Status Update: Research of Materials in Target Environment at ESS

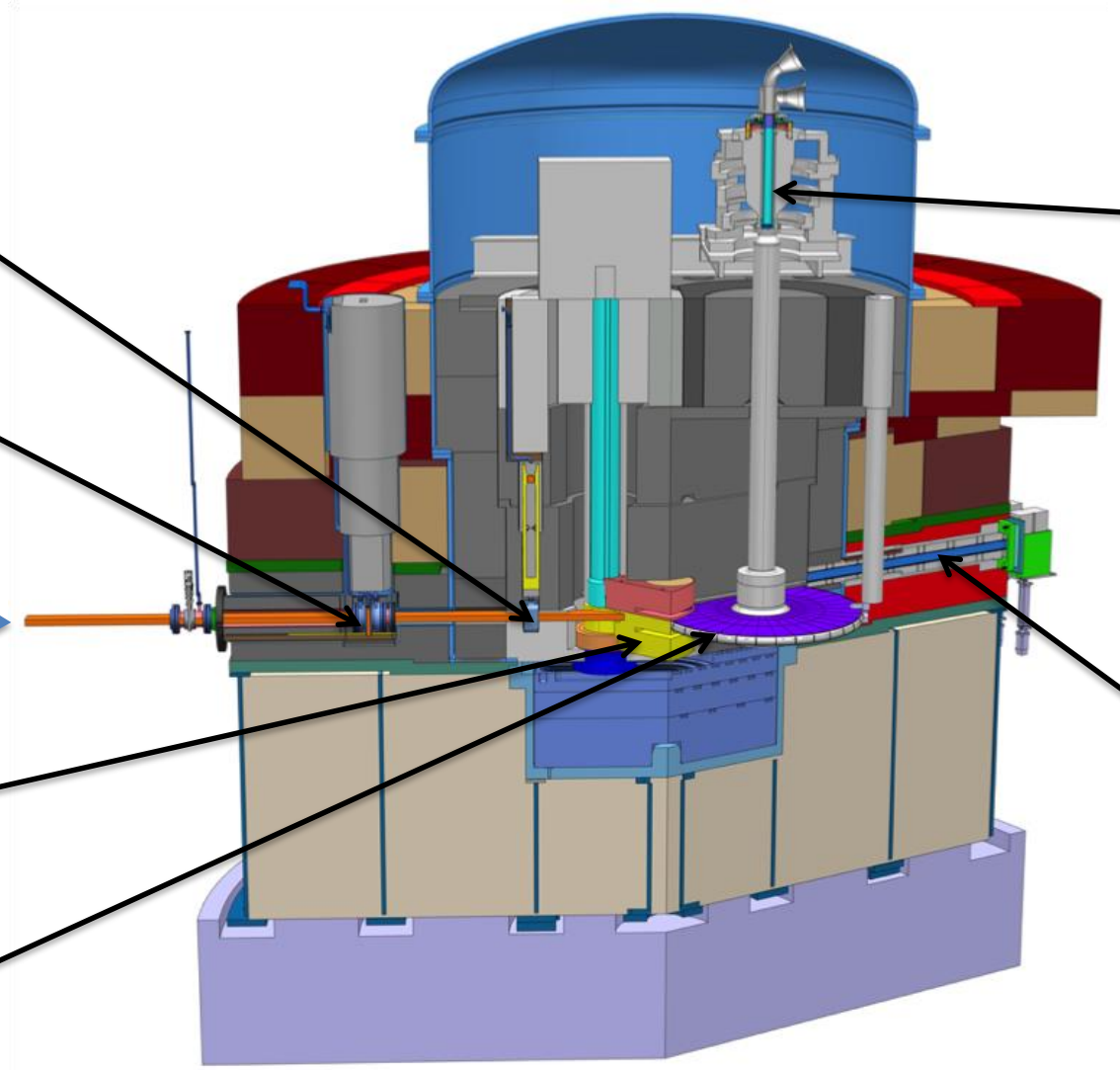
Yongjoong Lee
European Spallation Source ERIC

RaDIATE 2018 Collaboration Meeting
17 December, 2018 - CERN

ESS on Dec 13, 2018

EUROPEAN SPALLATION SOURCE

ESS Target Environment



Proton Beam Instrumentation

Proton Beam Window (PBW)

Proton beam (2 GeV/5 MW)

Moderator Reflector

Target Wheel

Target Wheel Drive Unit

Beam Extraction Unit

Materials Research in Target Environment

Motivation and Mission

- Degradation of functional and structural materials in target environment poses challenges to operational reliability and costs.

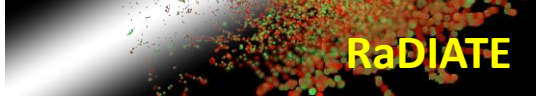
- The materials research at ESS is dedicated to
  - Selection of materials which endures intense radiation field in target environment
  - Determination of component lifetime, which are subject to radiation damage
  - Realization of the visions of materials R&D at ESS
  - Contributions to the high power target community with the knowledge acquired

Materials Research in Target Environment

Current Research Focus

Materials Research

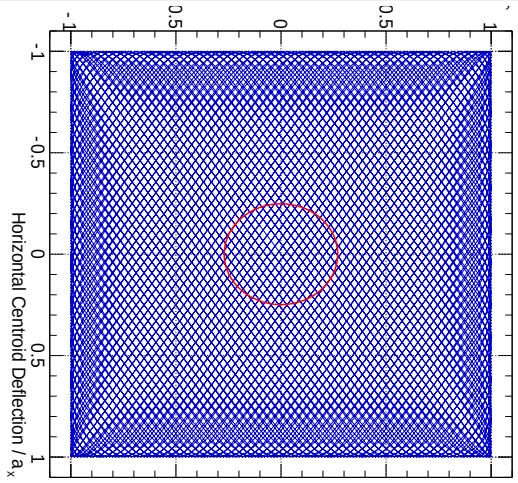
- Spallation Materials
- PBW Materials
- Polymers and Lubricants
- Moderator Materials
- Irradiation Module

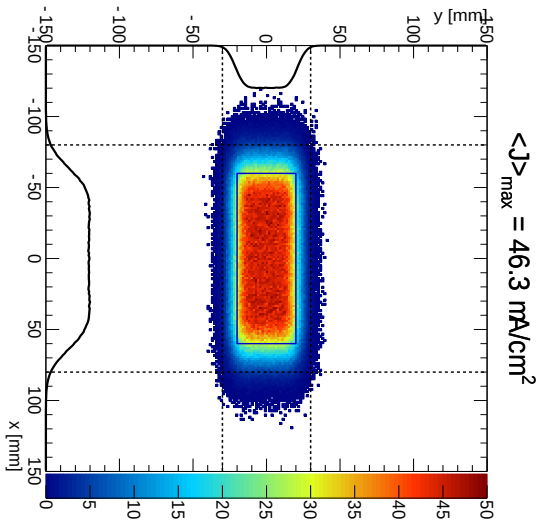


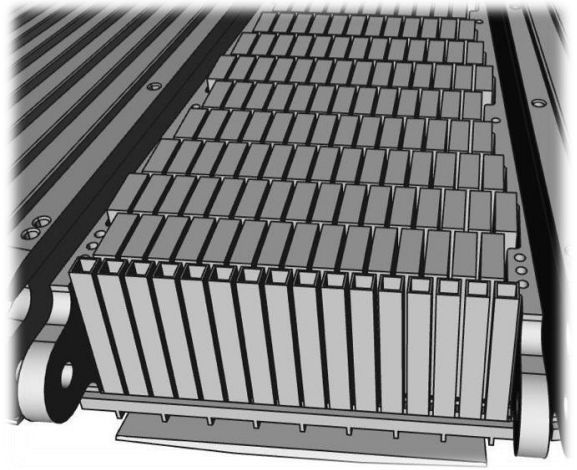
Spallation Materials Research

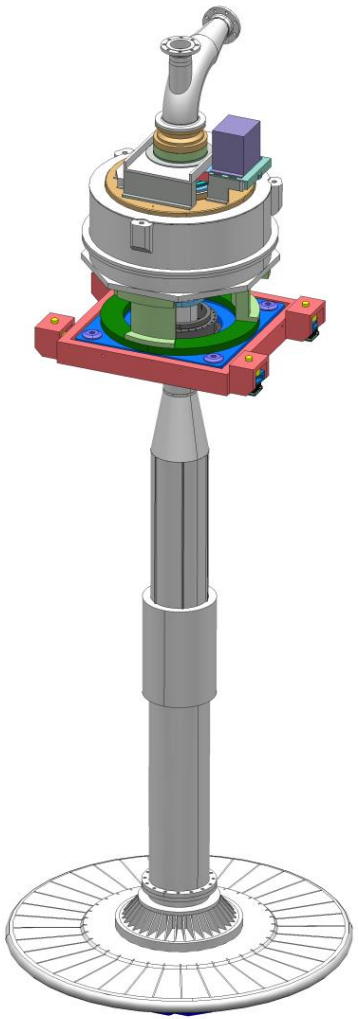
Operational Environment

Parameter	Unit	Value
Beam energy	GeV	2.0
Pulse length	ms	2.86
Repetition Rate	Hz	14
Raster deflection, horizontal	mm	60.0
Raster deflection, vertical	mm	20.0
Beam RMS, horizontal	mm	13.5
Beam RMS, vertical	mm	5.05
Peak current density	mA/cm^2	1.16

