EUROPEAN
SPALLATION
SOURCE

Materials Functional Scope and Lifetime at ESS Target Station

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www.europeanspallationsource.se
7 July, 2017

European Spallation Source ERIC

A European research facility for international researchers

The world’s most powerful neutron source for the study of materials

Produce our first neutrons in 2020

Estimated construction cost of 1 843 M€

Construction in Progress: June 9, 2017

EUROPEAN SPALLATION SOURCE

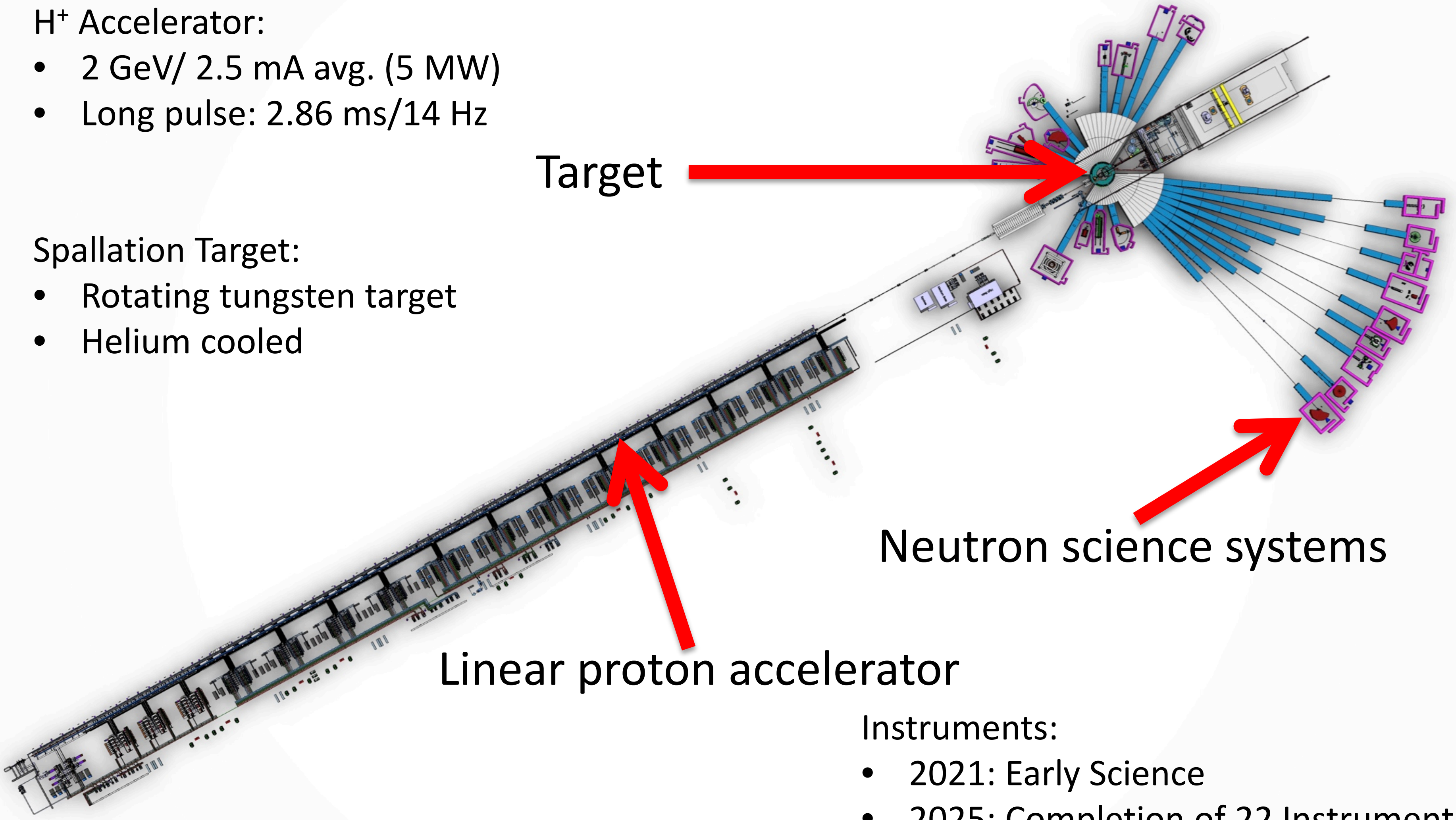
The ESS facility layout

H⁺ Accelerator:

- 2 GeV/ 2.5 mA avg. (5 MW)
- Long pulse: 2.86 ms/14 Hz

Spallation Target:

- Rotating tungsten target
- Helium cooled



Target

Neutron science systems

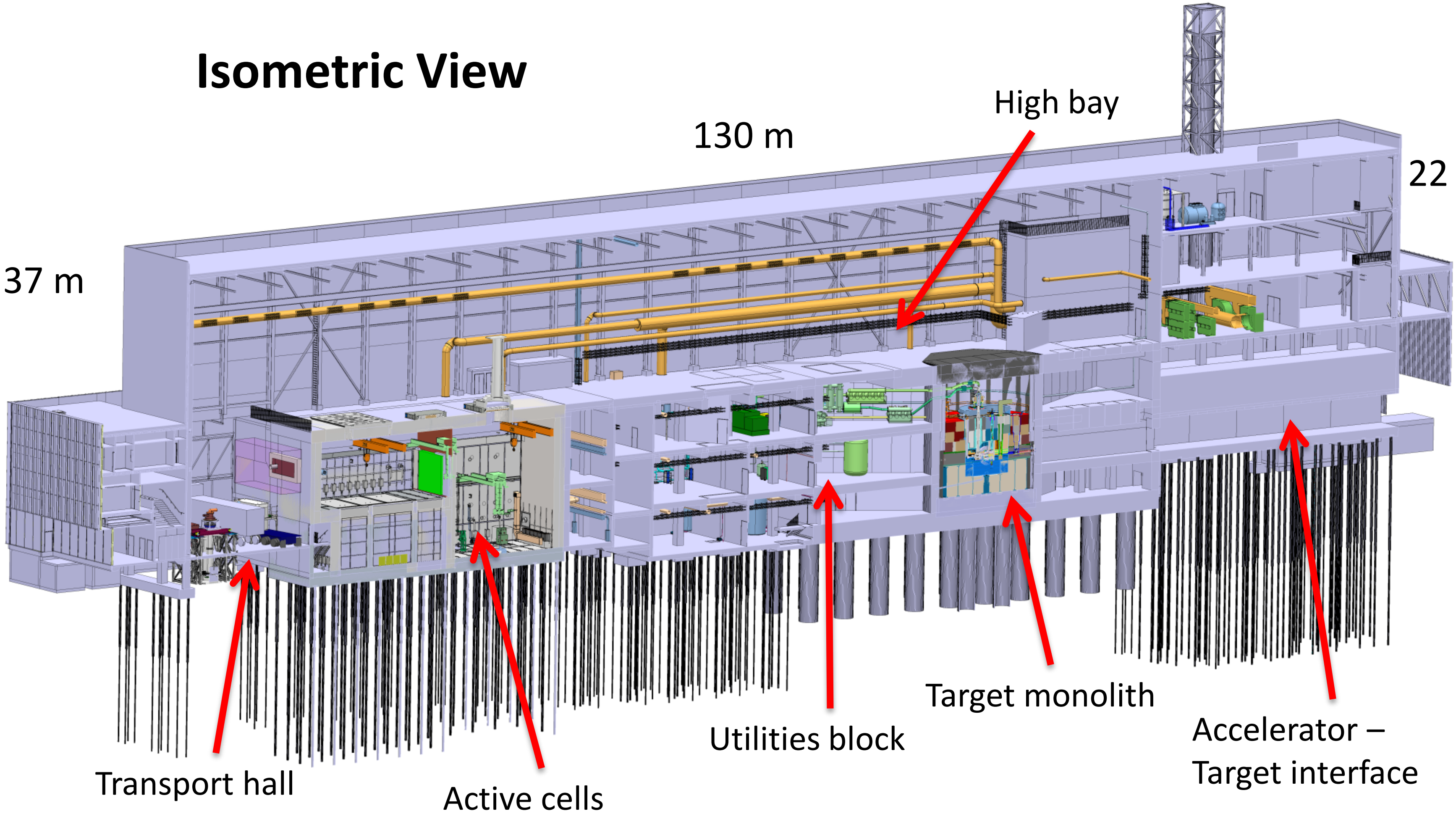
Linear proton accelerator

Instruments:

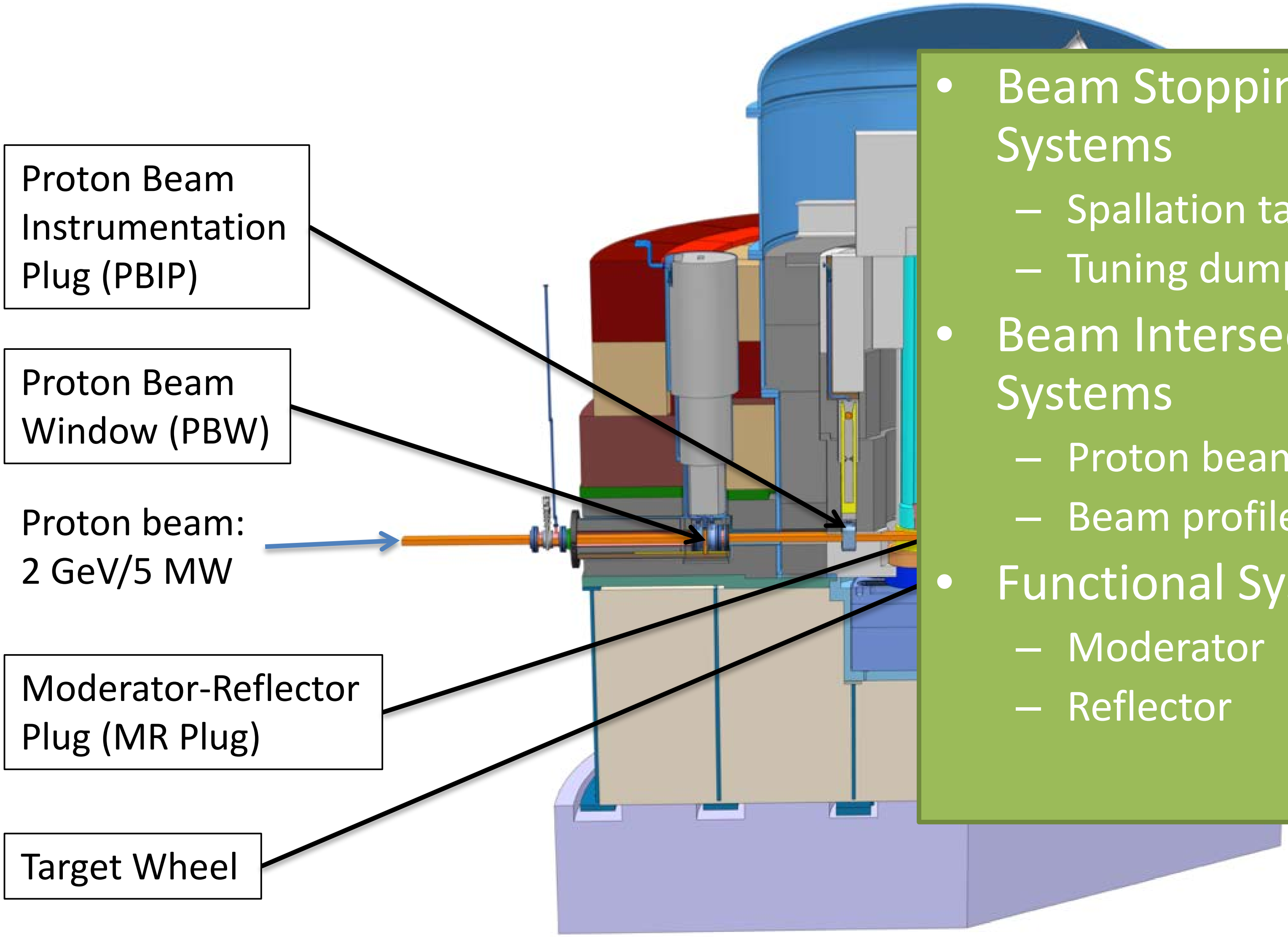
- 2021: Early Science
- 2025: Completion of 22 Instruments

The ESS Target Station Layout

Isometric View



Target systems under high dose



Proton Beam Instrumentation Plug (PBIP)

Proton Beam Window (PBW)

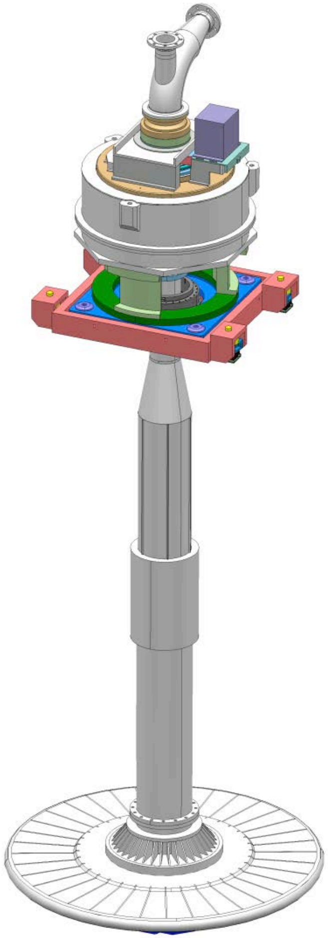
Proton beam:
2 GeV/5 MW

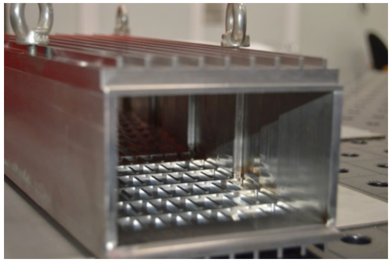
Moderator-Reflector Plug (MR Plug)

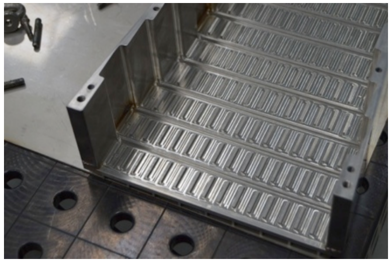
Target Wheel

- Beam Stopping Systems
  - Spallation target
  - Tuning dump
- Beam Intersecting Systems
  - Proton beam window
  - Beam profile monitor
- Functional Systems
  - Moderator
  - Reflector

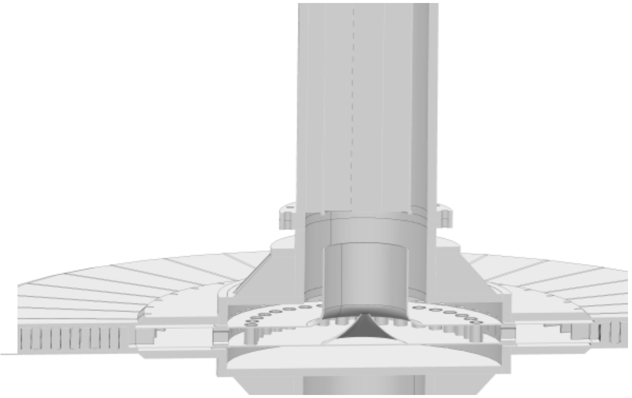
Spallation Target

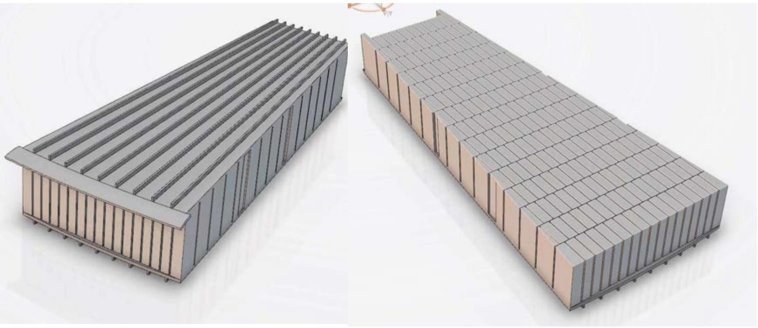




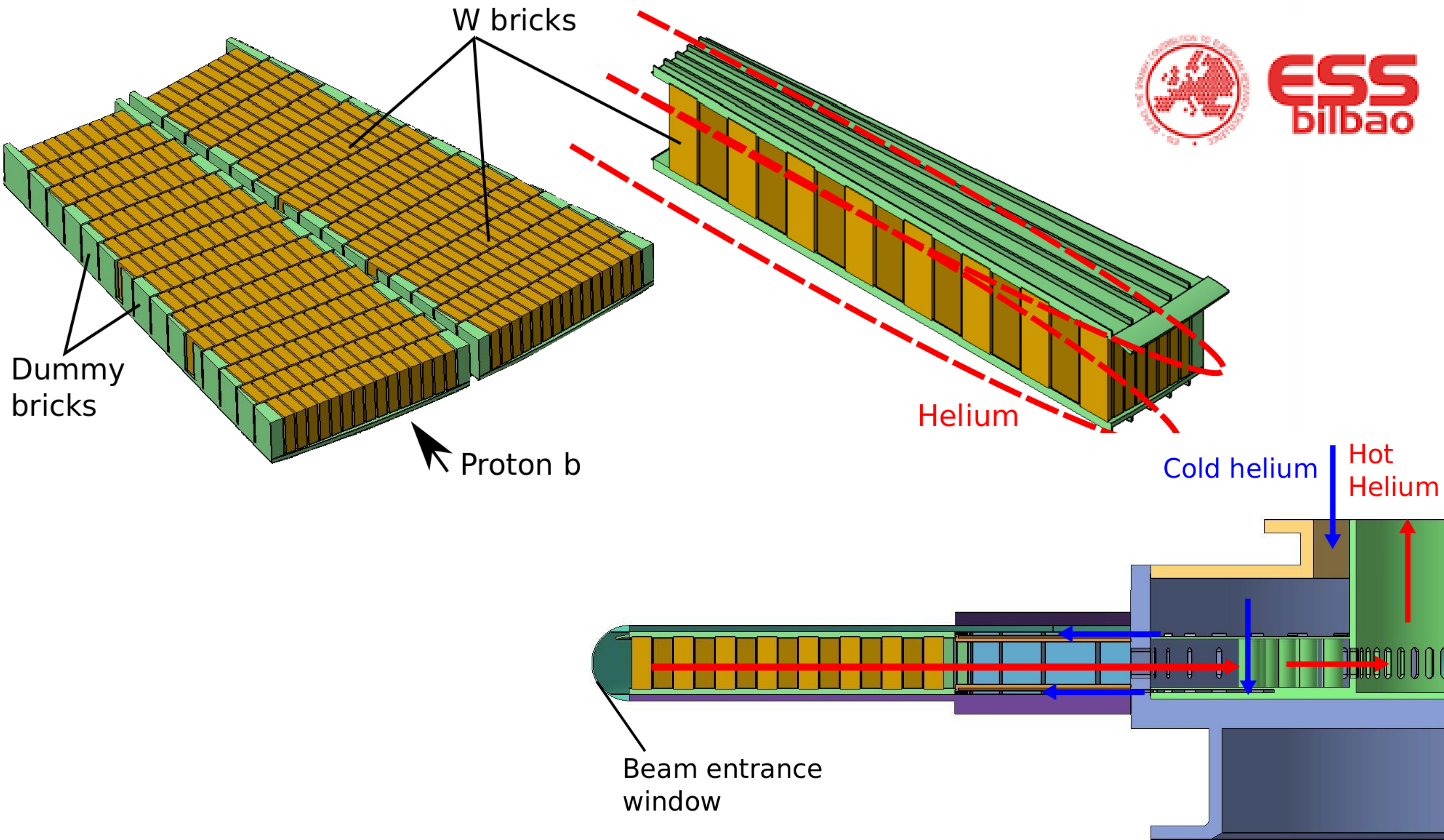


- Tungsten blocks in 36 segments
  - Max 0.1 GW/m^3 in tungsten
  - Beam stopping in a meter of tungsten
- Helium coolant
  - Mass flow 3.0 kg/s
  - Pressure 1.0 MPa
- Rotational speed 23.3 rpm
- Wheel diameter 2.6 m
- Shaft length > 5 m



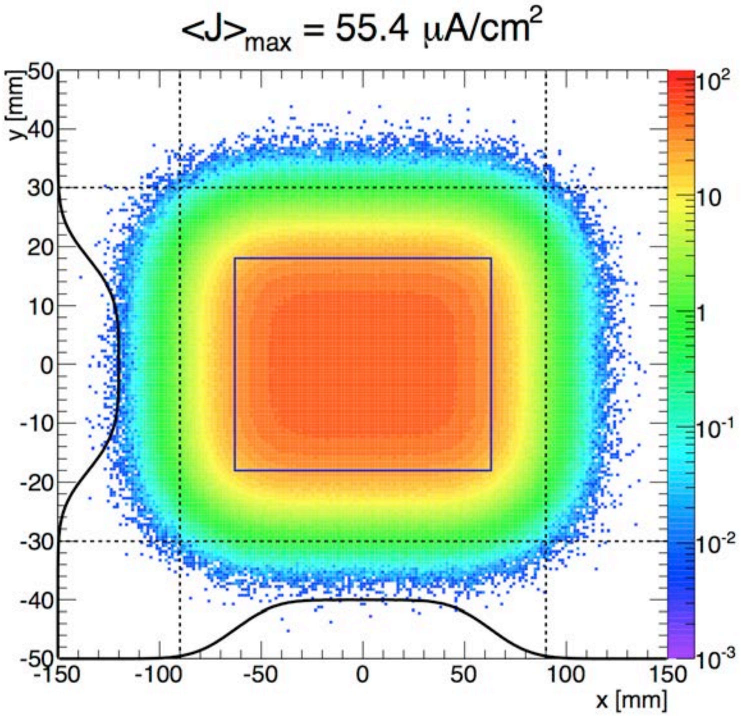


Spallation Target: Configuration



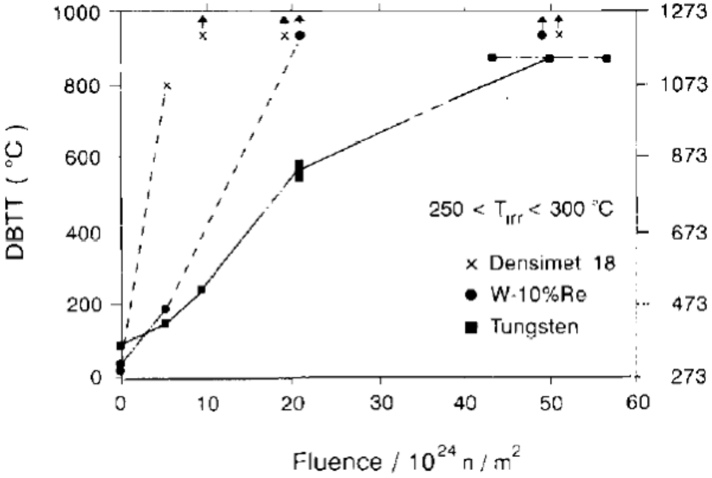
Beam on Target

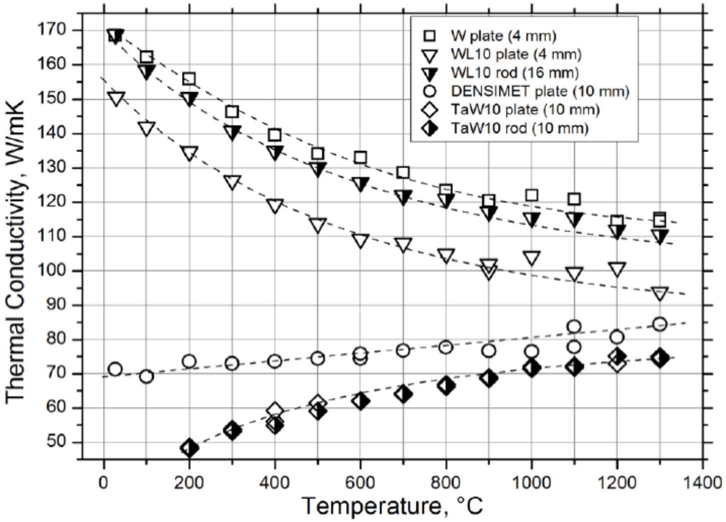
- Beam on target requirements:
  - Beam footprint enclosing 97.5% beam fraction: 180 mm (H) × 60 mm (V)
  - Beam footprint enclosing 99.9% beam fraction: 200 mm (H) × 64 mm (V)
  - Nominal time-averaged peak current density: 56 µA/cm^2
  - Maximum time-averaged peak current density: 81 µA/cm^2
  - Max displacement of footprint from nominal position: ±5 mm (H), ±3 mm (H)



Spallation Material: Selection

- Pure tungsten
  - Lower DBTT than W-10%Re for DPA > 0.3 [H. Ullmaier, F. Carsughi, NIM-B 101, 1995]
  - Higher thermal conductivity than other W-alloys [M. Rieth et al, Tech- Rep.-KIT]
  - Tantalum has a higher volumetric decay heat and lower neutron production density.





