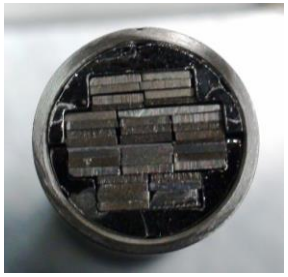
On the target

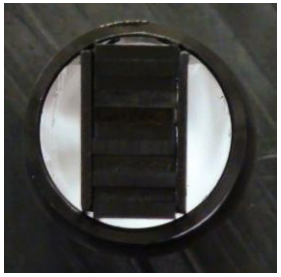
SINQ Target Irradiation Program (STIP)



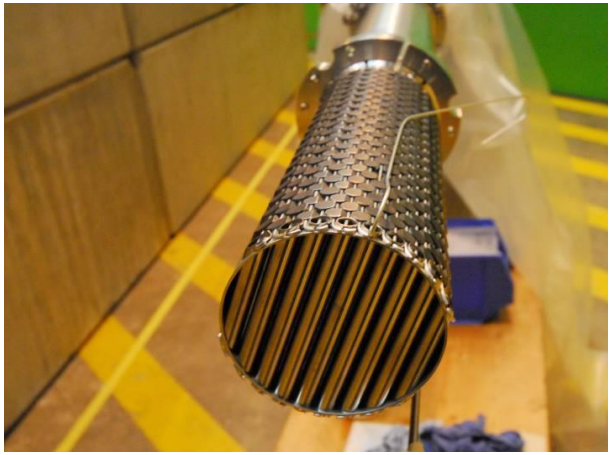


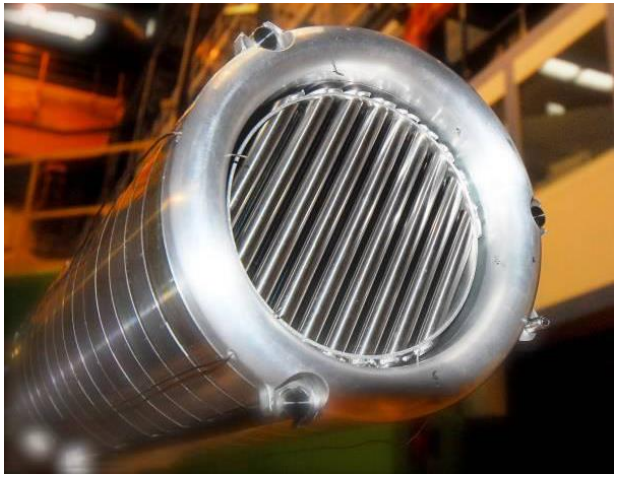


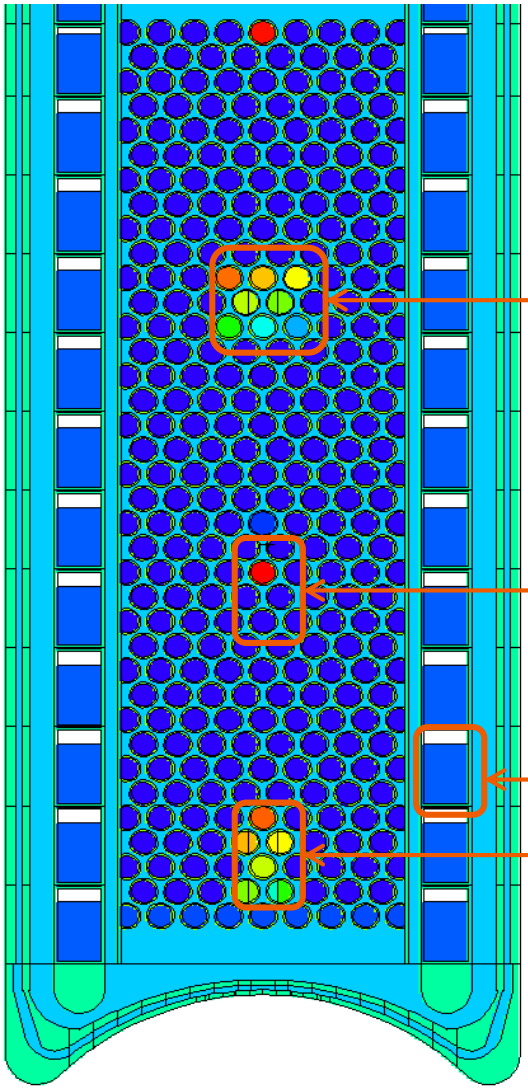




SINQ Target Irradiation Program (STIP)







Zone C
7 (14) dpa

Zone B
12 (24) dpa

Zone D
2.5 (5) dpa

Zone A
15 (30) dpa

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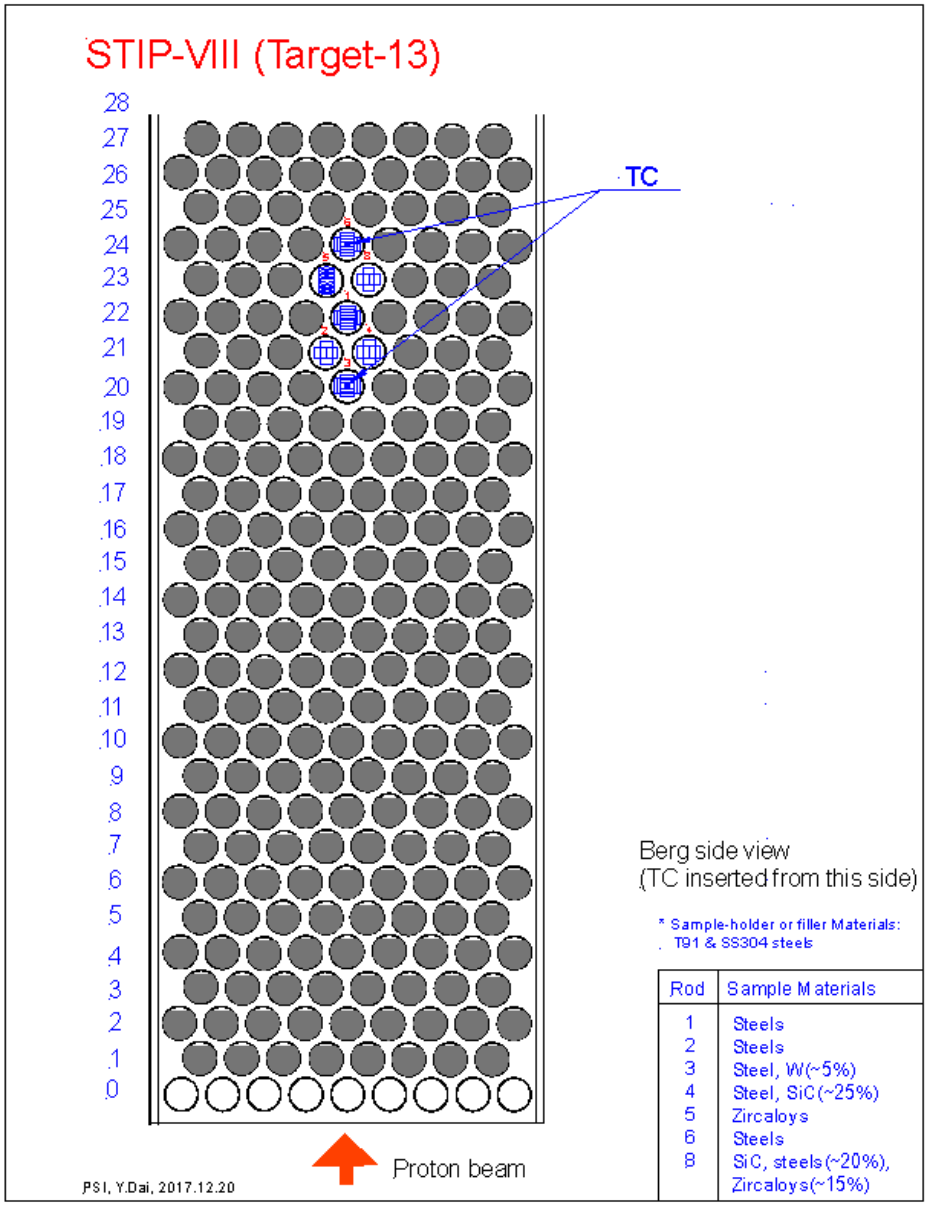
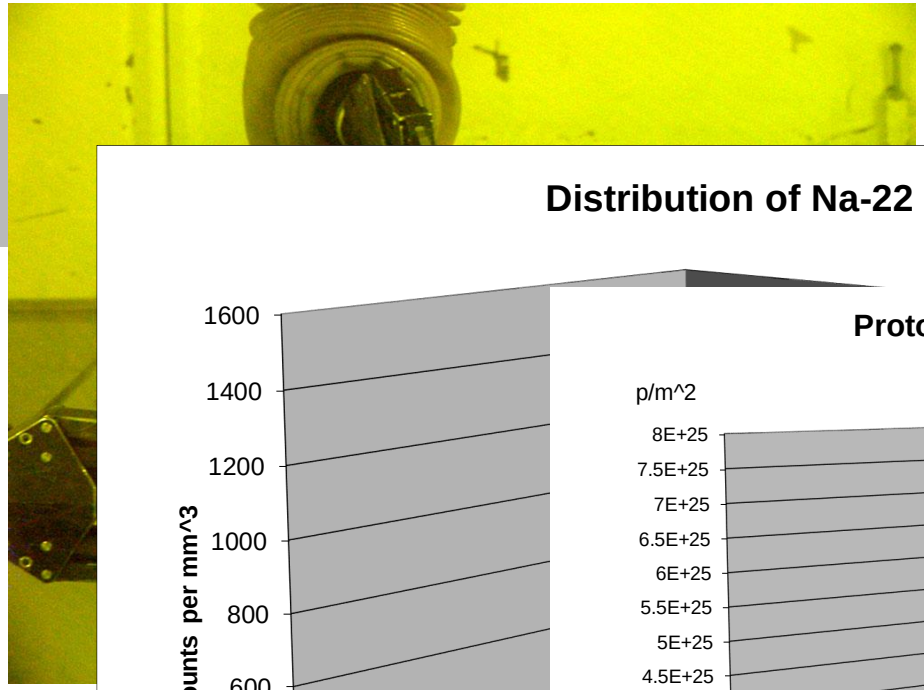
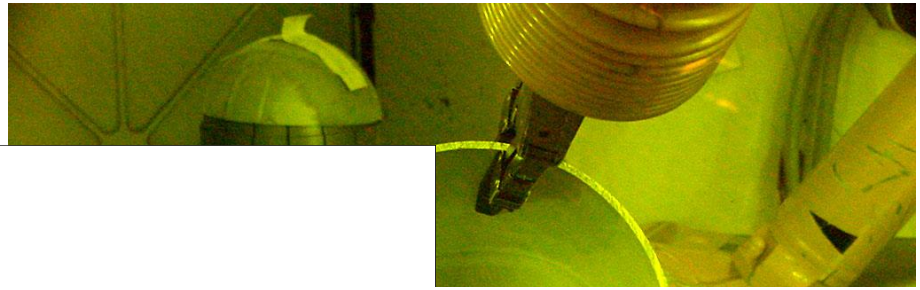
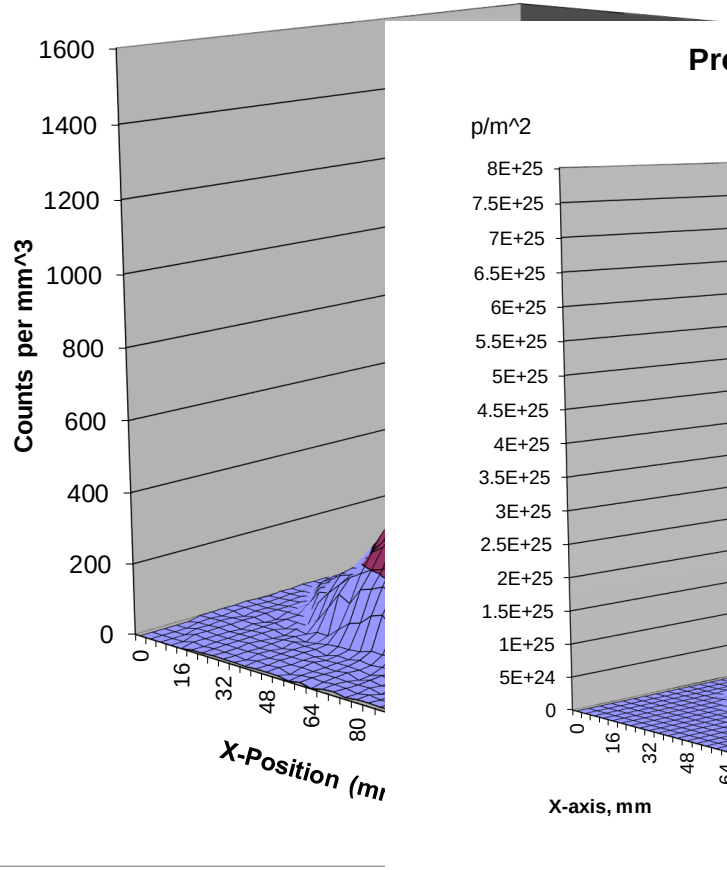
STIP-VIII