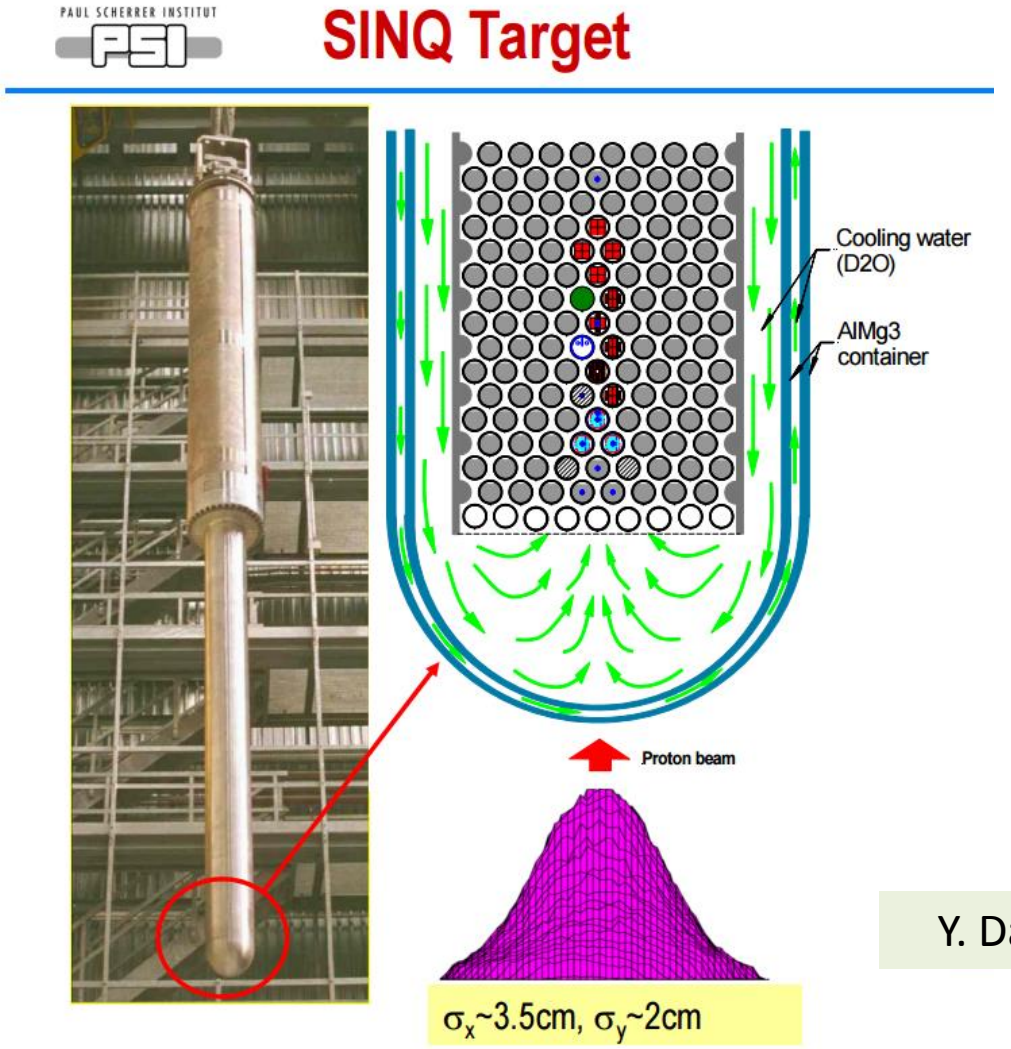




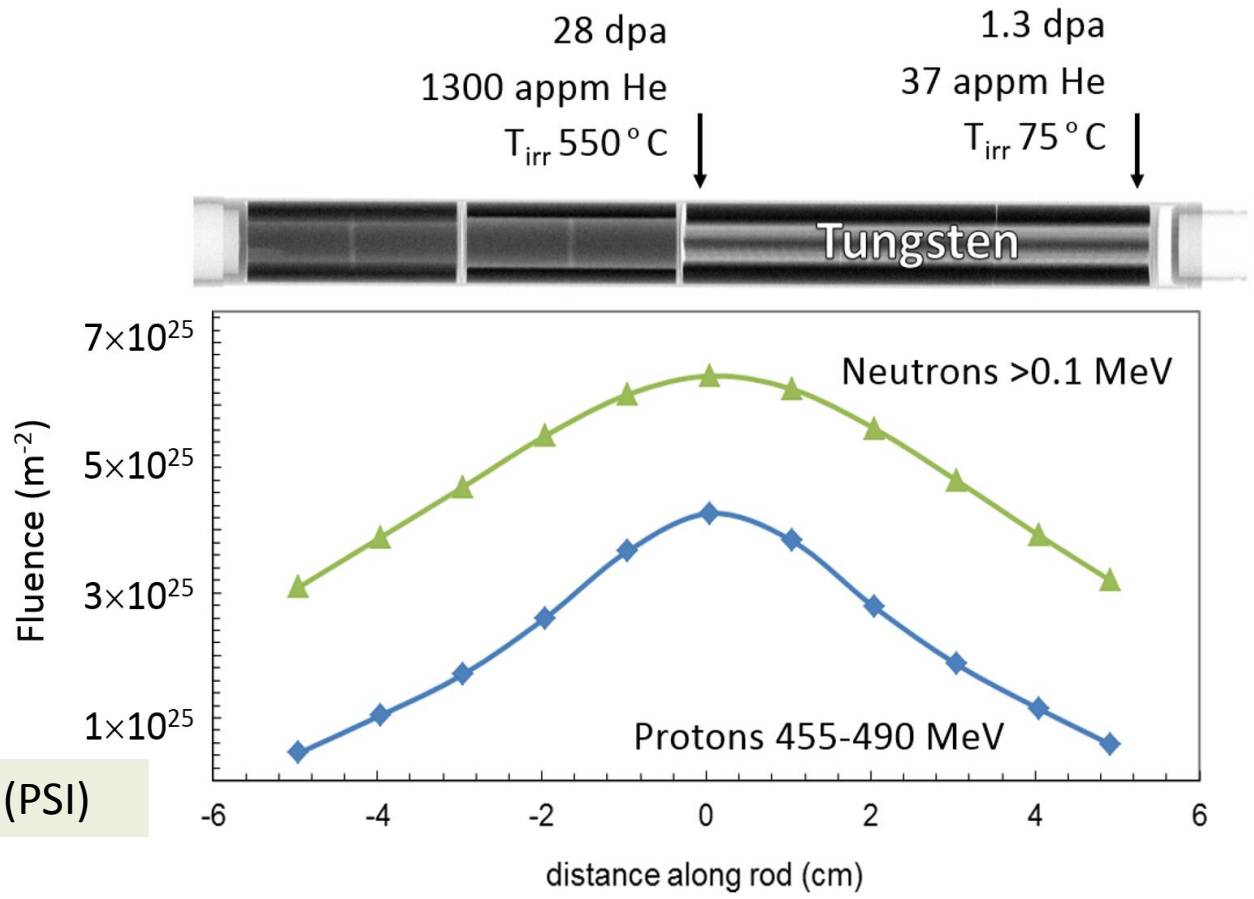




STIP-V Tungsten Specimen



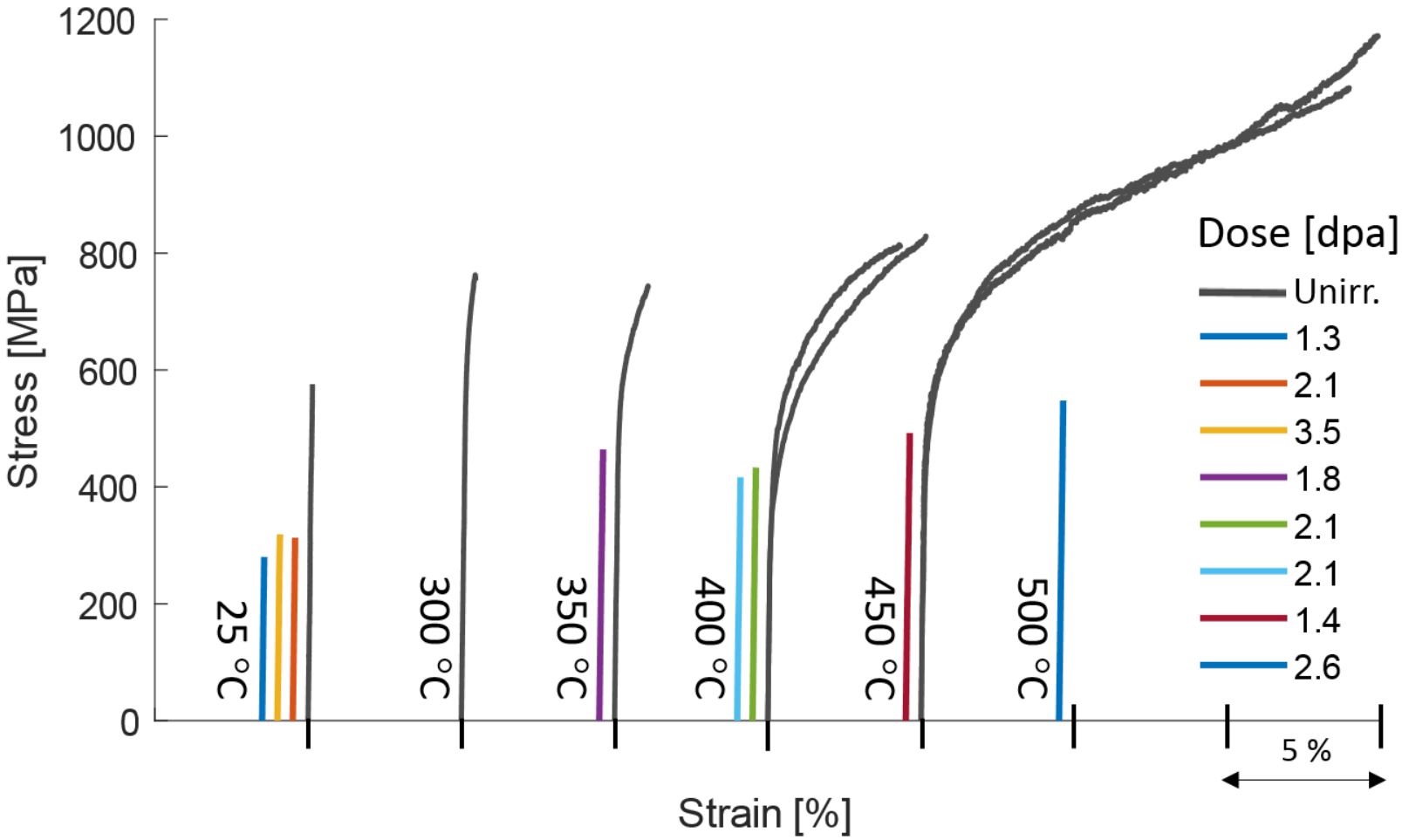
2 hot-rolled W bars: 60 x 8 x 1 mm^3

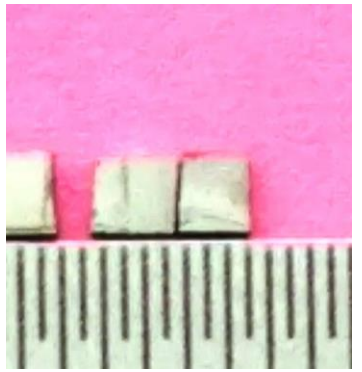


Y. Dai (PSI)

Mechanical Tests

Low Dose Specimens: J. Habainy and Y. Dai

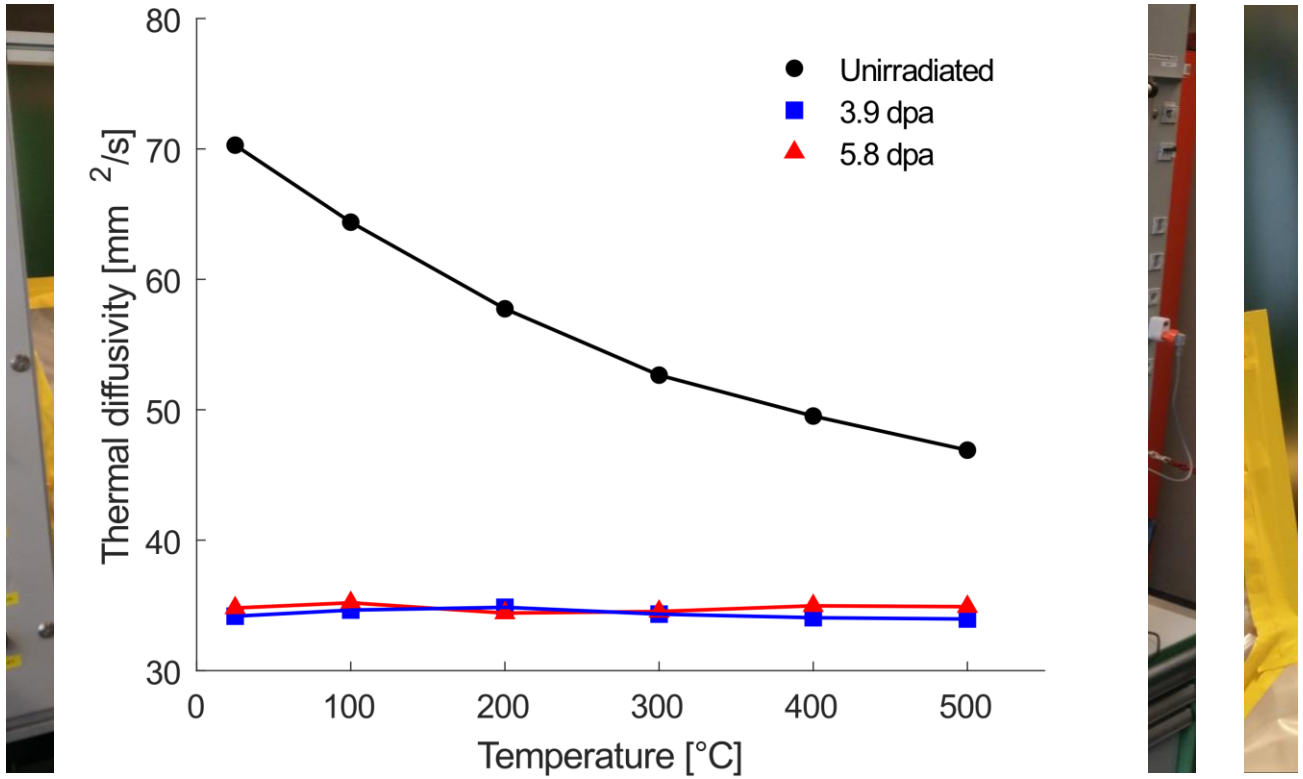


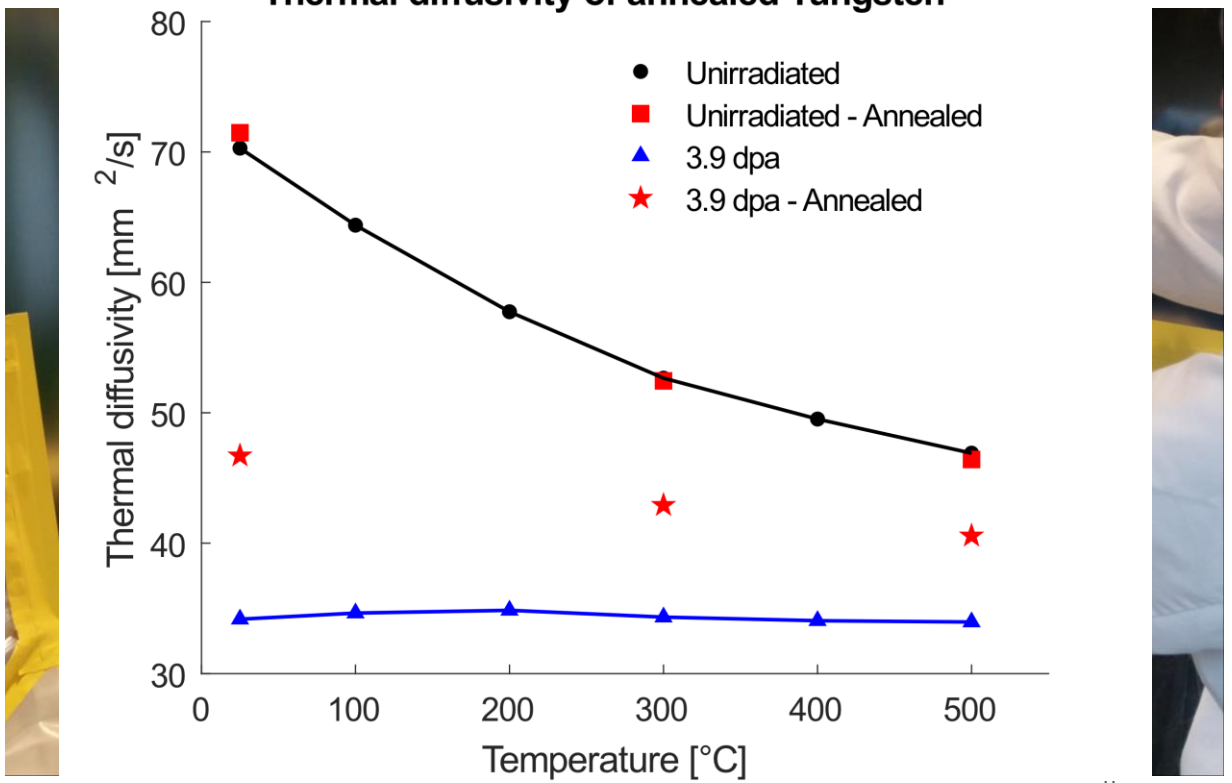


Thermal Diffusivity Tests

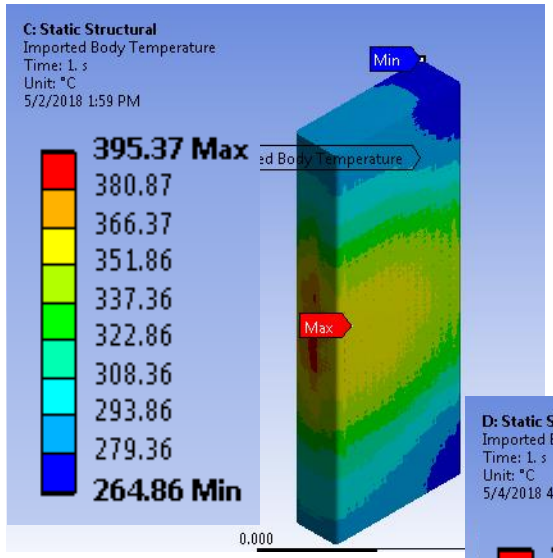
Low Dose Specimens: J. Habainy and Y. Dai

- Two specimens at 3.9 dpa and 5.8 dpa
- Post measurement annealing of the 3.9 dpa specimen

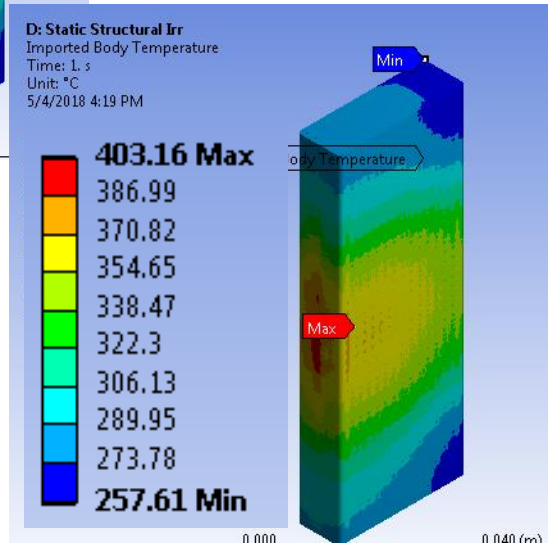




Impact on ESS Tungsten in Operation