Spallation Material: R&D

- Spallation Materials
  - Tungsten tensile and fatigue properties
  - Tungsten oxidation
  - STIP-V tungsten PIE
  - Heavy ion irradiation program
  - Vendor evaluation
  - Tungsten erosion

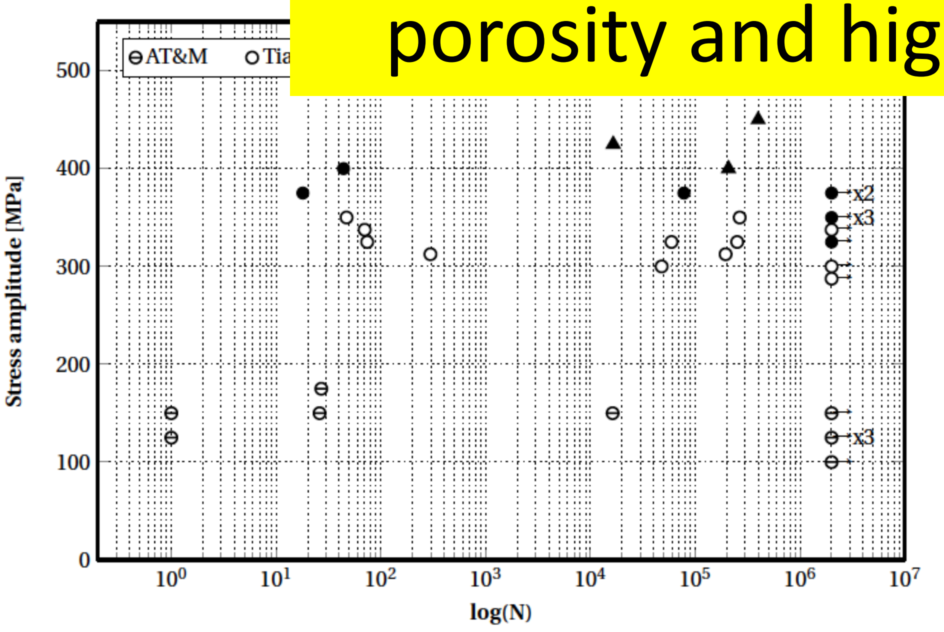
Question: Maximum allowed stress

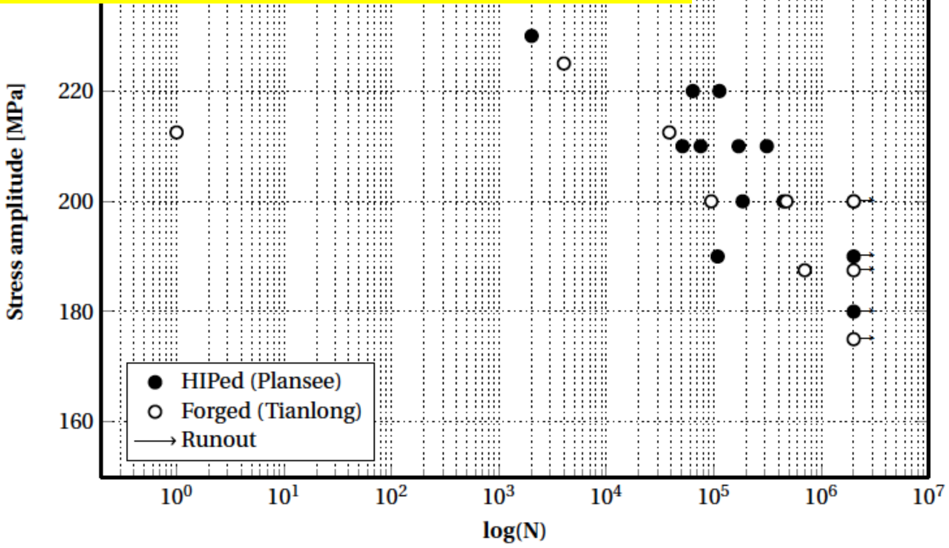
- What should be the maximum allowed stress in tungsten blocks?
  - Tungsten is not a structural material
  - Tungsten is under high thermal stress.
    - Loss of structural integrity of tungsten may lead to a creation of a hot spot in the target, which could cause a premature target failure
  - Cyclic thermal load may induce fatigue failure.
    - Tungsten undergoes a 100°C thermal cycle every 2.4 seconds ($7 \cdot 10^6$ cycles per year)

Tungsten Fatigue

Vendors	Raw material	Fatigue Limit [MPa]	Fracture
Vendor A	Hot rolled	125	Transgranular
Vendor B	Hot rolled	312	Transgranular
	Hot forged	185	Intergranular
Vendor C	Hot rolled	371	Transgranular
			ular

Rolled tungsten is chosen for its low porosity and high fatigue strength





Irradiation Effect: Tensile Strength

- For radiation damage above 0.1 dpa, all the tungsten specimens failed in a brittle manner with reduced yield strength, at the tested temperatures up to 500 C.
- Preliminary results from STIP-V tungsten tensile specimens also showed the similar behavi

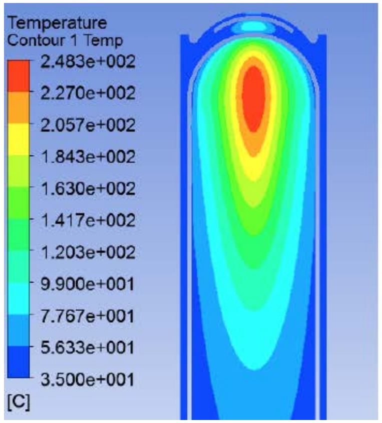
Estimated maximum damage dose in the tungsten block is **2 DPA/year**, or **10 DPA** during the 5 year lifetime

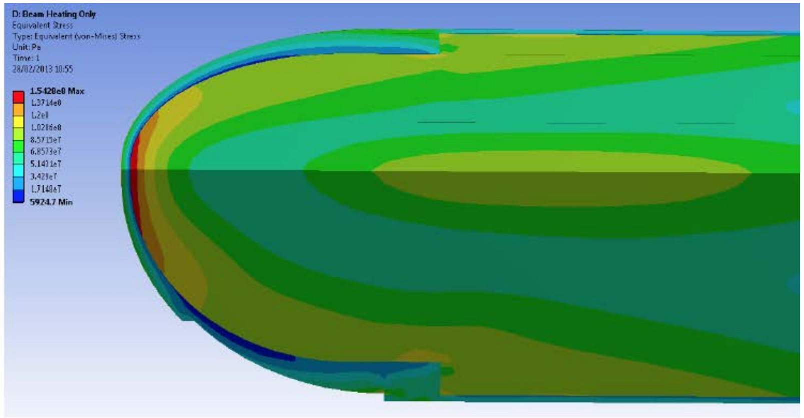
Tungsten sp					ss	Total elong. [%]
As received						2
As received						0
As received	$1.0 \cdot 10^{25}$	0.1	425	300	60	0
Pre-irrad. annealed at 1200 °C for 1h	Unirrad.	0.0	-	300	730	8
Pre-irrad. annealed at 1200 °C for 1h	$1.0 \cdot 10^{25}$	0.1	350	300	450	0
Pre-irrad. annealed at 1200 °C for 1h	Unirrad.	0.0	-	500	580	8
Pre-irrad. annealed at 1200 °C for 1h	$2.0 \cdot 10^{26}$	2.0	700	500	150	0
Pre-irrad. annealed at 1600 °C for 1h	Unirrad.	0.0	-	300	170	47
Pre-irrad. annealed at 1600 °C for 1h	$1.0 \cdot 10^{25}$	0.1	350	300	230	0
Pre-irrad. annealed at 1600 °C for 1h	$1.0 \cdot 10^{25}$	0.1	425	300	260	0
Pre-irrad. annealed at 1600 °C for 1h	Unirrad.	0.0	-	500	80	41
Pre-irrad. annealed at 1600 °C for 1h	$1.0 \cdot 10^{25}$	0.1	500	500	320	0

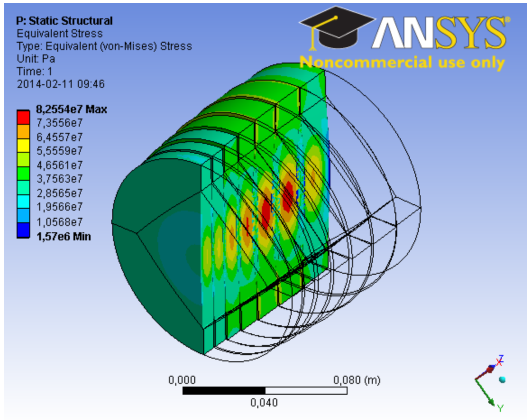
I. V. Gorynin, et al., Journal of Nuclear Materials , 191-194:421-425, 1992;
H. Ullmaier, F. Carsughi, NIM-B 101, 1995

Irradiation Effect: Benchmarking

- ISIS TS-2 Target
  - 800 MeV proton beam with 32 kW beam power.
  - 10 Hz pulse repetition rate with the pulse length 500 ns.
  - 154 MPa maximum steady stress.
  - 203 MPa peak dynamic stress with the 49 MPa stress amplitude.
- LANSCE Mark-III
  - 800 MeV proton beam with 80 kW beam power.
  - 20 Hz pulse repetition rate with the pulse length 250 ns.
  - Equivalent stress range as TS-2 Target





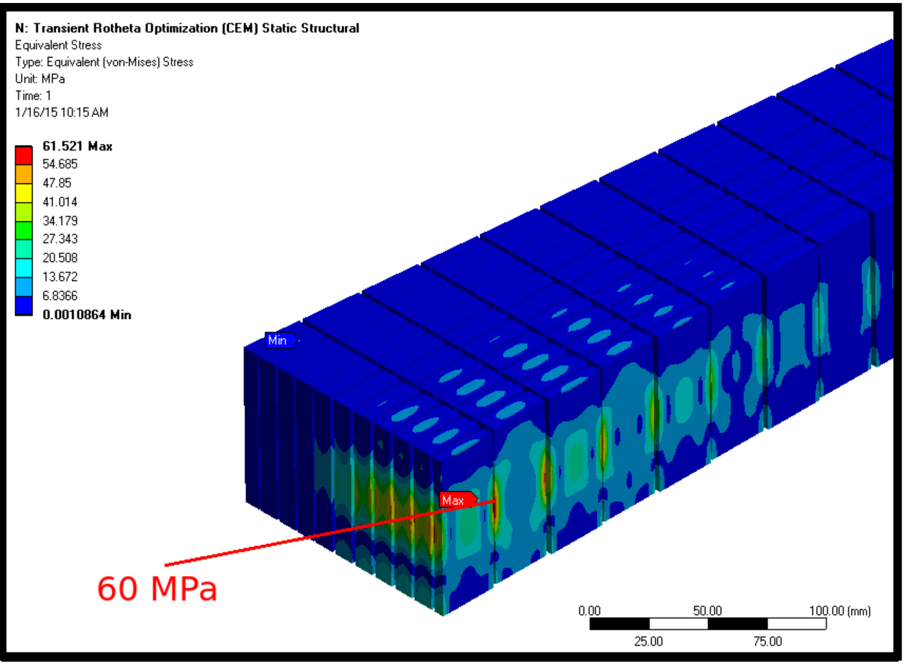


P. Loveridge and D. Wilcox. HPTW4, 2013

Design requirement: Thermal Stress

- Recommended mean stress: 100 MPa
- Recommended stress amplitude: 50 MPa

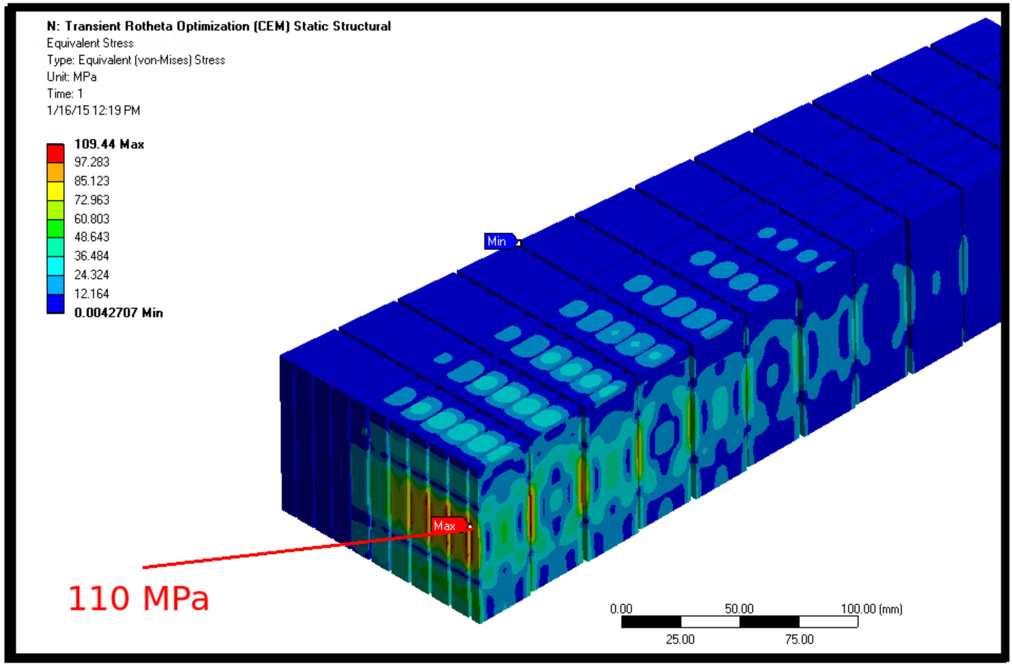
Poster: K. Sjögreen



N: Transient Rotheta Optimization (CEM) Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
1/16/15 10:15 AM

61.521 Max
54.685
47.85
41.014
34.179
27.343
20.508
13.672
6.8366
0.0010864 Min

Stres Before a Pulse



N: Transient Rotheta Optimization (CEM) Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
1/16/15 12:19 PM

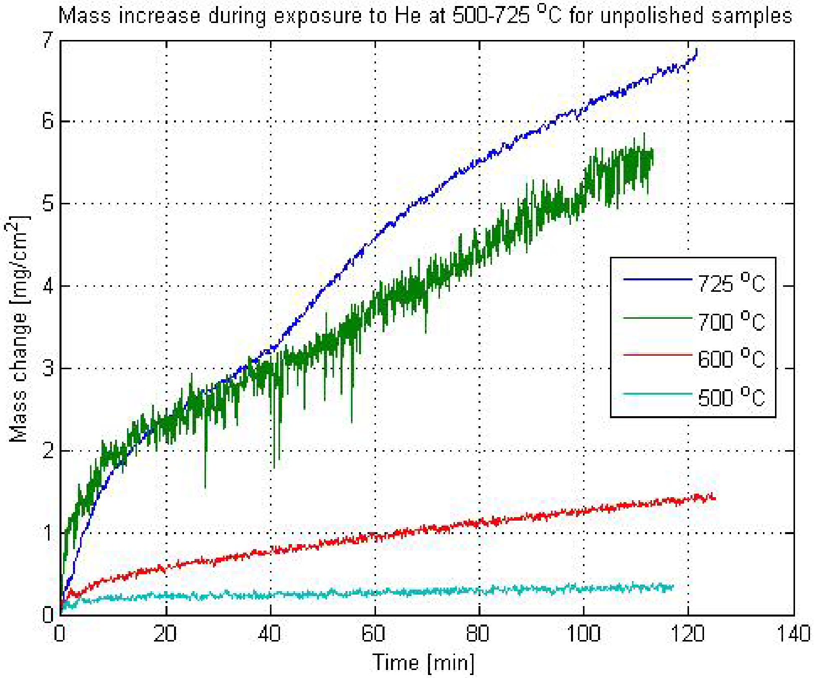
109.44 Max
97.283
85.123
72.963
60.803
48.643
36.484
24.324
12.164
0.0042707 Min

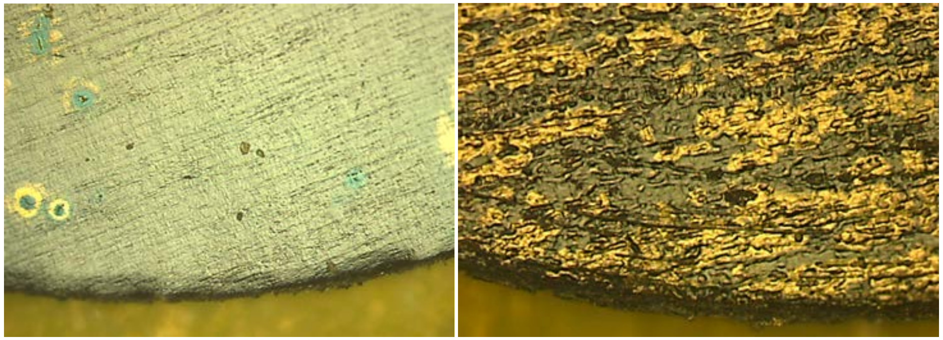
Stress After a Pulse

Question: Maximum allowed temperature

- What should be the maximum allowed temperature in tungsten blocks?
  - The melting point of tungsten is not an issue in normal operation.
  - In case of air/moisture ingression, the set-off point of tungsten oxidation is an issue.
  - Also an issue is the long-term effect of oxygen impurity in the “pure” helium coolant.

Spallation Material: Oxidation

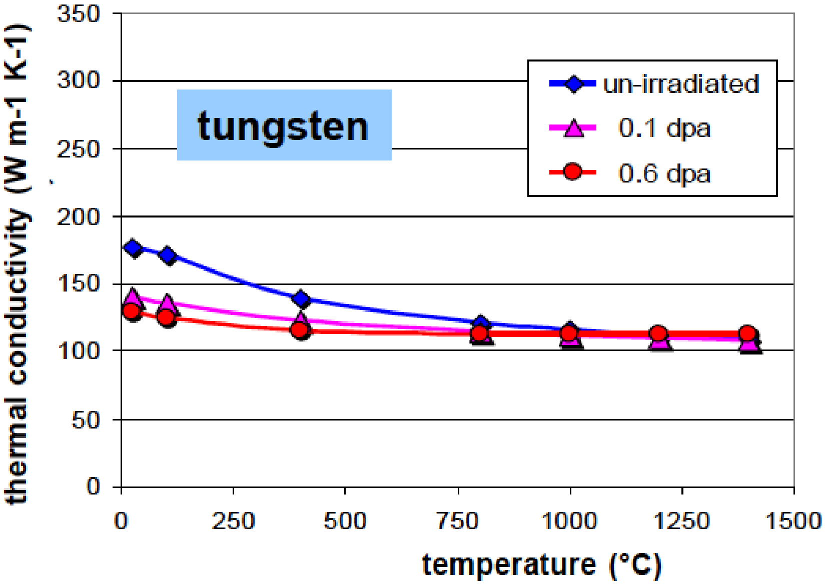




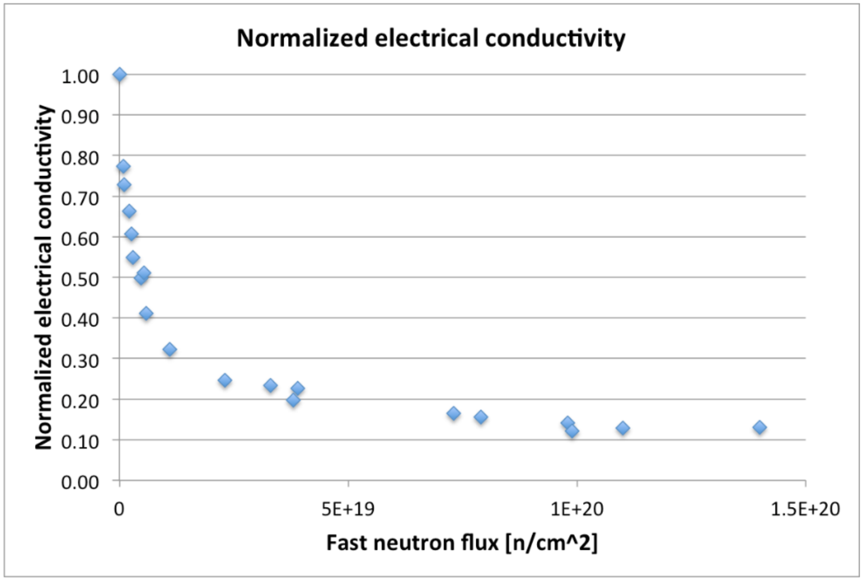
- Oxidation observed in He atmosphere with a small partial pressure of oxygen above 500°C [J. Habainy et al. IWSMT-12, 2014]
- Reactive vaporization of the hydrated oxide layer is observed in steam above 700°C [G. Greene, C. Frinfrock, Exp. Therm. Fluid Sci. 25 (2001)]

Spallation Material: Degradation of Thermal Conductivity

- Decrease in thermal conductivity by ~30% at 0.6 dpa
- Decrease in electrical conductivity by ~85% at 1.5e20 n/cm^2 neutron fluence
- Impact of 40% decrease in thermal conductivity:
  - ~37 ^{o}C increase in the maximum steady temperature
  - ~42 MPa increase in the maximum steady von Mises sterss
  - Requires a safety factor in temperature calculations



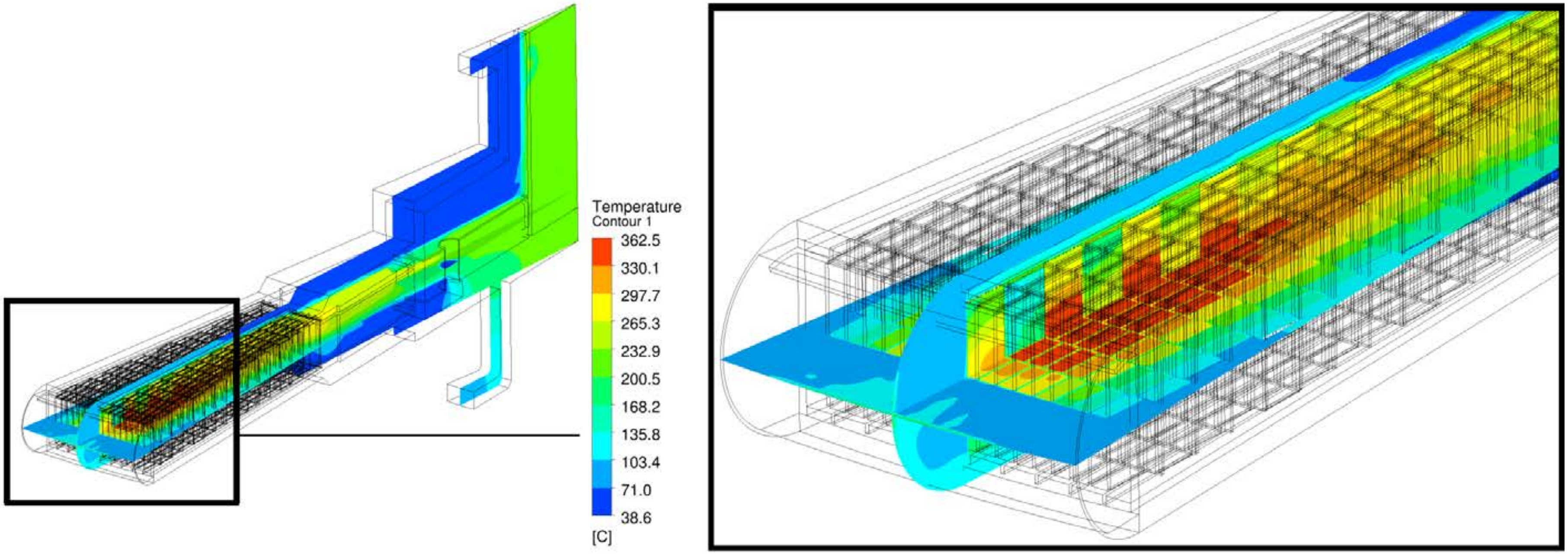
[J. Linke et al. First meeting of CRP on irradiated tungsten, Vienna, 26-28 Nov 2013]