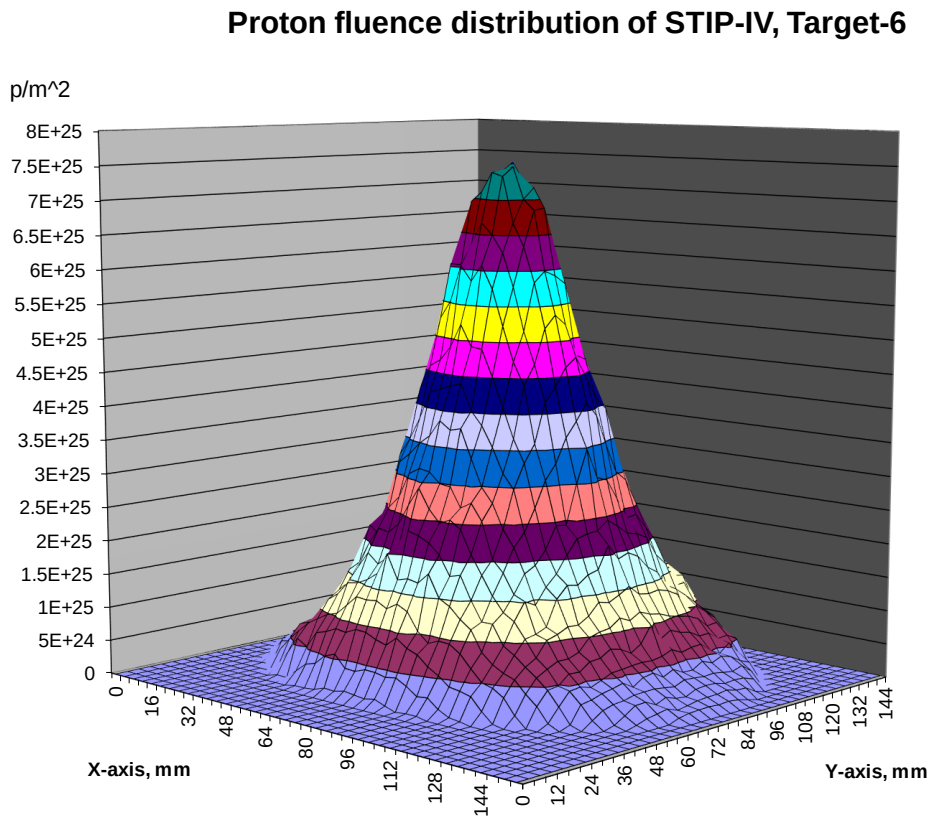


Proton and neutron flux distribution

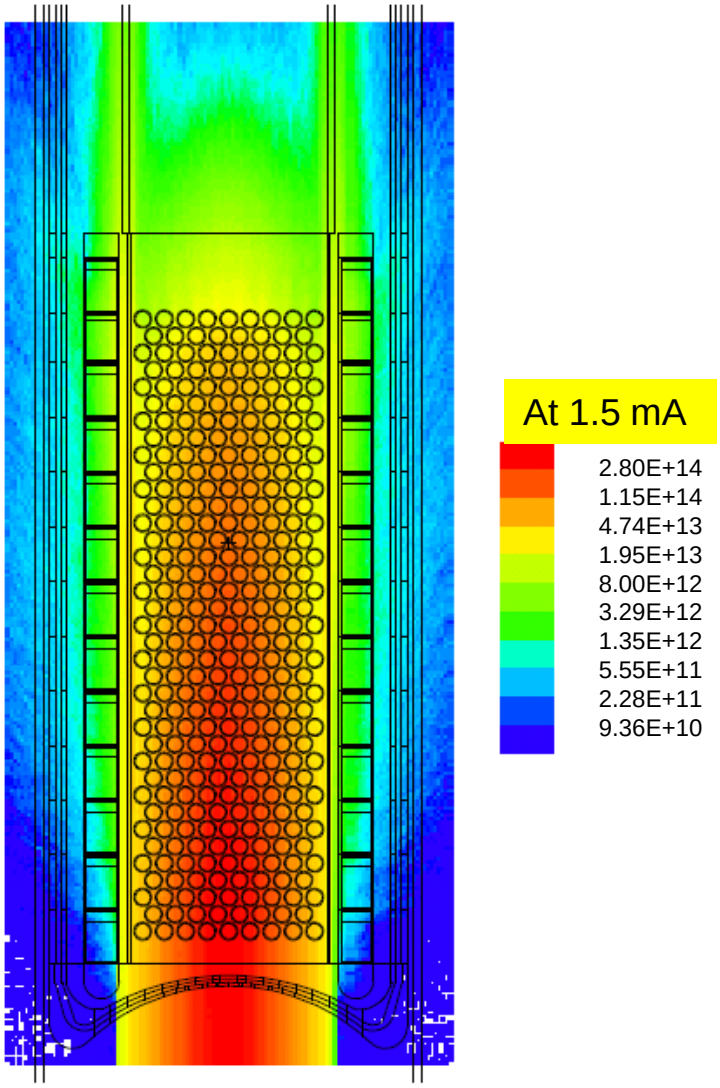




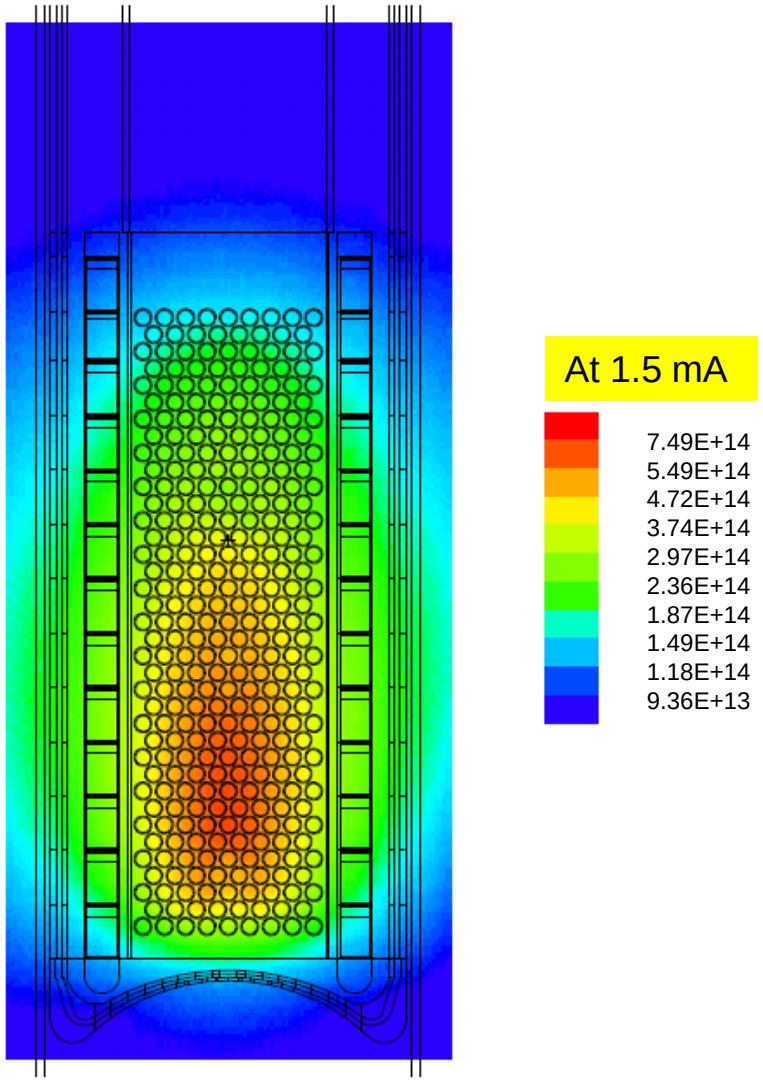




Proton and neutron flux distribution (STIP-VI)

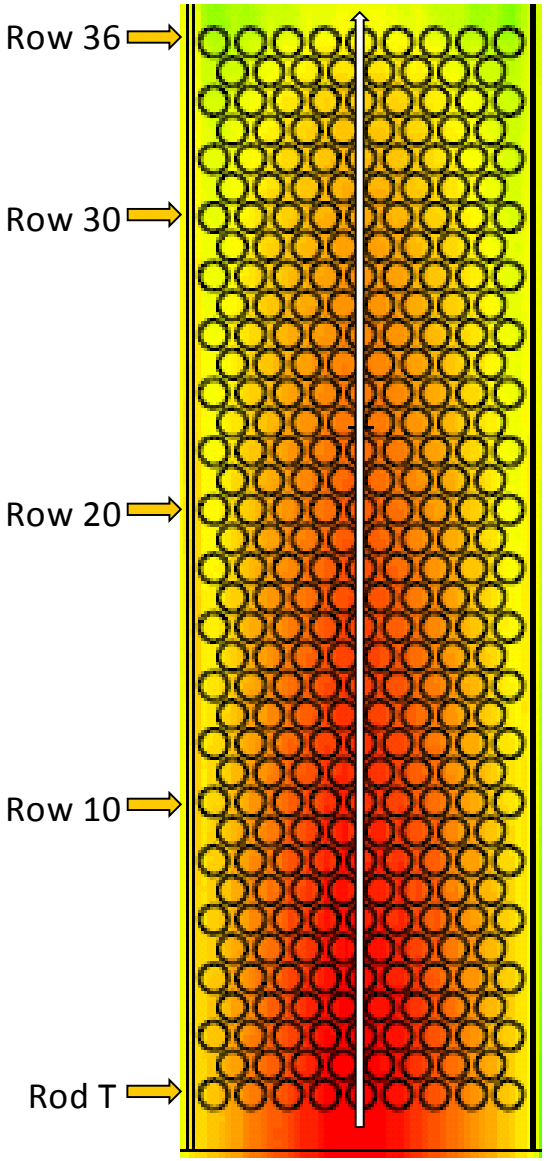


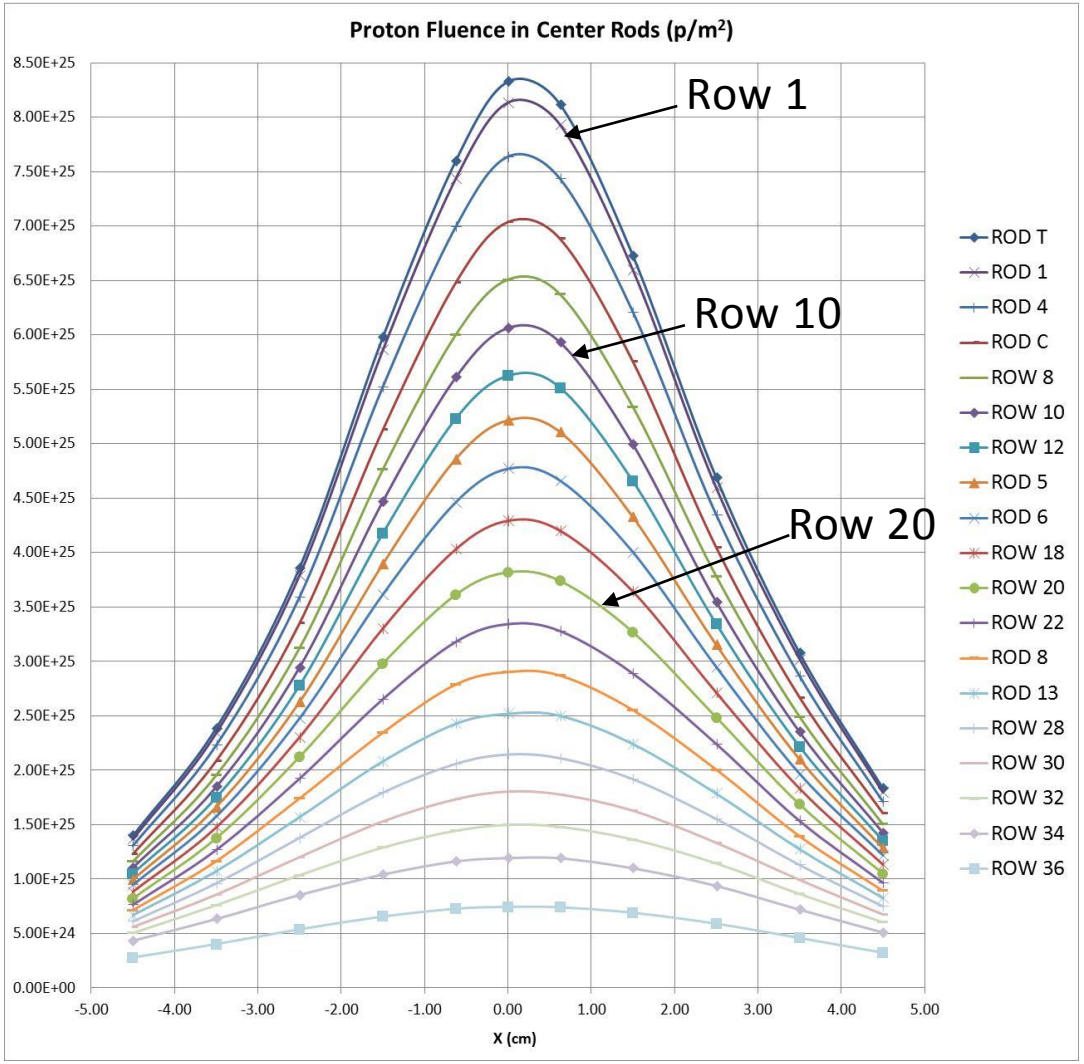
Proton flux



Neutron flux

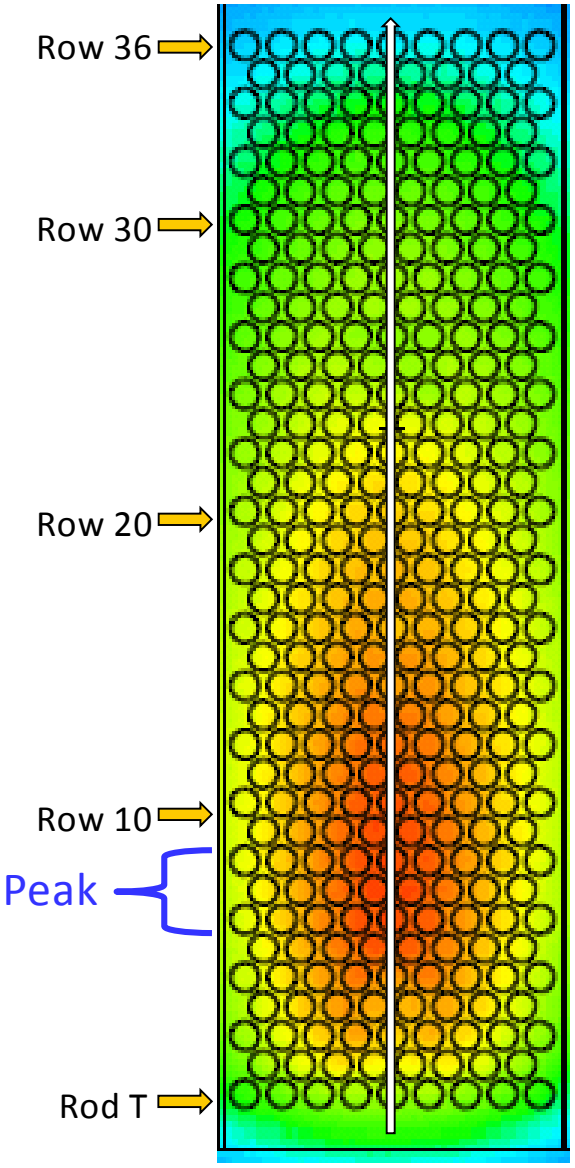
Proton fluence distribution (STIP-VI)