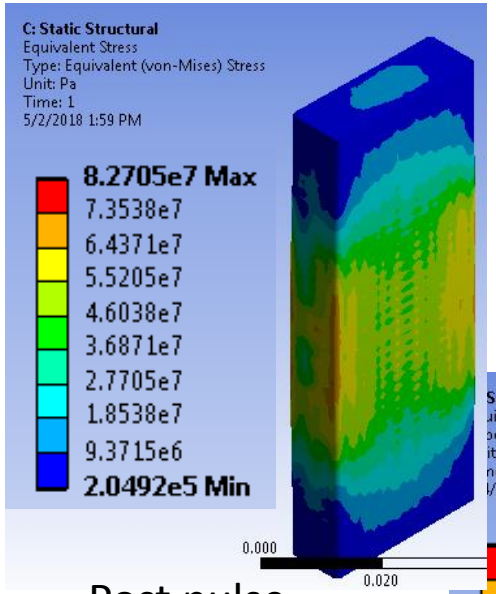


Temperature



Post pulse

- 20% therm. cond.

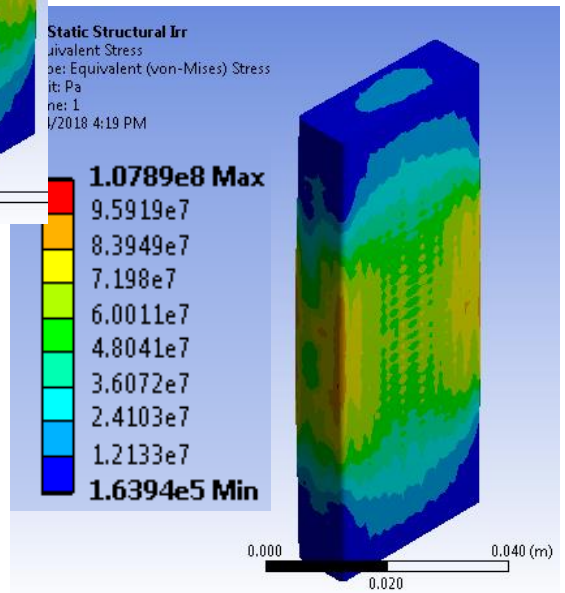


Equivalent stress

Post pulse

-20% therm. cond.

+ 20% stiffness

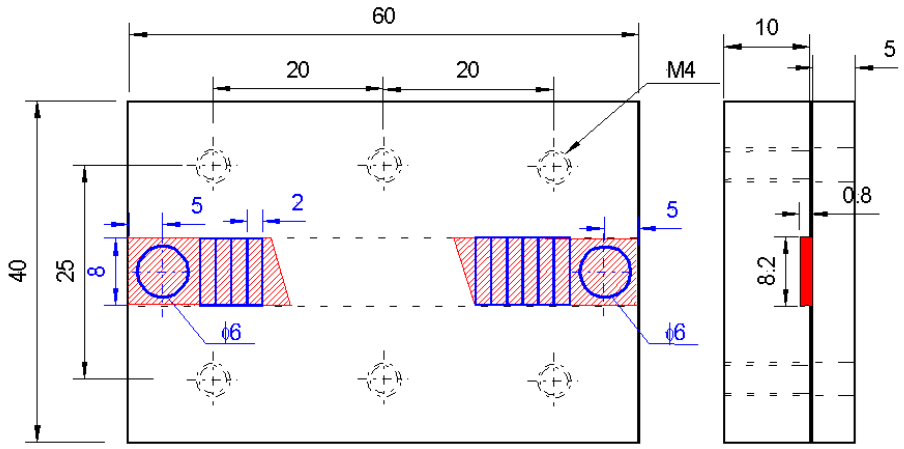


+ 25 MPa

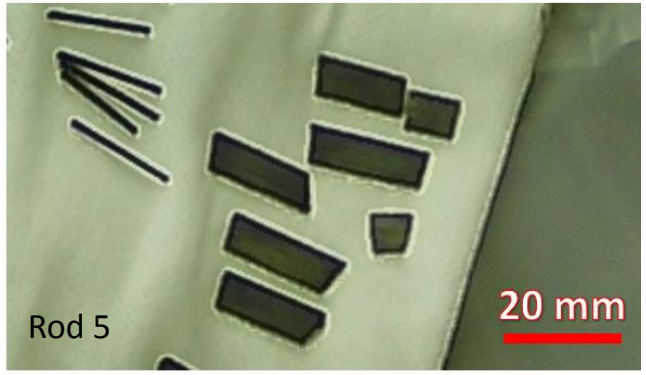
STIP-V Tungsten Specimen

Prospect for 2019

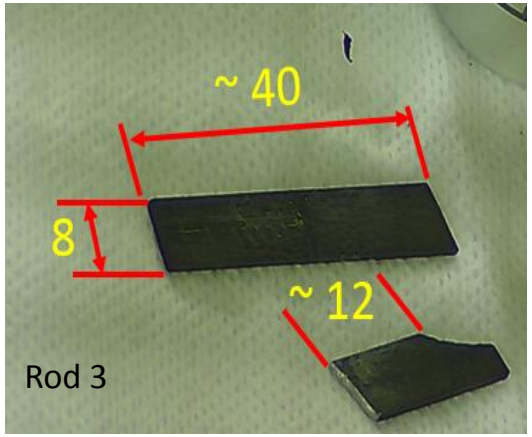
- Mechanical tests on 4 high dose tensile test specimens
- Mechanical tests on 16 high dose bend test specimens
- LFA tests on 3 high dose discs

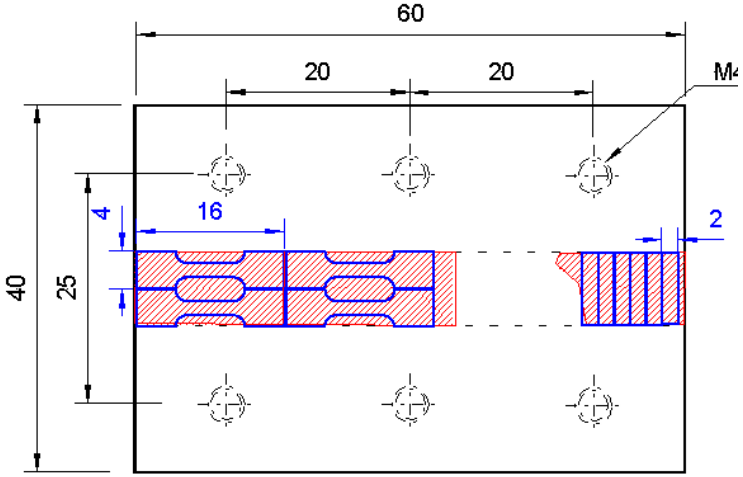


One 6 mm diameter disc and 4-6x bend samples of 8x2 mm were cut from each of the 5 larger pieces.



