

PAUL SCHERRER INSTITUT



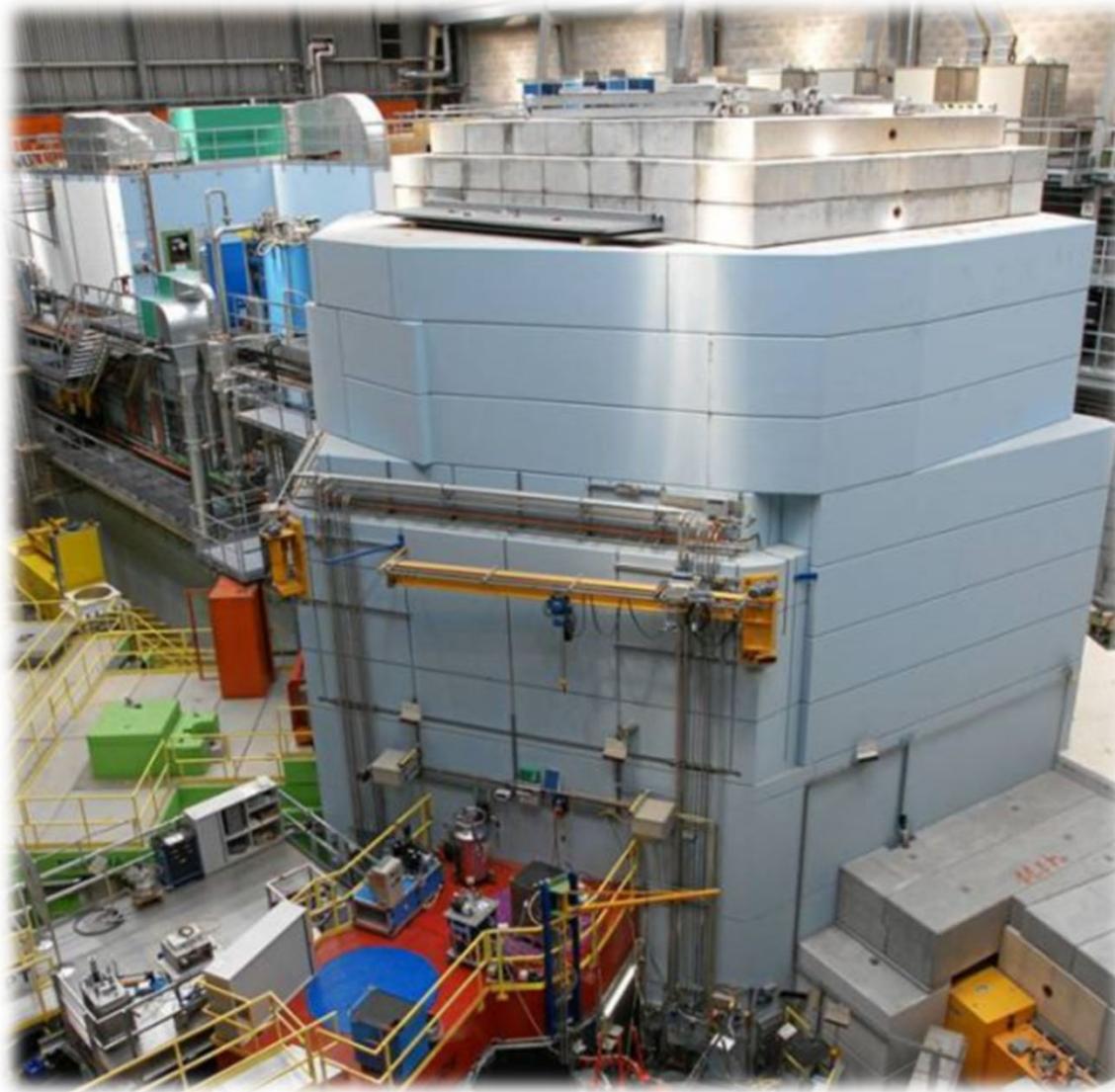
WIR SCHAFFEN WISSEN – HEUTE FÜR MORGEN

Irradiation Experiments at SINQ – STIP and PIE capability at PSI

Yong Dai
Paul Scherrer Institut, Switzerland

Snowmass'21 – Irradiation Stations and Alternatives Workshop, 17-18.06.2021

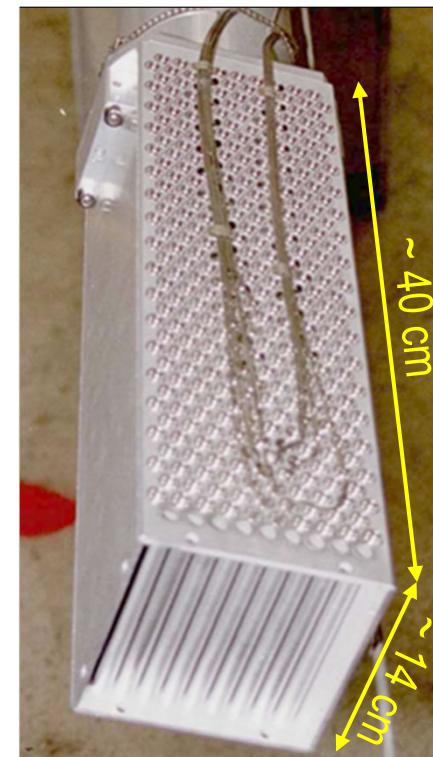
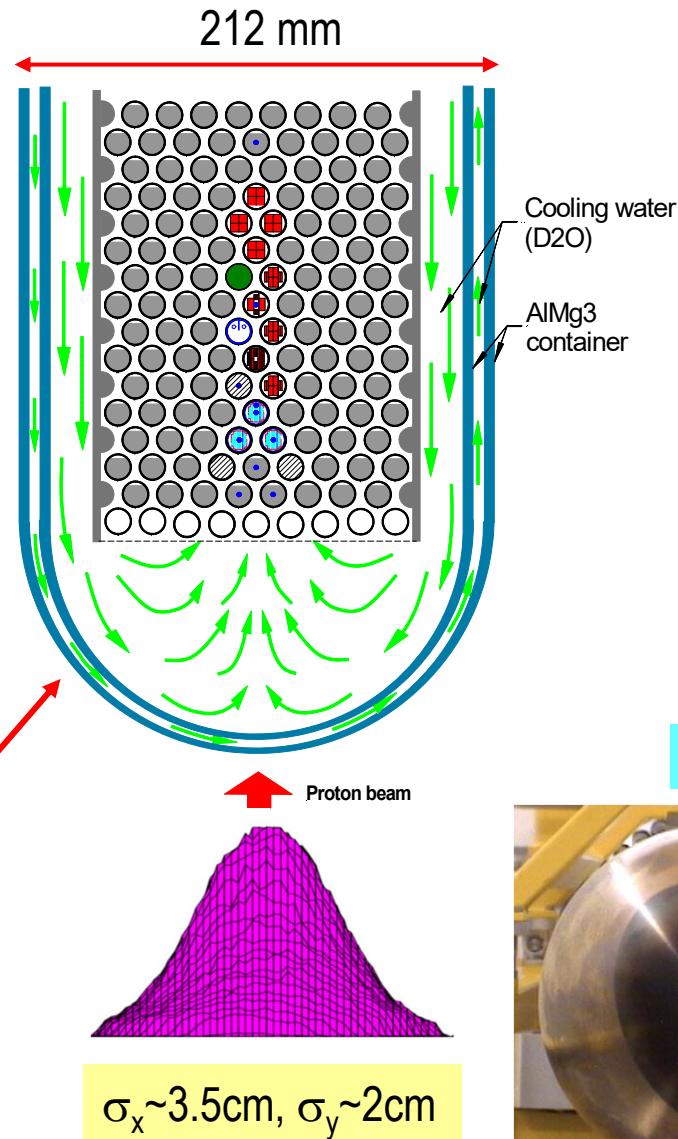
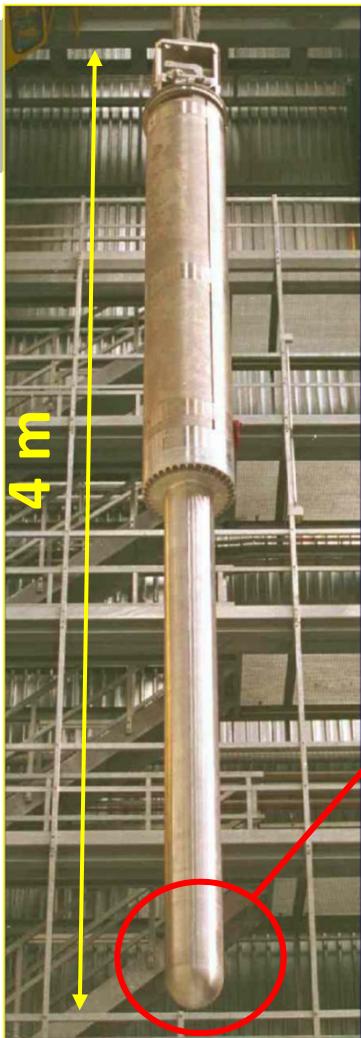
SINQ – Swiss Spallation Neutron Source



SINQ Target Irradiation Program- STIP

- Mission:
 - 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 corrosion and embrittlement effects on structural materials in spallation irradiation environments.
- Specimens irradiated inside SINQ targets with high energy protons and spallation neutrons: **3–15 dpa/yr** with **20–90 appm He/dpa, 80–300 appm H/dpa** in steels.
- Each irradiation lasts **2 years**. But, it takes ≥ 5 years from sample preparation to the start of PIE.
- Eight irradiation experiments were conducted during 1998 and 2020.
- 9000+ 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 up to 30 dpa (in steels) at temperatures up to $\sim 600^{\circ}\text{C}$.

SINQ Target

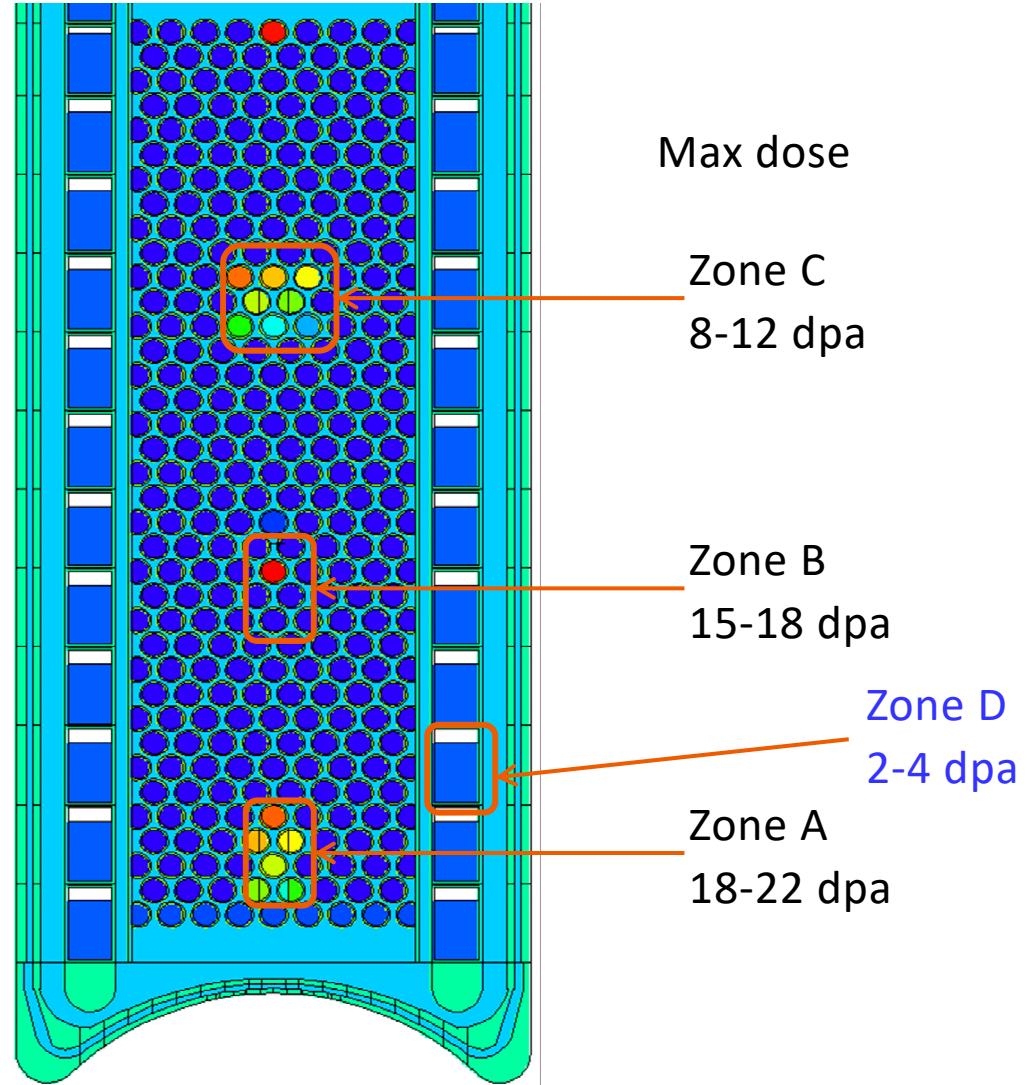
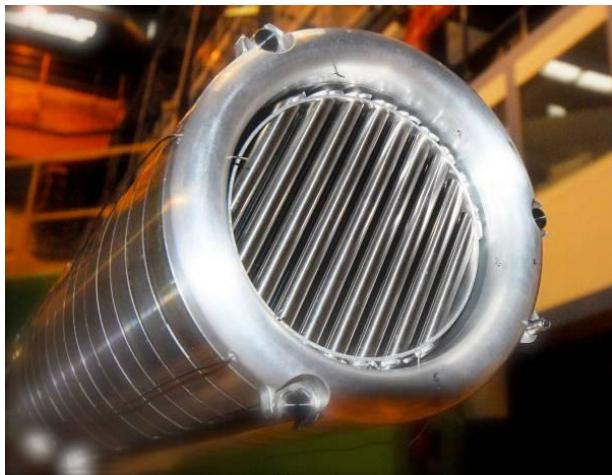