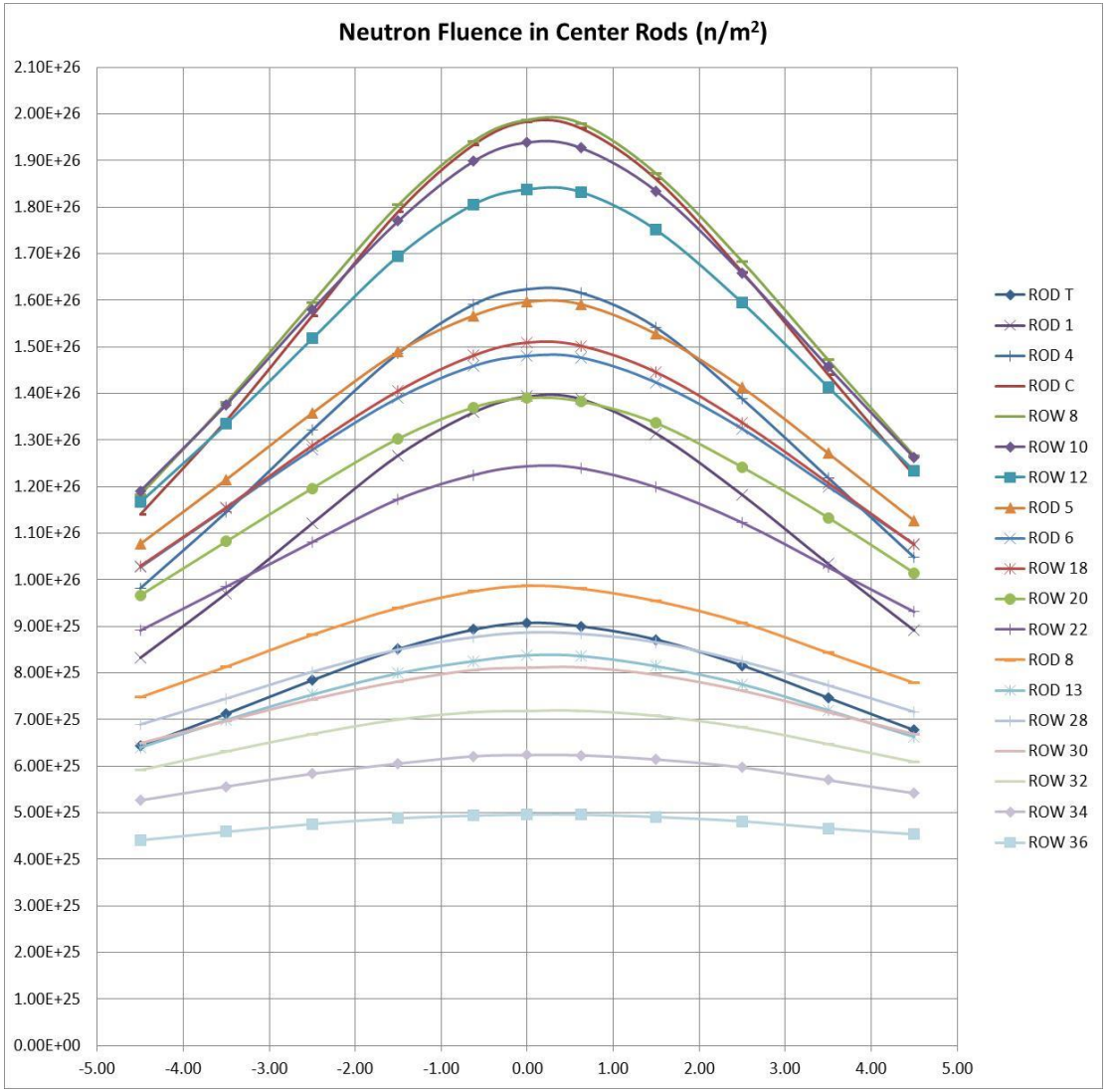




Proton fluence (STIP-VI)

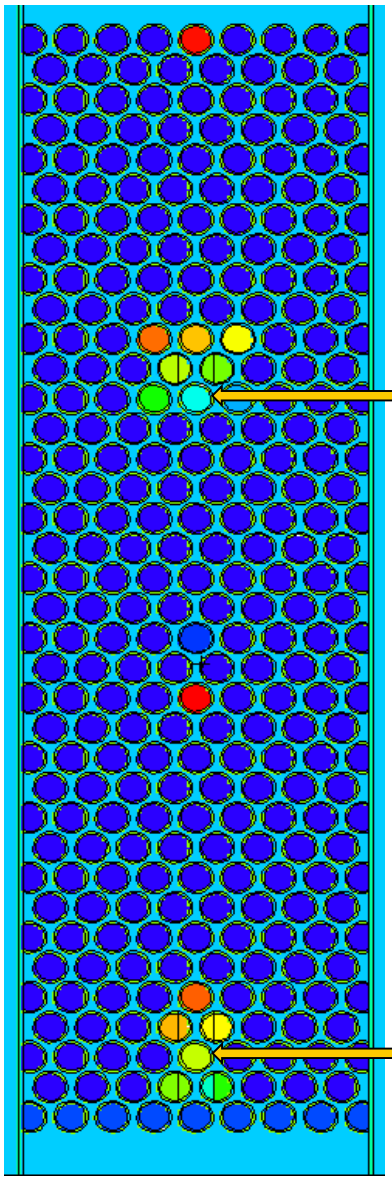
Neutron fluence distribution (STIP-VI)

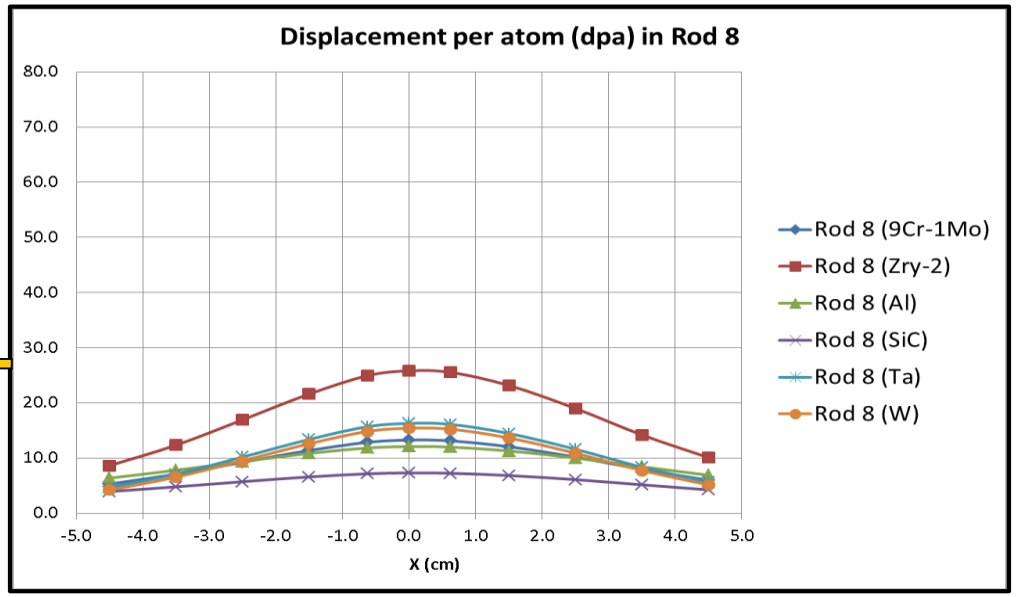


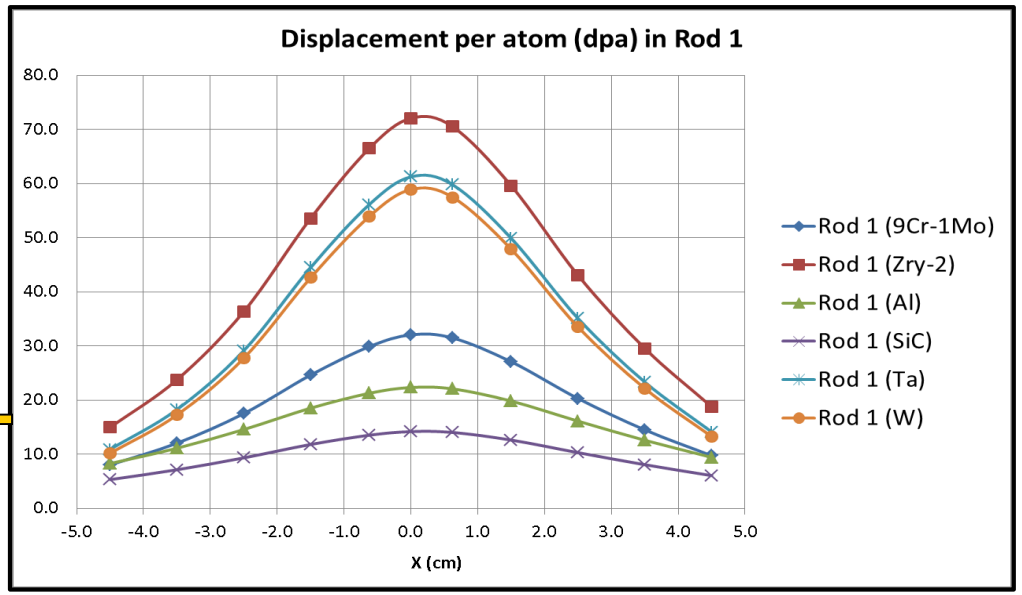


Neutron fluence (STIP-VI)