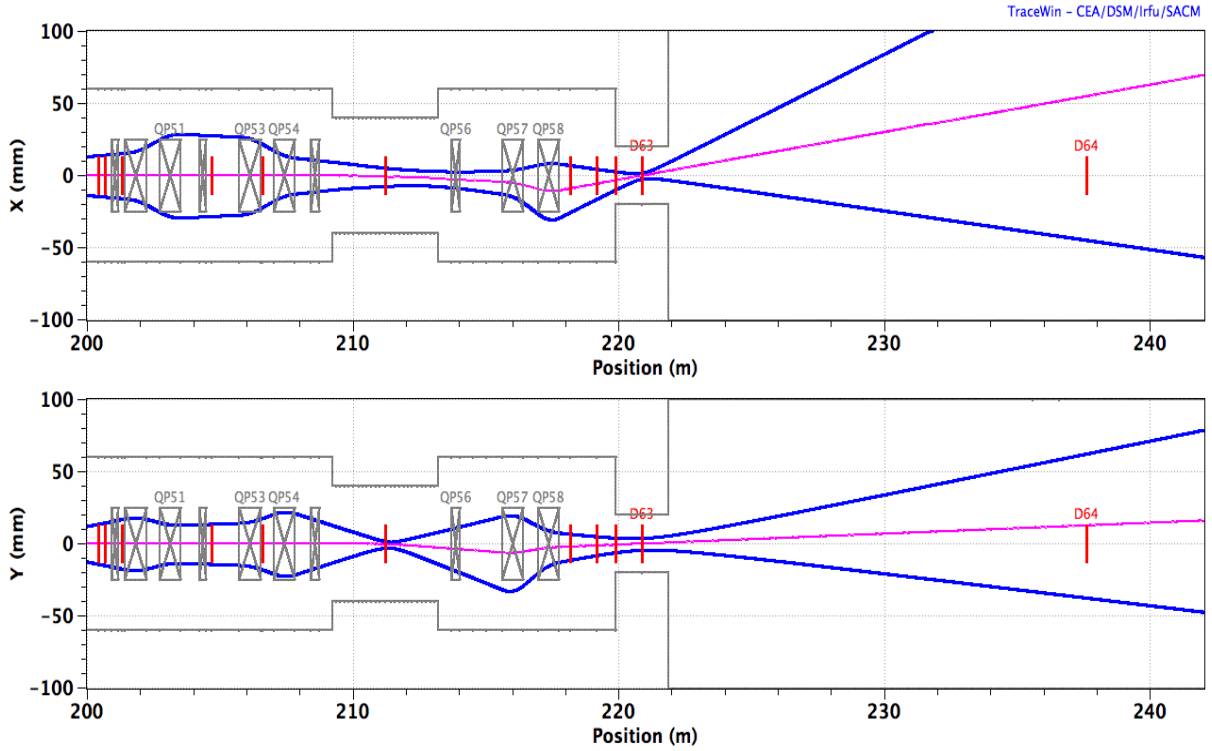
The 5 larger pieces are about 15-20 mm long.

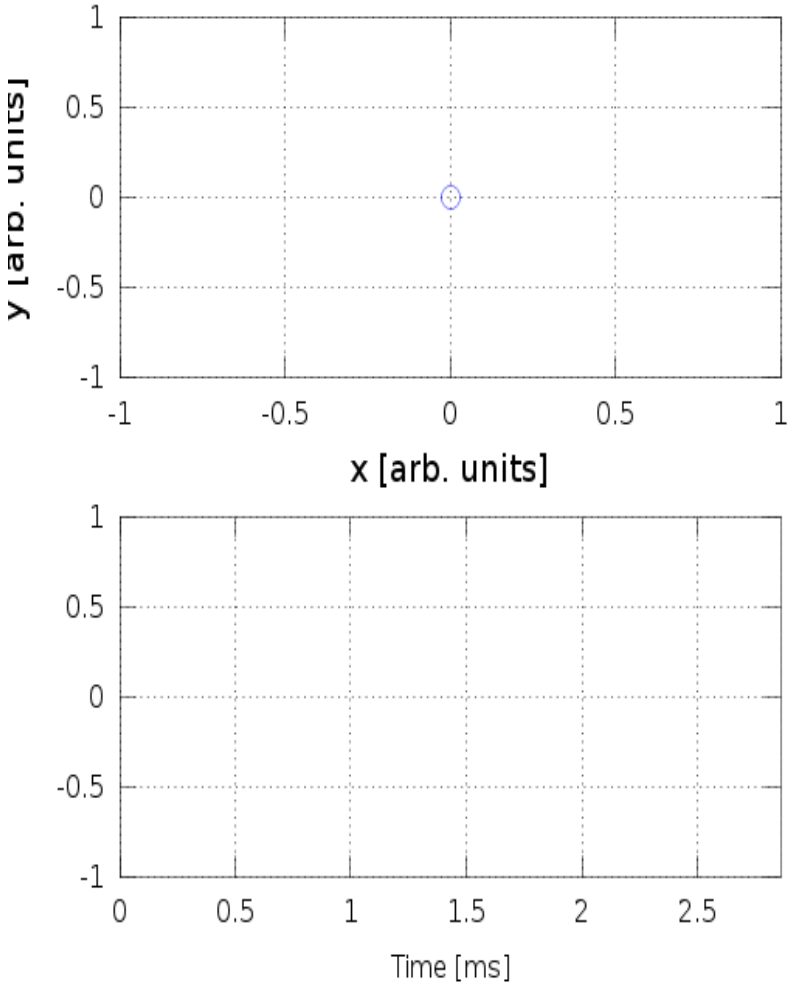




6x small bend samples, 8x2x1 mm
4x tensile samples, 4x16 mm

Raster Beam and Tungsten Interaction



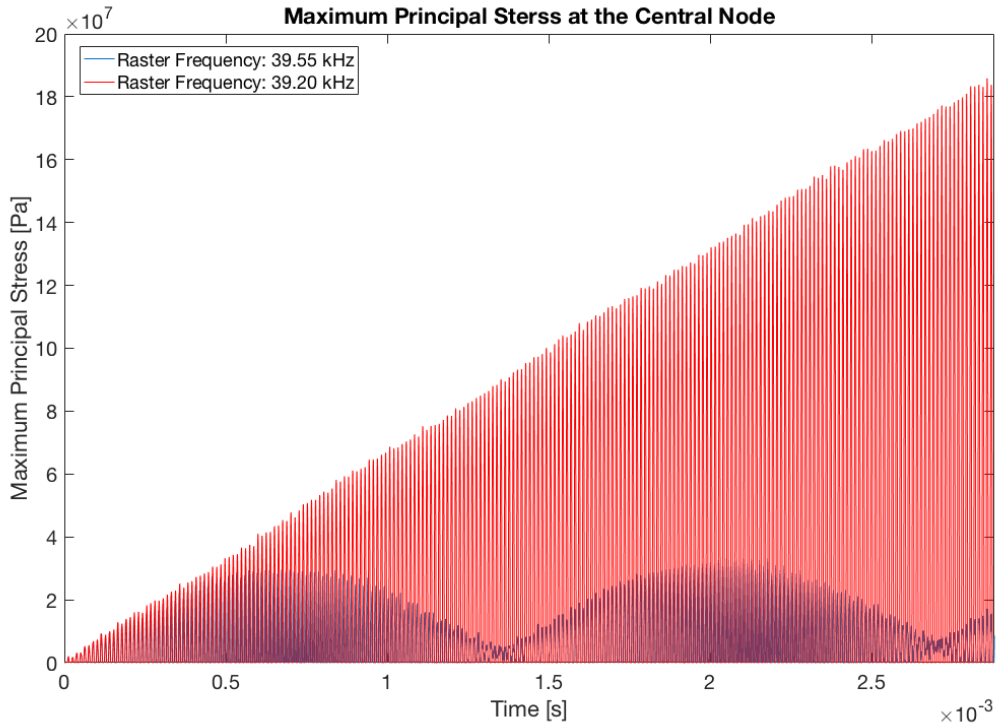


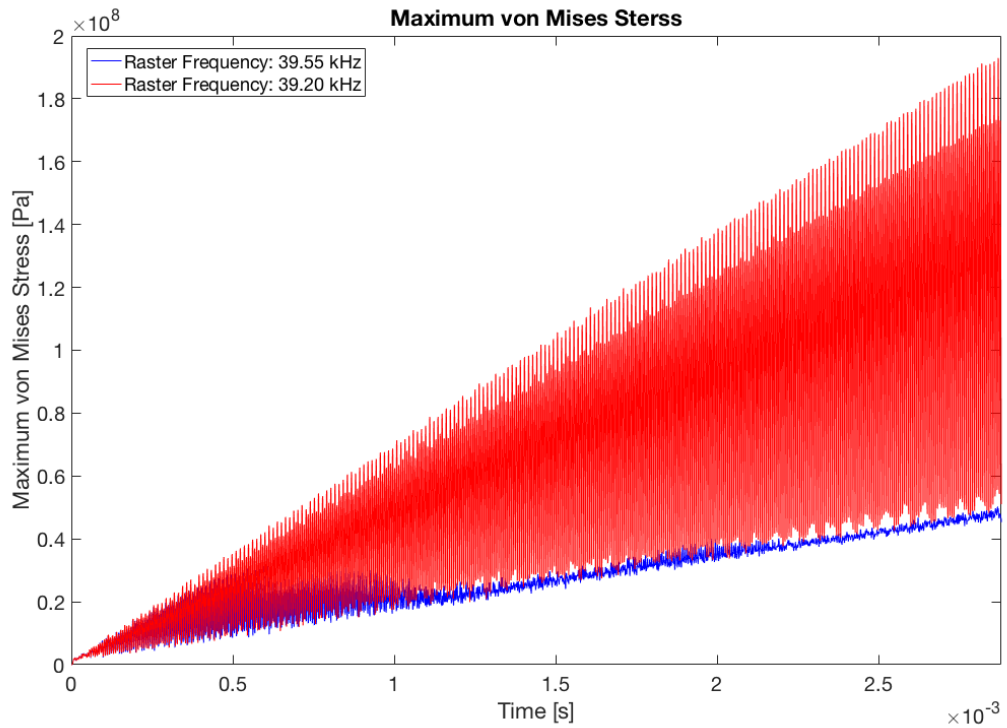
H. D. Thomsen

Raster Beam and Tungsten Interaction

Prospect for 2019

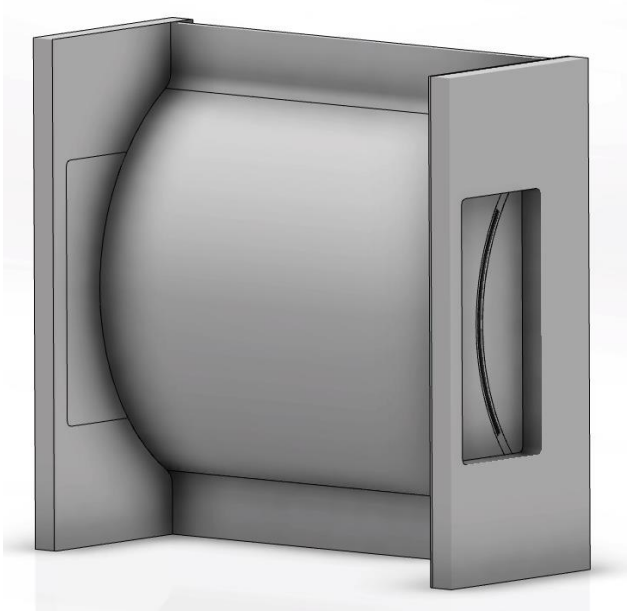
- Risk of coherency between the raster frequency and resonance mode of tungsten brick is identified.
- Mechanical resonance test will be performed for different temperatures and the frequency bandwidth will be identified.