[I. V. Gorynin et al. JNM 191-194 (1992) 421-425]

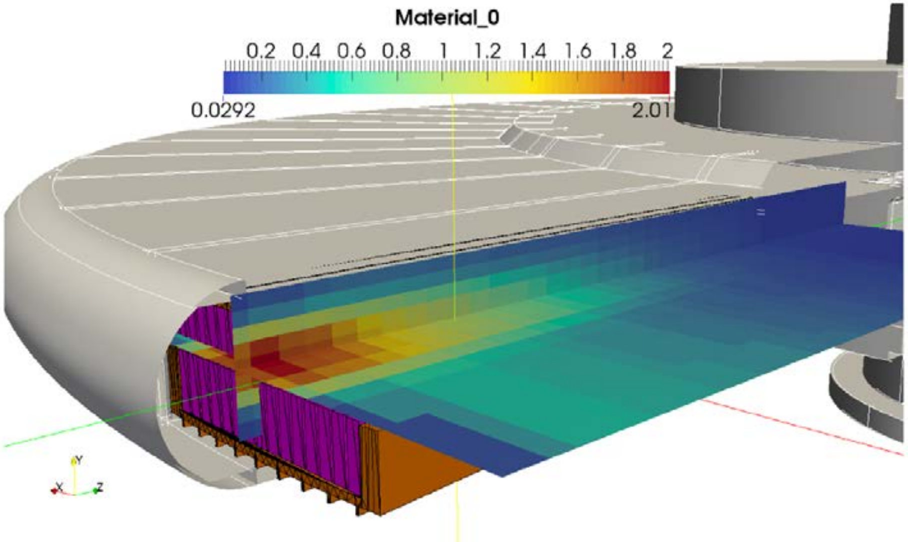
Design requirements: Temperature

- Normal operation: max. 500°C
- Loss of coolant accidents: max. 700°C

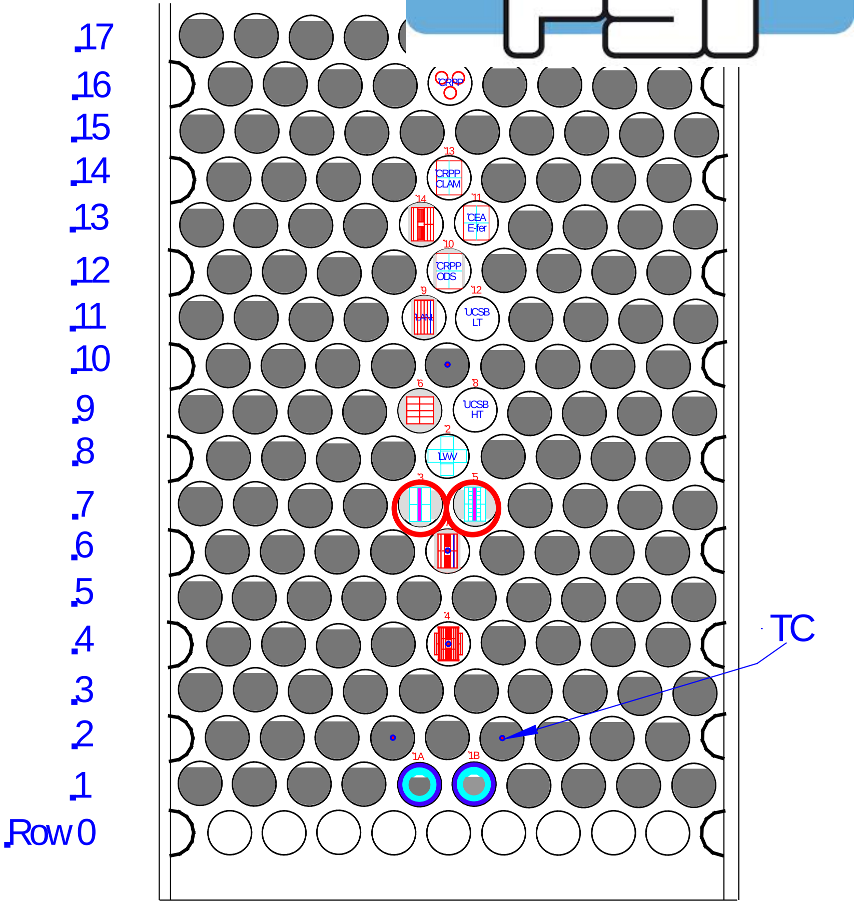


STIP-V Tungsten PIE

- A damage rate of 2 dpa/year in the ESS tungsten
- STIP-V: Two 60 x 8 x 1 mm^3 tungsten bars
  - Irradiation period: 2007-2008 for total 9.83 Ah p-charge.
  - Irradiation condition: 5-28 DPA at 100-800 C

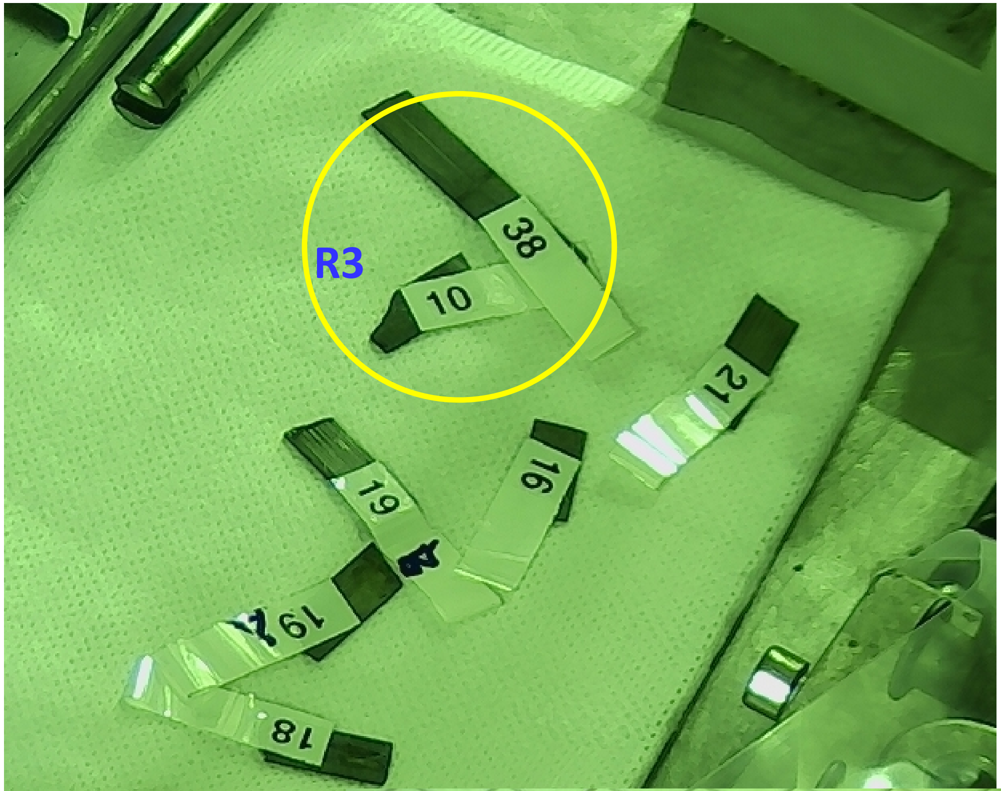


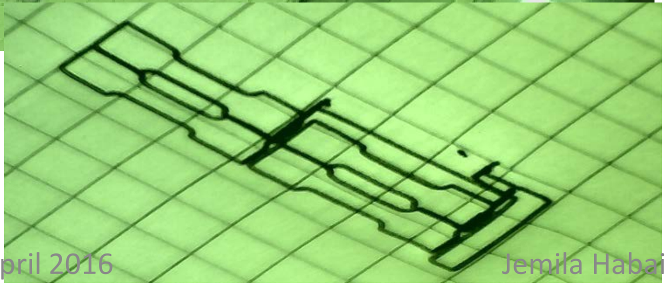
STIP-V (Target-7)

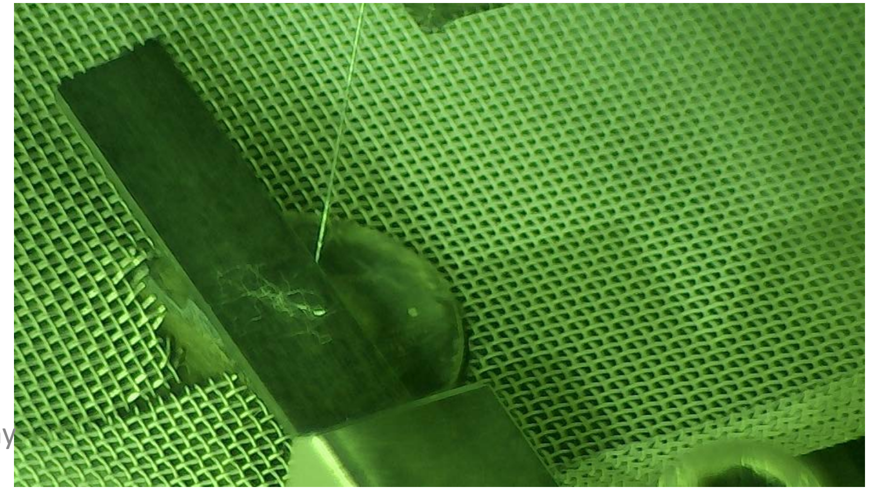


Y.Dai, 18.12.2006

Cutting of active samples in Hotcell







PIE plan for STIP-V tungsten specimen

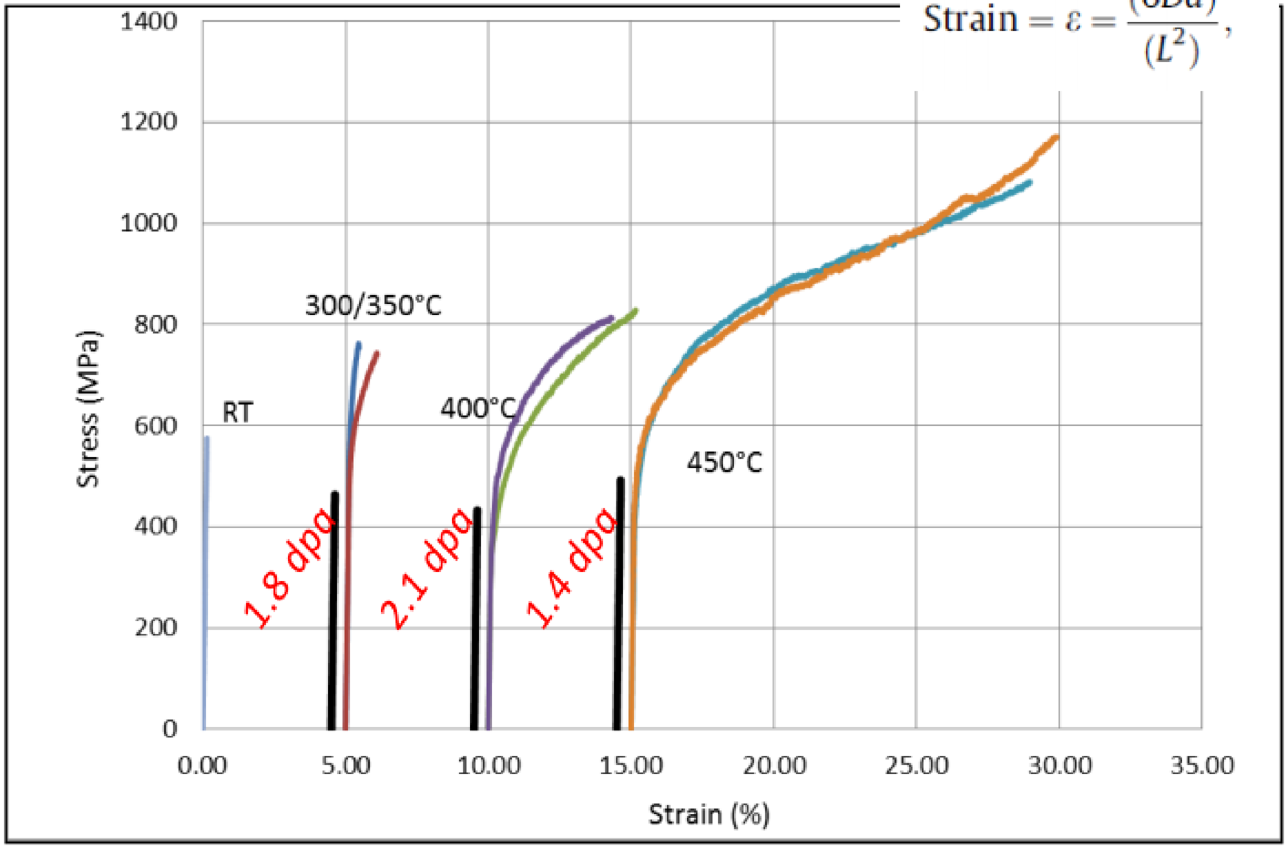
- Bend tests
  - 6 low dose , 16 high dose bars
  - Ductility and flexural strength
- Tensile tests
  - 4 high dose specimen
  - Yield and tensile strength
- Hardness tests
  - Irradiation hardening as a function of dose
- Thermal diffusivity with Laser Flash Apparatus
  - 2 low dose, 3 high dose discs
  - Thermal conductivity and specific heat capacity
- SEM & TEM microscopy
  - Fracture mode and microstructural changes at different doses and temperatures

Initial Results: 3P bend tests

8 mm samples, Ti: 60-140˚C

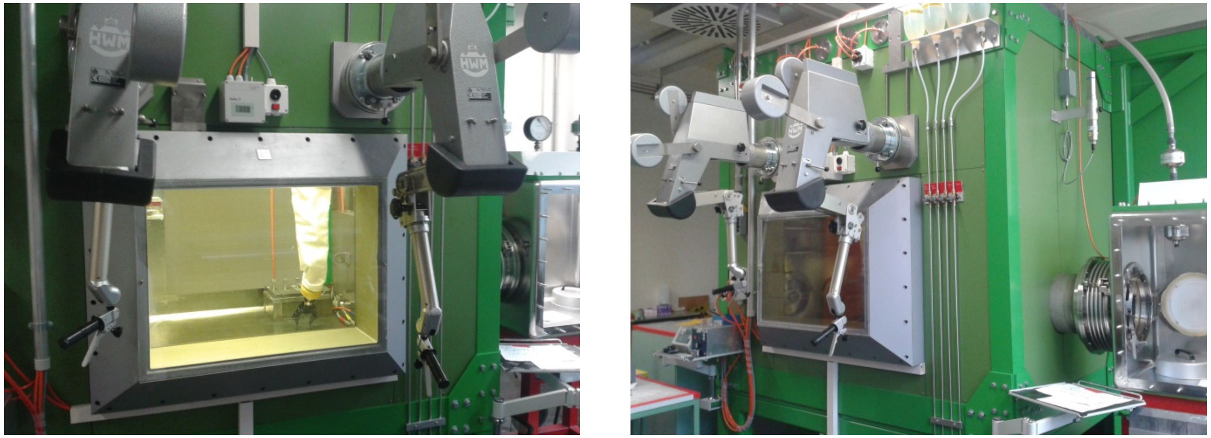
$$\text{Stress} = \sigma = \frac{(3FL)}{(2bd^2)},$$

$$\text{Strain} = \varepsilon = \frac{(6Dd)}{(L^2)},$$



Next step

- High dose specimen cannot be handled in glove box
  - Currently waiting for licensing of new semi hot cell



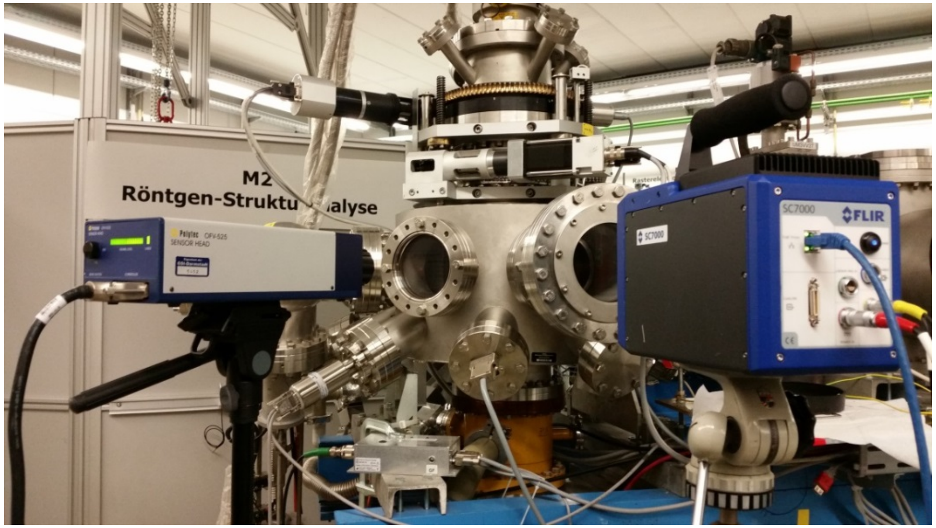
- Low dose discs to be tested with LFA (thermal diffusivity) as soon as it is allowed

Spallation Materials R&D: M3-beamline of GSI UNILAC

- Uranium beam on tungsten coins
  - Charge state +28
  - Beam energy: 4.8 MeV/u
  - Ion flux: Max. 1e10 ions/cm^2/pulse
  - Pulse length: 100 us
  - Repetition rate: 1 Hz

<u>ESS beam</u>

- Energy - 2.5 GeV
- Rep. rate - 14 Hz
- Pulse length - 2.86 ms

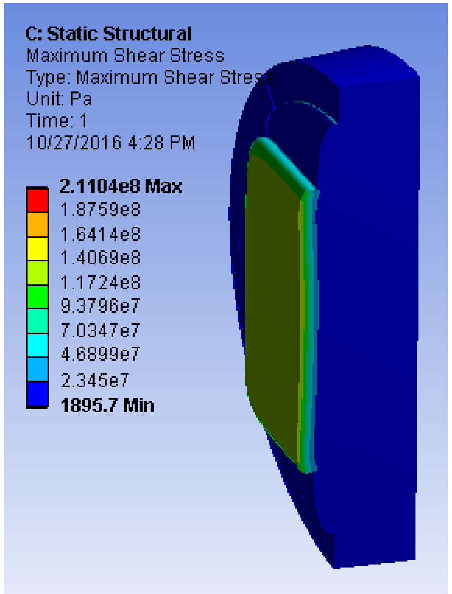


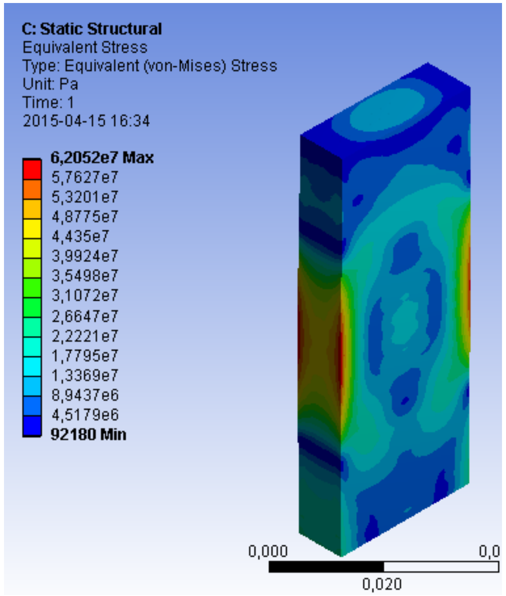
Purpose of experiment is to study:

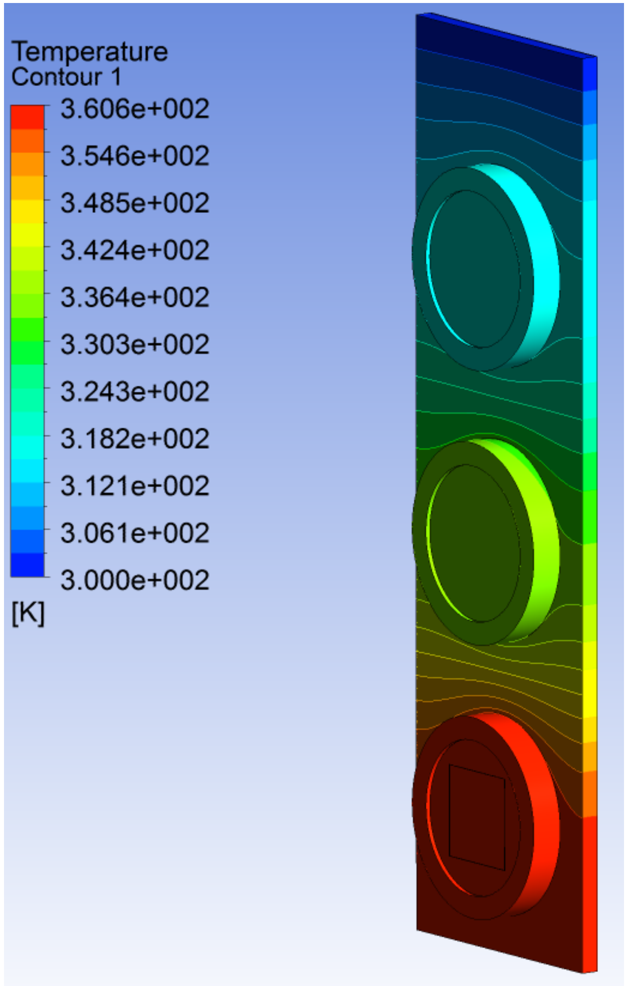
- Mechanical integrity of W under dynamic beam loads
- Radiation induced changes of mechanical properties
- Stability of W-oxide layer
  - Sample pre-oxidized at 500°C in air for 24h
- Changes in electrical and thermal conductivities
- Shock response of W foil under pulsed beam and its change due to irradiation

Calculations on uranium beam irradiation

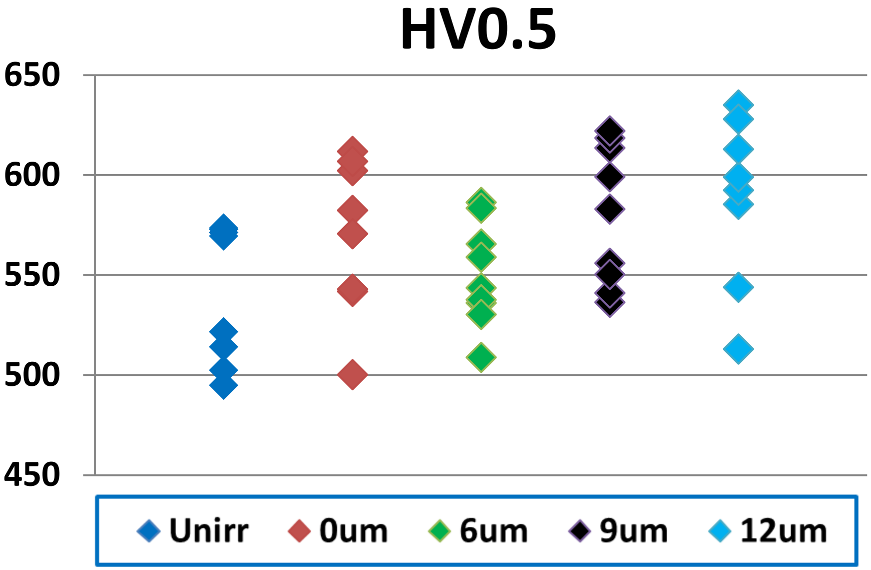
- Assumptions for calculation: Max. U-beam flux
- Main result:
  - Steady temperature: 87 C
  - Temperature range during pulse: 113 C
  - Max. post-pulse temperature: 200 C (ESS block: Max. 447 C)
  - Max. post-pulse shear stress on sample surface: 130 MPa (ESS block: Max. 110 MPa von Mises stress)