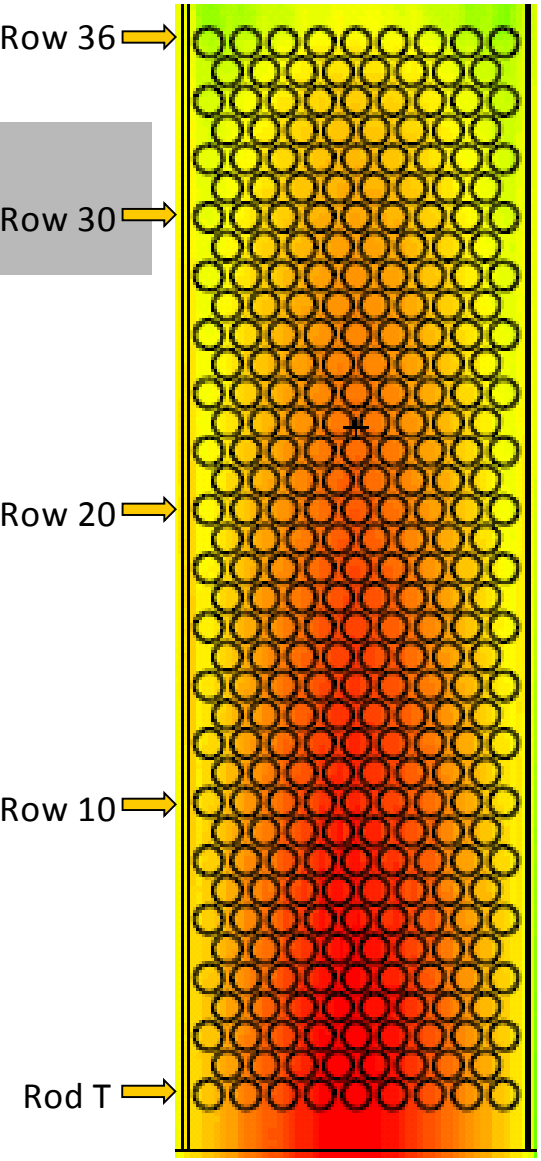
dpa distribution in SINQ target-9 (STIP-VI)