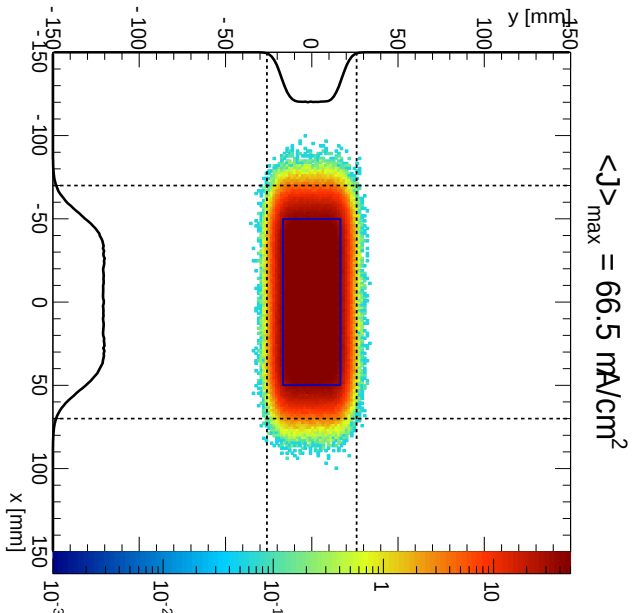




Proton Beam Window Materials Research

Parameter	Unit	Value
Material	Al6061-T651	
Raster deflection, horizontal	mm	47.4
Raster deflection, vertical	mm	15.8
Beam RMS, horizontal	mm	10.67
Beam RMS, vertical	mm	3.99
Peak current density	mA/cm^2	1.66

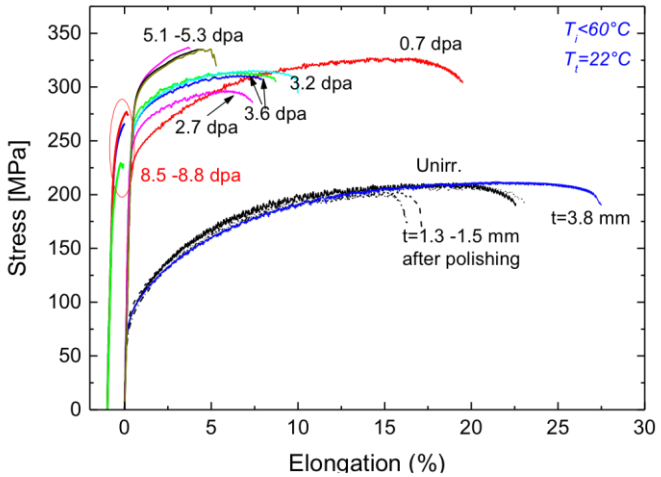




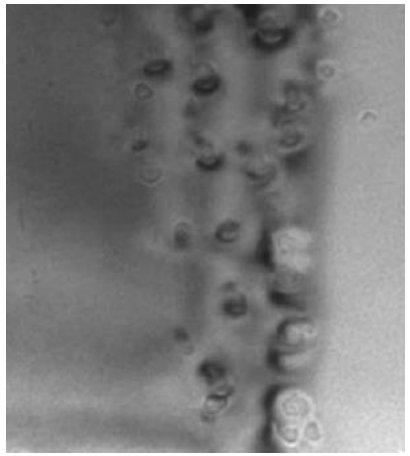
Proton Beam Window Radiation Damage and Lifetime

- Helium embrittlement determines the lifetime
  - The SINQ target window at PSI doesn't show much ductility at the accumulated helium production of 2400 appm.

Beam energy	Lifetime at full beam current	Lifetime in accumulated beam power
571 MeV	5780 hours	8.25 GWh
1.3 GeV	4110 hours	13.3 GWh
2.0 GeV	3580 hours	17.9 GWh



SINQ safety hull made of AlMg3:
Picture courtesy by Y. Dai (PSI)



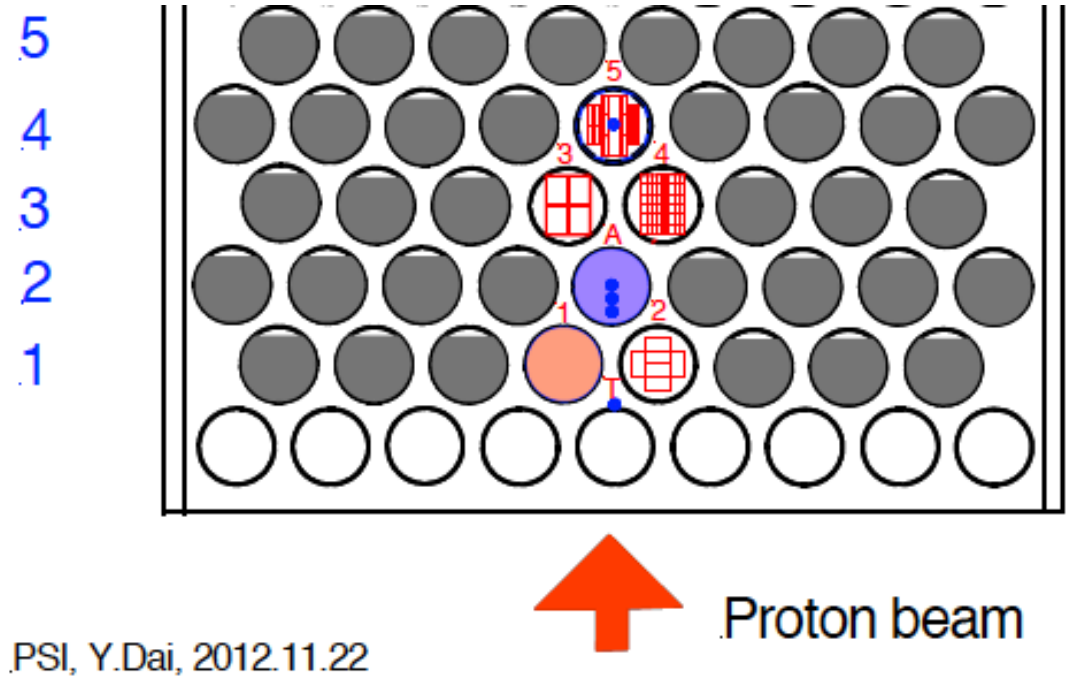
D. Hamaguchi and Y. Dai,
JNM 329-333 (2004) 958-962

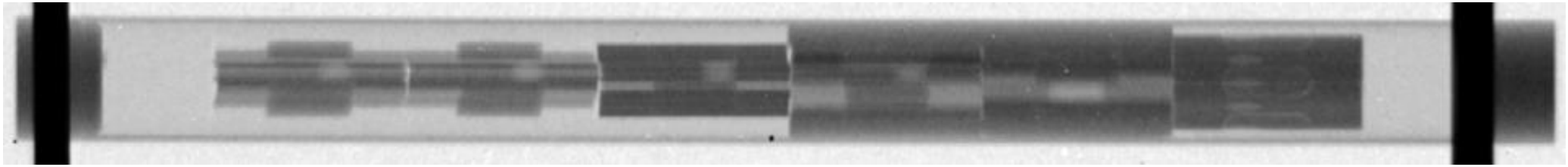
ISIS-TS2 PBW:
Picture courtesy by D. B. Lopez (ISIS)

Proton Beam Window Materials Research

Prospect for 2019-2021

- Candidate Materials
  - Al6061-T6: STIP-VII specimens in Target 10 (11.7 Ah)
  - Ti-6Al-4V: STIP-VII specimens in Target 10 (11.7 Ah)
  - Inconel 718: STIP-II specimens (max. 20 dpa)

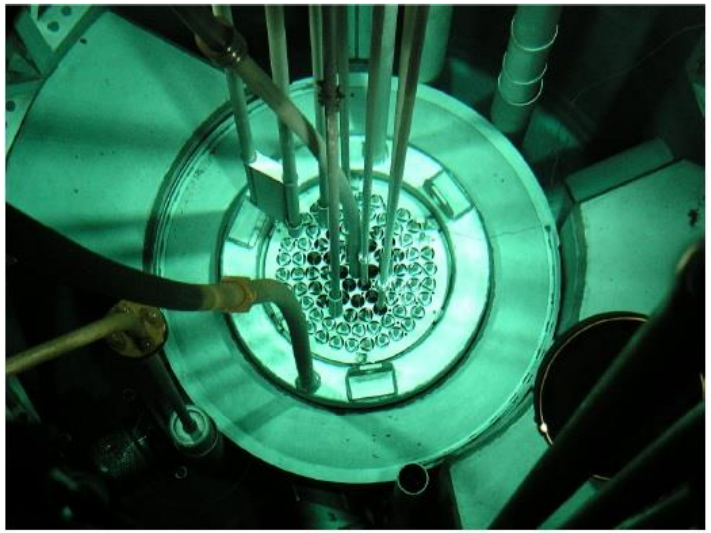


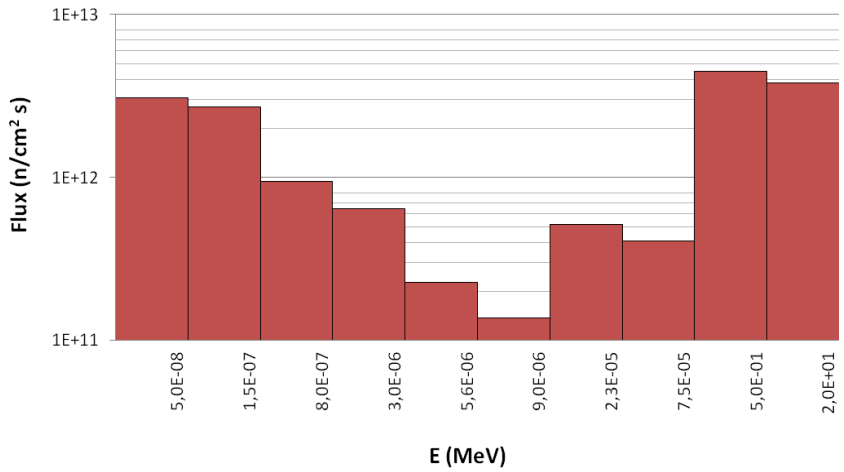


Polymers and Lubricants: LENA Irradiation Camapaign

Matteo Ferrari

- TRIGA MARK-II Nuclear Research Reactor in Pavia
  - 250 kW maximum power
  - Central thimble with a diameter of 3.8 cm houses the test specimens
  - Total maximum neutron flux: 1.72e13 neutron/cm^2/s
    - Thermal (E < 0.8 eV): 6.75e12 neutron/cm^2/s
    - Fast (E > 0.5 MeV): 3.80e12 neutron/cm^2/s
  - Maximum irradiation temperature: 60 C