~360 Pb rods with SS / Zy-2 tubes



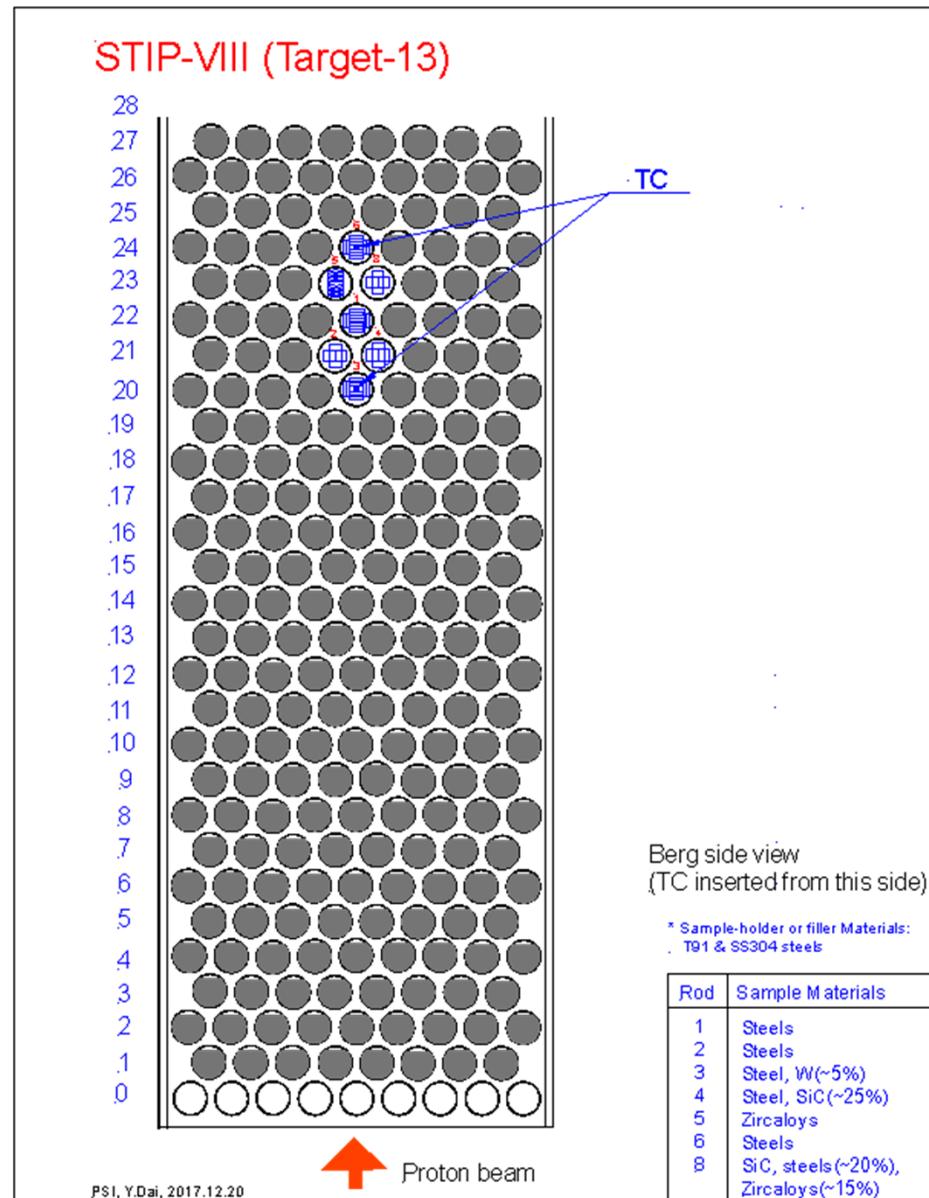
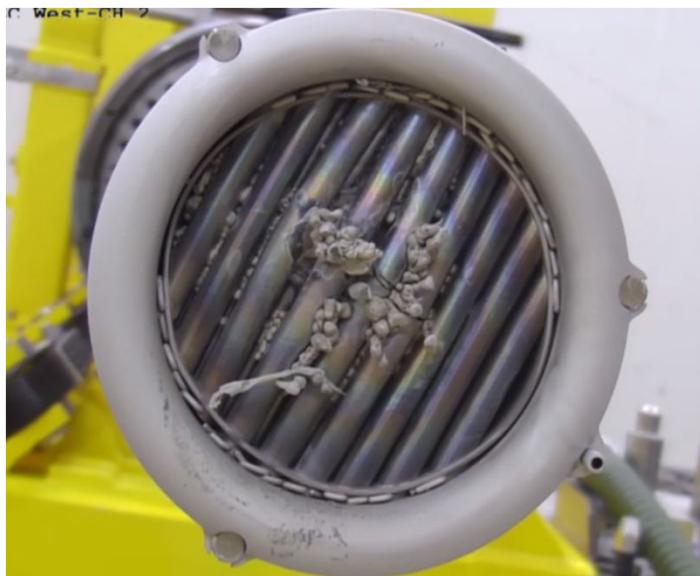
Proton beam:
570 MeV, 1.5 mA
On the target

Irradiation positions in a target



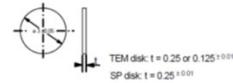
STIP-VIII

Due to the failure of Target-11 (without STIP samples) , high p/n flux zone is limited for STIP samples temperately.



STIP samples

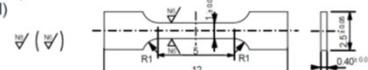
TEM & SP speimen



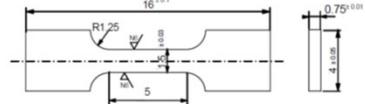
t = 0.25 or 0.125^{+0.01}

SP disk; t = 0.25^{+0.01}

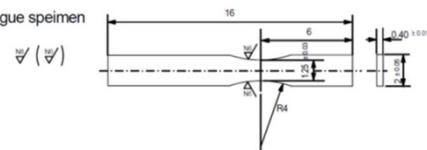
Tensile speimen S
(Small)



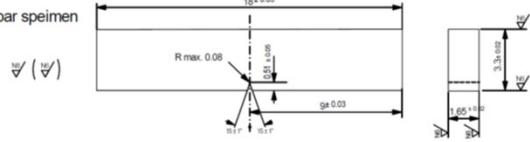
Tensile speimen L
(Large)



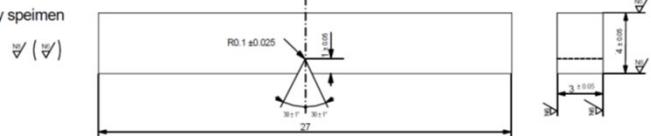
Bend fatigue speimen



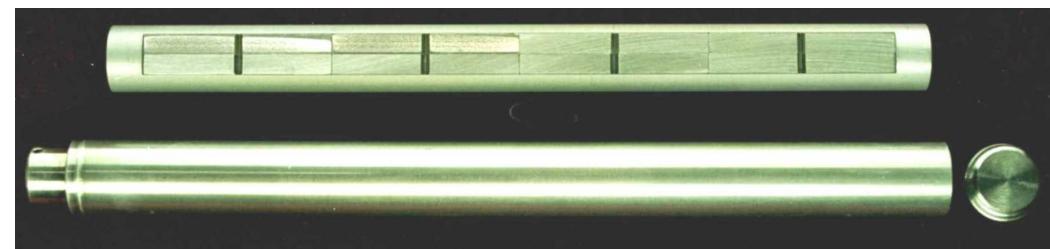
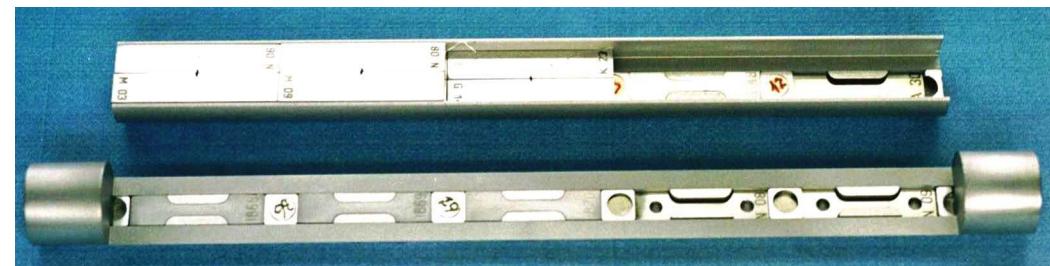
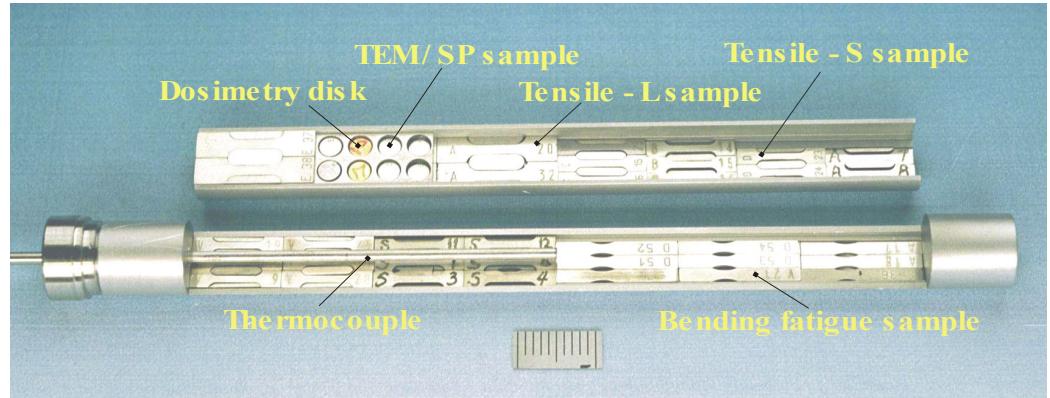
Bend bar speimen