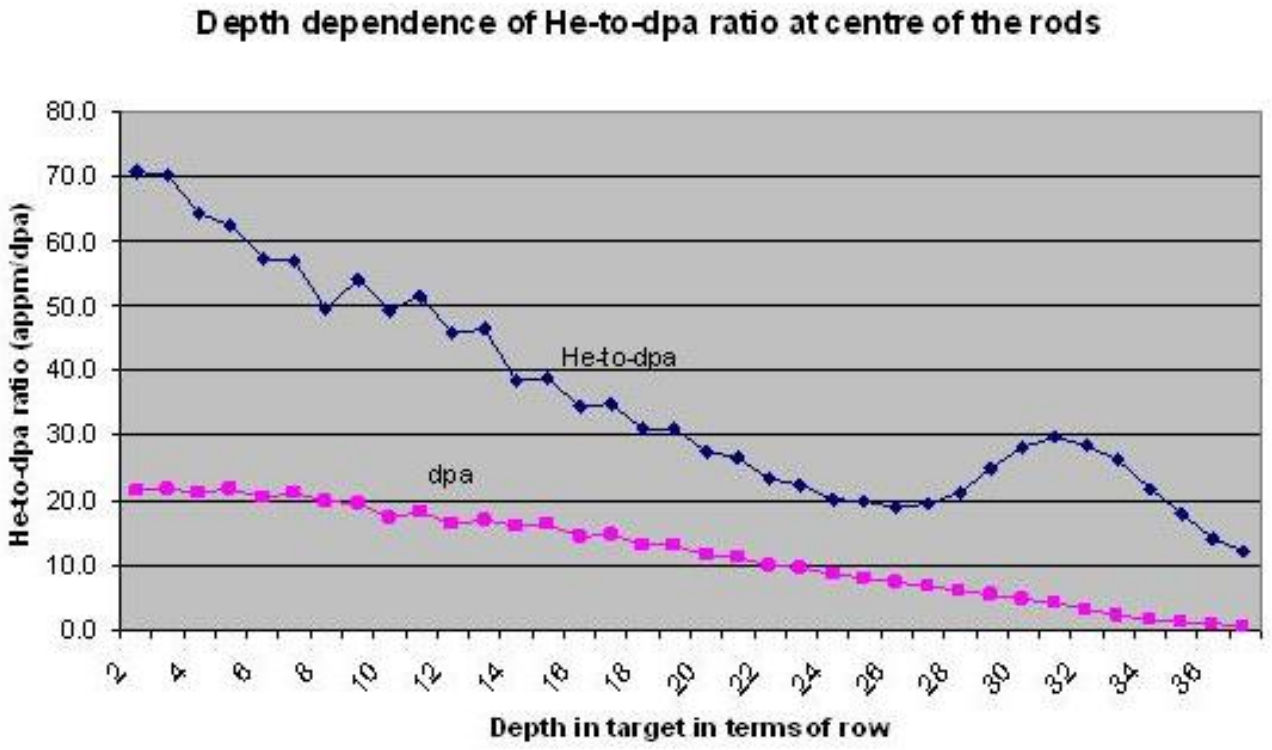






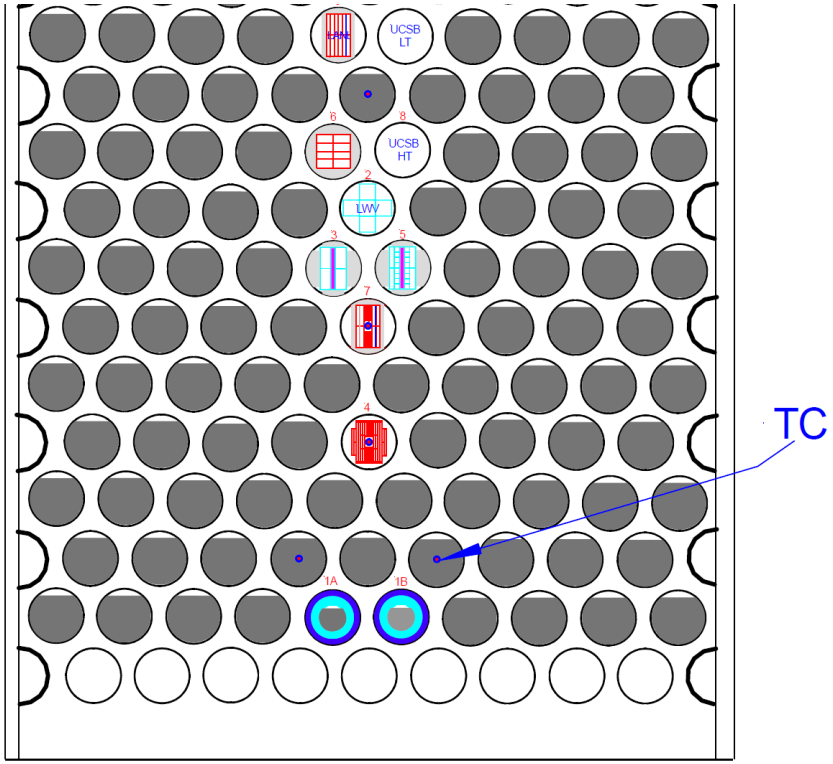
He/dpa distribution in a SINQ target

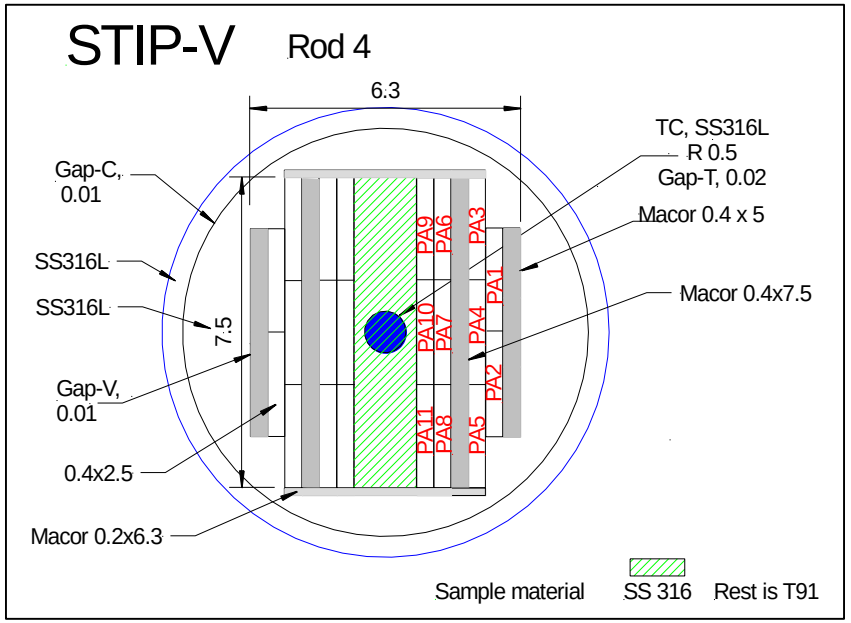


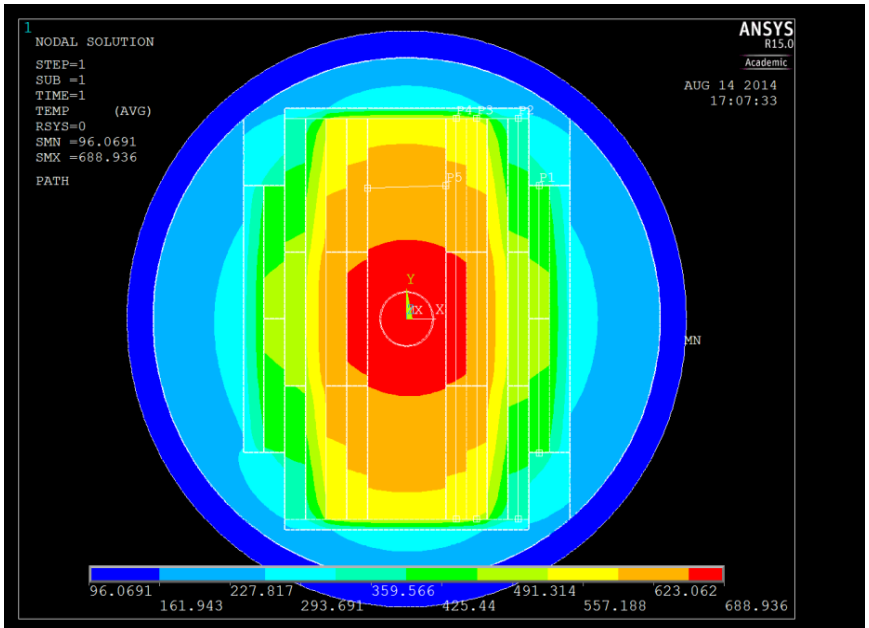


STIP-III

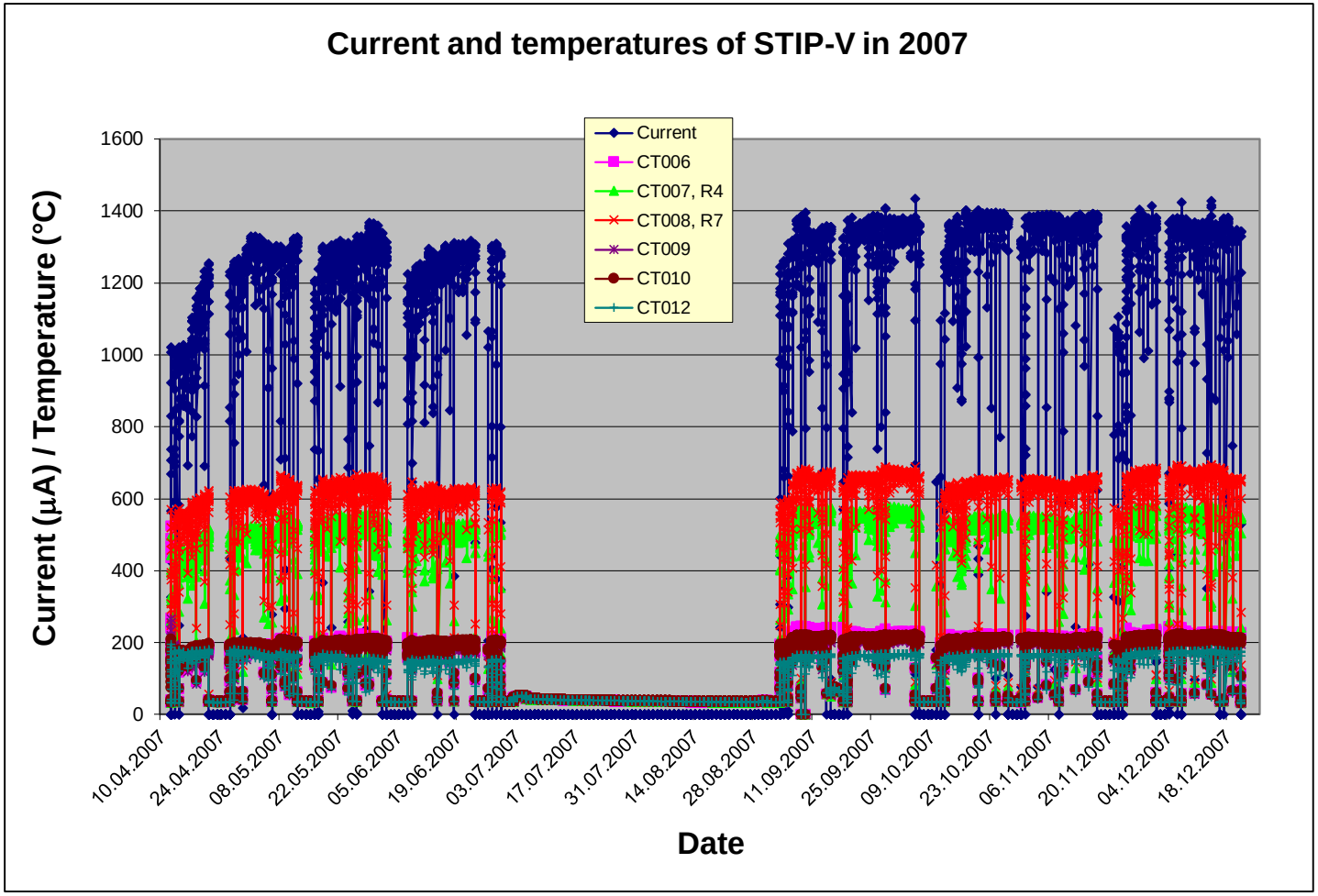
Irradiation temperature assessment







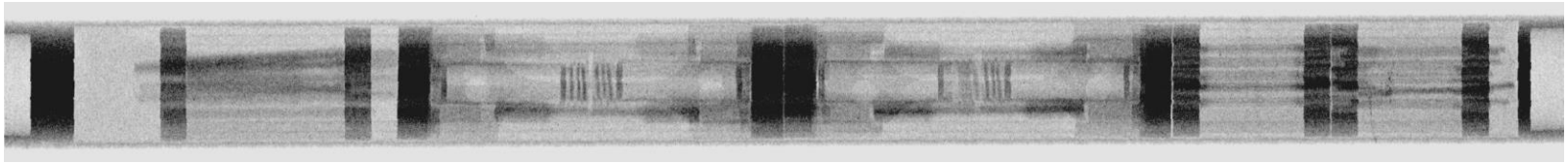
Proton beam and temperature variation during operation



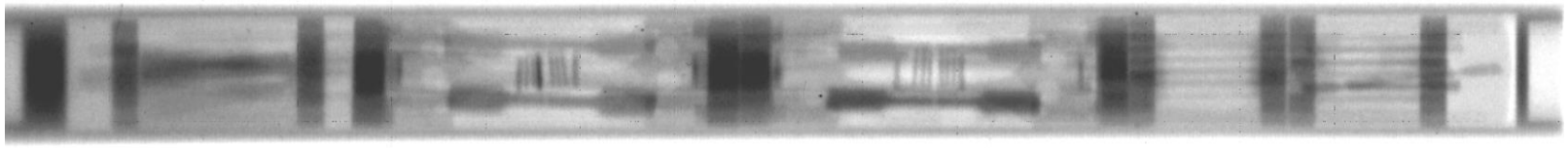
For Rod 4: $T_{meas.} \approx 0.8\, T_{cal.}$