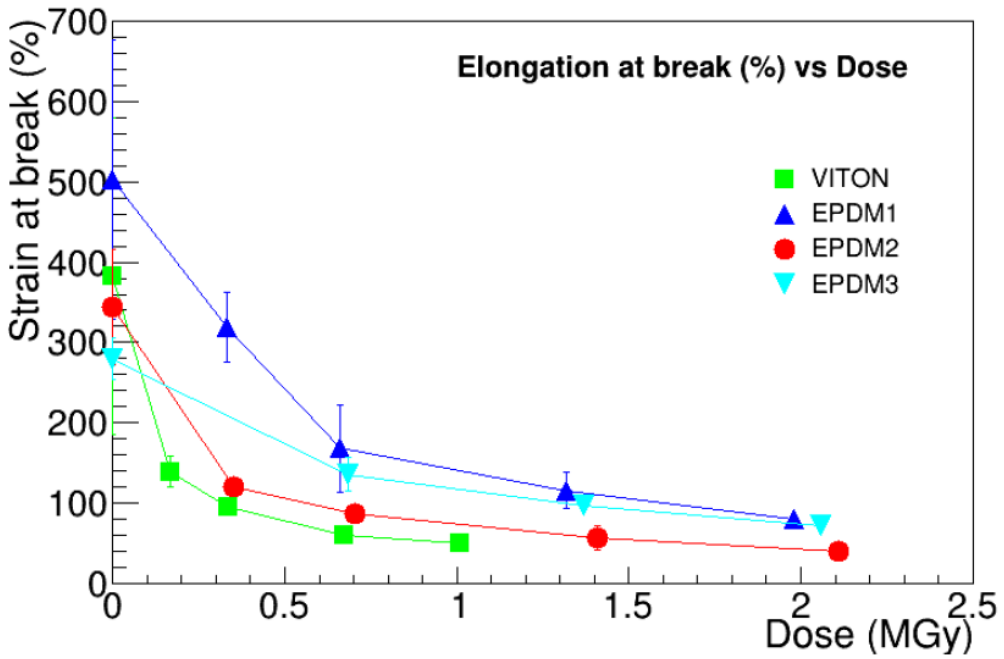




Polymers and Lubricants: PIE of Elastomers

Matteo Ferrari

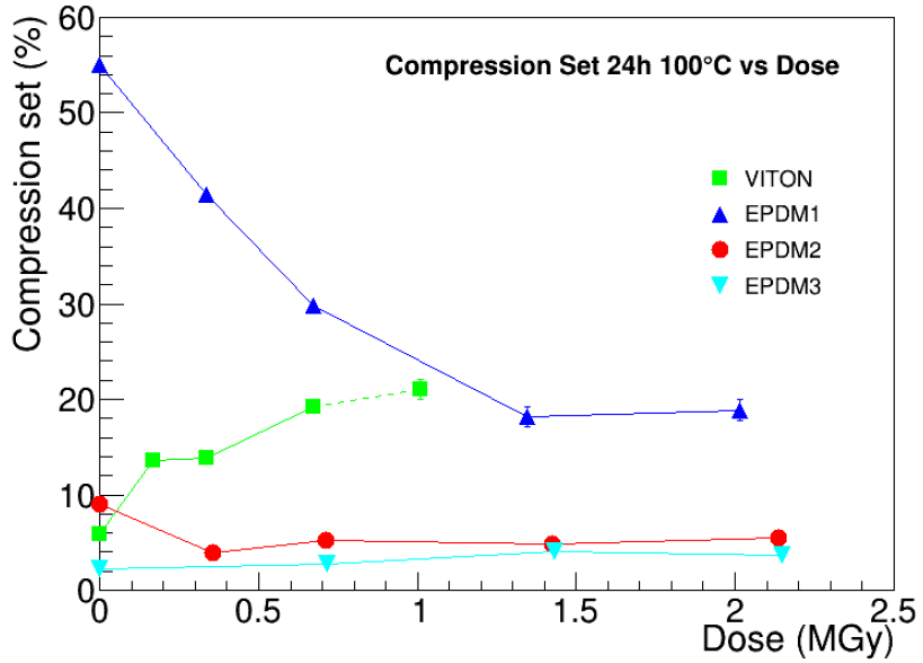
FPM - 5 Pascal; **Fluoroelastomer**



- Standard price

DICHTOMATIK

EPDM 1 - UTS



- **Rad-hard**: tested with γ at **1.6 MGy**

Very expensive

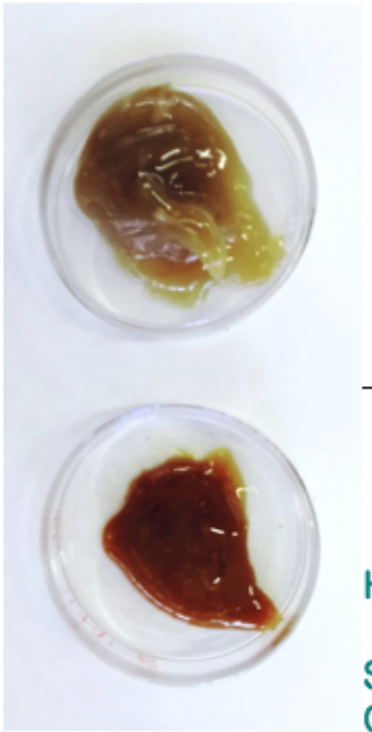
James Walker

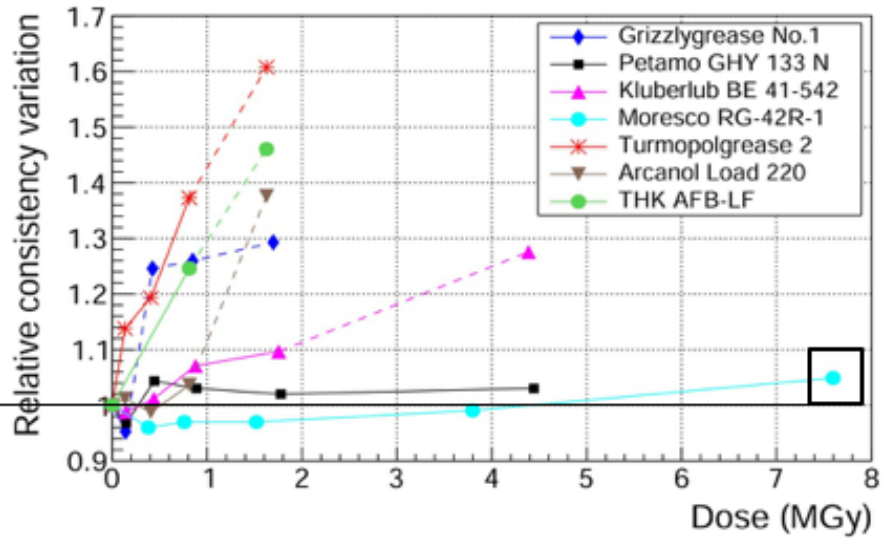
Polymers and Lubricants: PIE of Lubricants

Matteo Ferrari

EXPERIMENTAL RESULTS

Moresco RG-42R-1





Chemical modifications

HIGH STABILITY

SLIGHT COLOR CHANGE

- Rad-hard base oil (15 MGy)
- NLGI class: 1
- Polyphenylether + polycarbonate thickener
- **interesting for ESS**

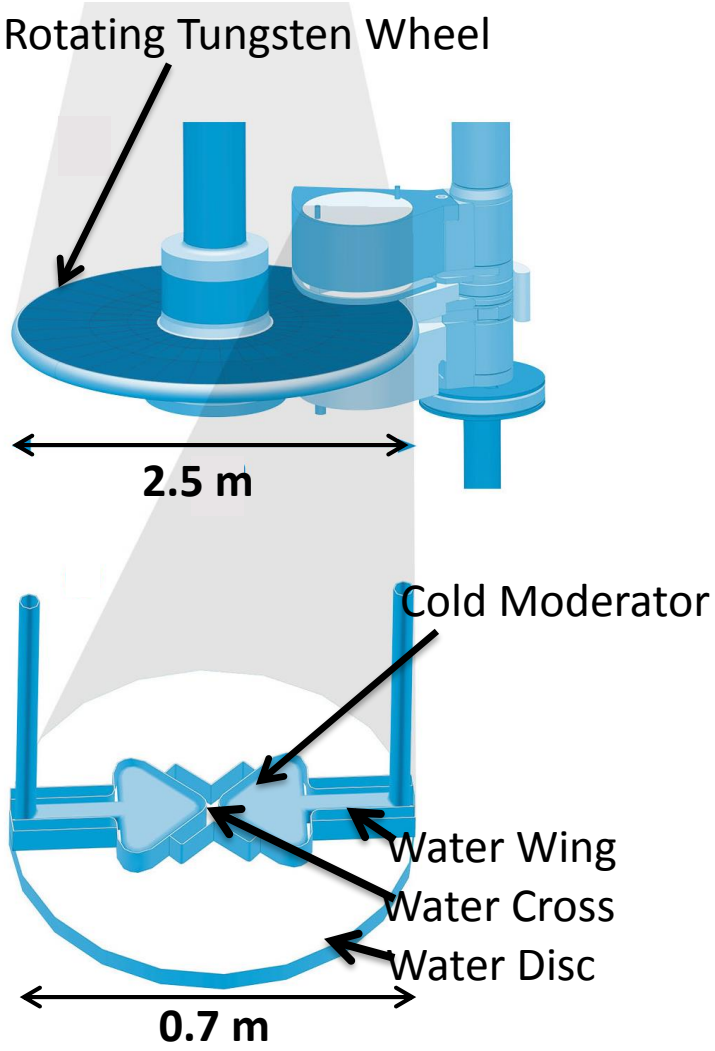
Polymers and Lubricants
Prospects for 2019

- Completion of Phase 1:
  - Neutron Scattering Experiments
  - Further analyses at MORESCO
  - PhD dissertation
- Planning for Phase 2:
  - Identification of Research Reactor for beam time
  - Identification of Research Partners

Operation Condition at ESS

Ortho to Para Back Conversion

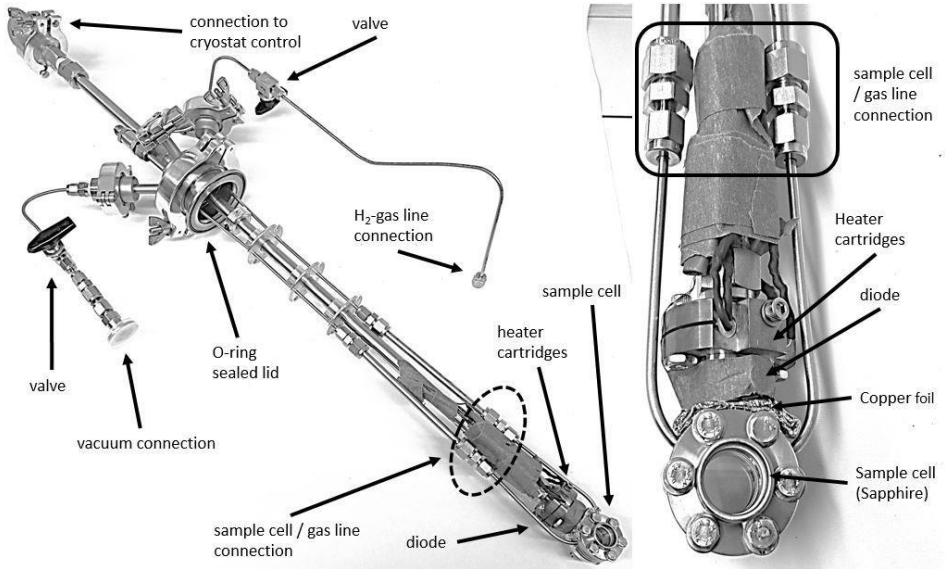
- Fast neutrons and γ rays dissociate hydrogen
  - $H_2 + n/\gamma \rightarrow H + H$
- Immediate recombination leads statistically to 3:1 ortho:para H_2
  - $H + H \rightarrow 0.75$ ortho-H_2 + 0.25 para-H_2
- Estimated back conversion rate at ESS cold moderator:
  - 3-mol ortho-H_2/min [*E.B. Iverson, J.M. Carpenter, Collaboration on Advanced Cold Moderators, Jülich 2002*]
- Need to keep converting ortho-H_2 to parahydrogen while beam is on.
  - ortho-$H_2 \rightarrow$ para-H_2 + 670 J/g