Charpy speimen

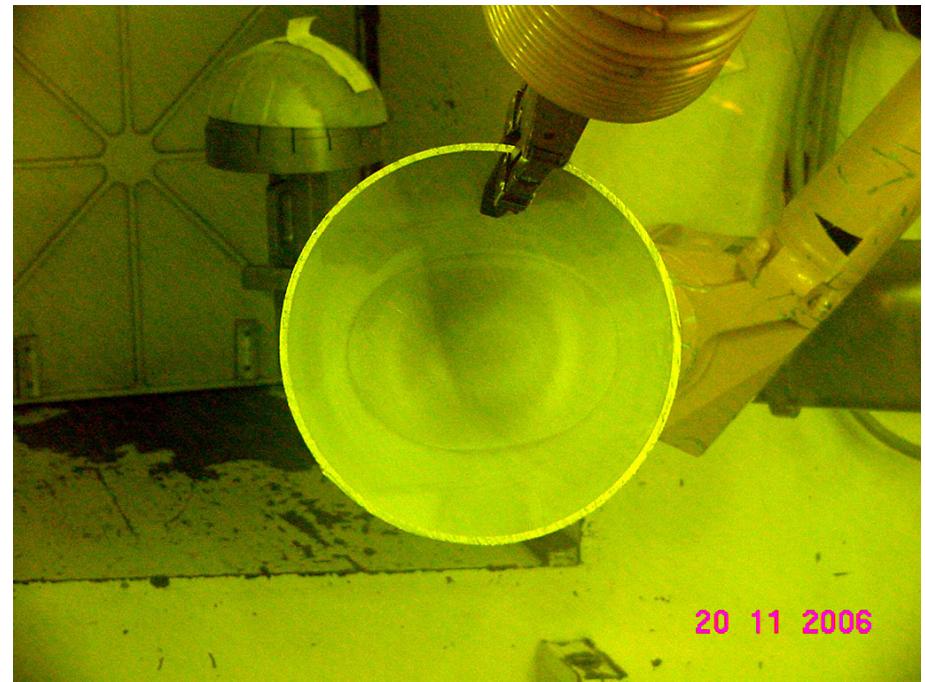
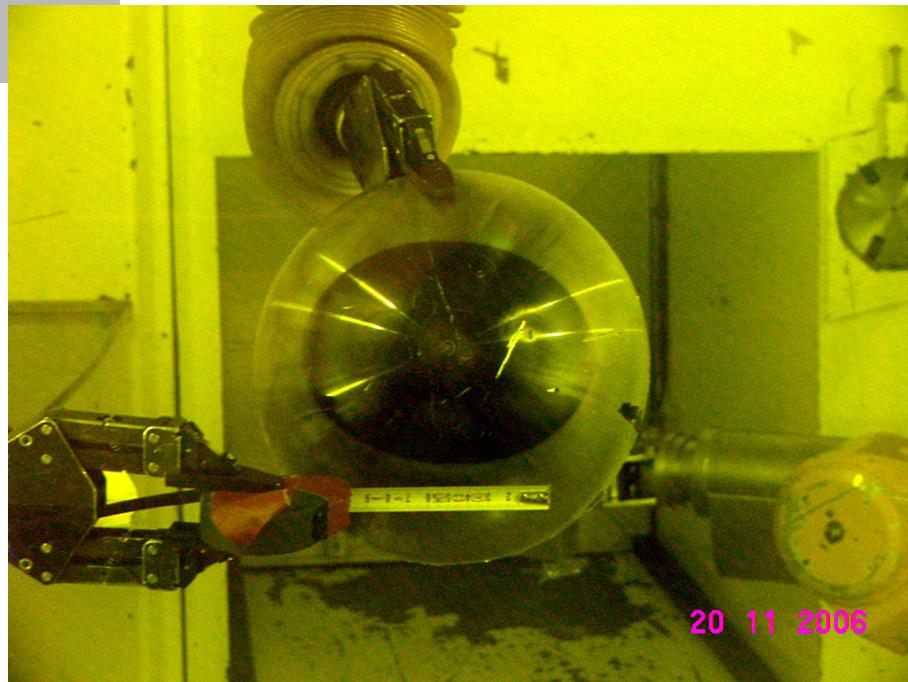