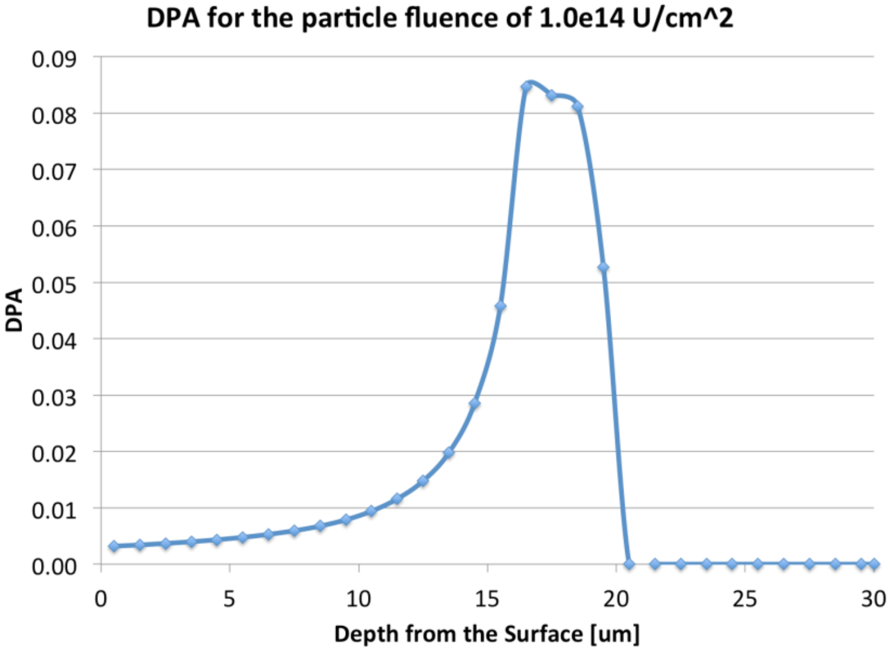


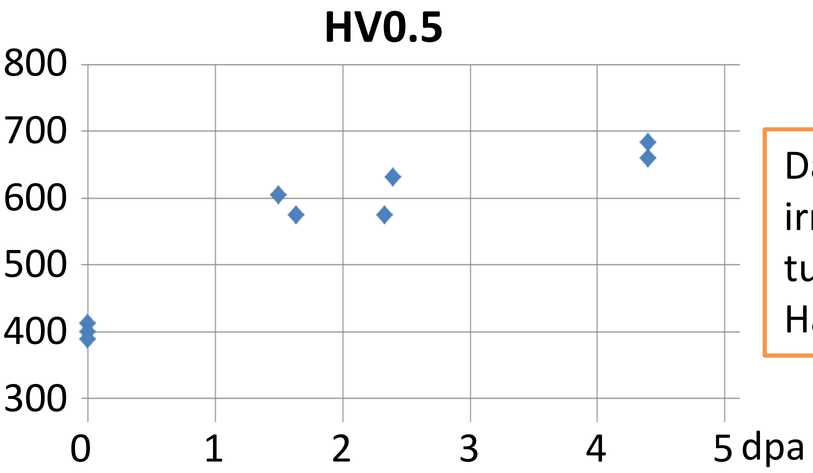




Hardness increases with depth



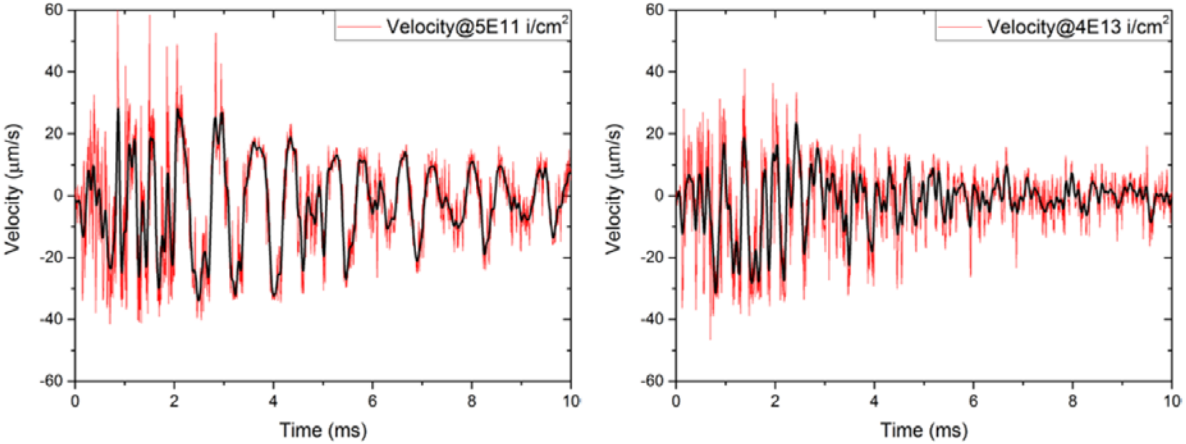




Data from proton irradiated STIP-V tungsten (Y. Dai , J. Habainy)

Vibrational analysis - Preliminary results

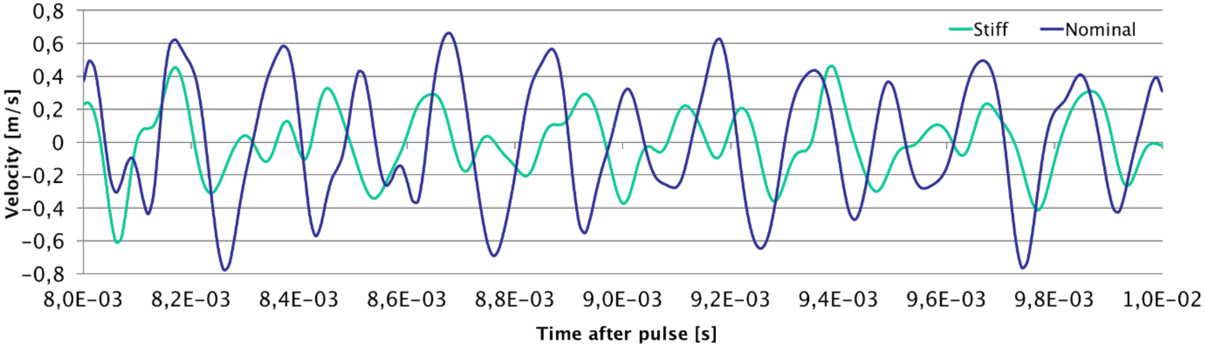
- Surface velocity of W foil as a function of time at an accumulated fluence of $5e10^{11}$ U/cm^2 (left) and $4e10^{13}$ U/cm^2 (right)



By Pascal Simon, GSI

Frequency of vibrations increased with irradiation – shock waves reflecting off boundary of non-damaged material?

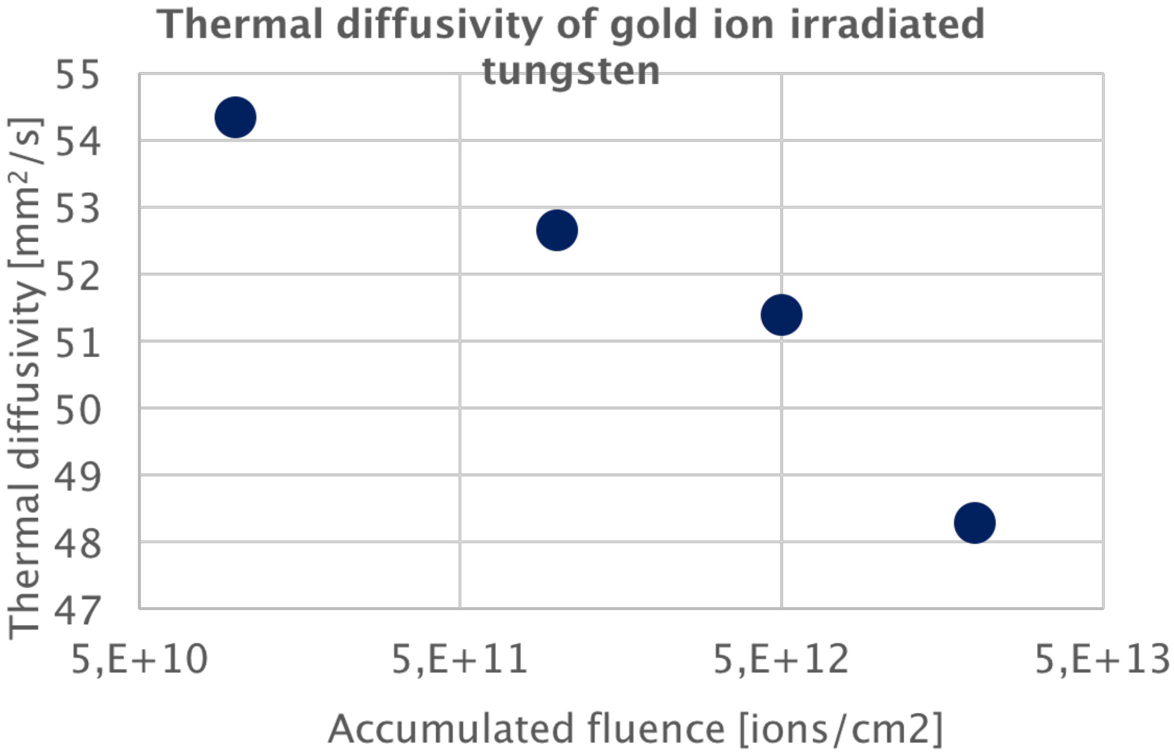
Simulated surface velocity – a comparison between normal and stiffer tungsten



Response of High-Power Accelerator Materials to a short pulse 4.8 MeV/u Uranium beam, Pascal Simon, Advanced Research Lab summary report, January 2016, GSI Darmstadt.

Thermal diffusivity measurement

- Four tungsten foils were irradiated with gold ions to different fluences.

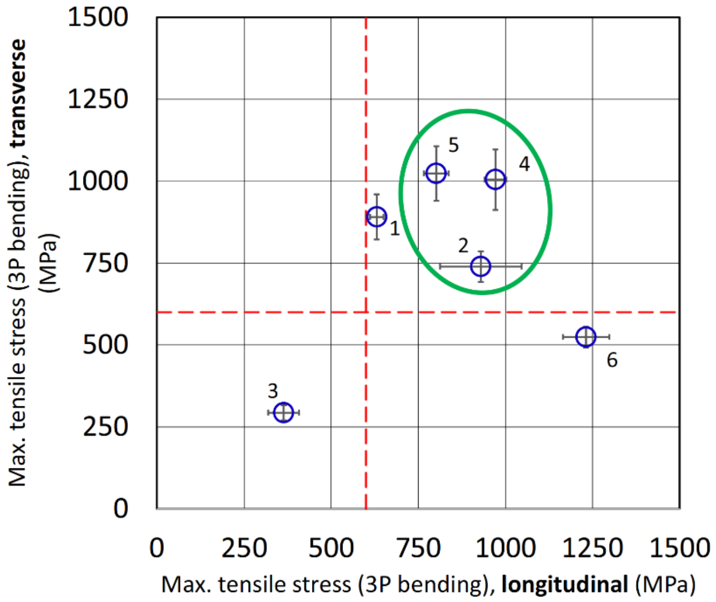


Summary: Heavy ion irradiated tungsten

- Hardness tends to increase with depth
  - from 540 to 590 HV0.5, on average
  - 590 HV0.5 corresponds to ~0.02 dpa
- Frequency of shock waves increased with irradiation
- Oxide easily blown off during irradiation
  - ~1.3 µm layer removed
- Thermal resistivity of irradiated samples decreased with increasing fluence
- Nano-hardness on cross-section of coin in progress

Vendor Evaluation

- Tungsten blocks from 6 vendors were evaluated.
    - Visual Inspection
    - Dimensional compliance
    - Chemical composition
    - Density
    - Young’s modulus
    - Hardness
    - Residual stress
    - Tensile strength (3-point bending tests)



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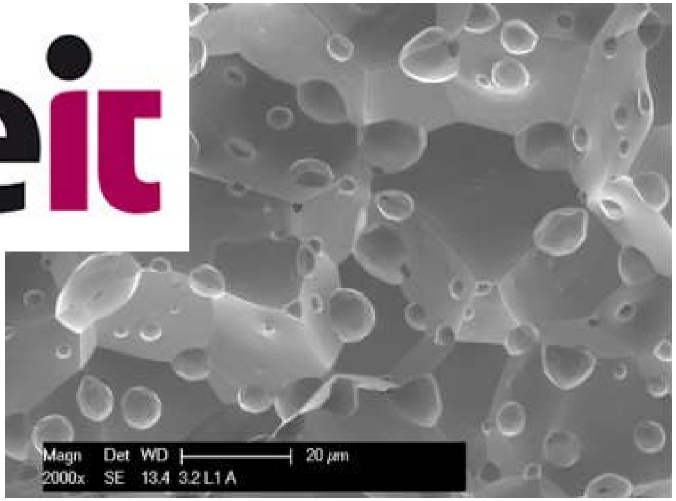
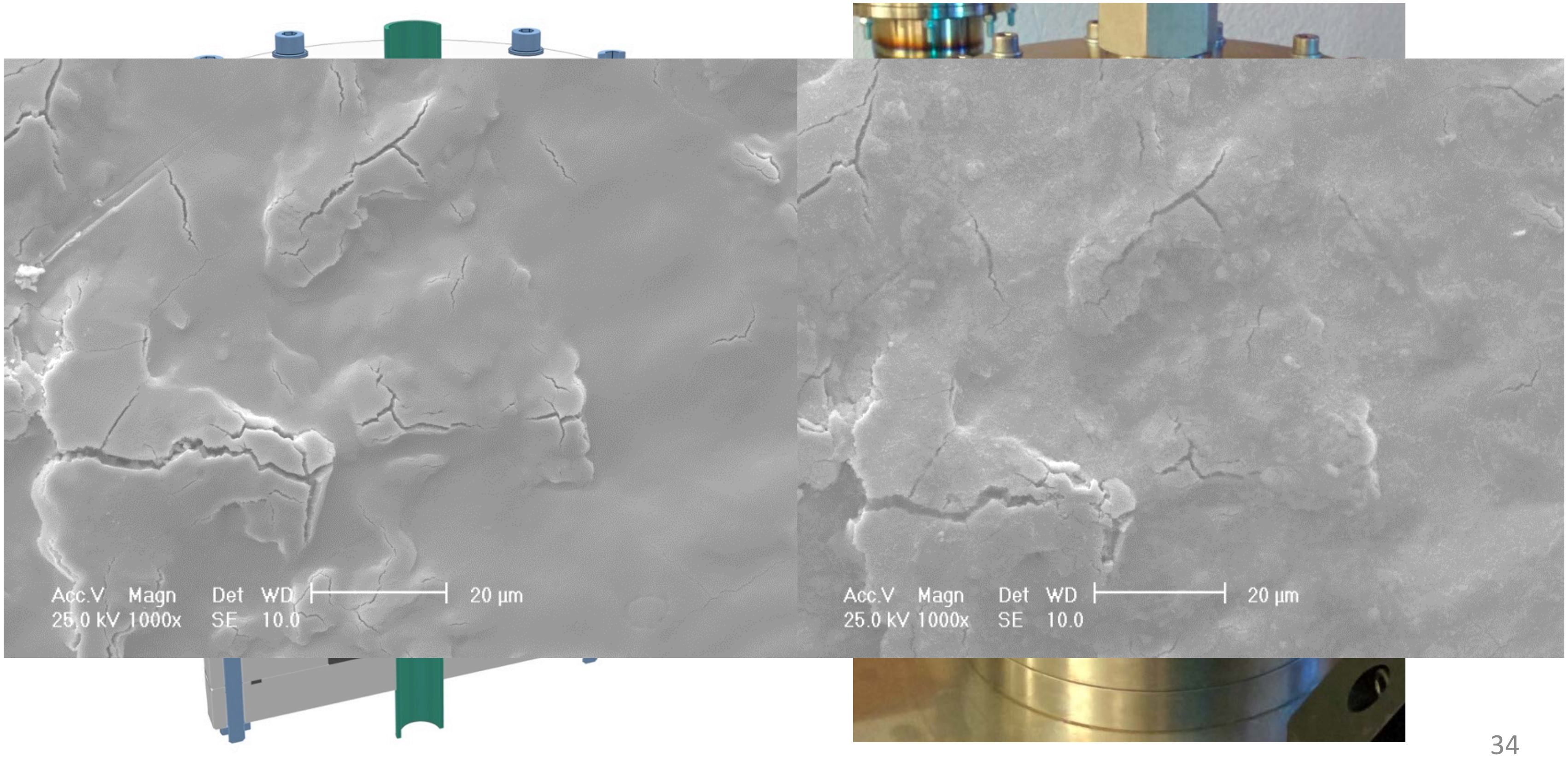


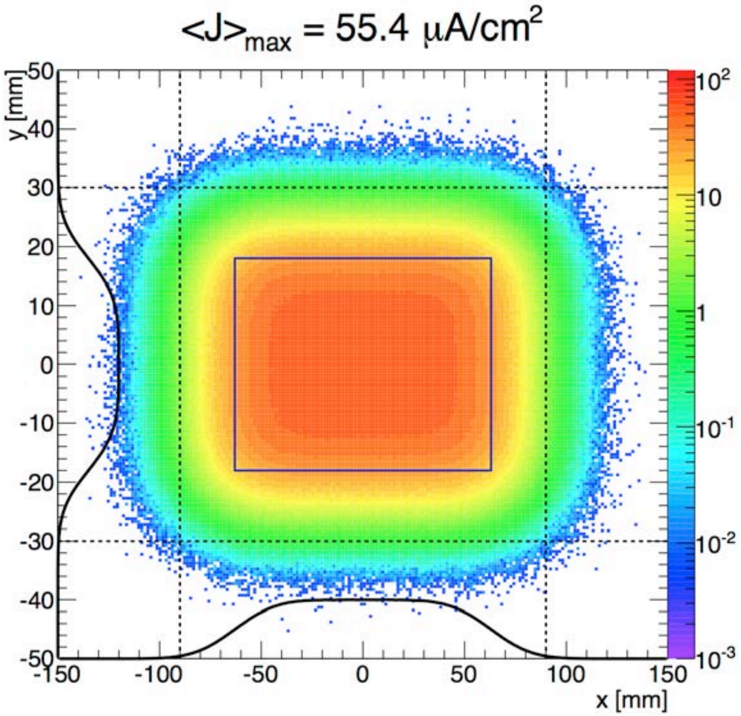
Spallation Material: Corrosion

- ESS Target Helium Experiment at LTH (ETHEL)
  - 3 g/s at 6 bar



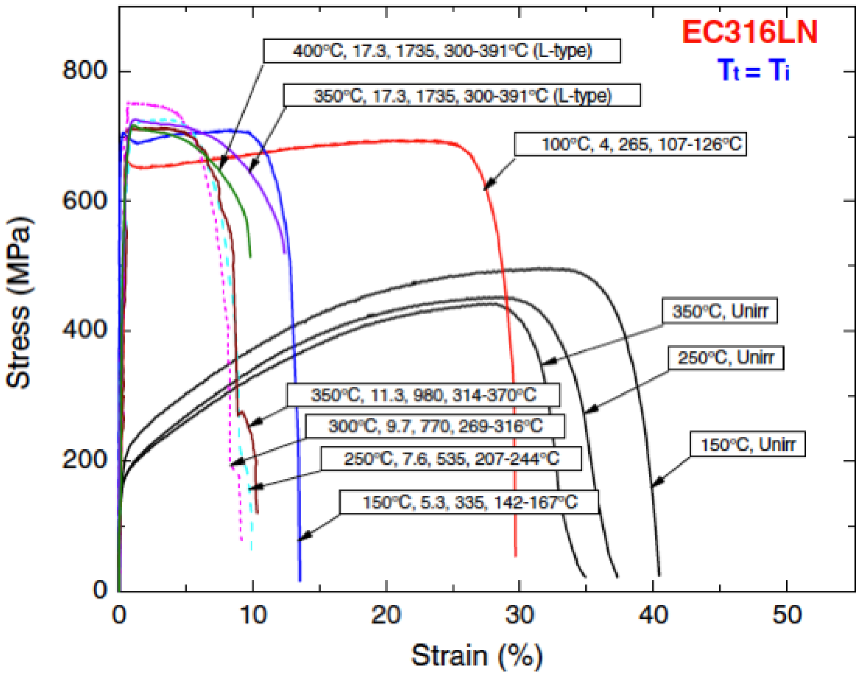
Spallation Target: Vessel

- Beam on target requirements:
  - Beam footprint enclosing 97.5% beam fraction: 180 mm (H) × 60 mm (V)
  - Beam footprint enclosing 99.9% beam fraction: 200 mm (H) × 64 mm (V)
  - Nominal time-averaged peak current density: 56 µA/cm^2
  - Maximum time-averaged peak current density: 81 µA/cm^2
  - Max displacement of footprint from nominal position: ±5 mm (H), ±3 mm (H)



Target Vessel: Materials Choice

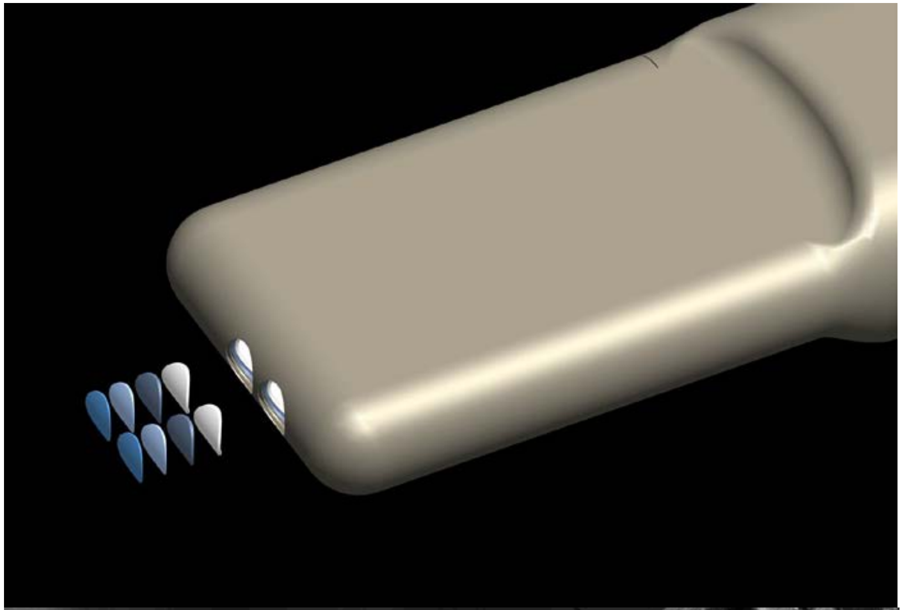
- Primary choice: SA 316L
  - Fracture mode is still ductile up to 17 DPA
  - Operational experiences at SNS and ISIS
  - The DBTT of BCC-steel (e.g. T91) increases with dpa.
- Considered Material:
  - SA-Inconel 718
    - Operational experiences at LANSCE, ISIS, SNS
    - SA alloy 718 shows a good ductility to 18 dpa
  - T91
    - MEGAPIE target beam window sustained up to 6 DPA.
    - Higher strength which allows thinner top and bottom plates of the target vessel.