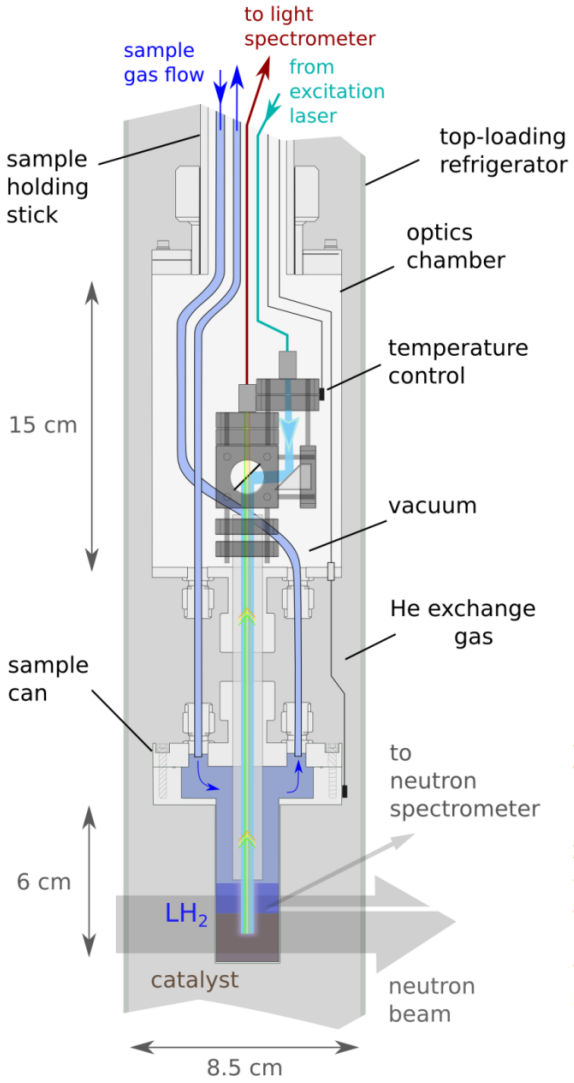


Catalyser Research at ESS

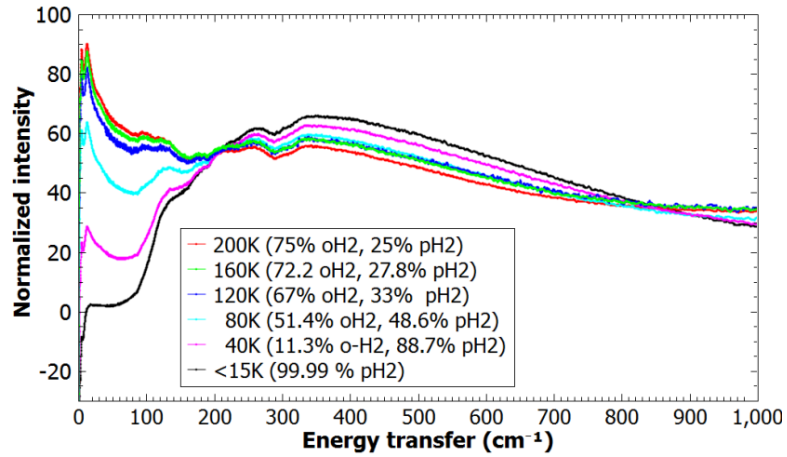
Measurement Techniques

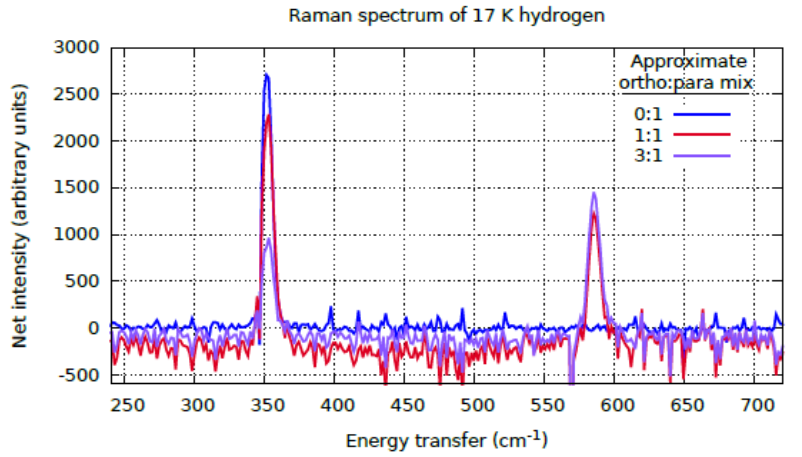
- In-situ Raman and Neutron Vibrational Spectroscopy
  - In collaboration with SNS
- Raman Spectroscopy in Chemistry Lab





R.C. Gillis et al., Rev. Sci. Inst, 2018
M. Hartl et al, PCCP 2016



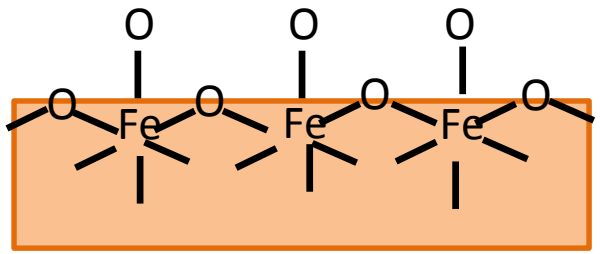


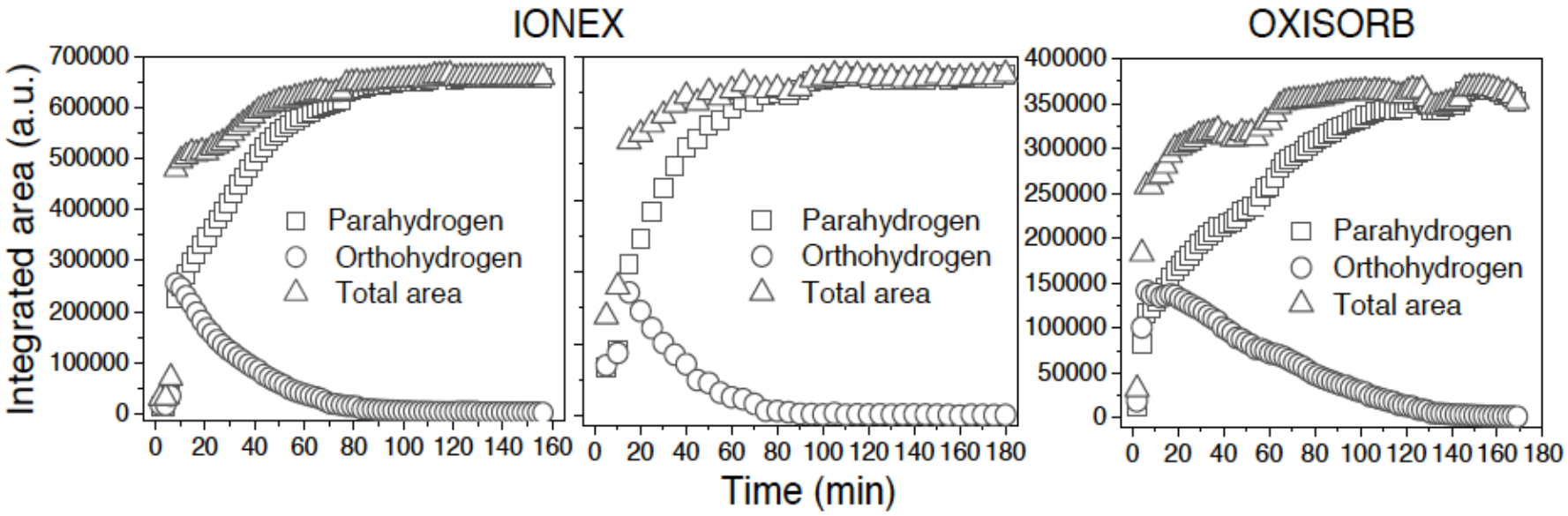
Catalyser Research at ESS
Conversion Kinetics

- Conversion kinetics of two candidate catalysing materials are studied.
- Conversion Rate:
  - 0.0164 mol-ortho-H_2/min/g-OXISORB®
  - 0.0505 mol-ortho-H_2/min/g-IONEX®

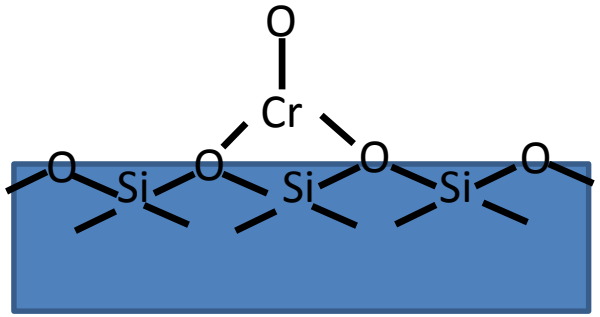
Emil Karlsson, "Catalytic ortho-to-parahydrogen in liquid hydrogen," MSc Thesis, Lund University

IONEX (C-CHEM)





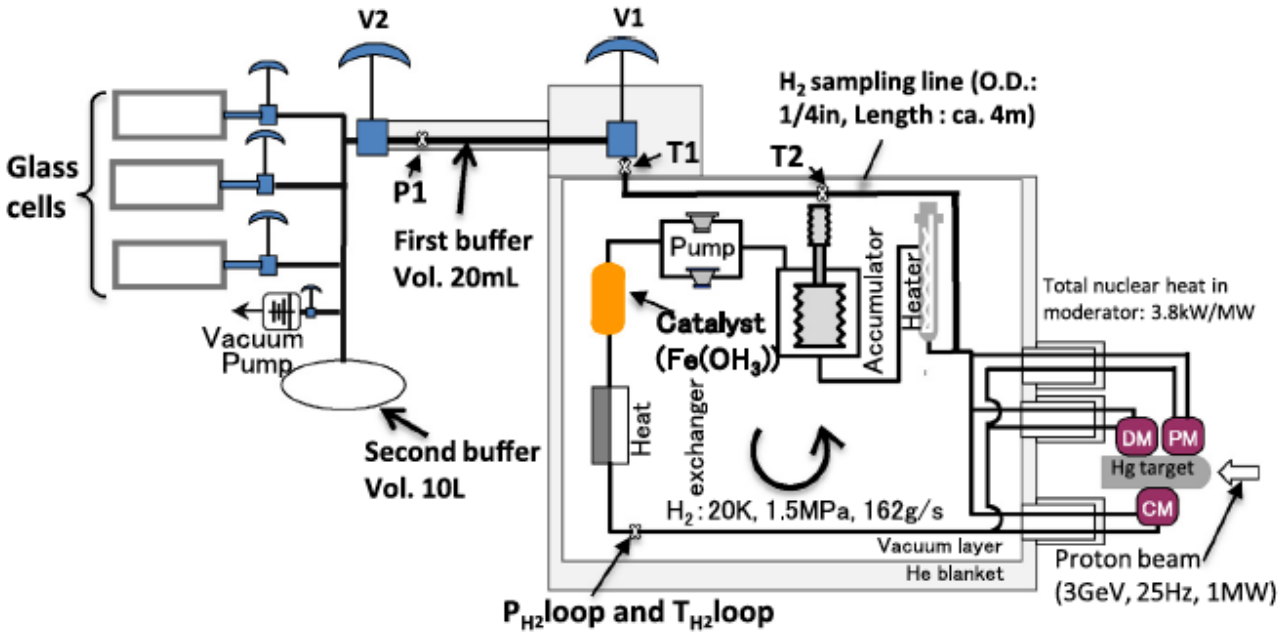
OXISORB (SPECTRAMOL)