Dimension: mm
Other tolerance: ± 0.1

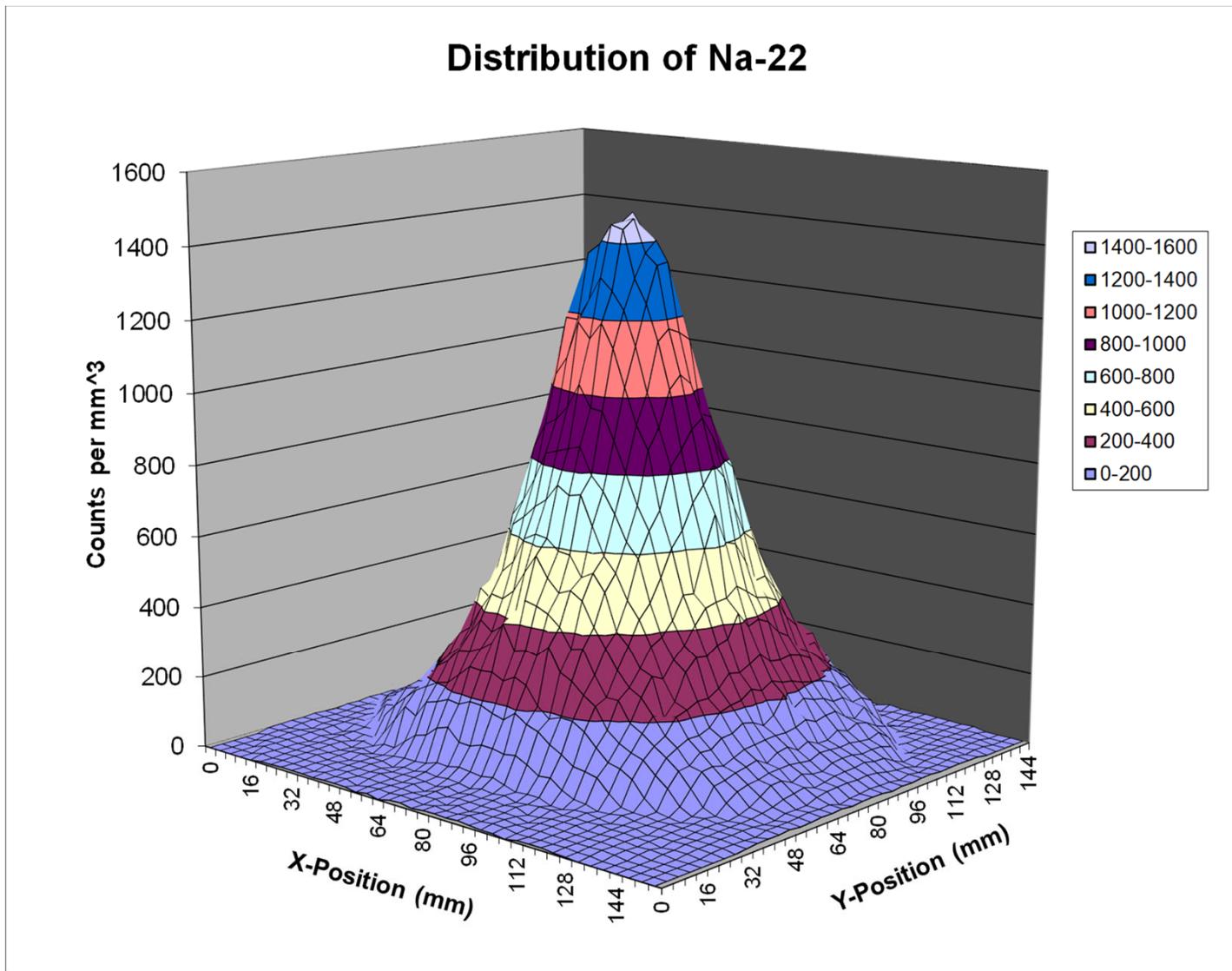


Evaluation of primary proton fluence distribution

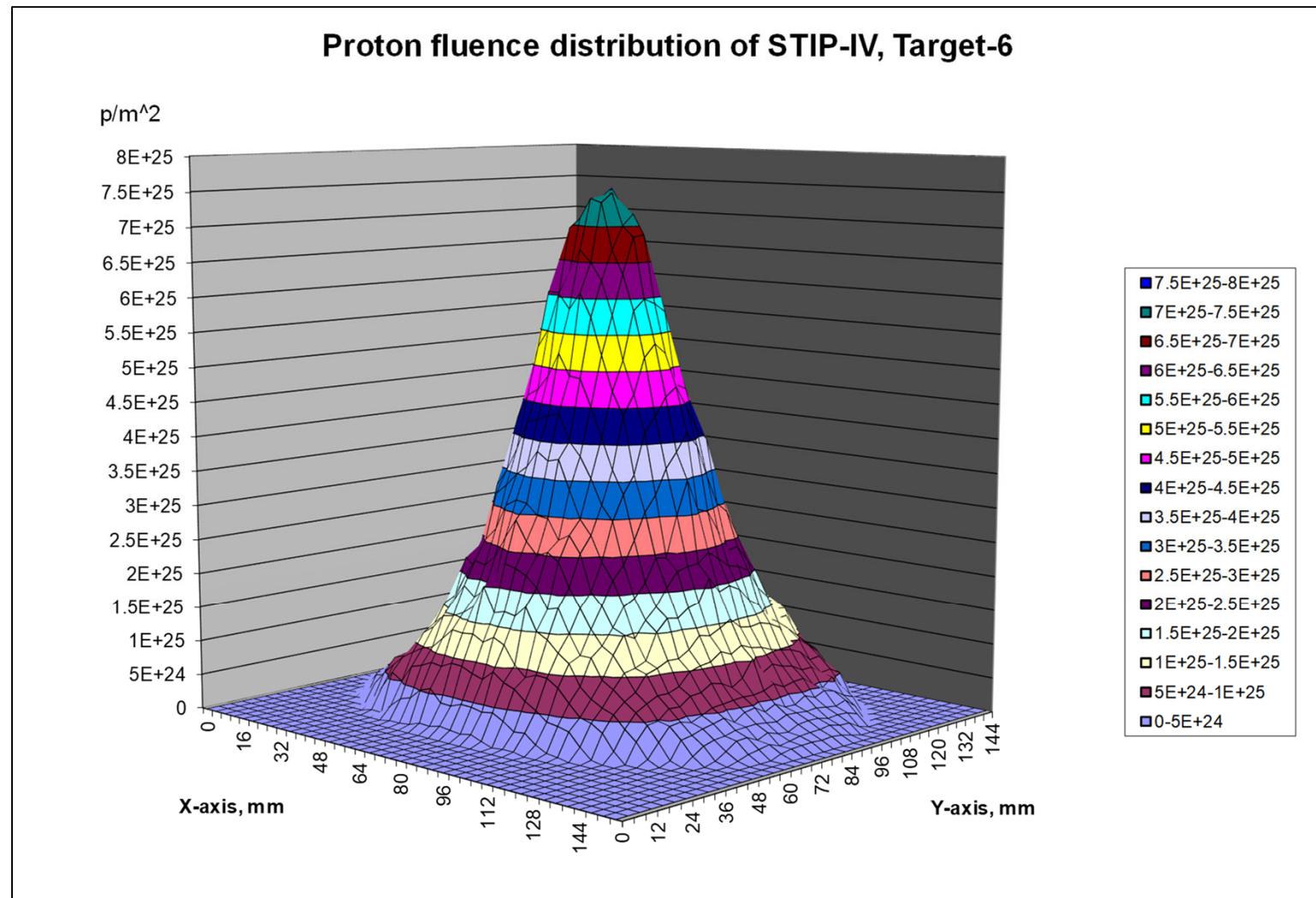
Gamma measurement of beam window



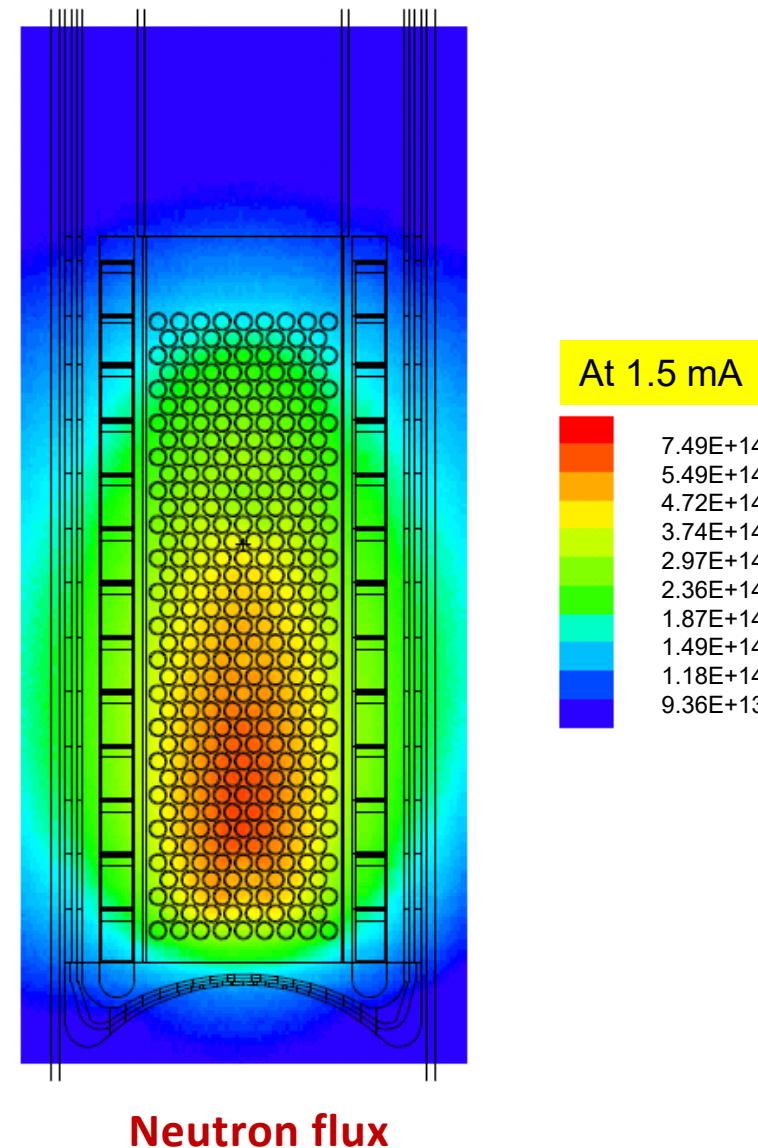
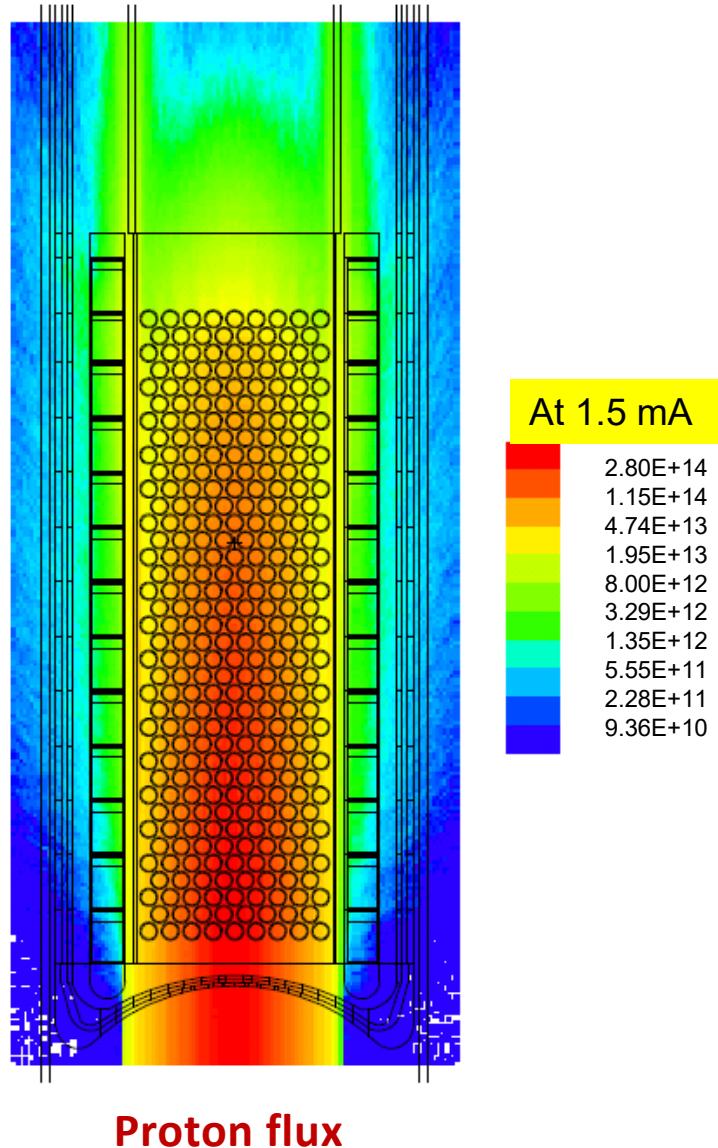
Evaluation of primary proton fluence distribution



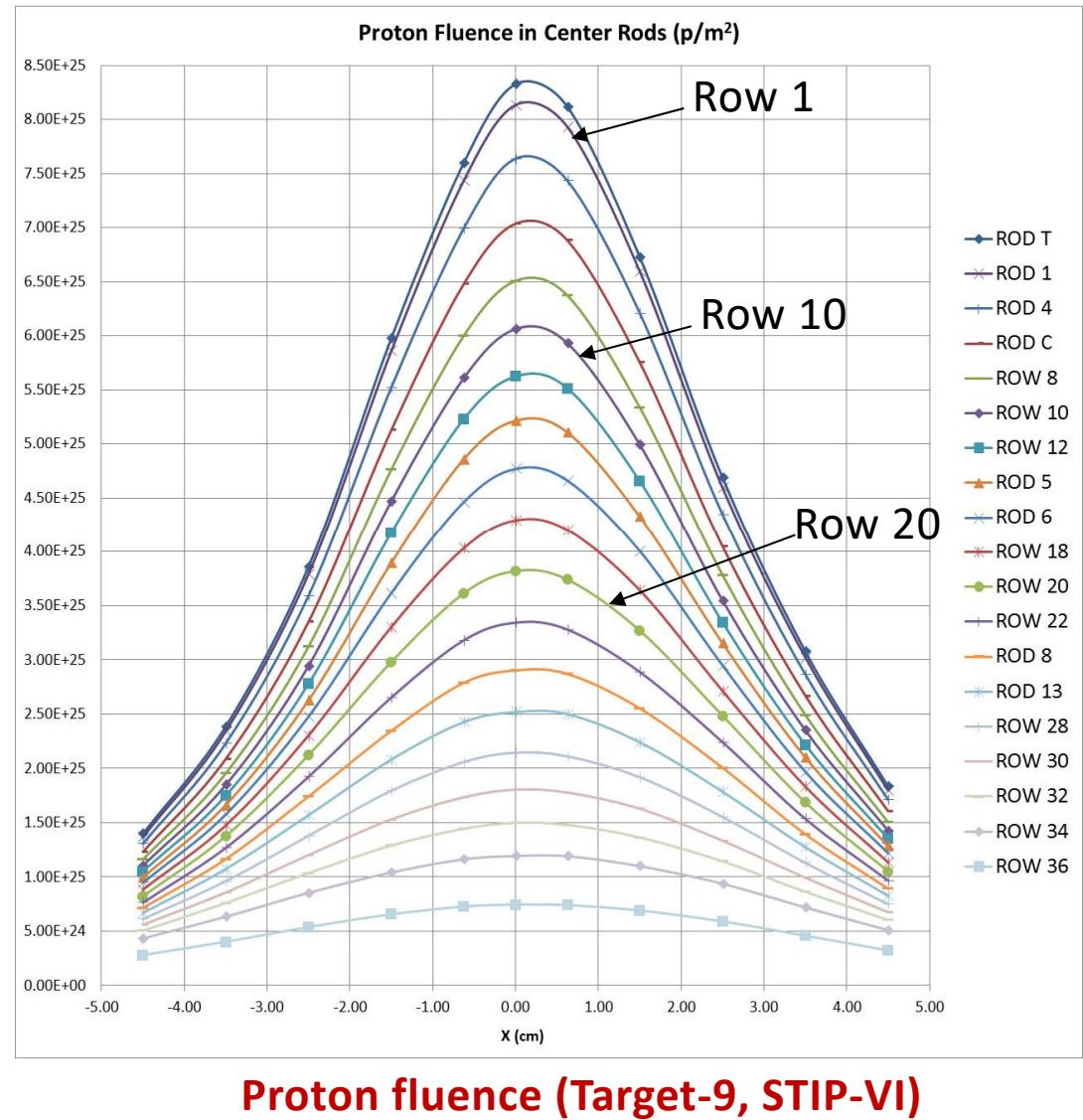
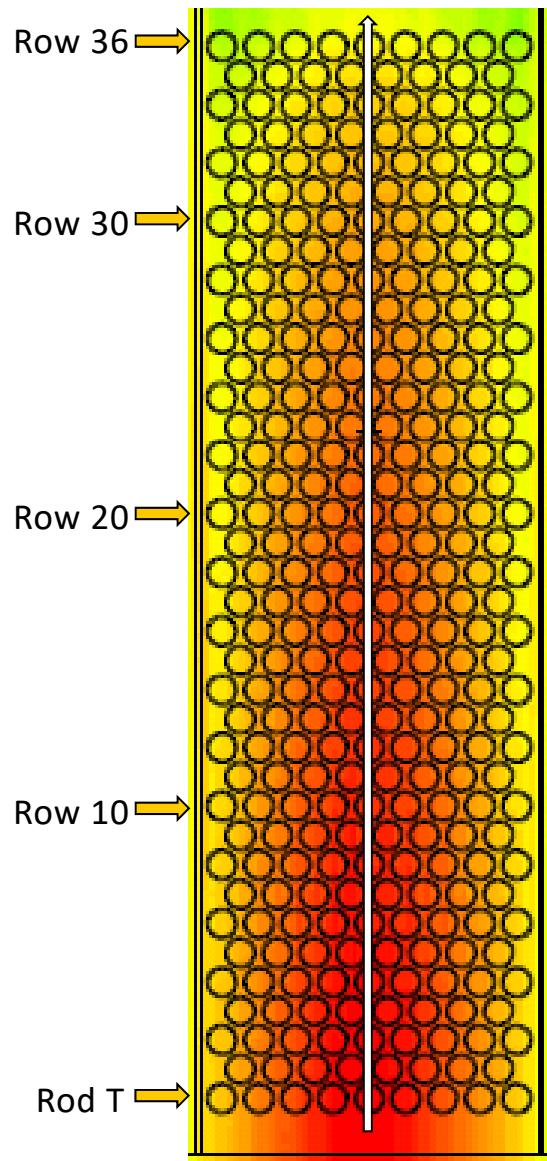
Evaluation of primary proton fluence distribution