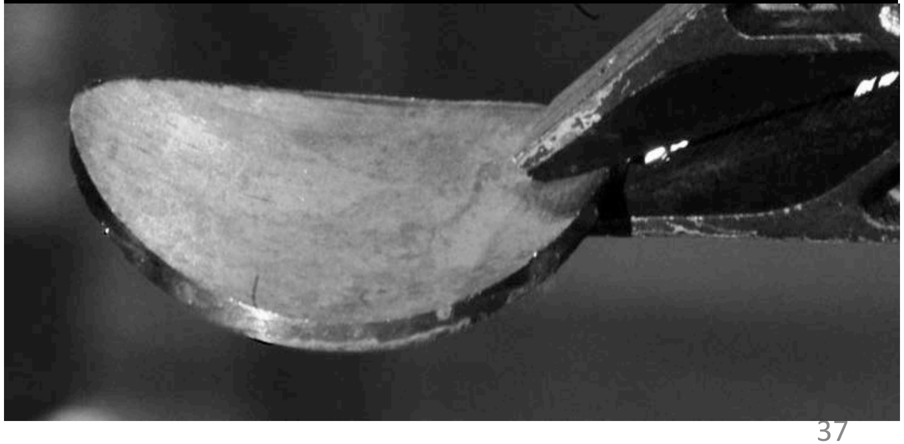


Y. Dai, et al., JNM 377 (2008) 109

Target Vessel: Lifetime estimates

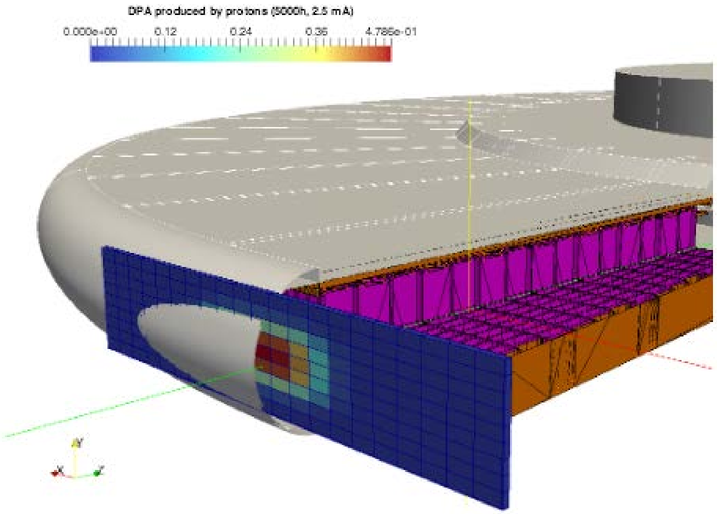
- A maximum damage rate of 1.4 dpa/GW-d in the beam entrance window of the ESS target.
  - Lifetime limit guide: 10 dpa of accumulated dose: SNS
  - Thermal fatigue might impose more conservative lifetime limits

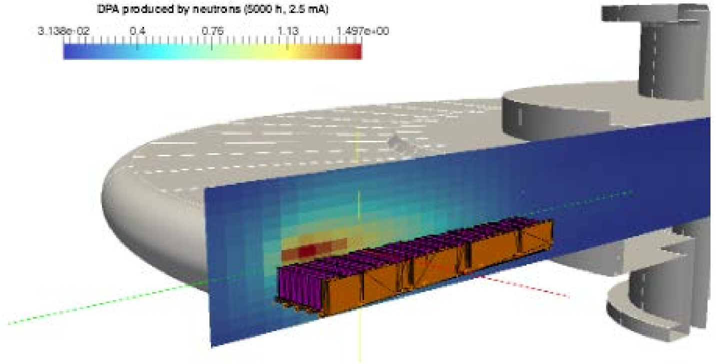




Target Vessel: Lifetime

- Annual Damage Rate
  - 1.6 dpa/year @5MW-5400h
- Lifetime is set to be maximum displacement damage of 8 dpa:
  - 5 years of lifetime: max. 8 dpa
  - Potential for longer lifetime benchmarking SNS experience



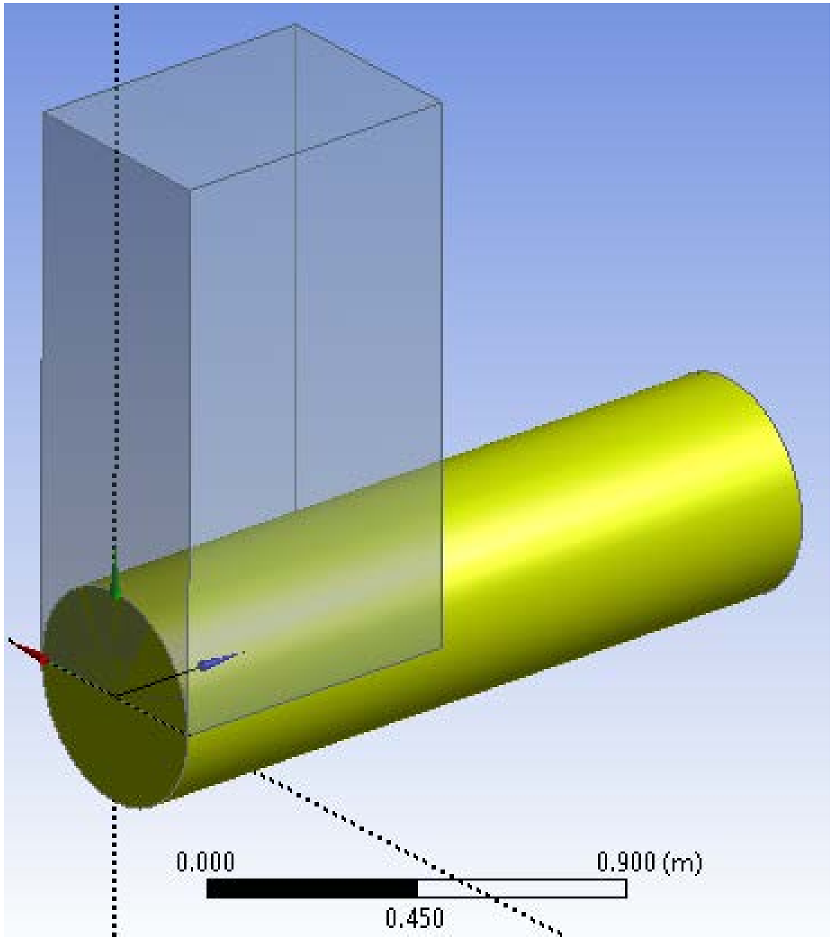


Tuning dump: Beam parameters

Tuning Mode	Energy [MeV]	Current [mA]	Pulse [us]	Rep. Rate [Hz]
Probe	90	6.25	5	1
	220	6.25	5	1
Fast Tuning	570	62.5	5	1
	1300	62.5	5	14
	2000	62.5	5	14
Slow Tuning	570	62.5	50	1
	1300	62.5	50	1
	2000	62.5	50	1
Long Pulse	570	62.5	2857	1/10
	1300	62.5	2857	1/20
	2000	62.5	2857	1/30

Tuning Dump Specification

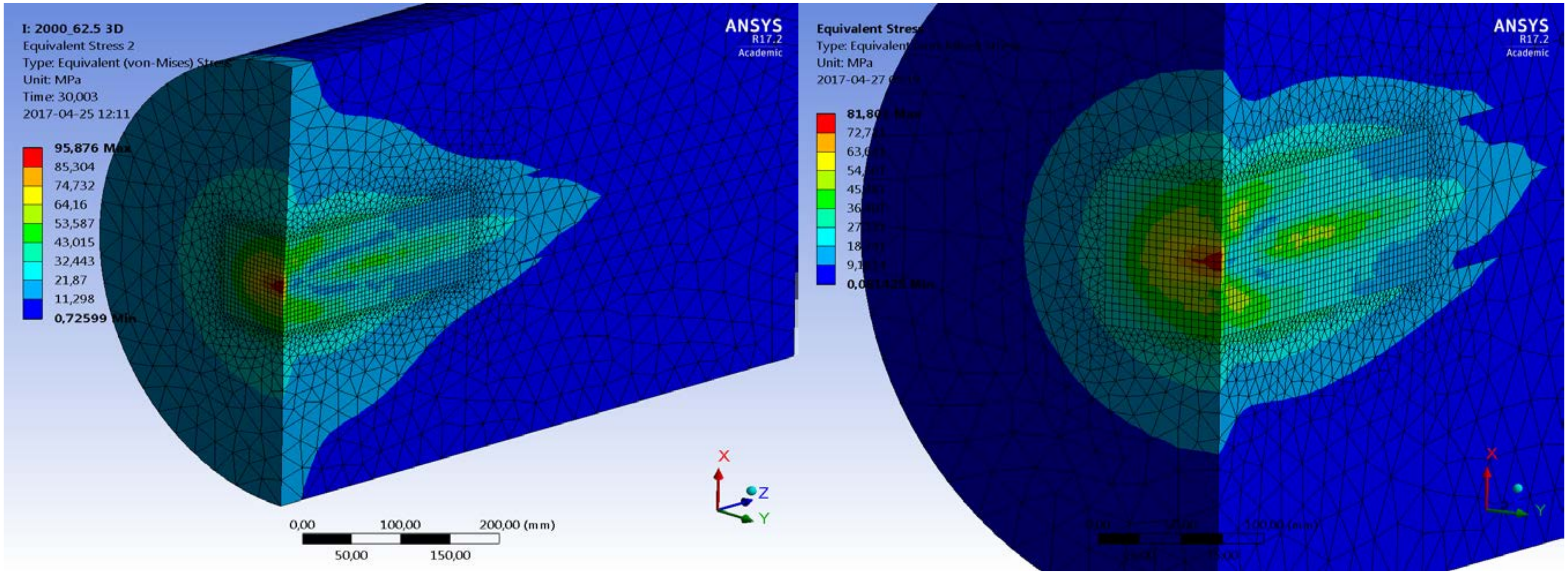
- Dump Core:
  - Material: CuCr1Zr
    - Higher Mechanical Strength than OF-Cu
- Conducting Column:
  - Material: OF-Cu
    - High Thermal Conductivity
  - Active water cooling on the top



Stress: Full-Pulse and Full Current

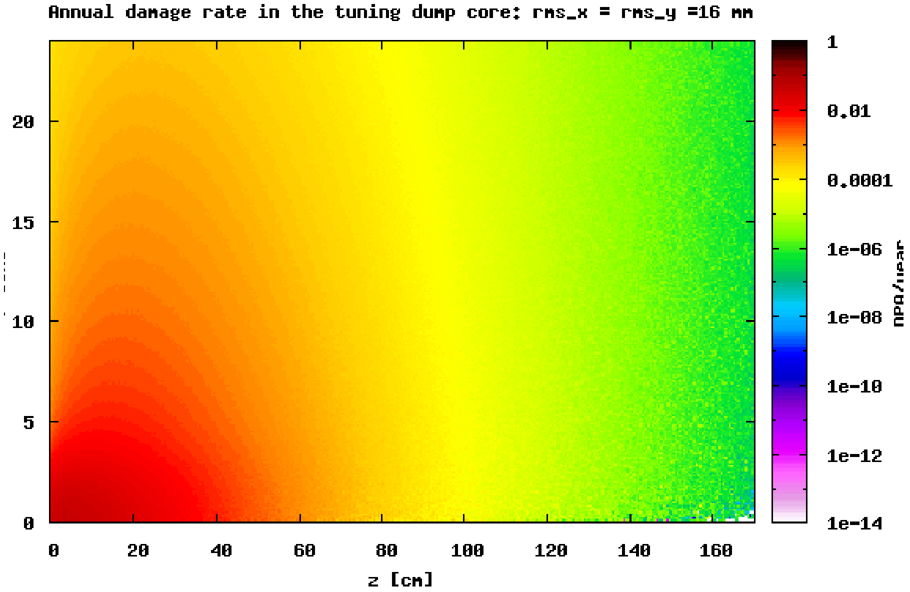
Beam Footprint	Energy [MeV]	Max. Stress Post-pulse [MPa]	Max. Stress Range [MPa]	Fatigue Limit [MPa]
16 x 16 mm^2	570	101	70	**200**
16 x 16 mm^2	1300	106	86	**200**
16 x 16 mm^2	2000	122	106	**200**
16 x 25 mm^2	2000	96	82	**200**

B. Singh et al. Rosø-R-1528, 2005



Radiation Damage Effect

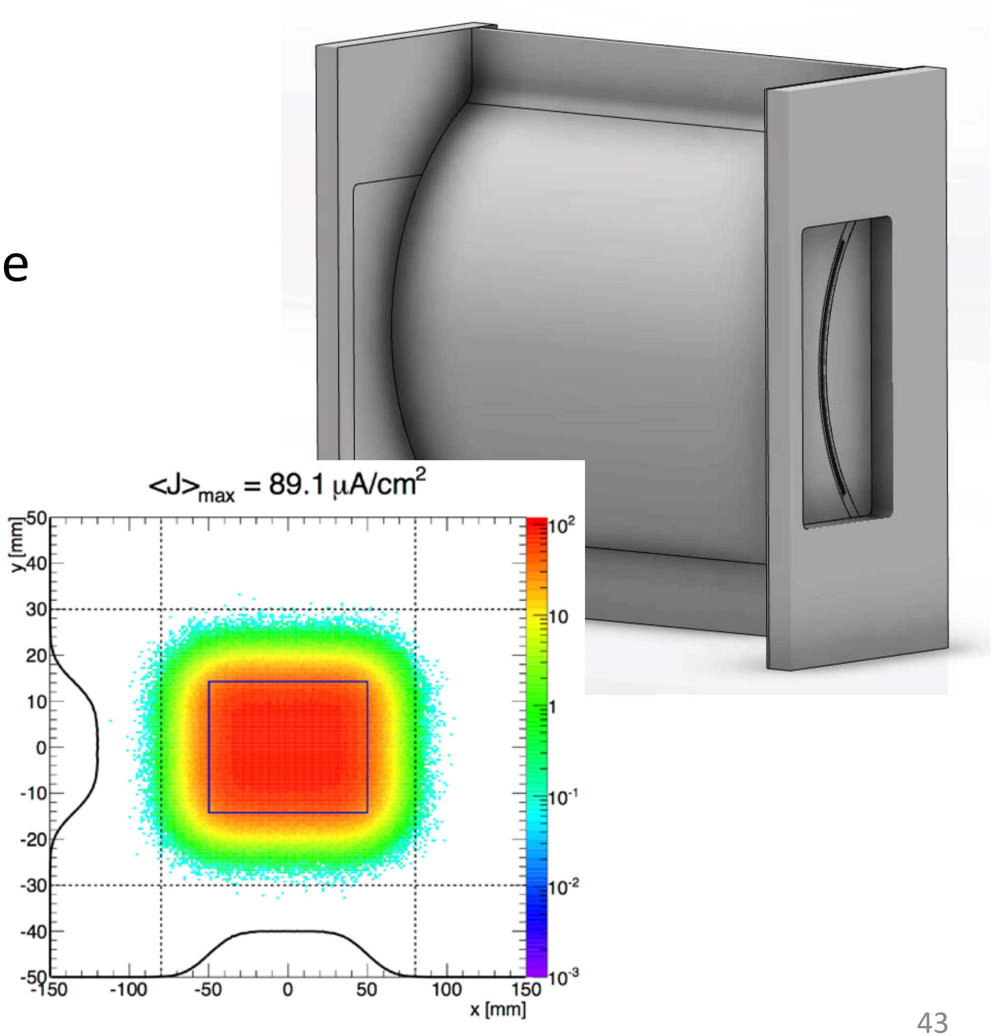
- Maximum 0.05 dpa/year.
  - Maximum 2 dpa damage for the 40 years of lifetime
  - Maximum 10% degradation of thermal conductivity estimated
- No real impact on the dump lifetime, with a good safety margin
  - Maximum 2% increase in peak temperature for 2 dpa
  - Almost no change in stress amplitudes for 2 dpa.



Proton Beam Window (PBW) Materials

Courtesy Mattias Wilborgsson

- The PBW receives peak proton current density 89.1 μA/cm².
  - Al-6061-T6 is the baseline material.
  - Al-5754-O is the backup material.

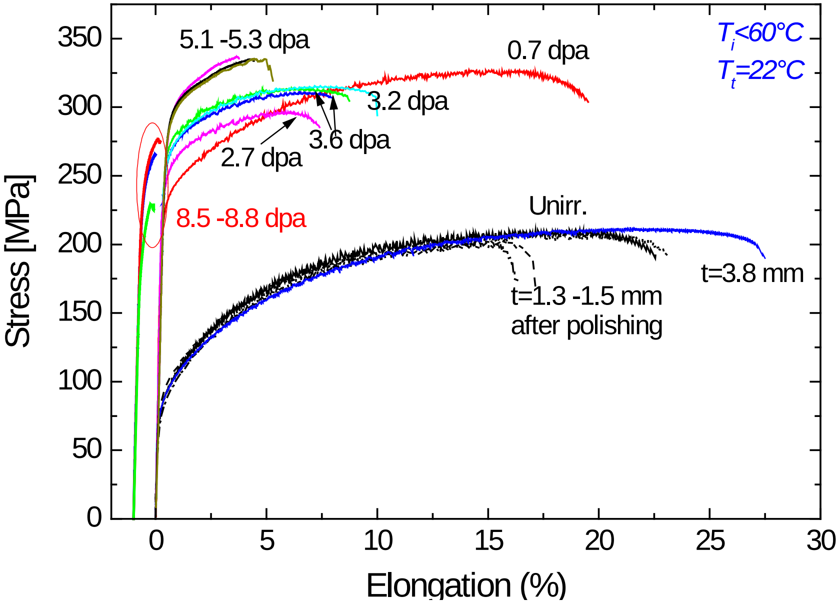


Objectives: Lifetime of Aluminum Alloys under Proton Irradiation

- Al-5754-O
  - Operation Record of PSI safety hull: Max. 2750 He-appm (8.8 DPA)
  - ESS Window will have 4388 He-appm (7.1 DPA)/5400h damage at PBW
- Al-6061-T6
  - Has shown superb radiation resistance in neutron irradiation environment.
  - But, there are no proton irradiation data.

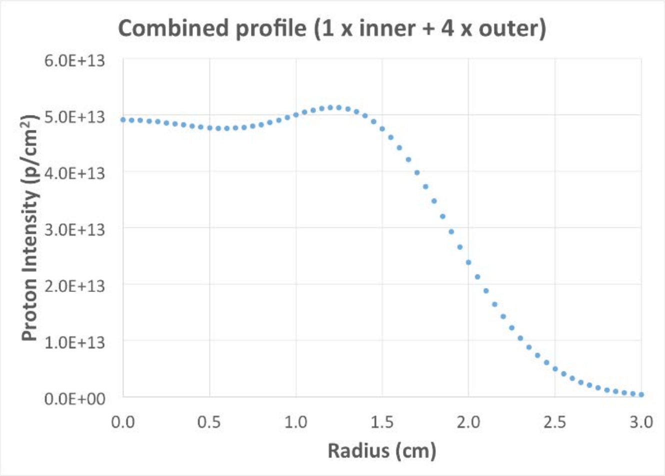
Courtesy Yong Dai

Y. Dai et. al. IWSMT 2016

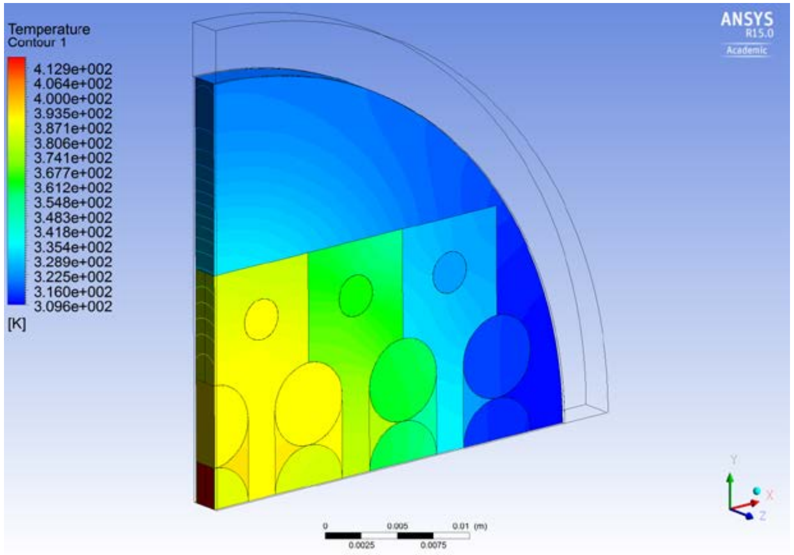


PBW Material R&D: BLIP Irradiation Program at BNL

- Purpose: Characterization of helium bubble distribution in Al6061-T6 and Al5754-O
- Beam Parameters
  - Energy: 181 MeV
  - Current: 165 uA
  - Rastered Beam Profile
  - Assessment of the material properties of PBW under proton irradiation



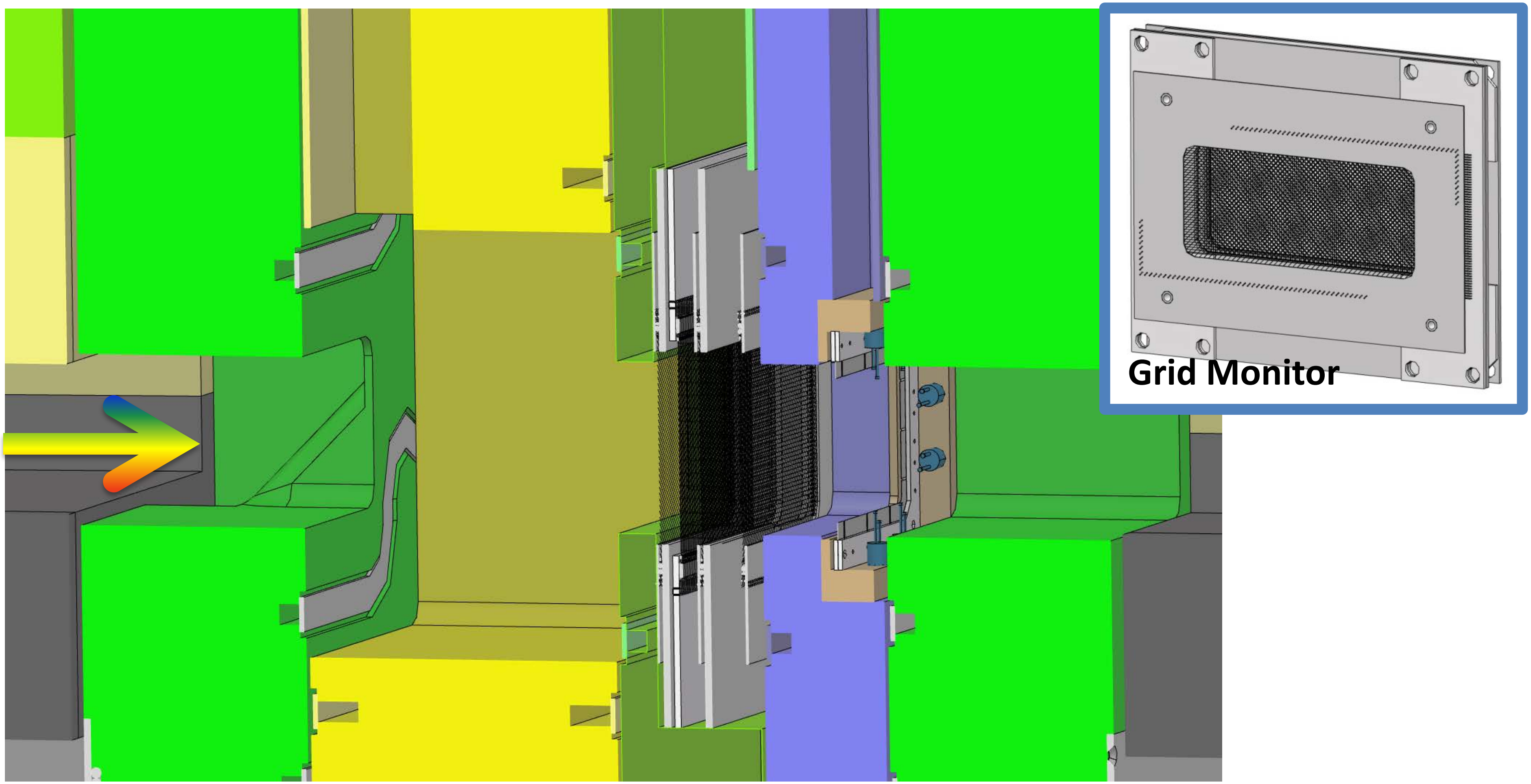
Forschungszentrum Juelich



Beam Profile Monitoring System

- All the BPM systems planned is based on beam-intersecting
  - High irradiation damage induced short service lifetime
  - High thermal load induced structural failure
- Baseline scope of the BPM Systems at the Target Station:
  - Multi-wire profile monitor (MWPM):
    - Set of conducting wires intersecting proton beam
  - Aperture monitor:
    - Set of thin metal blades intersecting the proton beam edge
  - Luminescent coating:
    - Proton beam window (PBW)
    - Beam entrance window (BEW) of the target wheel