Neutron radiography: STIP-II Pb-Bi Rod

Before irradiation



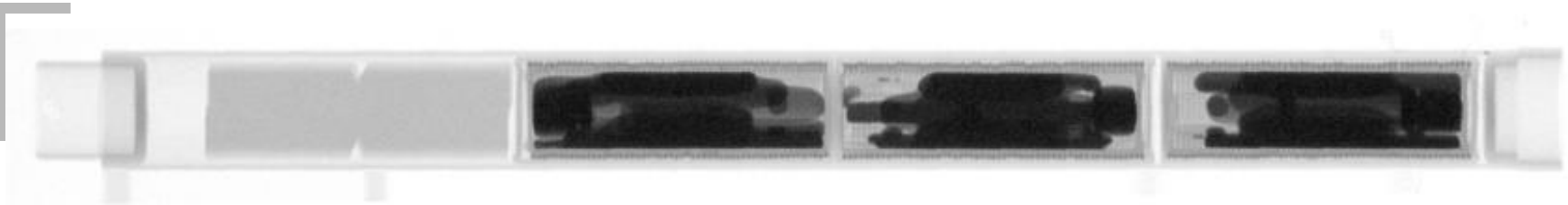
After irradiation (max dose: 20 dpa)



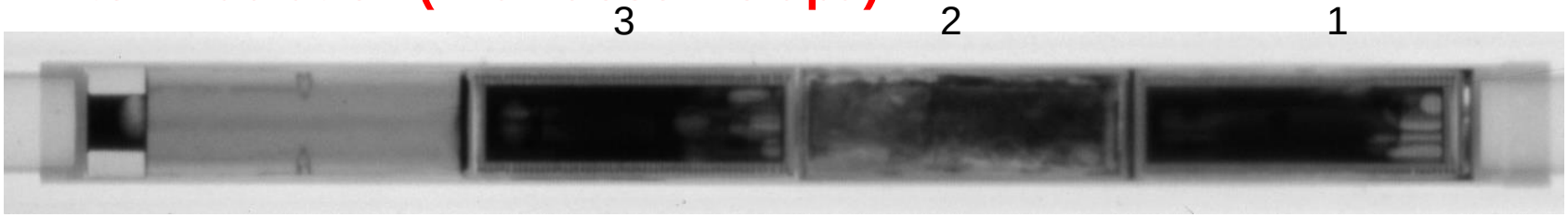
Dai et al. / JNM 343 (2005) 33–44

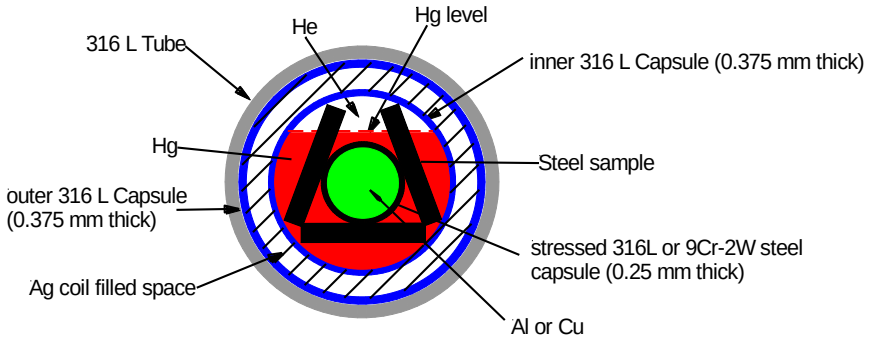
Neutron radiography: STIP-II Hg Rod

Before irradiation



After irradiation (max dose: 19 dpa)





Target Rod A:
It contains three Hg (about 19 g in total) filled SS 316 L capsules for studying irradiation assisted corrosion effects of Hg on two kinds of steels.