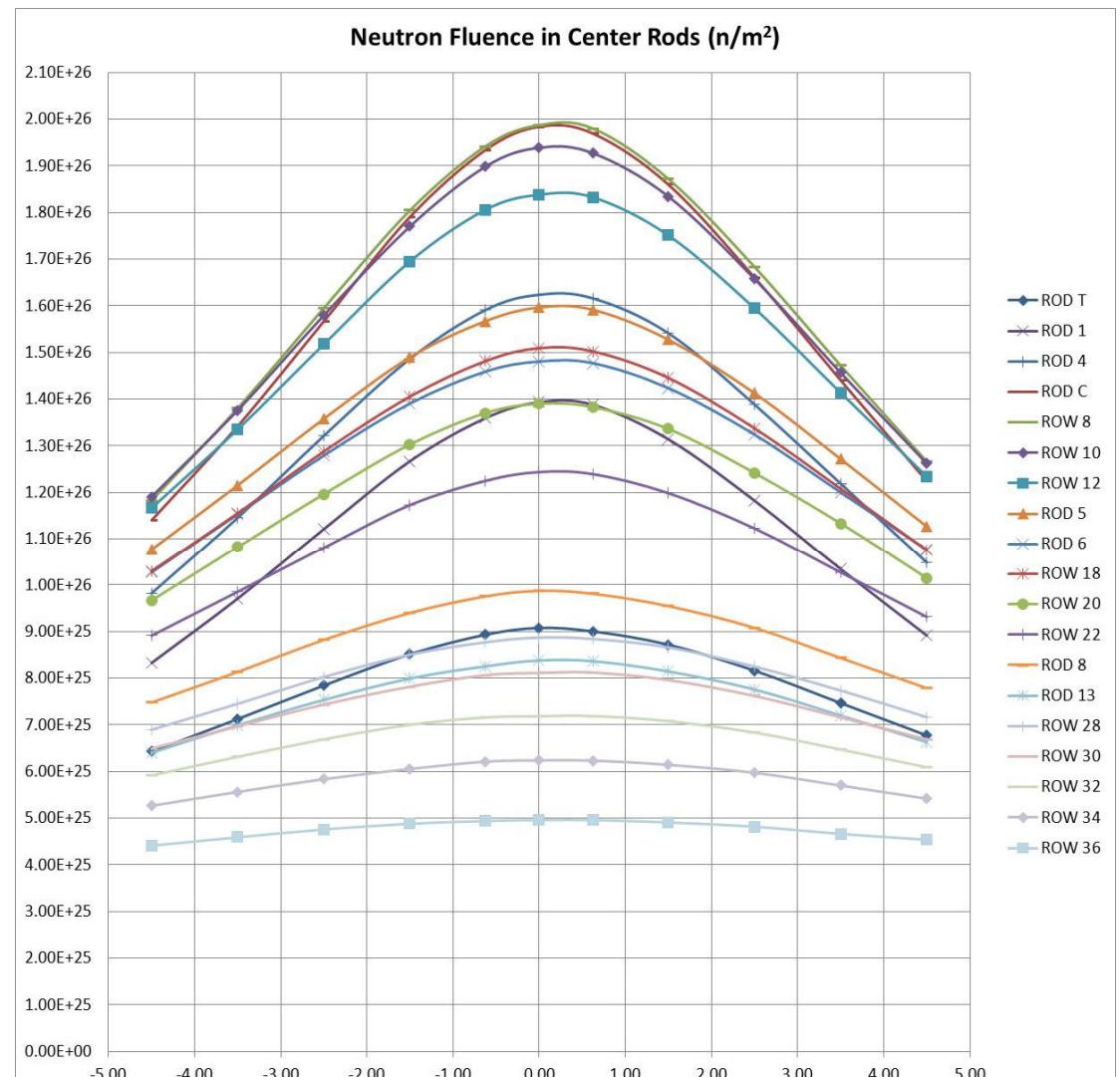
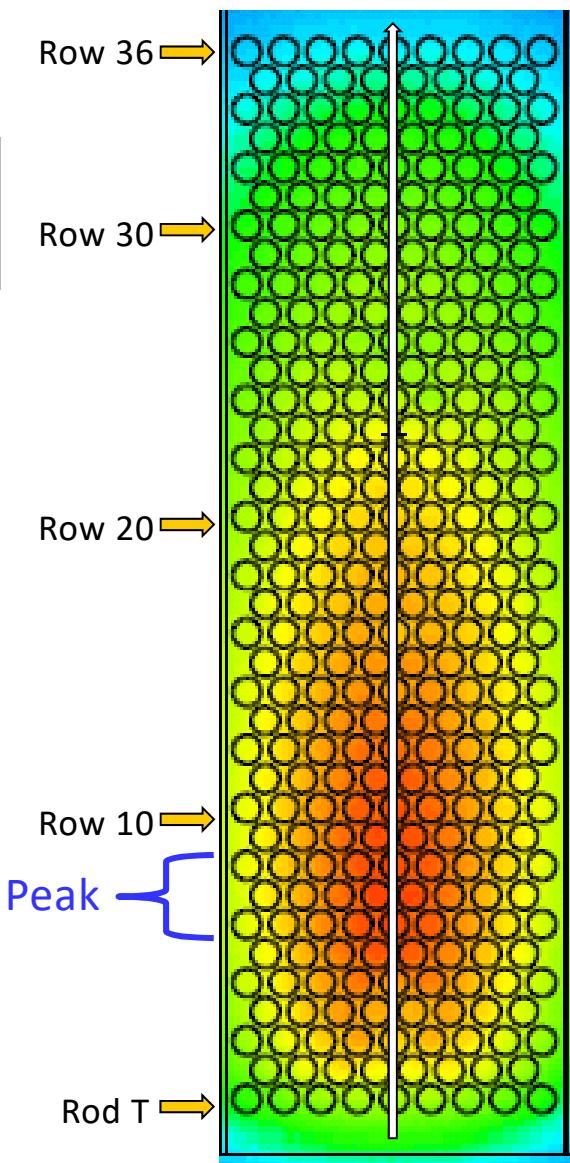
Proton and neutron flux distribution (in Target-9)



Proton fluence distribution in rods (central column)

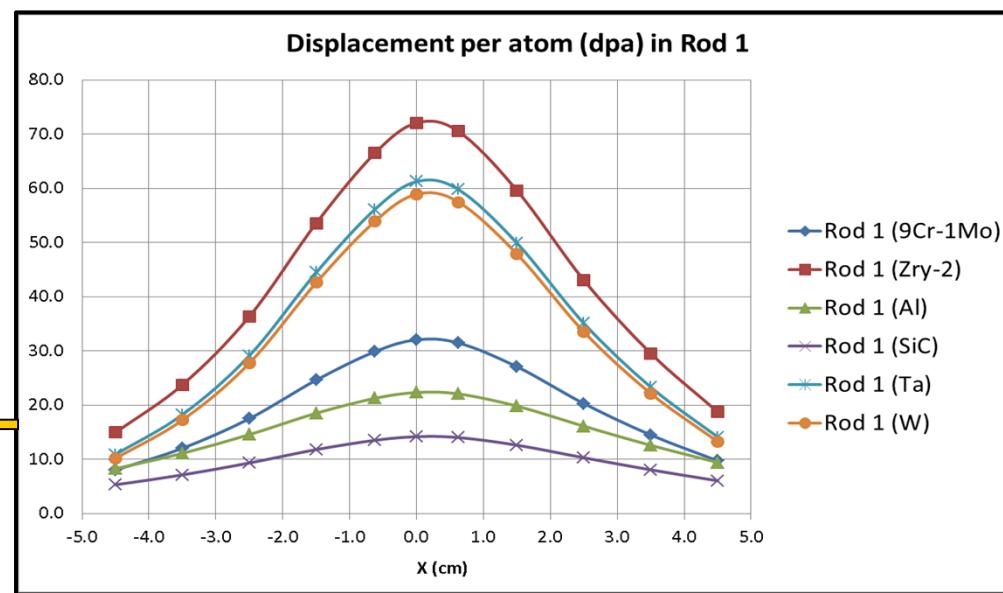
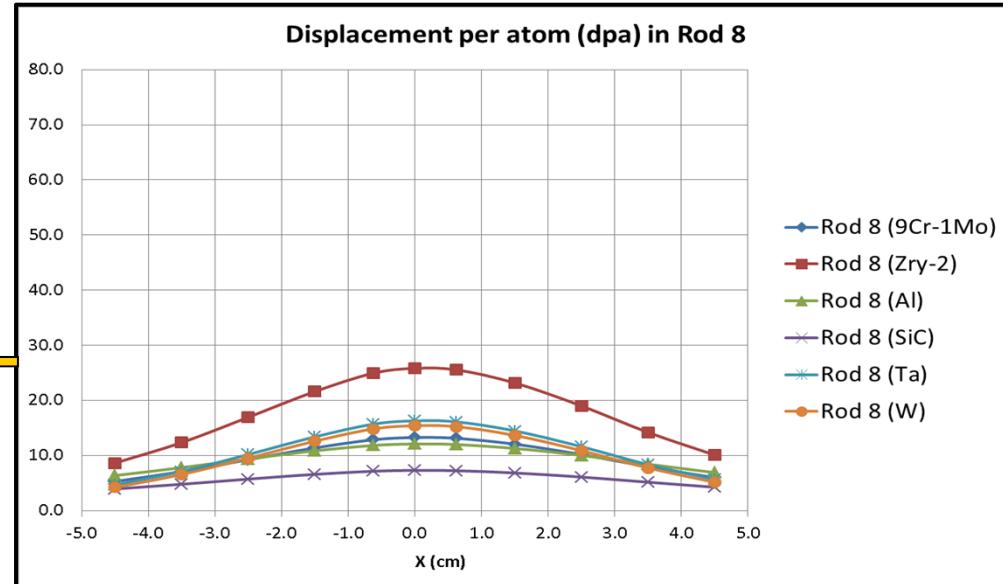
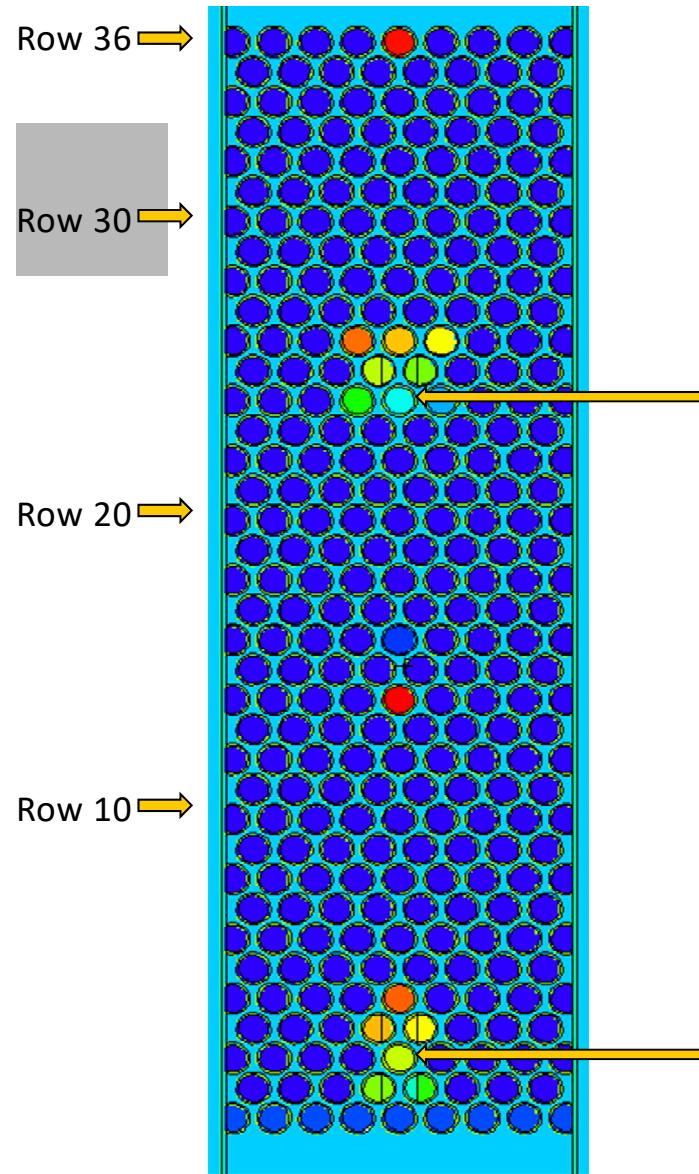


Neutron fluence distribution in rods (central column)