Proton Beam Instrumentation Plug

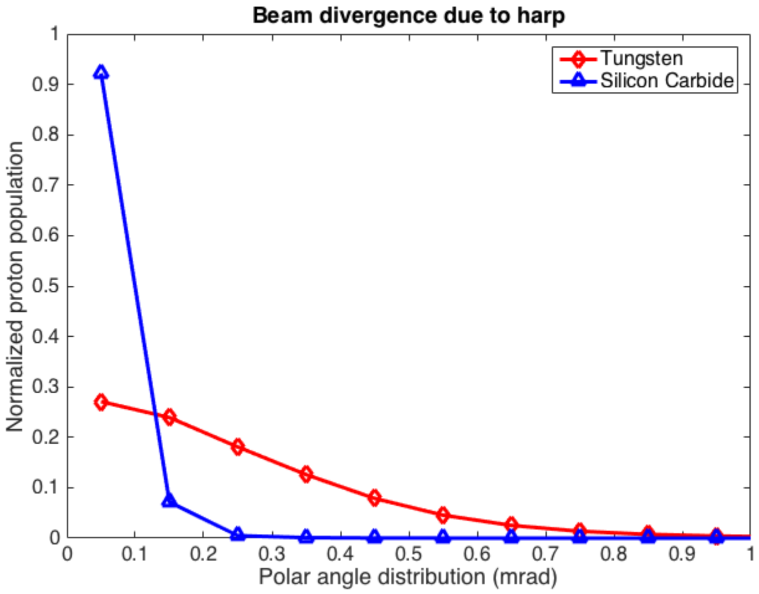


Material choice for harp

- Candidate Materials
  - Pure tungsten: SNS
  - Tungsten-Rhenium alloy: BLIP
  - SiC: JSNS, ISIS, LANSCE
- Material Selection Criteria
  - Disturbance to beam optics
  - Signal characteristics
  - Lifetime limited by radiation damage
  - Endurance to thermal and mechanical loads

Harp material: Disturbance to beam optics

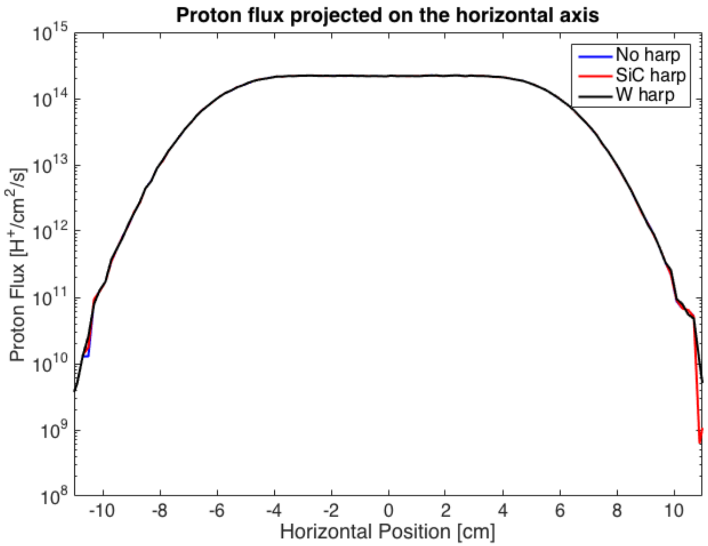
- There are five layers of harp made of 100 um thick wires with a pitch of 2 mm.
- For a pencil beam, the beam diverges with:
  - SiC harp: 0.06 mrad
  - W harp: 0.25 mrad

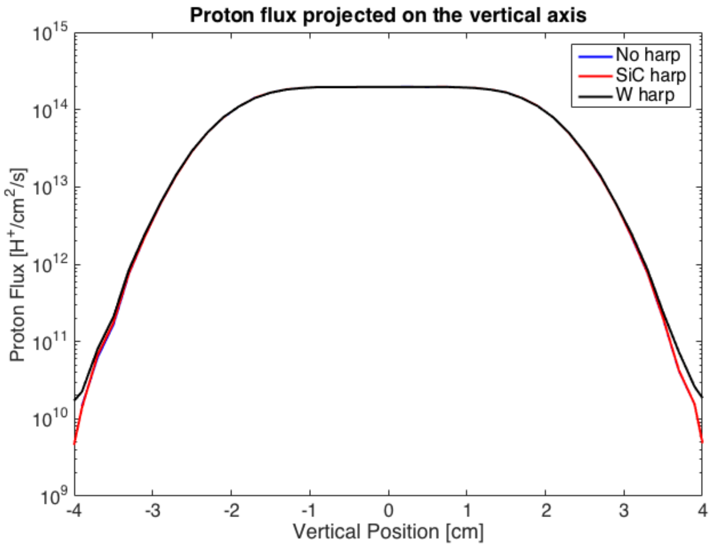


Effect of harps on beam-on-target requirement

Harp	**Envelop 180 mm (H) × 60 mm (V)**	**Envelop 200 mm (H) × 64 mm (V)**
No harp	99.38%	99.89%
SiC harps	99.37%	99.88%
W harps	99.33%	99.85%

- With the W harps, the beam shooting off the target is in an order of 1 kW compared to SiC harps.



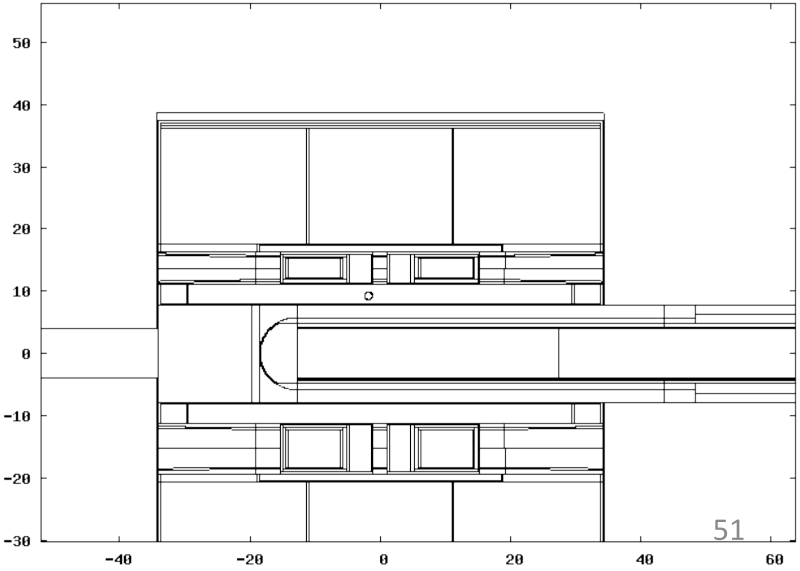


Signal strength

- Negative charge deficiency
  - Secondary electron emission (SEE)
    - Ionization, diffusion of slow secondaries to the surface, subsequent escape of electrons
    - Secondary electron yield (SEY) is calculated by an empirical formula:

$$SEY = \frac{P \cdot d_s}{E^*} \frac{dE}{dz}$$

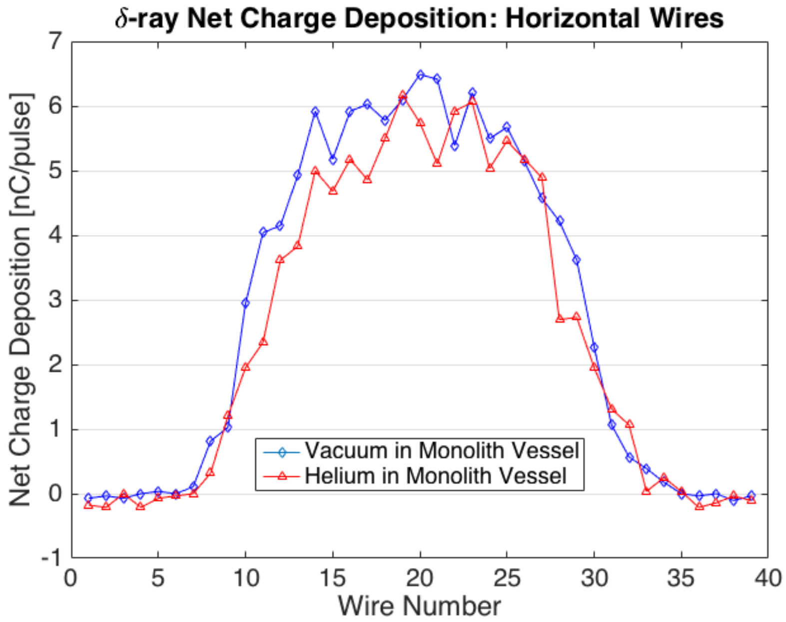
  - Recoiled delta ray electrons
    - Directly calculated by FLUKA

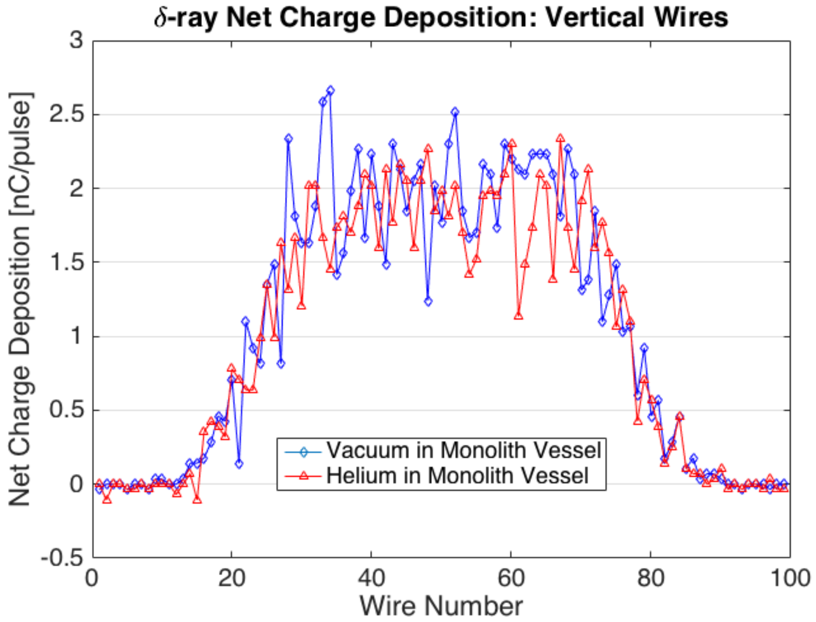


Signal Strength

Harp Material	dE/dz [MeV/cm]@2GeV-H^+	Secondary electron yield	Delta ray electron yield	Total Yield	Benchmark
W	24.4	0.049	0.026	0.075	0.07 SNS: 1 GeV-H^+
SiC	5.16	0.010	0.013	0.023	0.01 LANSCE: 0.8 GeV-H^+

- The signal from the tungsten harp is more than three times higher.


δ-ray Net Charge Deposition: Horizontal Wires


δ-ray Net Charge Deposition: Vertical Wires

Radiation Damage

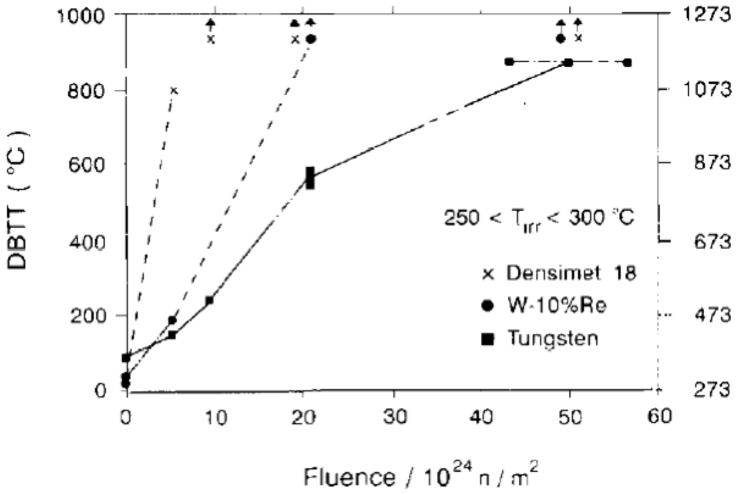
Harp Material	Max. DPA Rate [dpa/hour]	Annual Beam on Target Time	Max. DPA per Year
W	0.012	5400	64.8
SiC	0.001	5400	5.4

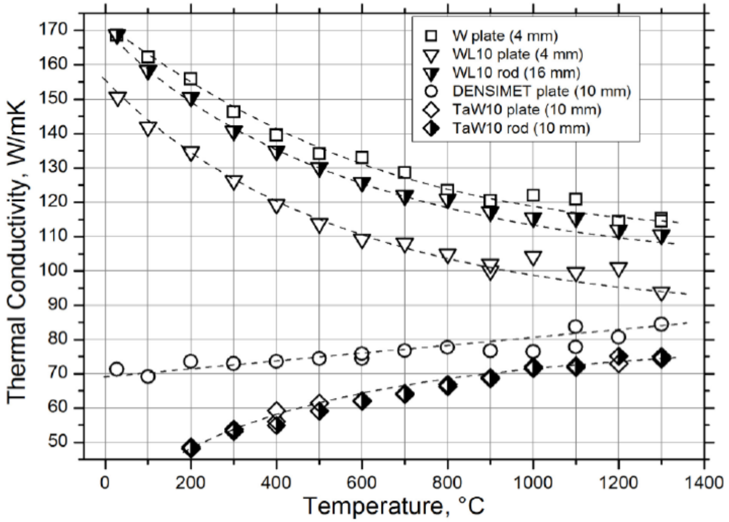
- The tungsten harp at SNS and the SiC harp at TS2 of ISIS have been operating without failure since its commissioning of the facilities.
- The accumulated damage dose on the harp in both facilities is roughly equivalent to one year dose at ESS.

Benchmarking Institution	Harp Material	Total Beam Energy/Charge	Accumulated Max. DPA
ORNL-SNS	W	32000 MWh	70
ISIS-TS2	SiC	1.5 Ah	3

Early failure of W-Re Harp at BLIP

- The DBTT of W-Re alloy gets higher than pure tungsten after irradiation [H. Ullmaier, F. Carsughi, NIM-B 101, 1995]
- The thermal conductivity of W-Re alloy is lower than pure tungsten, which should lead to a higher thermo-mechanical stress and fatigue stress amplitude [M. Rieth et al, Tech- Rep.-KIT]



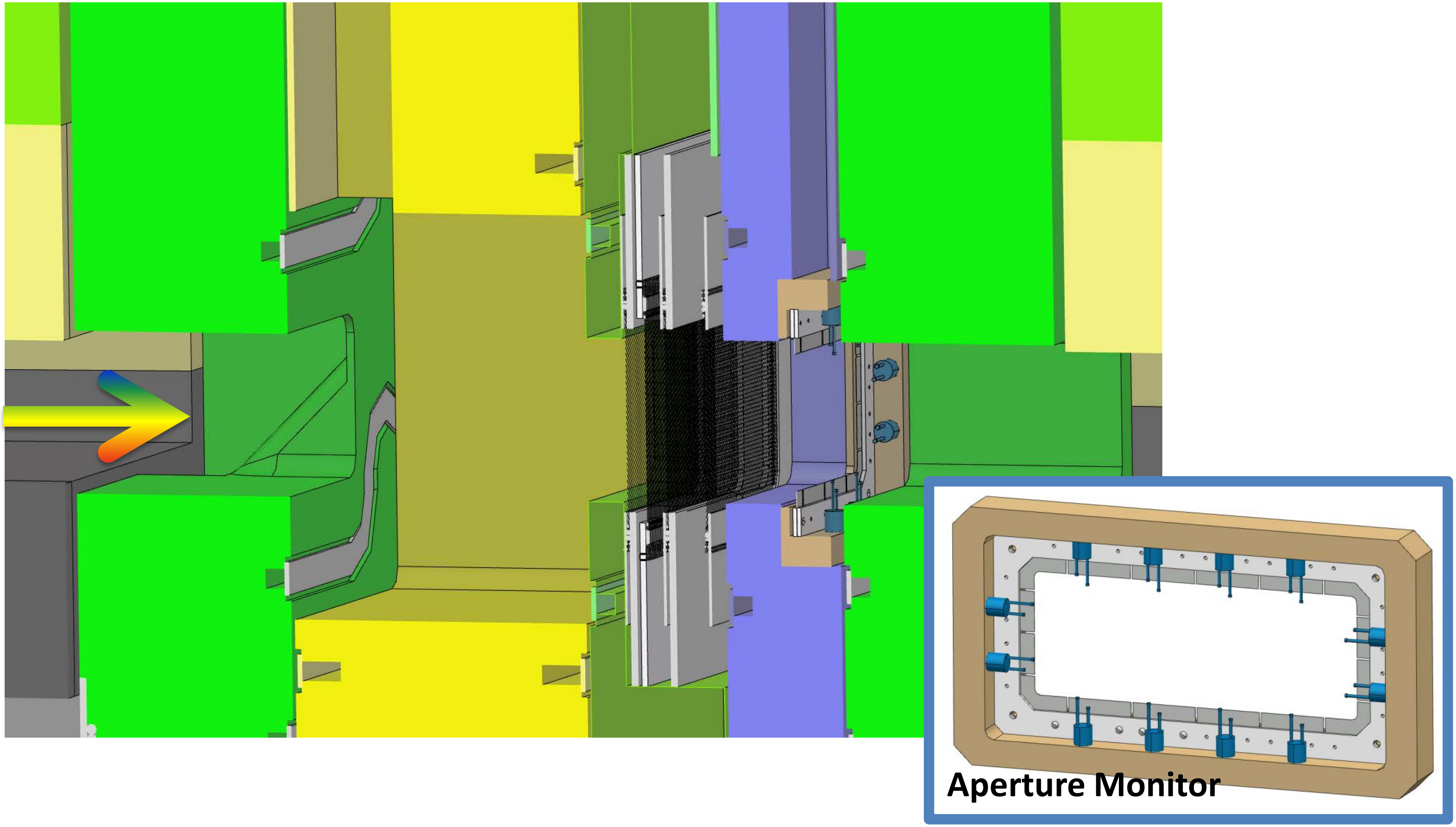


Tungsten vs. SiC

Properties	Tungsten	SiC
Beam optics disturbance	-	o
Δ-ray production	--	-
Radiation damage limit	1 year@5 MW	1 year@5 MW
Signal strength	+	-
Surface corrosion	-	+
Operation temperature	High	Medium
Mechanical load during operation	High	Low

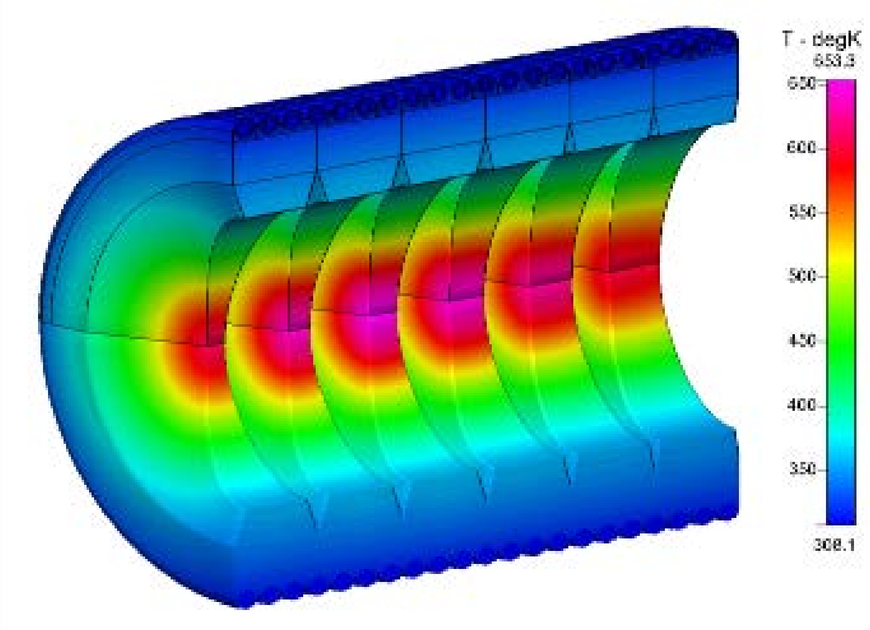
- Silicon Carbide is preferred for the ESS application

Proton Beam Instrumentation Plug



Aperture Monitor

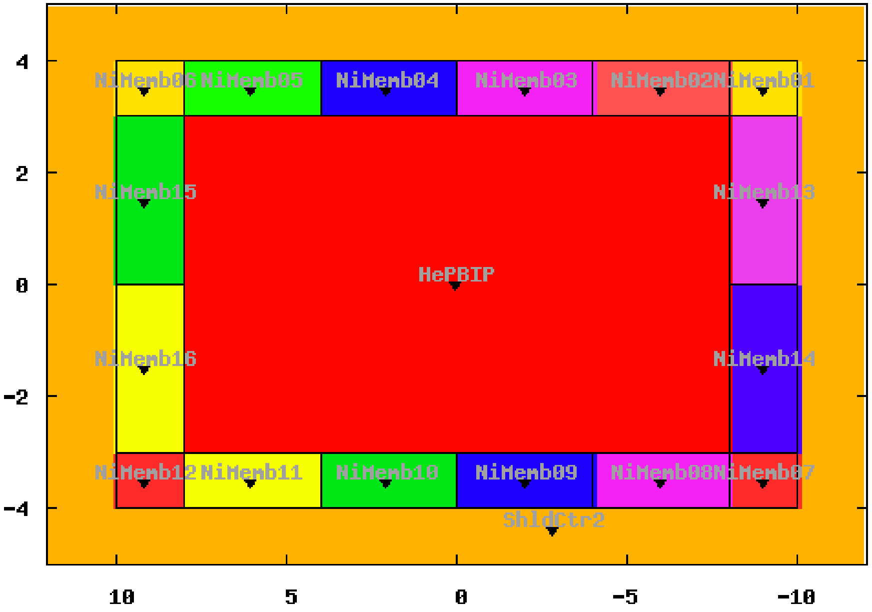
- Material Selection: Nickel
  - The halo monitor mounted at the direct beam upstream of KHE-2 is made of 100 um thick nickel membrane.