Dai et al. / JNM 343 (2005) 33–44

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Ti, Mo and W-alloys and pure Ta irradiated in STIP

Ti, Mo and W-alloys irradiated in STIP-I

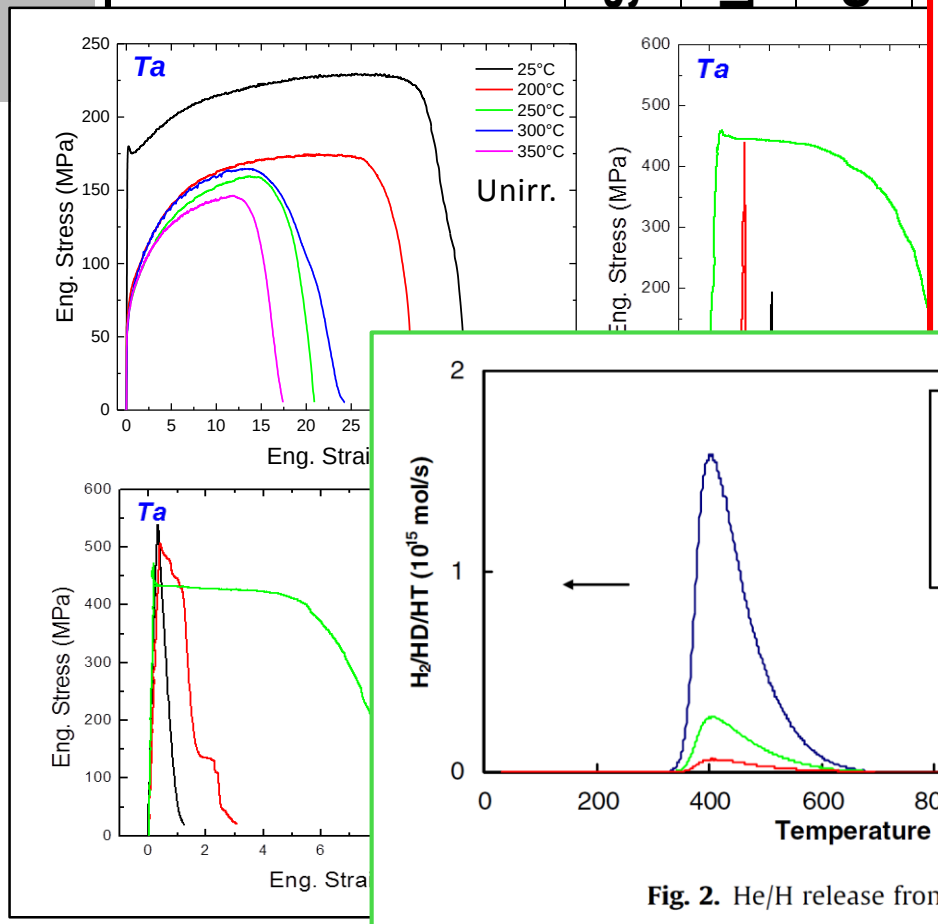
STIP-I Matrix								
Materials	Tensile	B-fatigue	Tear	Bend bar	Charpy	S.Punch	TEM	Supplier
Ti-Zr	8				4		14	PSI
W								FZJ
W - 5% Re								FZJ
W - 26% Re								FZJ
Mo								FZJ
Mo-W								FZJ

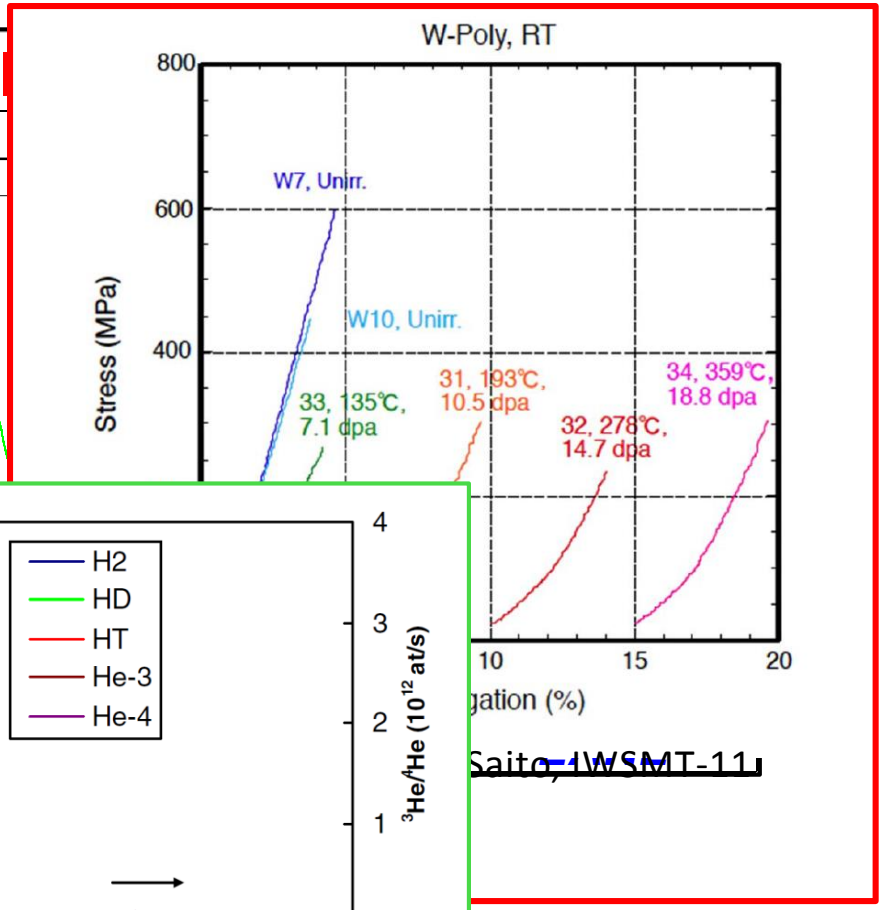
No results!

Samples no more available!

Ti, Mo and W-alloys irradiated in STIP-II

Irradiation Matrix of STIP-II





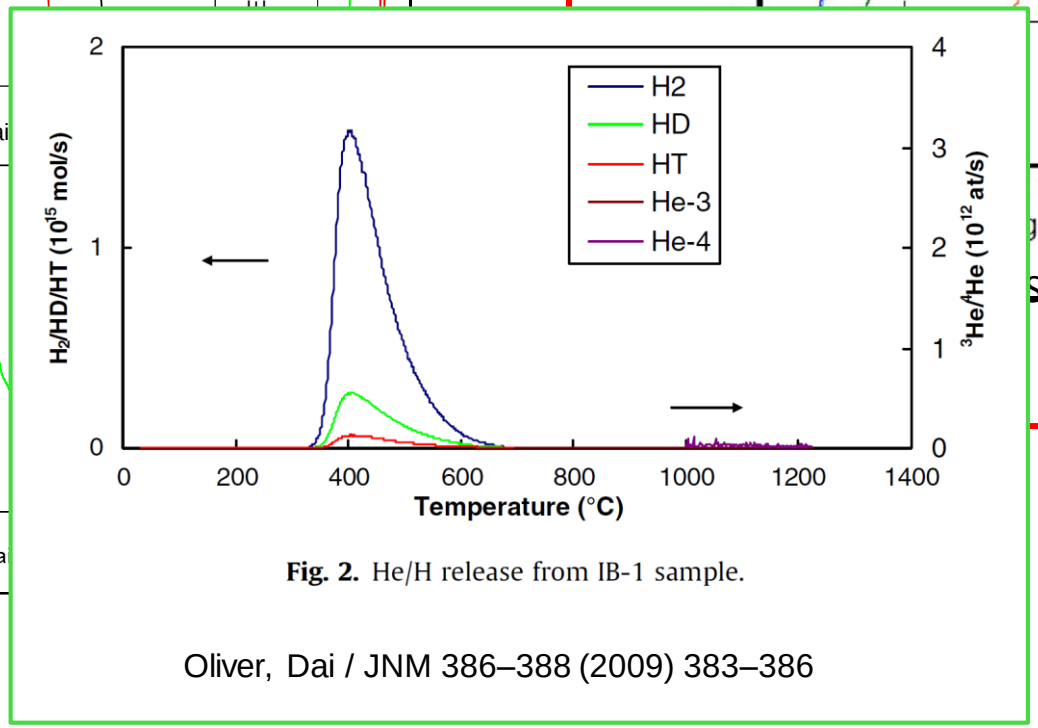


Fig. 2. He/H release from IB-1 sample.