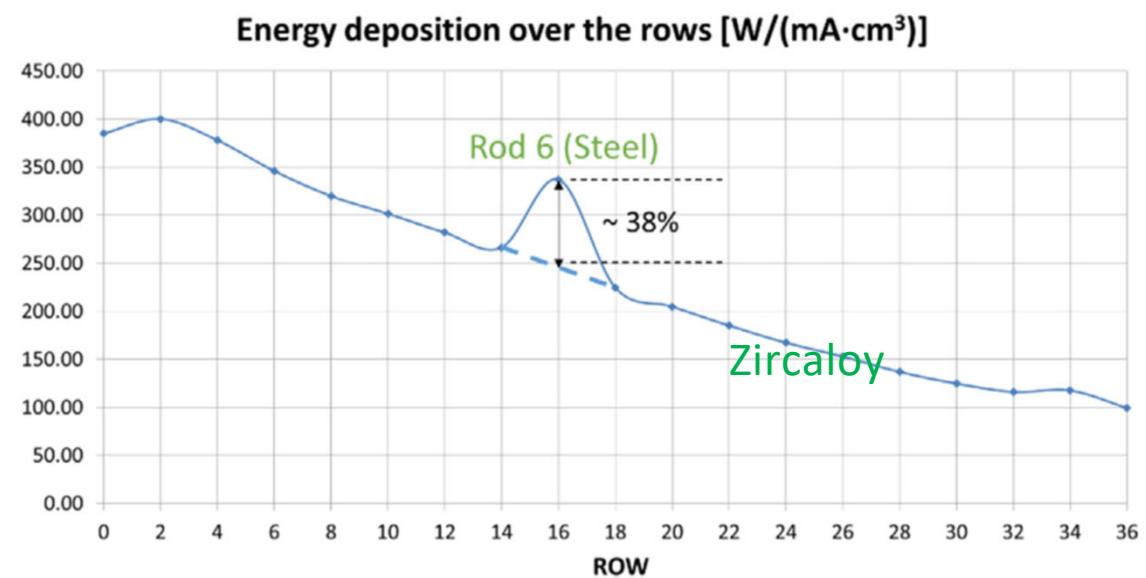
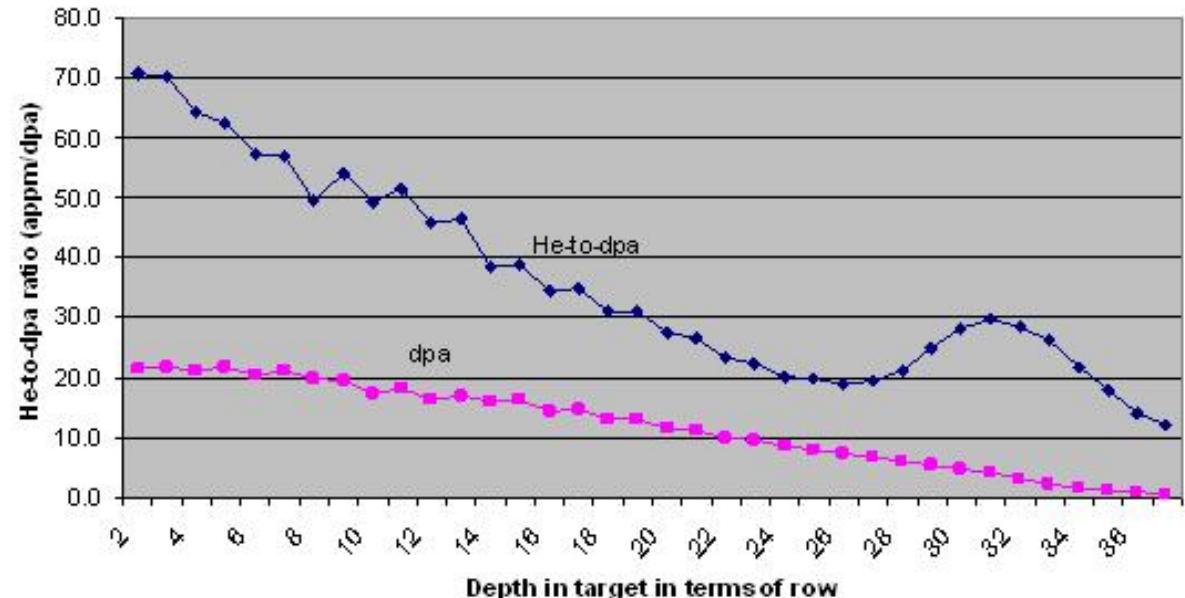
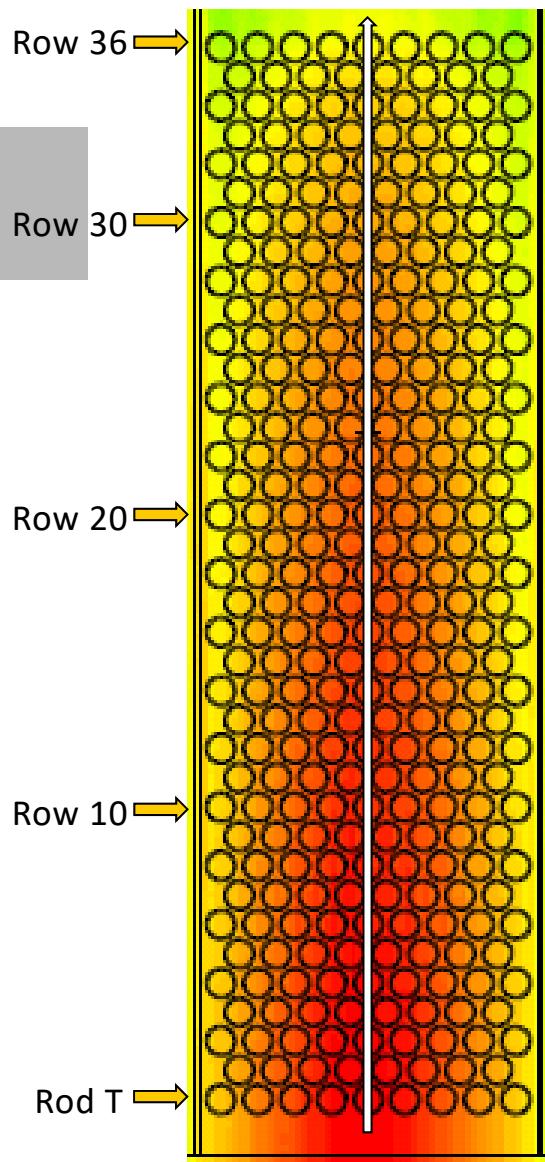


Neutron fluence (Target-9, STIP-VI)

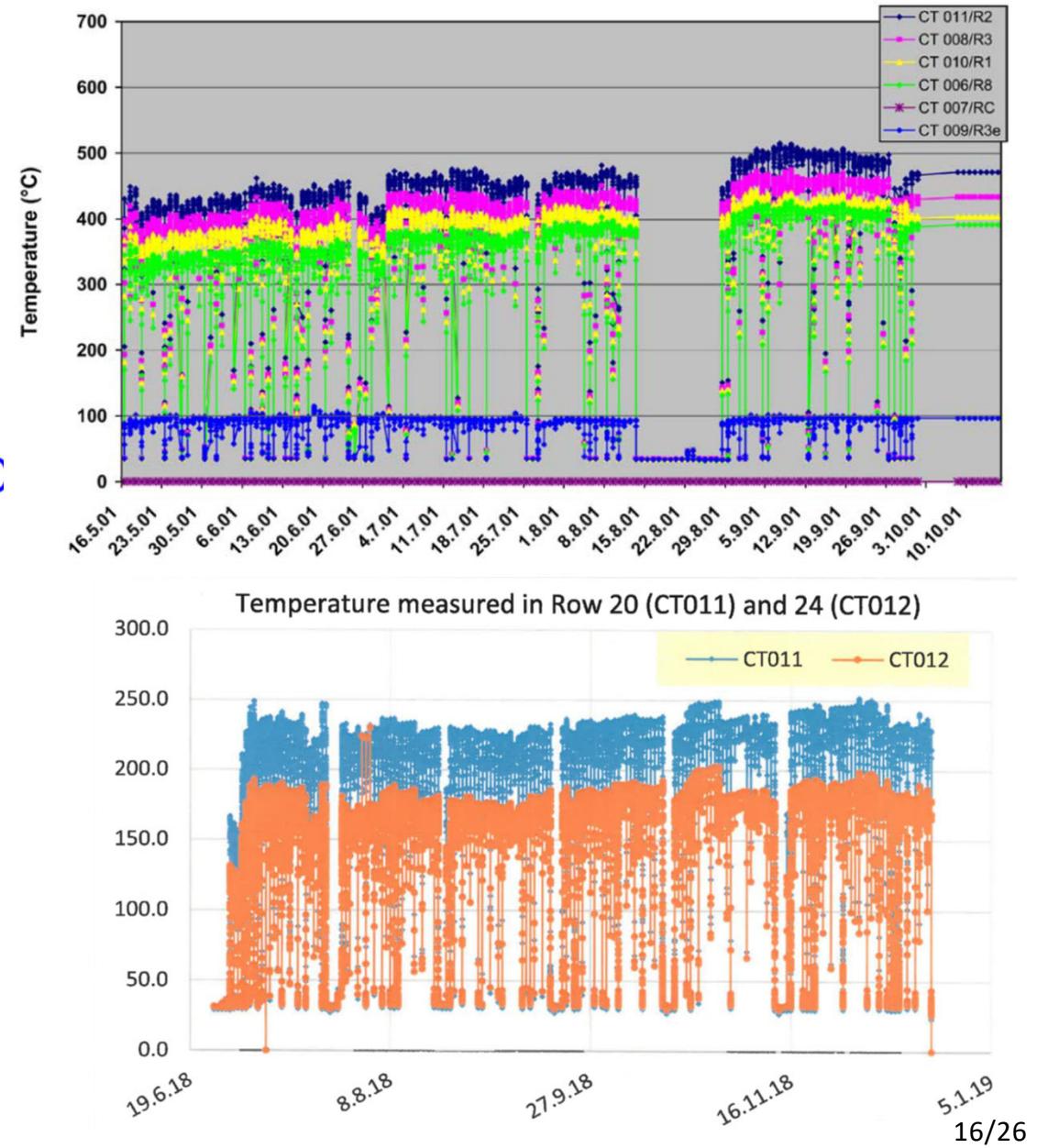
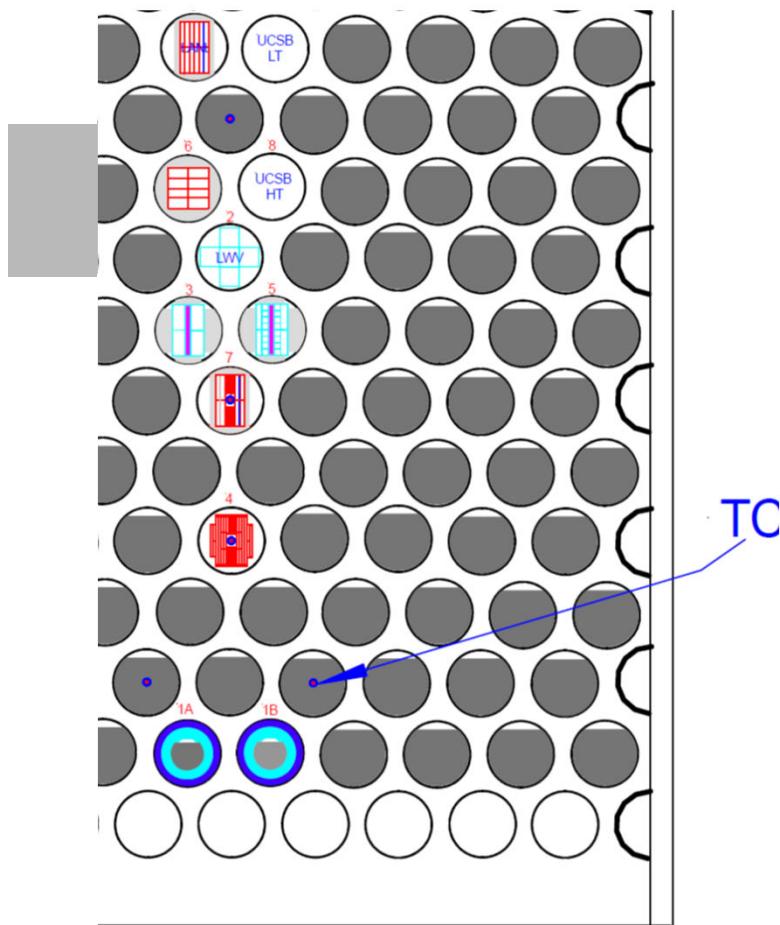
dpa distribution in STIP-VI samples