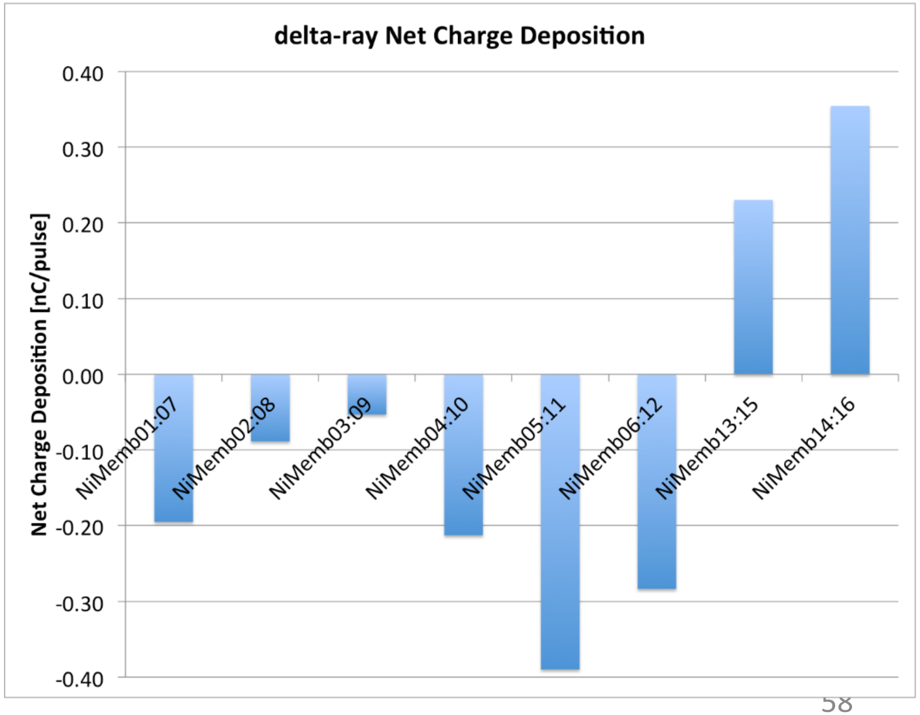


A. Strinning, et. al. HB2010

Signal Strength: 100 um thin Ni-Diaphram

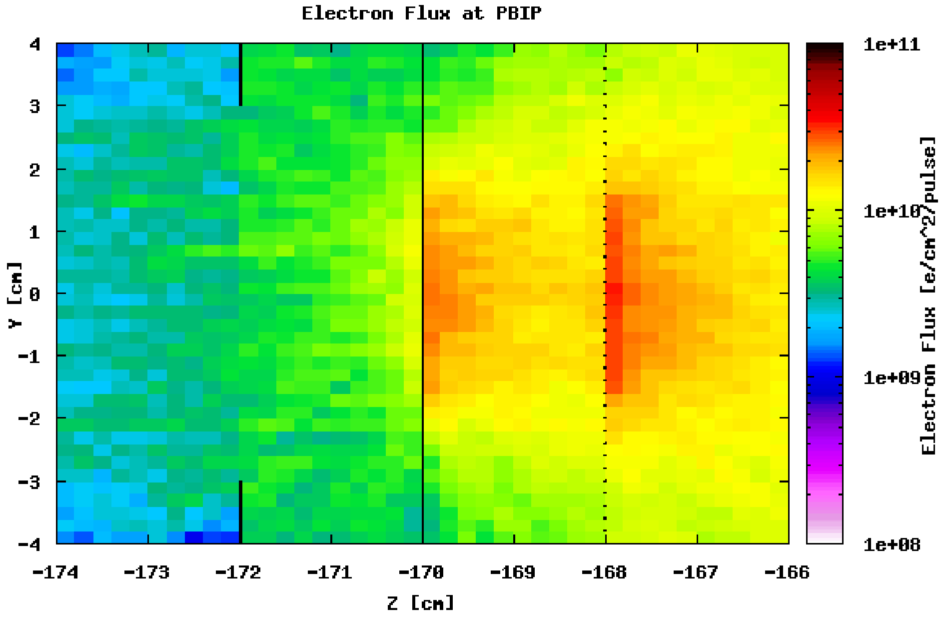
Facility	dE/dz [MeV/cm]	Secondary Electron Yield	δ-Ray Yield	Total Yield
PSI	16.7	0.033	0.023	0.056
ESS	13.6	0.027	0.019	0.046

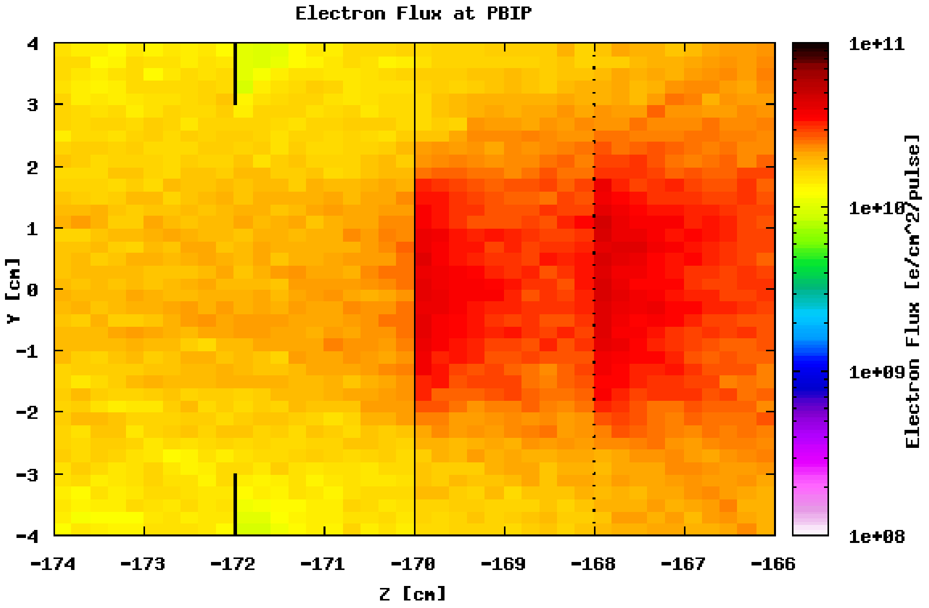




Negative Net-Charge Deposition

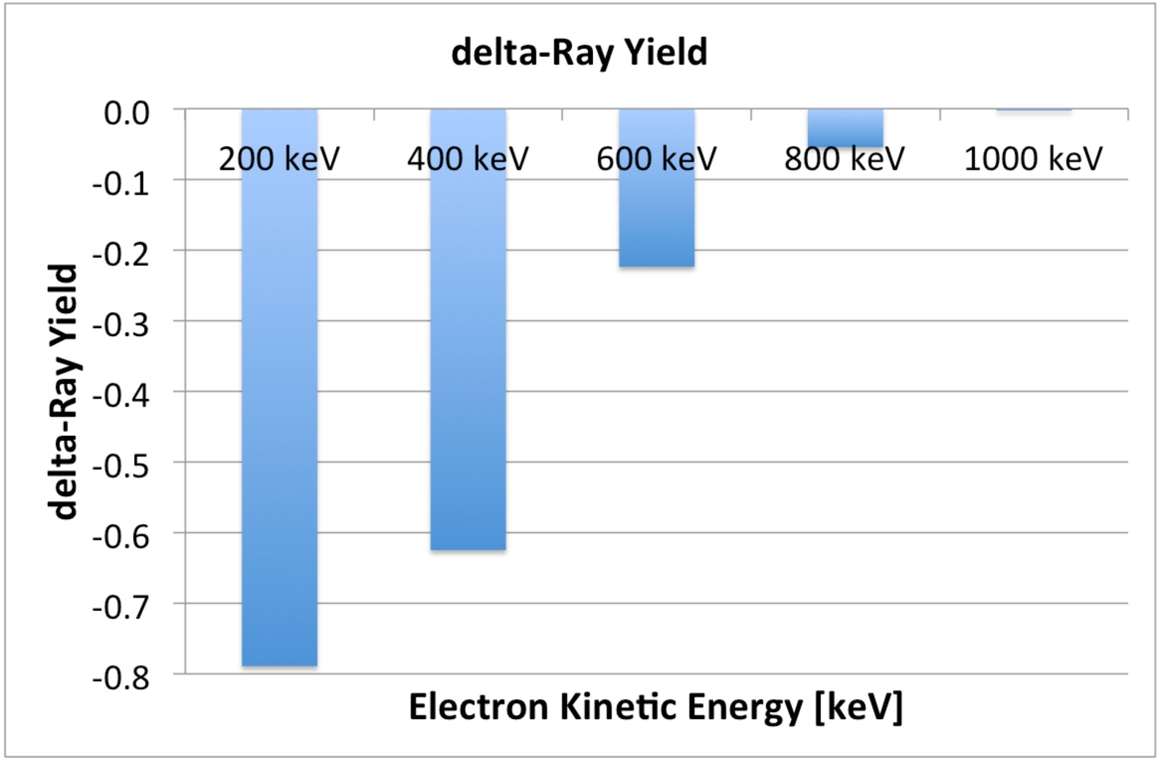
- Δ-rays from harp and helium atmosphere





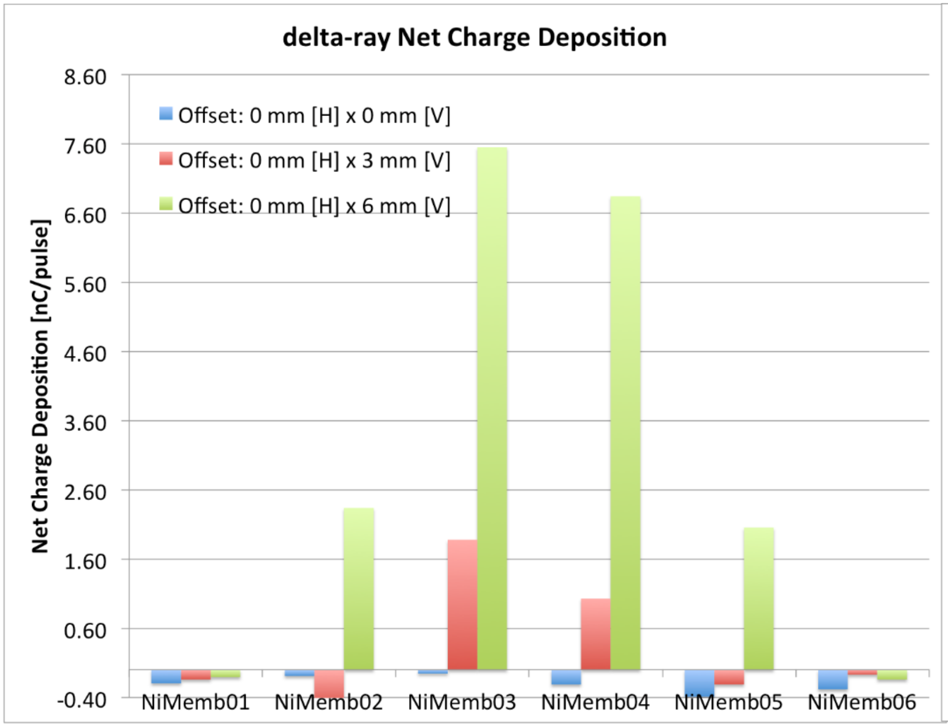
Δ-ray yield due to impinging δ-ray electrons

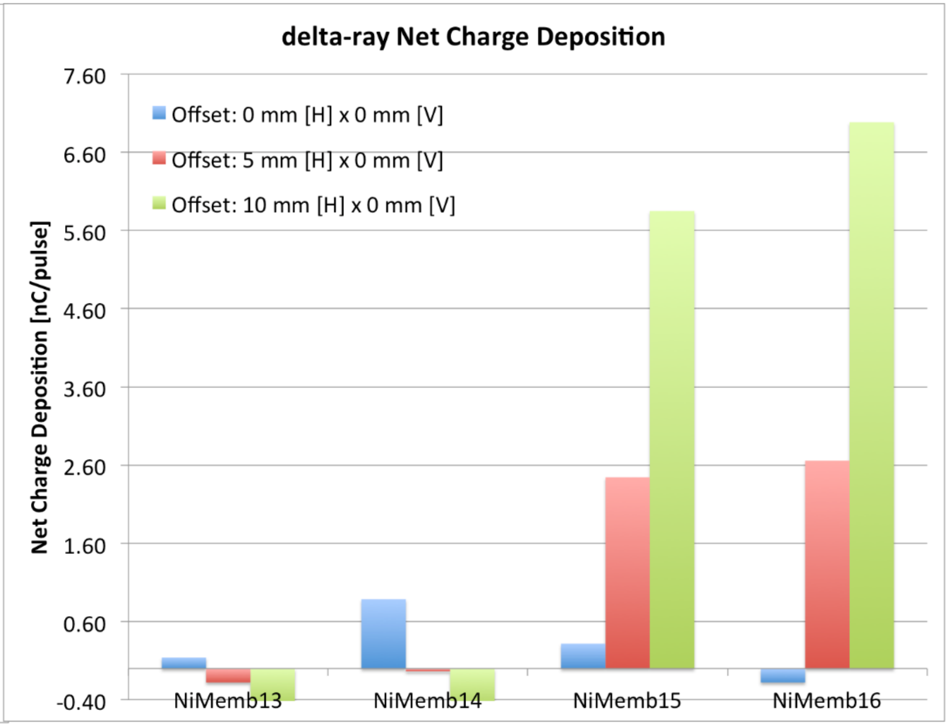
- The calculated δ-rays are in the energy range between 10 keV and 1 MeV
- Low energy δ-rays are stopped within the 100 um thickness of the Ni-diaphragm, creating negative net charge deposition.



Beam offset and δ-ray yield

- As there are more protons bombarding the blade, the net charge yield turns to “positive”





Radiation Damage and Lifetime

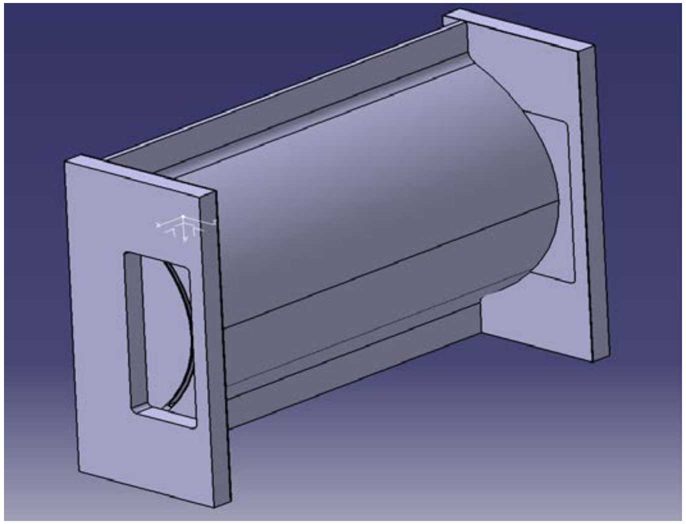
- Benchmarking: PSI
  - Integrated beam charge up to 2010: 120 Ah
  - Maximum integrated DPA: 100
- Aperture monitor at ESS
  - Maximum damage rate: < 10 dpa/year for 27000 MWh/y
  - The lifetime of the aperture monitor is conservatively estimated to be 10 years

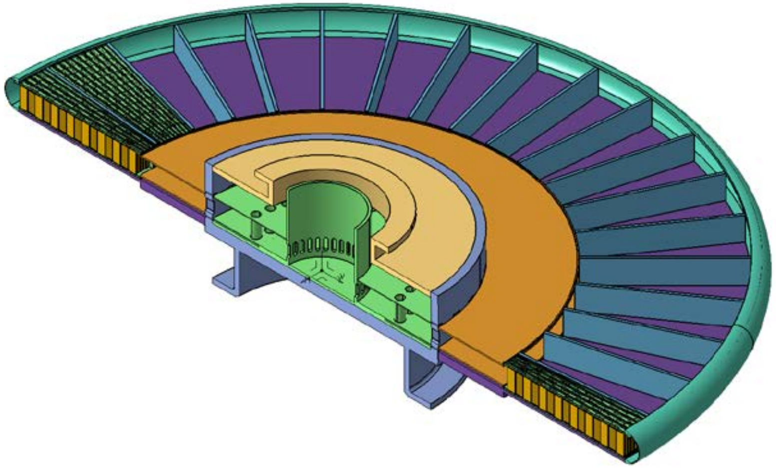
Halo monitoring and δ-ray

- Δ-ray introduces negative charge deposition in the aperture monitor intersecting halo
  - During normal operation, the aperture monitor expects to produce noise signal.
  - In case of beam offset, more protons will be intersected by nickel diaphragms, producing “positive net charge deposition.”

Luminescent coating

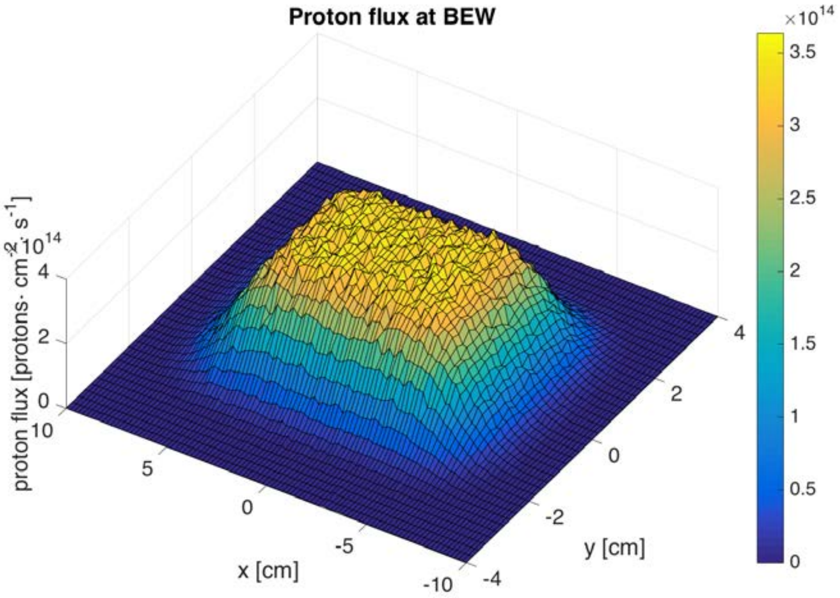
- Luminescent coatings on PBW and target for the beam profile imaging
- Baseline material:
  - Benchmarking SNS
  - Cr (1%) doped alumina (Al_2O_3)