Oliver, Dai / JNM 386–388 (2009) 383–386

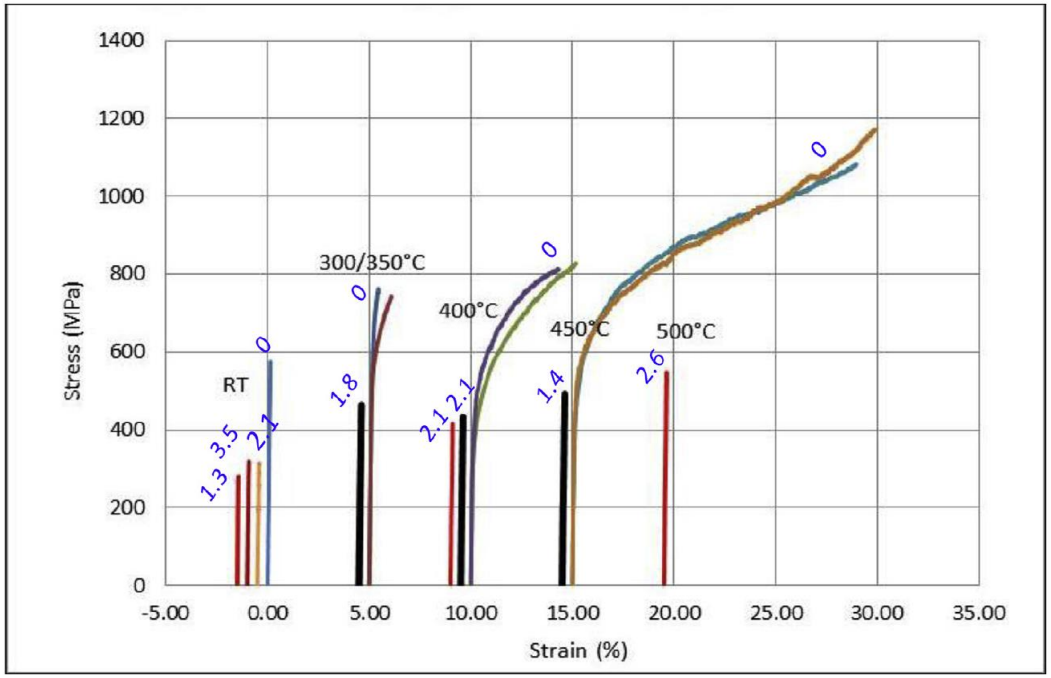
Ti, Mo and W-alloys irradiated in STIP-IV, -V

Irradiation Matrix of STIP-IV (Target-VI)

Materials	Tensile S	Tensile L	B-fatigue	Bend bar	Charpy	SP	TEM	SANS	Supplier
Ti-alloy					4				CRPP
Ti-Al		9		6					PSI
TZM									

Irradiation Matrix

Materials	Tensile S
TZM	
W-26%Re	
W	2 sheets



Habainy et al. / JNM 514 (2019) 189-195

Ti, Mo and W-alloys irradiated in STIP-VI

Irradiation Matrix of STIP-VI											
Materials	Tensile S	Tensile L	TEM / SP	SANS	Bend Bar	Charpy	LiSoR-6	total	Compression	Complete rod	Supplier
W/W Alloy			74					74			PSI / USTB
W-0.5ZrC											
W-0.5Y-1Mo											
Rolled W											
Pure W	~20 sheets, (20-30)x(5-7)x0.4 mm										PSI

Irradiation Matrix of STIP-VII								
Materials	Tensile S	Tensile L	B-fatigue	HT-1/3 CVN	KLST Charpy	TEM	Clad rod	Supplier
Ti-6Al-4V	18	10	6	12				PSI
Ta,SS, Zry clad W							9	PSI
W-KIT				5				PSI
W-CSNS				10				PSI
W-Ta joint		4						PSI
Pure W	15 sheets (20-30)x(5-7)x0.4 mm							PSI

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STIP samples

Materials	max dose / T
Austenitic steels SA316L, SA316LN, CW316, 316L-EBW, 316-TIG	32dpa / 500°C
FM steels T91, Eurofer97, …….	32 dpa / 500°C
ODS steels 9Cr-, 12Cr-ODS, PM2000	32 dpa / 600°C
Inconel 718, & EBW	20 dpa / 400°C
Al-alloys AlMg3, Al6061	8.8 dpa / 60°C 10 dpa / 200°C
Zircaloy 2	50 dpa / 250°C
Ti-6Al-4V	tbd (25 dpa in Fe) 450°C
W, W-alloys, TZM, Ta	40 dpa (in W, eq. for Mo & Ta) / 500°C
SiCf/SiC composite C composite	7 dpa / 500°C

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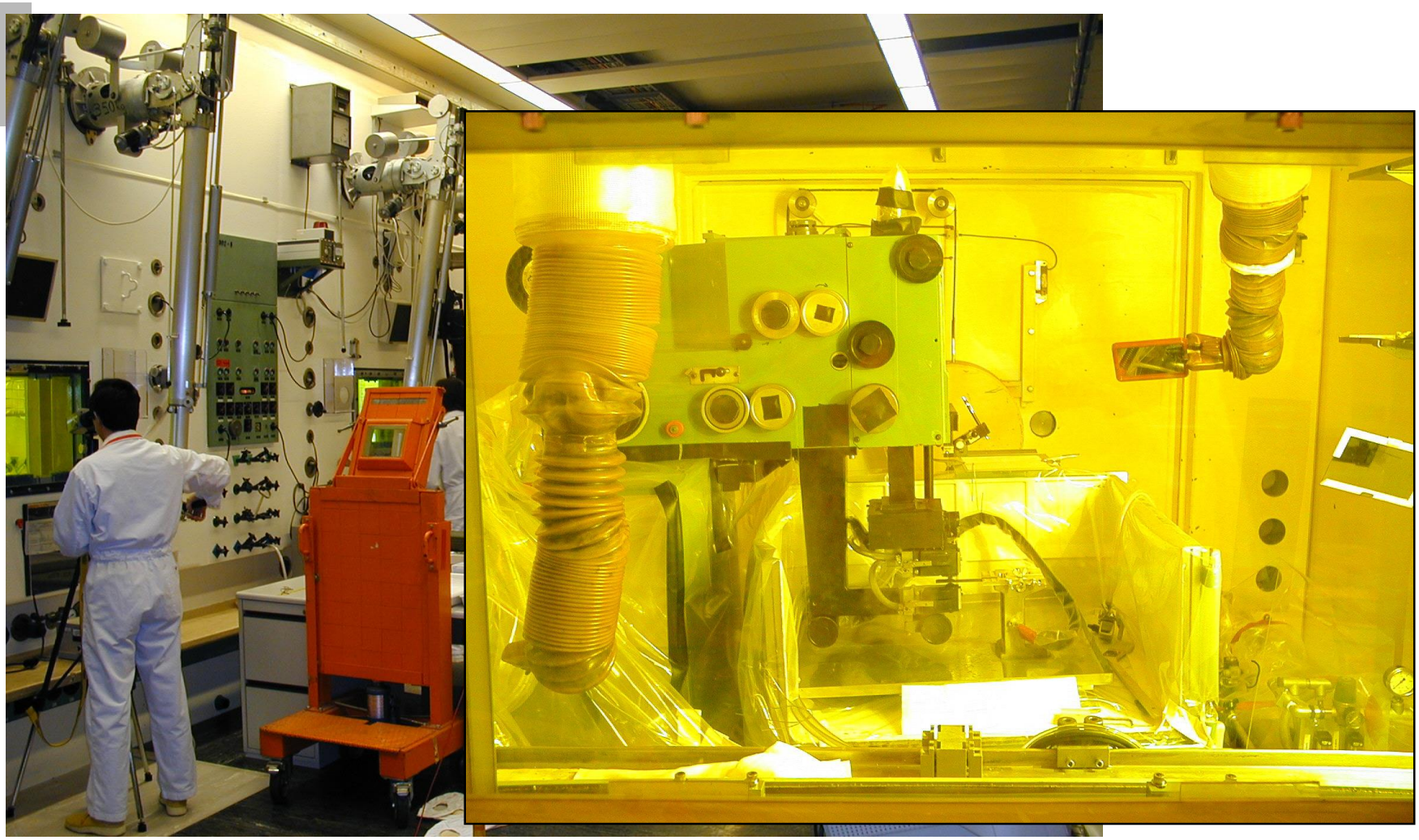
The PIE capabilities at PSI

Fully equipped (α,β,γ) hot-cells:

Hot cells



Fully equipped (α,β,γ) hot-cells

Semi-hot cells

PIE conducted in fully equipped (α,β,γ) hot-cells:

Mechanical testing

- Tensile test (<20kN, <800°C)
- 3PB test (fracture toughness) (<10kN, <800°C)
- Charpy test (3x4x27mm samples, <1200°C)
- Hardness
- Nano-indentation (-100 to 300°C)

Microstructural analyses

- TEM (FIB sample preparation possibility)
- SEM (in-situ observation possibility)
- Atom Probe Tomography (at ETHZ)
- Positron Annihilation Spectroscopy
- Micro-, Nano-XAS (X-ray Absorption Spectroscopy)
- SANS

Others

- He, H release measurements
- Neutron radiography

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