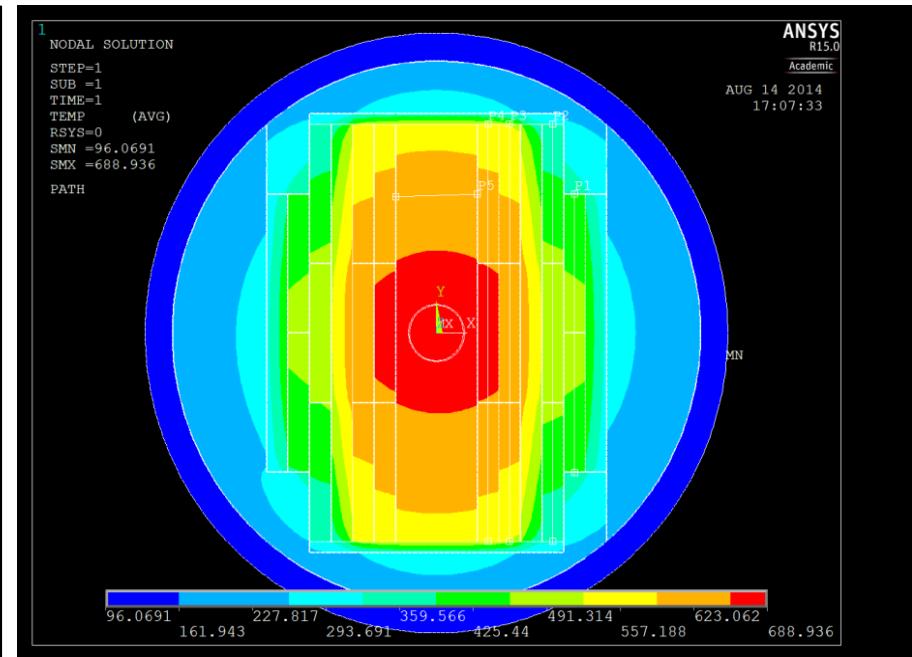
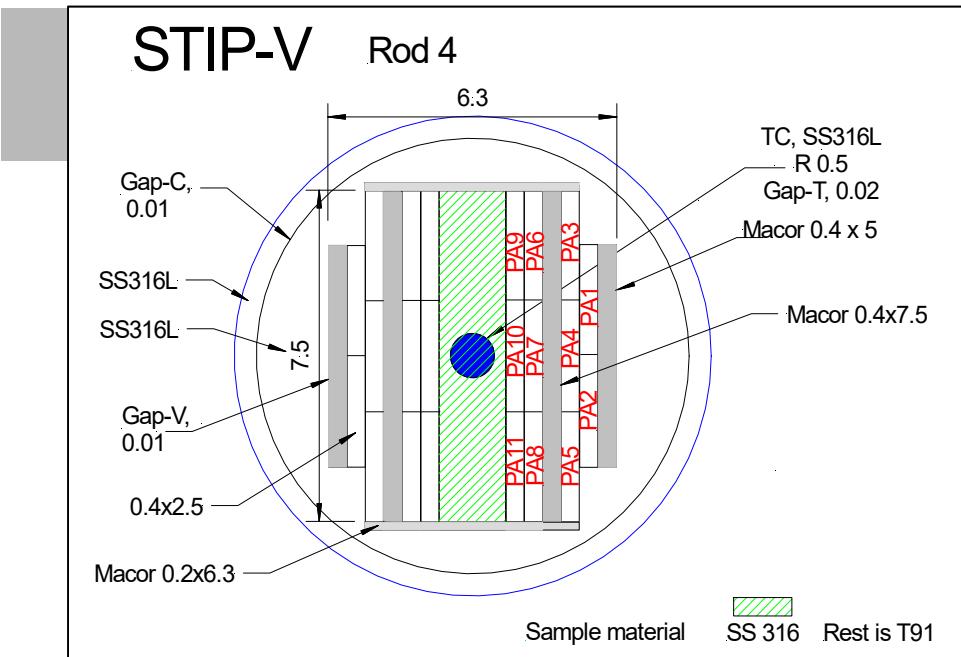
He/dpa and energy deposition distribution



Irradiation temperature monitoring

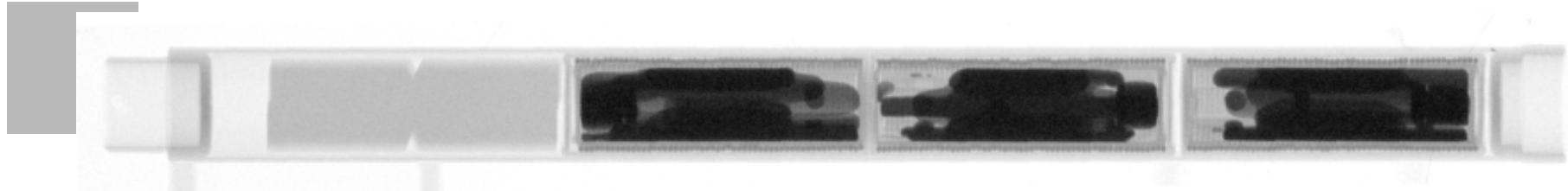


Irradiation temperature assessment

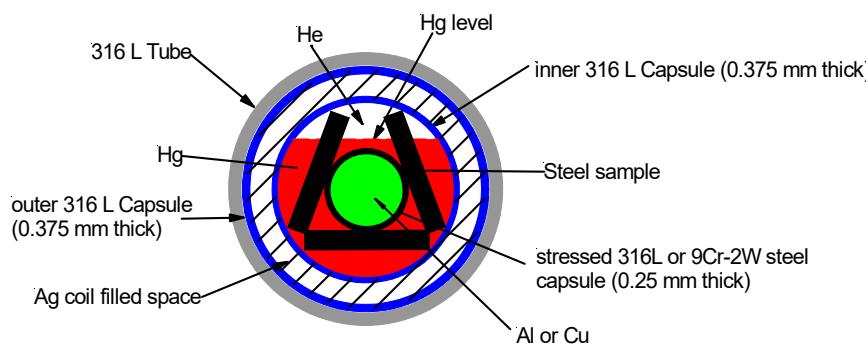
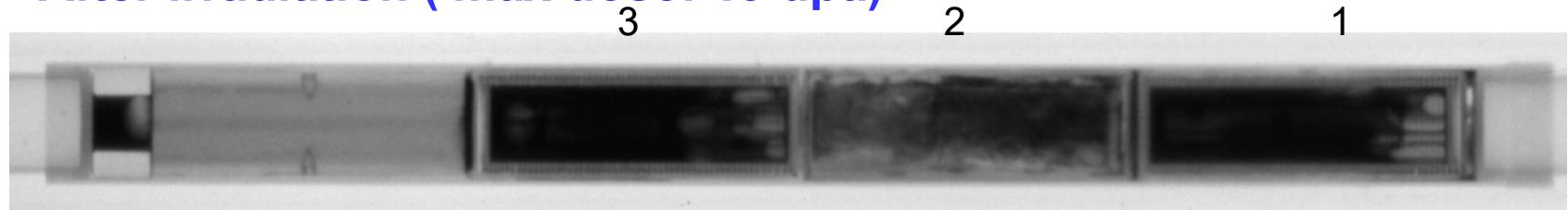


Neutron radiography inspection

Before irradiation



After irradiation (max dose: 19 dpa)



STIP-II Hg rod:

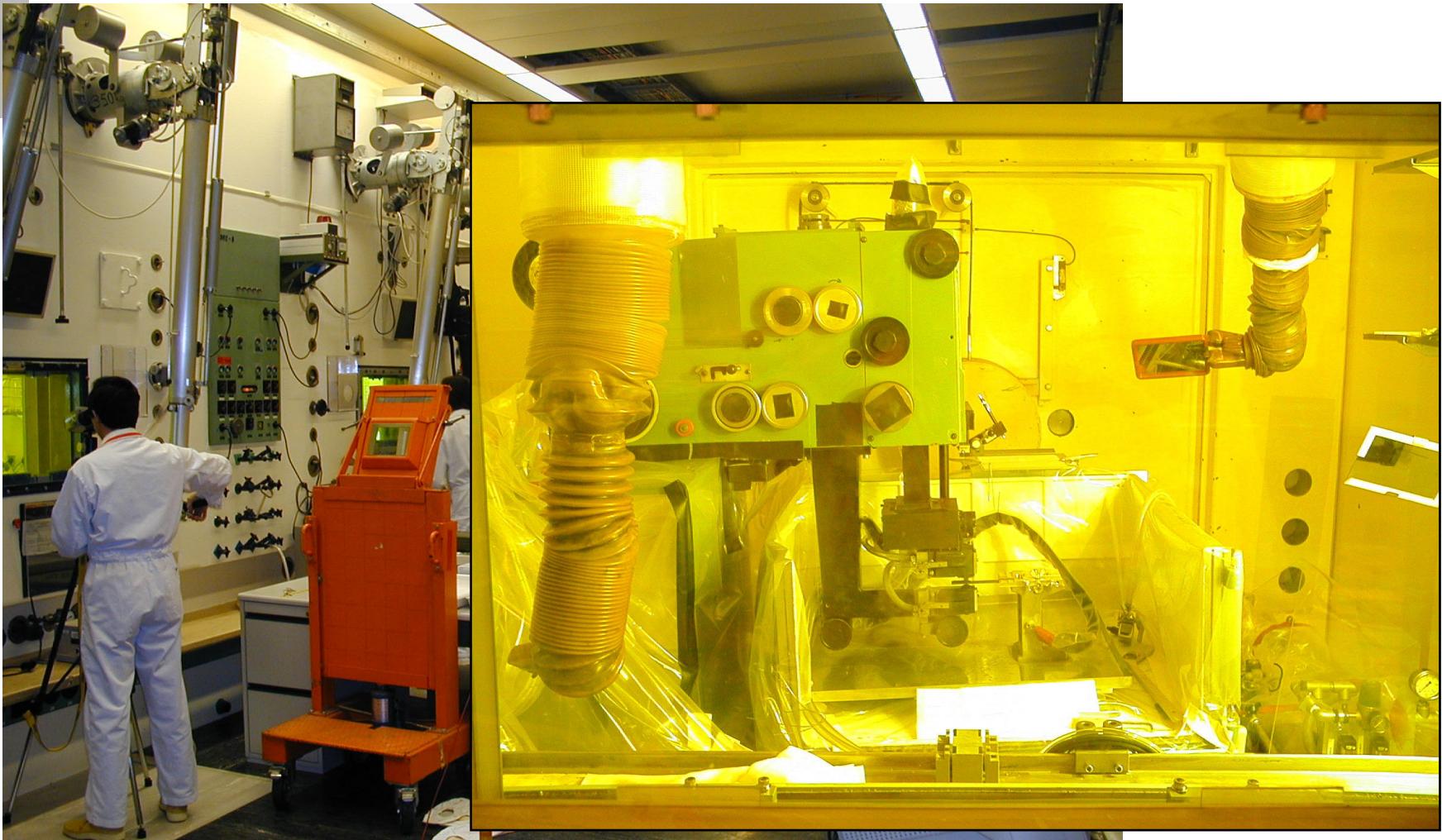
It contains three Hg filled SS 316 L capsules for studying irradiation assisted corrosion effects of Hg on two kinds of steels.

Hg penetrated 2 316L capsules!