Kinetics of Ortho-Para Conversion

Prospects for 2019

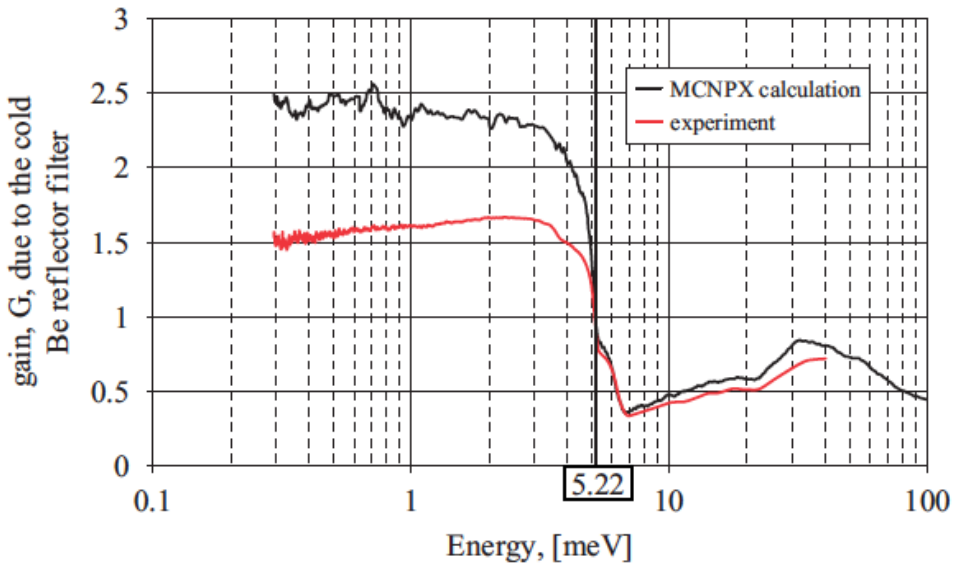
- Active Collaboration with JPARC and SNS on Raman Spectroscopy Measurement Techniques
- Resolution of Safety and Licensing Issues for is situ online measurement



M. Teshigawara et al., *NIM-B 368 (2016) 66-70*

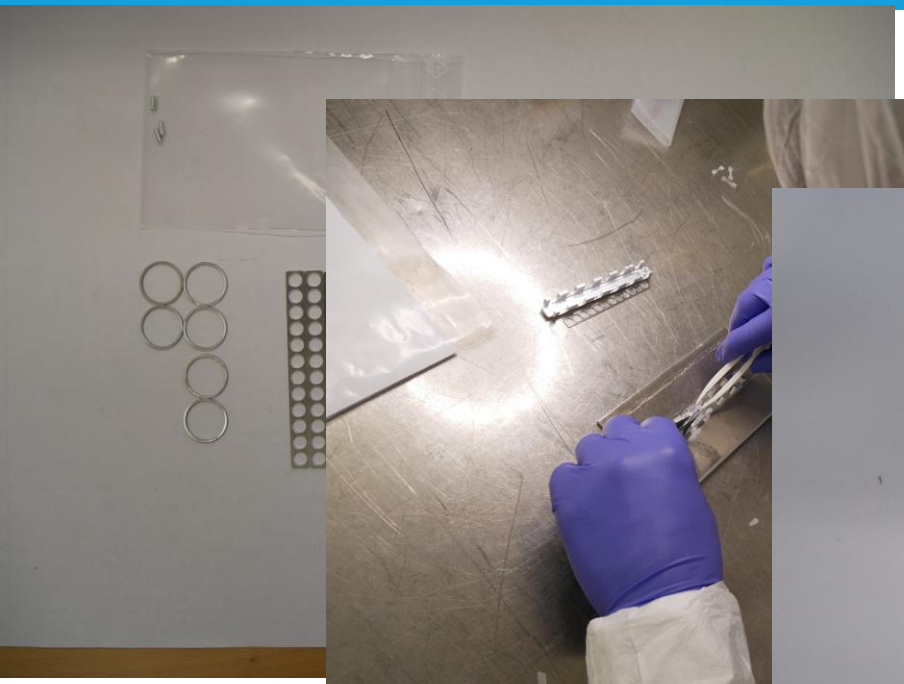
Neutronic Characterisation of Beryllium

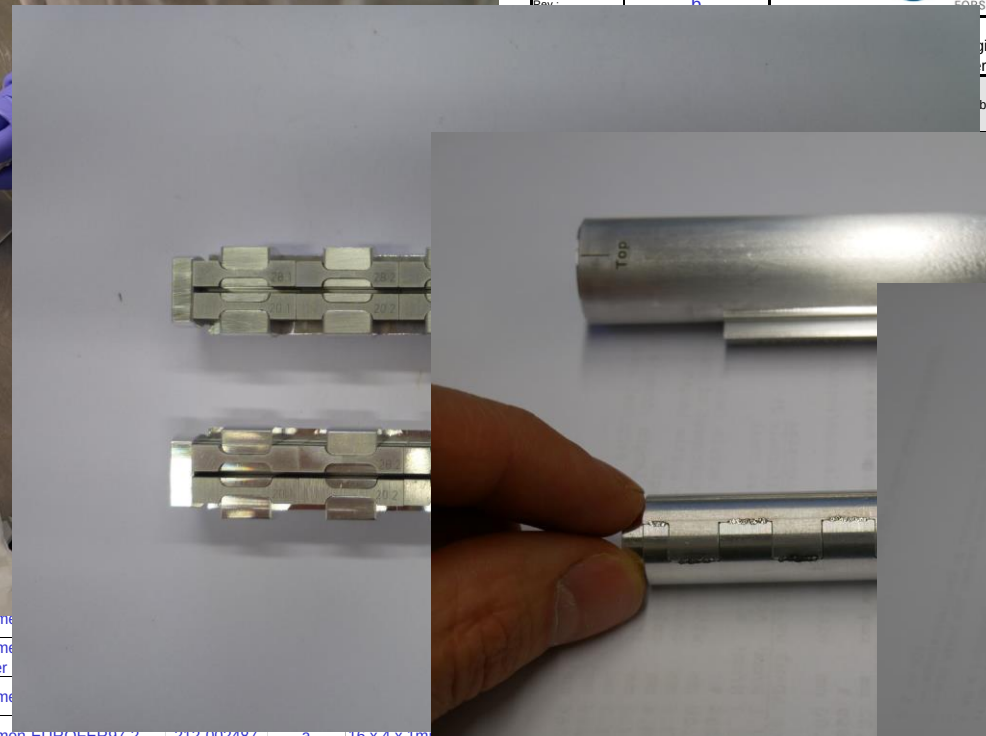
- Beryllium Selection Criteria
  - Isotropic texture
  - Small grain size
  - High purity
- Research on the correlation between neutron scattering cross-section and different beryllium grades is launched
  - S-65: Vacuum Hot Pressed
  - S-65-H: Hot Isostatic Pressed
  - S-200-F: Vacuum Hot Pressed
  - Sintered/Forged Be from Ulba
- Prospects for 2019:
  - Collaboration with UKAEA and SNS



G. Muhrer et al., NIMA, 2007

Irradiation Module





BOM

Specimen_Holder
Construction-Phase

JÜLICH
FORSCHUNGSZENTRUM

ZEA - 1
ngineering, Electronics und Analytics
ring and Technology -

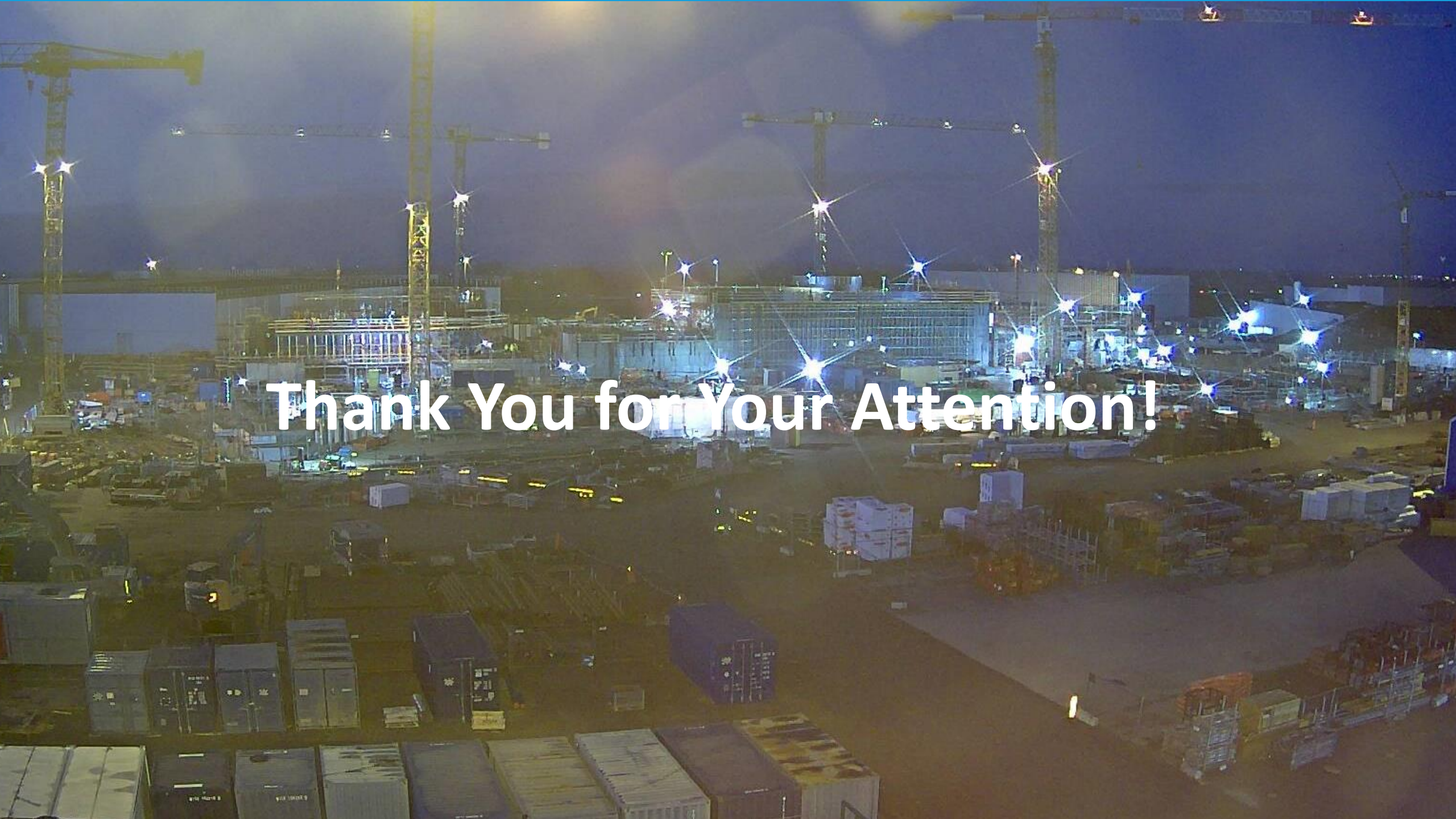
ber	Notes

27		6	Tensile_Specime								
28		6	Tensile_Specime weld_with_Filler								
29		6	Tensile_Specime								
30		6	Tensile_Specimen-EUROFER97-2	212-002487	a	16 x 4 x 1m					
31		6	Tensile_Specimen-ODS_EUROFER	212-002488	a	16 x 4 x 1m					
40		6	EC_Sampel-AL6061T6	212-002476	a	16 x 1 x 1m					
41		6	EC_Sampel-AL5754-0	212-002477	a	16 x 1 x 1m					
42		6	EC_Sample-SS316L	212-002481	a	16 x 1 x 1mm			1.4404 (SS316L)	/	

Concluding Remarks

- Research of Materials in Target Environment Provides Support for Target Project
- External Materials Research Collaborations are essential for the Acquirement of Materials Knowledge
- Radiation Damage Driven Lifetime Limits of Main Functional Systems are explored for Enhanced Overall System Reliability and Operational Cost Saving
- Visions of Materials R&D at ESS are under work.

Any good ideas on collaboration for the benefit of high power target community will be highly appreciated!


Thank You for Your Attention!