Materials irradiated in STIP

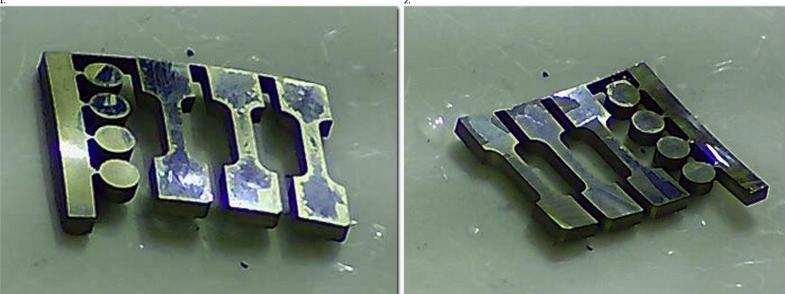
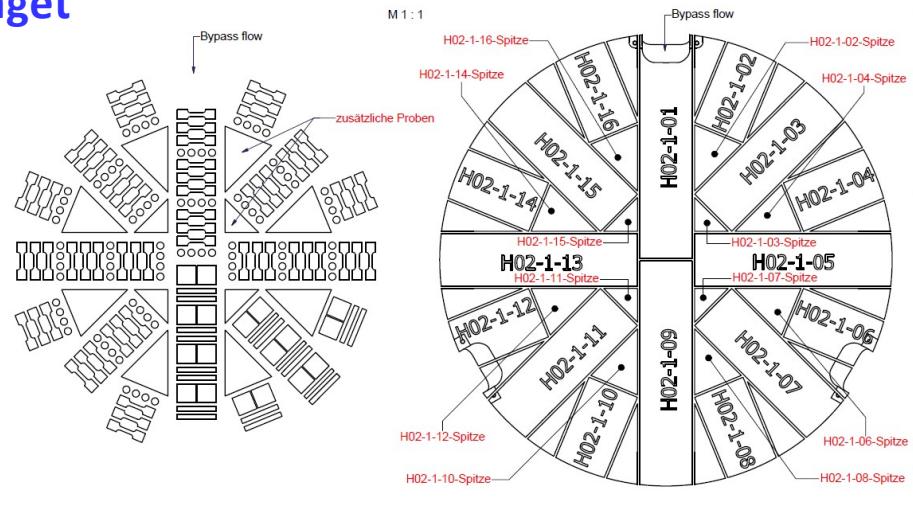
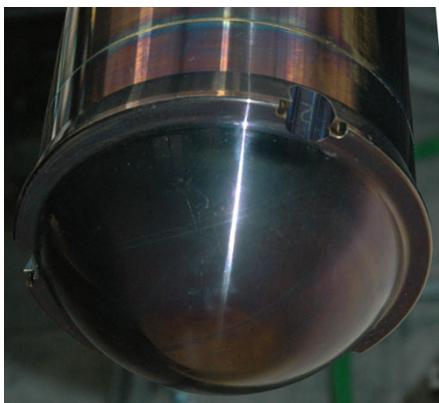
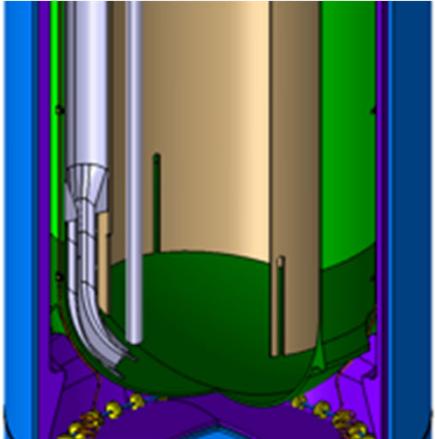
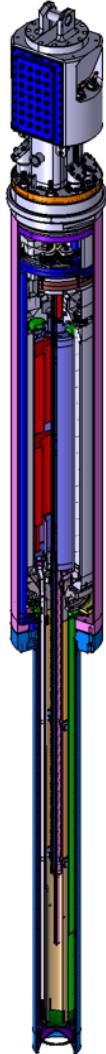
Materials	max dose / T
Austenitic steels SA316L, SA316LN, CW316, 316L-EBW, 316-TIG	32dpa / 500°C
FM steels T91, EM10, HT9, Eurofer97,	32 dpa / 500°C
ODS steels 9Cr-, 12Cr-ODS, PM2000, MA957...	32 dpa / 600°C
Inconel 718, & EBW, Inconel 600	20 dpa / 400°C
AlMg3 Al6061	8.8 dpa / 60°C 10 dpa / 200°C
Zircaloy 2, Zircaloy-4.....	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
Pure metals: Al, Ti, Fe, Cu, Ni, Nb, Au	

PIE Capability: (α, β, γ) hot-cells



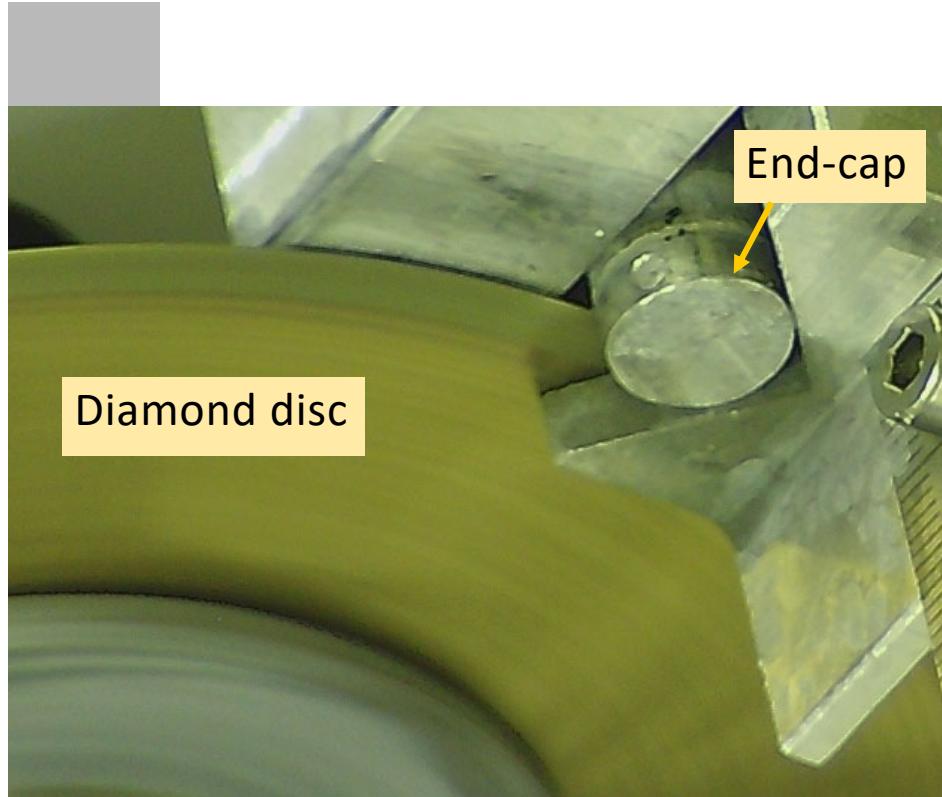
PIE Capability: (α, β, γ) hot-cells

Sample extraction of the MEGAPIE Taget

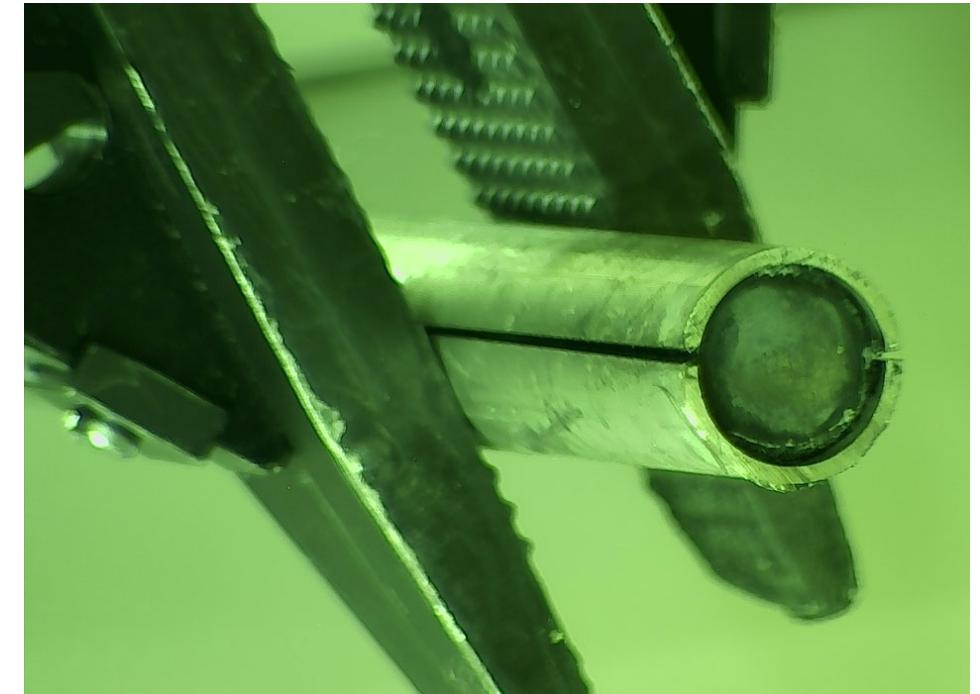


PIE Capability: (α,β,γ) hot-cells

Sample extraction of STIP



Diamond disc

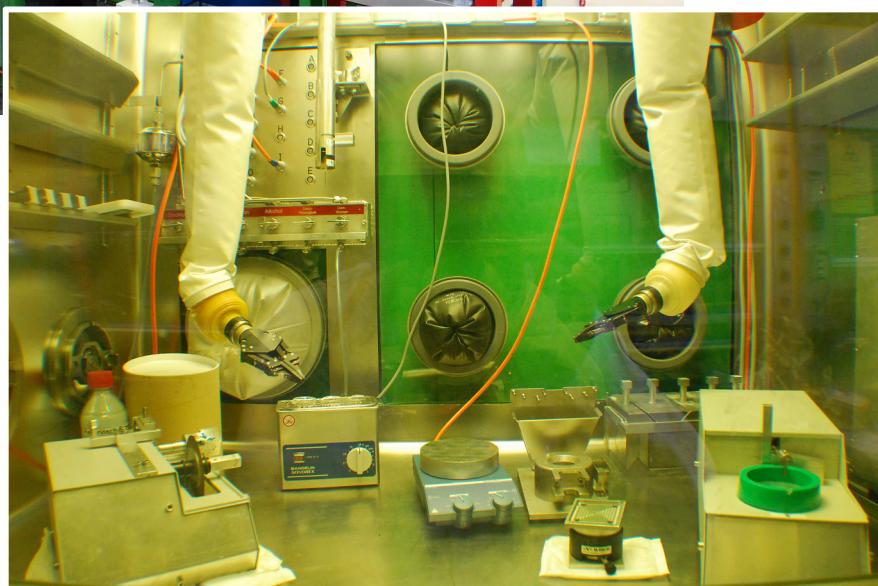


Cut along tube

Cut end-cap

PIE Capability: (α, β, γ) semi hotcells

Dose rate limit up to ~0.5 Sv/h @10cm



Machines in semi hot-cells:

- Sample preparation, incl. FIB
- Analysis: SEM, EPMA, SIMS, ICPMS
- Mechanical testing: universal testing machines, Charpy



PIE Capability: labs for low activation samples

Sample preparation

- Fully equipped

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 analysis

- TEM (FIB sample preparation possibility)
- SEM (in-situ observation possibility)
- Atom Probe Tomography at ETHZ (*quantitative analysis of transmutation products*)
- Positron Annihilation Spectroscopy
- Micro-, Nano-XAS (X-ray Absorption Spectroscopy) at SLS
- Neutron radiography, SANS at SINQ

Others

- Density measurement
- Thermal diffusivity measurement
- He, H release measurements

Summary and outlook

Irradiation

- During 1998-2020, 8 irradiation experiments were performed.
- Numerous materials were irradiated.
- In future, irradiation experiments will still be possible, but with much lower frequency.
No fixed plan for the next STIP.

PIE

- A full spectrum of instruments are available at PSI to perform PIE on various highly activated materials.
- PSI's hotlab is able to extract test samples from large irradiated components.

Collaboration

- Normally contracts, rather than proposals, are needed.



Thank you!