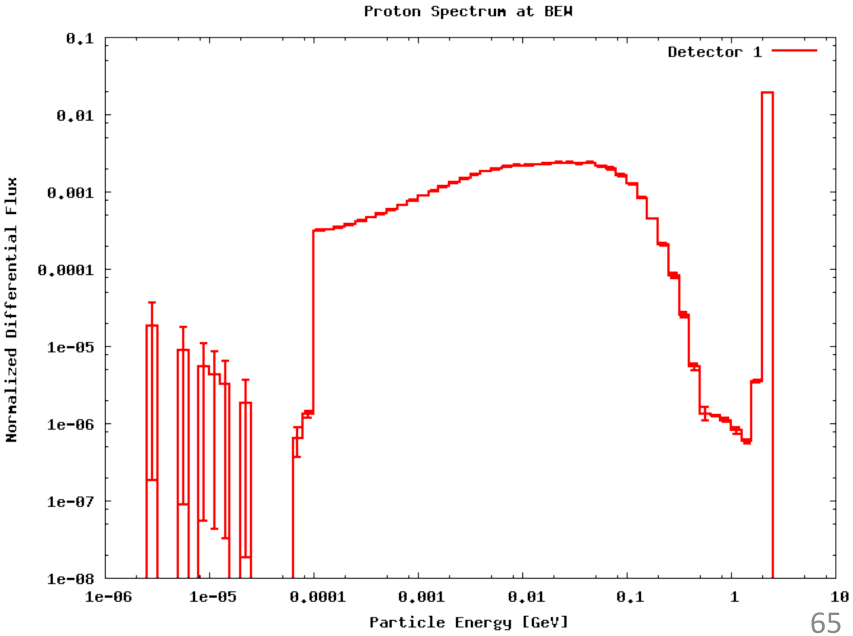




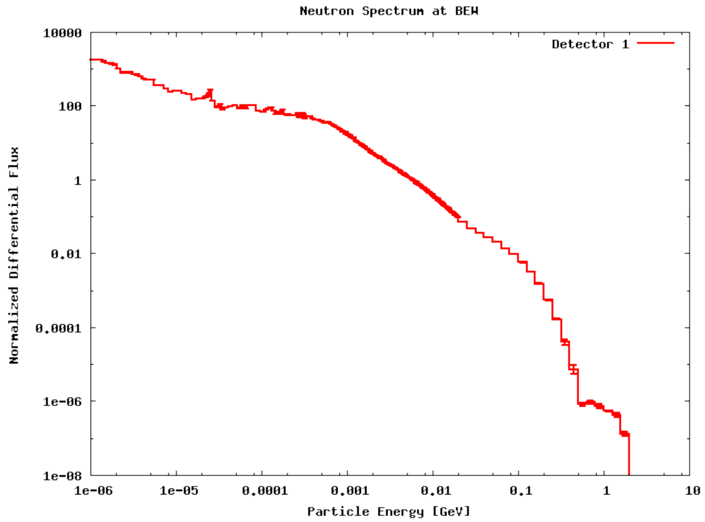
Proton flux at BEW

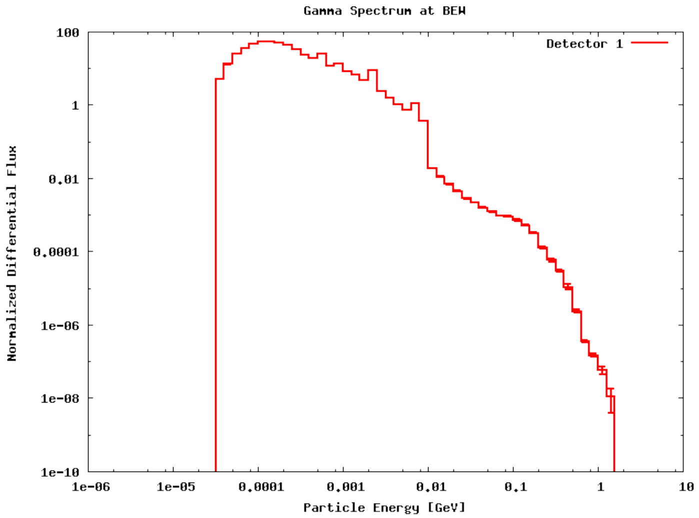
- Secondary protons from the harp

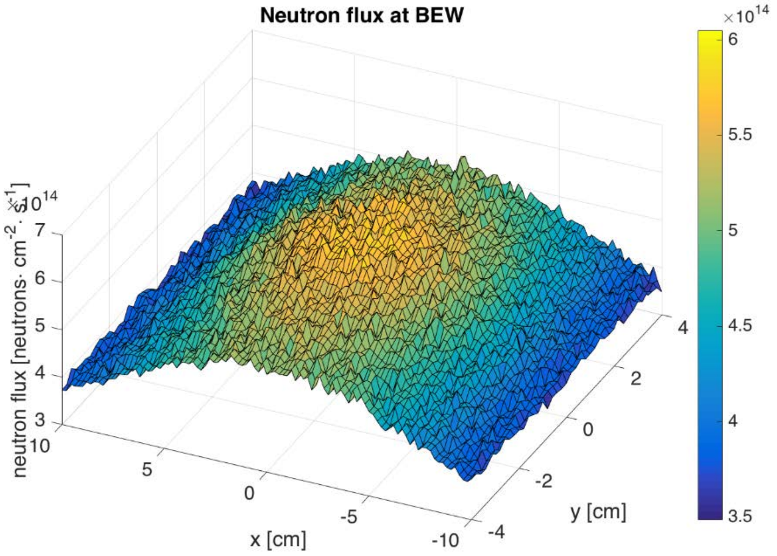


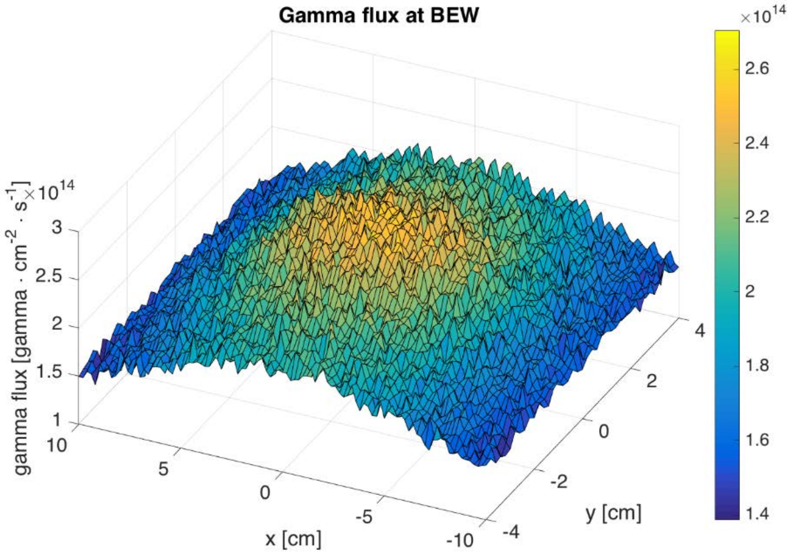


Neutron and gamma flux at BEW



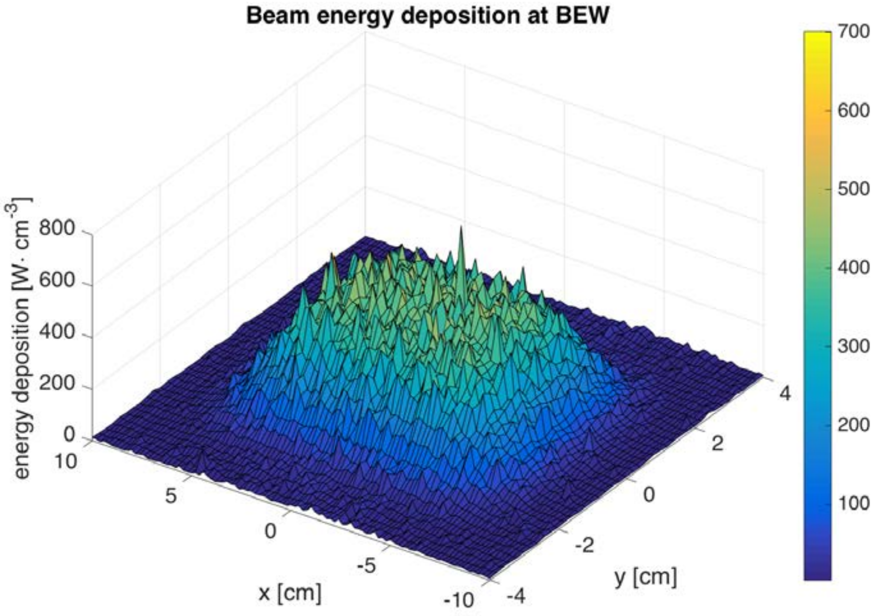


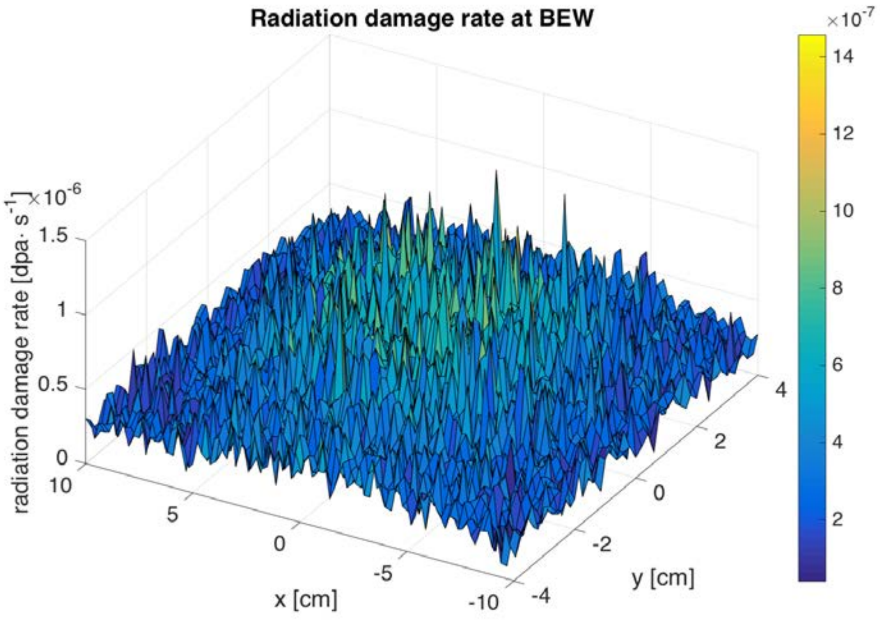




Energy deposition and radiation damage at BEW

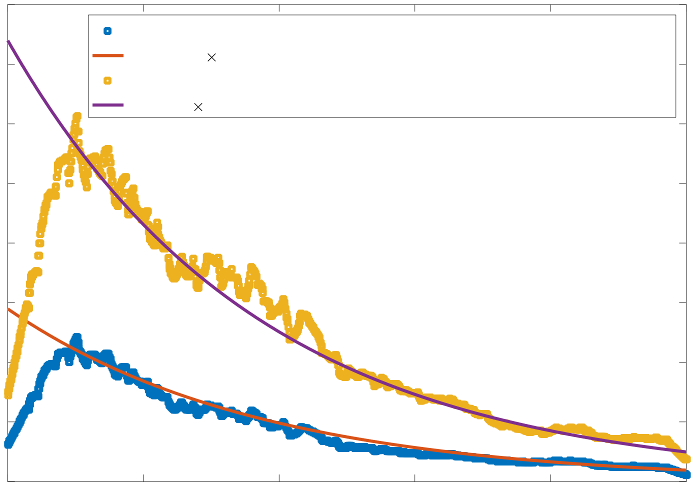
- The radiation damage doesn't follow the proton beam profile

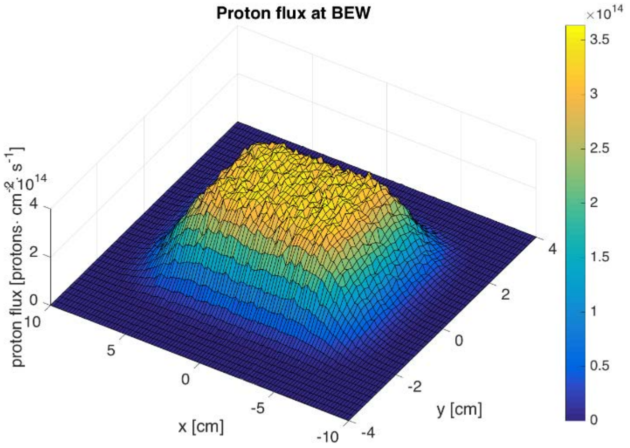




BLIP Irradiation Campaign: Characterization of Luminescent Coating Materials

- The radiation resistant luminescent coating material:
  - The proton beam induced degradation of the luminescence has been observed at SNS, and there is a need to search for a radiation resistant coating material.
  - The radiation damage induced degradation of luminescence has been confirmed with U-beam at GSI
  - Candidate materials: Cr:Al_2O_3, Y_2O_3, Y_2WO_6

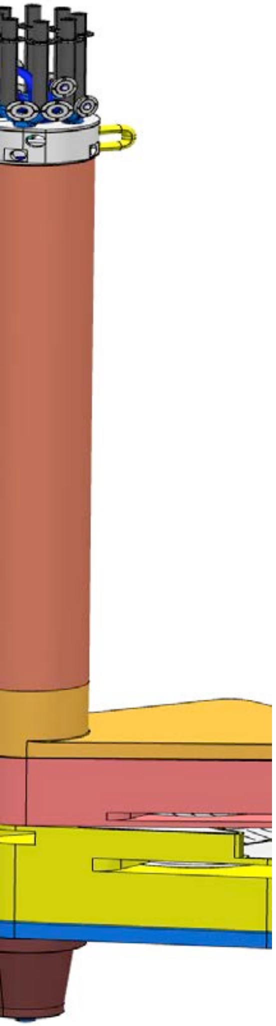




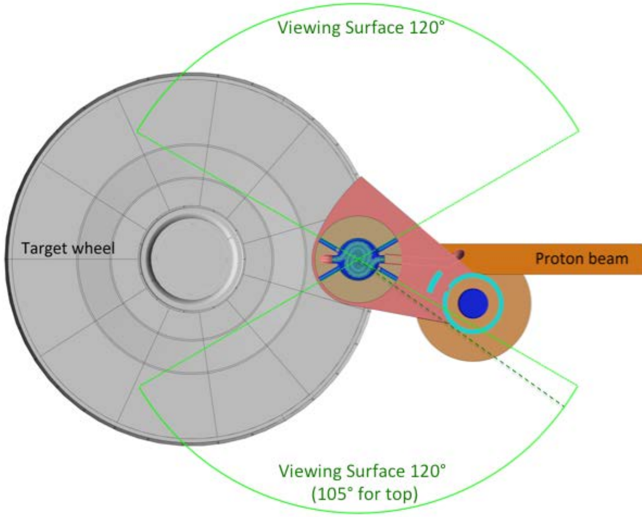
Summary: Beam profile monitoring

- The SiC is chosen to be the baseline material for the harp
- The Ni-diaphragm for halo monitoring will generate noises during normal beam operation, due to δ-rays from the harp and upstream components. But, it should be able to detect the anomalous beam position offset.
- There is on-going research on the luminescent coating material. Currently, baseline material is $Cr:Al_2O_3$ as at SNS.

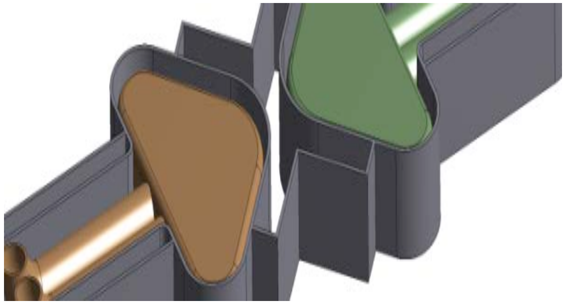
Moderator & reflector



- Cold moderators
  - Hydrogen at 20 K and 1.5 MPa (super-critical pressure)
  - Vessel in aluminium alloy
  - Vacuum jacket for insulation



Water moderators
- Thermal water
- Pre-moderator surrounding the cold moderator vessel
- Extended wings to facilitate thermal or bi-spectral beam extraction

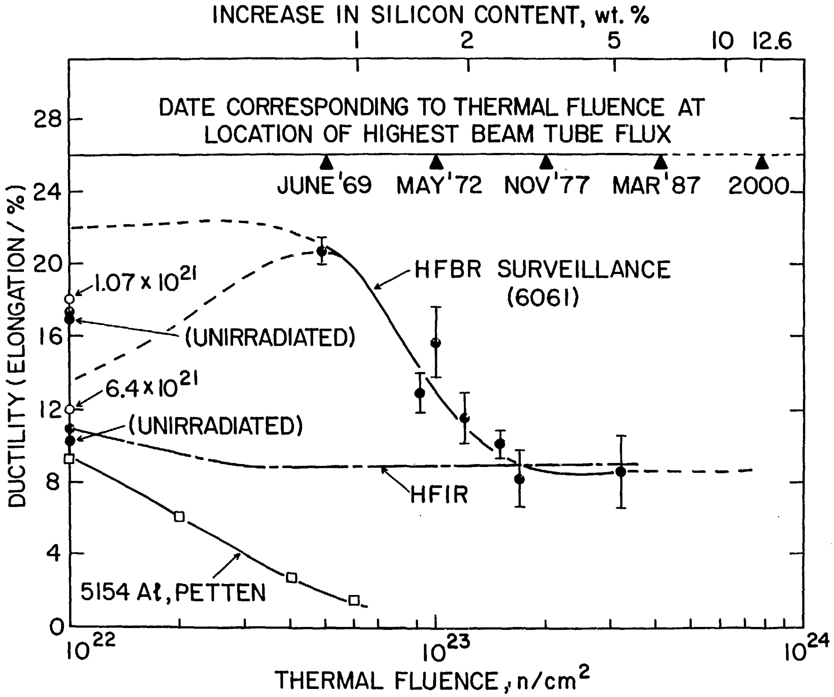


- Inner reflector
  - Beryllium
  - Water cooled
- Outer reflector
  - Steel
  - Water cooled
- Cut-outs
  - for the view path to the beam extraction
  - For the target wheel

Moderator Canister: Lifetime Estimates

Source of Damage	Operational limit	Data source
Thermal neutron fluence	1.0 a% of Si production	HFIR
DPA	40 DPA	HFIR/SNS
He production	2000 appm	PSI

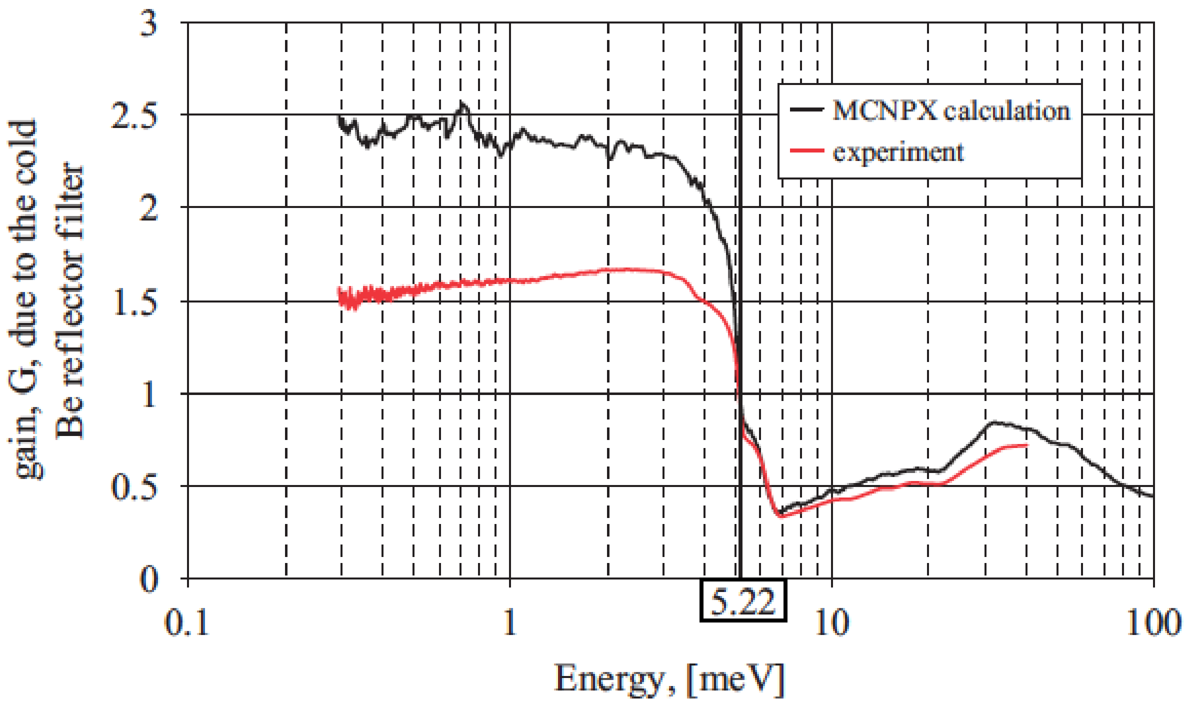
Maximum production rates	Al@20K	Al@300K
H (appm/GW-d)	775	1067
He (appm/GW-d)	195	310
Si (a%/GW-d)	0.85	0.25
Displacement rate (dpa/GW-d)	9.3	28.8
Thermal neutron fluence (n/cm^2/GW-d)	2.4×10^{22}	1.2×10^{22}



- Proposed MR-plug lifetime:
    - Initially one operational year 1.0 GW-d.

Reflector Material: Beryllium

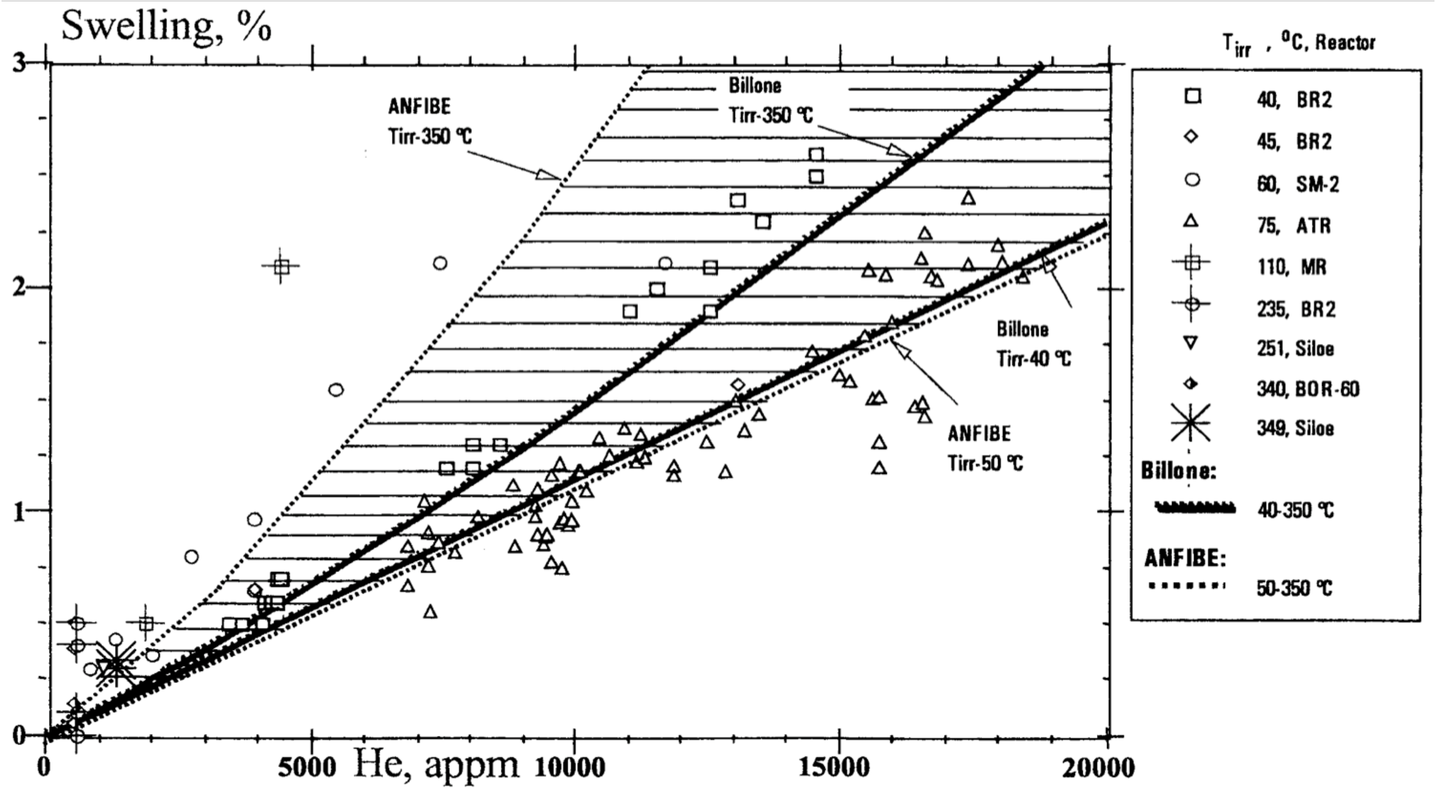
- Beryllium Selection Criteria
  - Isotropic texture
  - Small grain size
  - High purity
- R&D on correlation between neutron scattering x-section and different beryllium will be launched.



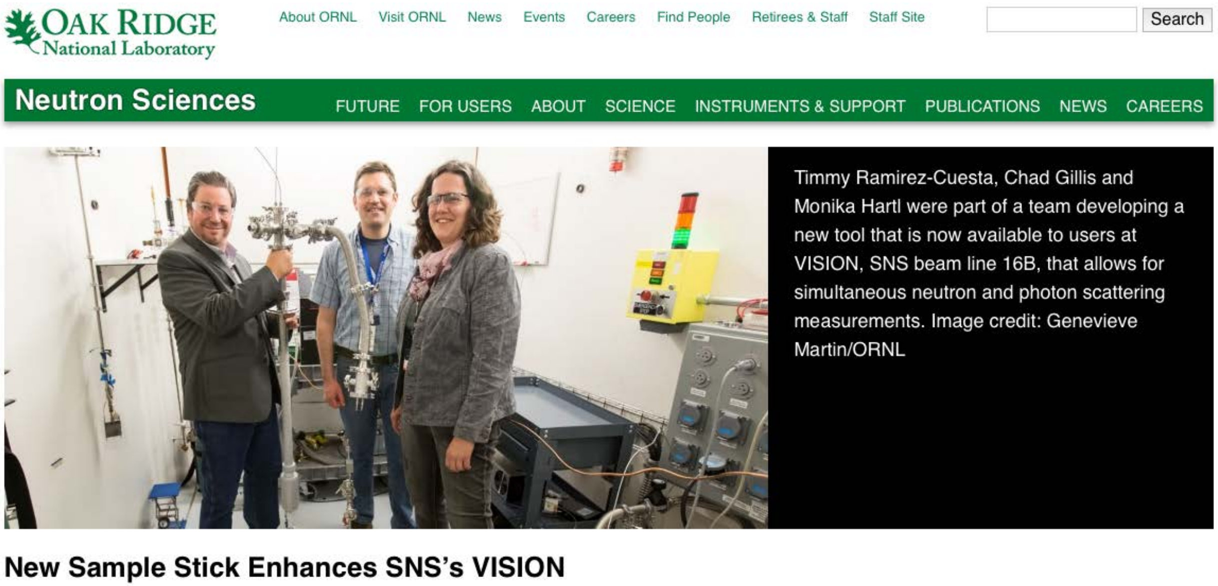
G. Muhrer et al.
NIMA, 2007

Reflector: Beryllium swelling and hydrogen reaction

- Swelling rate is correlated to helium production rate [ITER-EDA, ITER materials properties handbook (1998)]

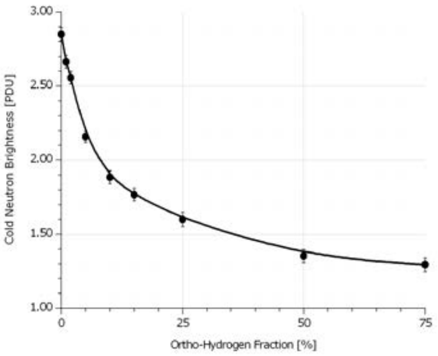


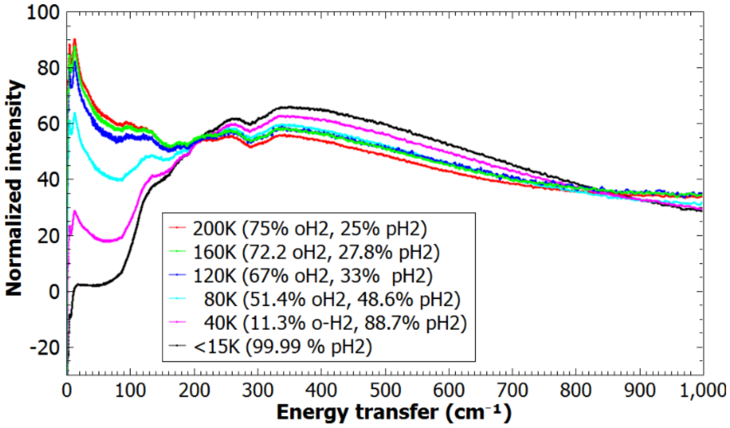
Ortho-Para Catalyst R&D

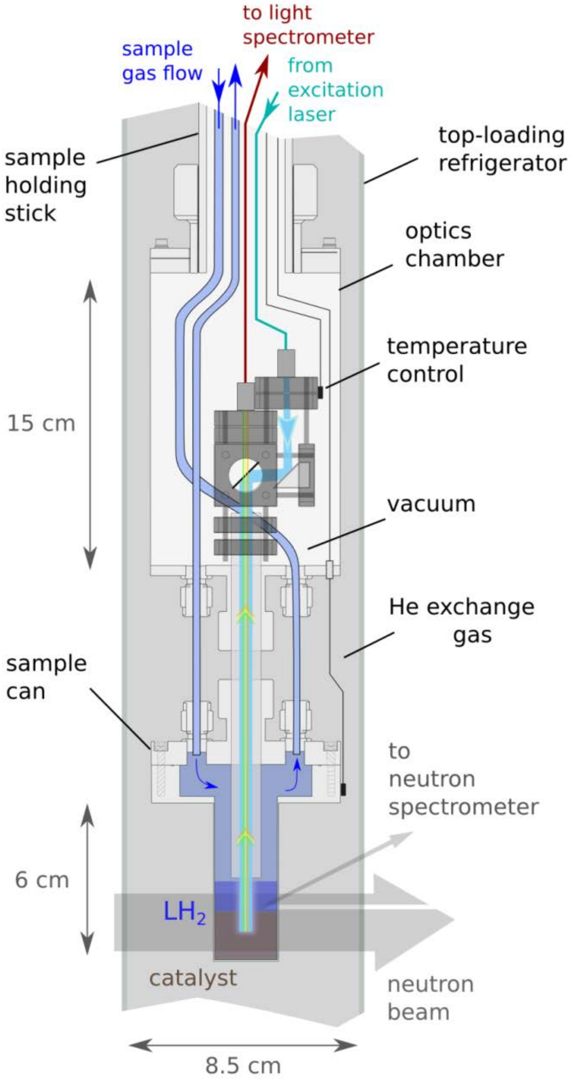


Timmy Ramirez-Cuesta, Chad Gillis and Monika Hartl were part of a team developing a new tool that is now available to users at VISION, SNS beam line 16B, that allows for simultaneous neutron and photon scattering measurements. Image credit: Genevieve Martin/ORNL

New Sample Stick Enhances SNS's VISION





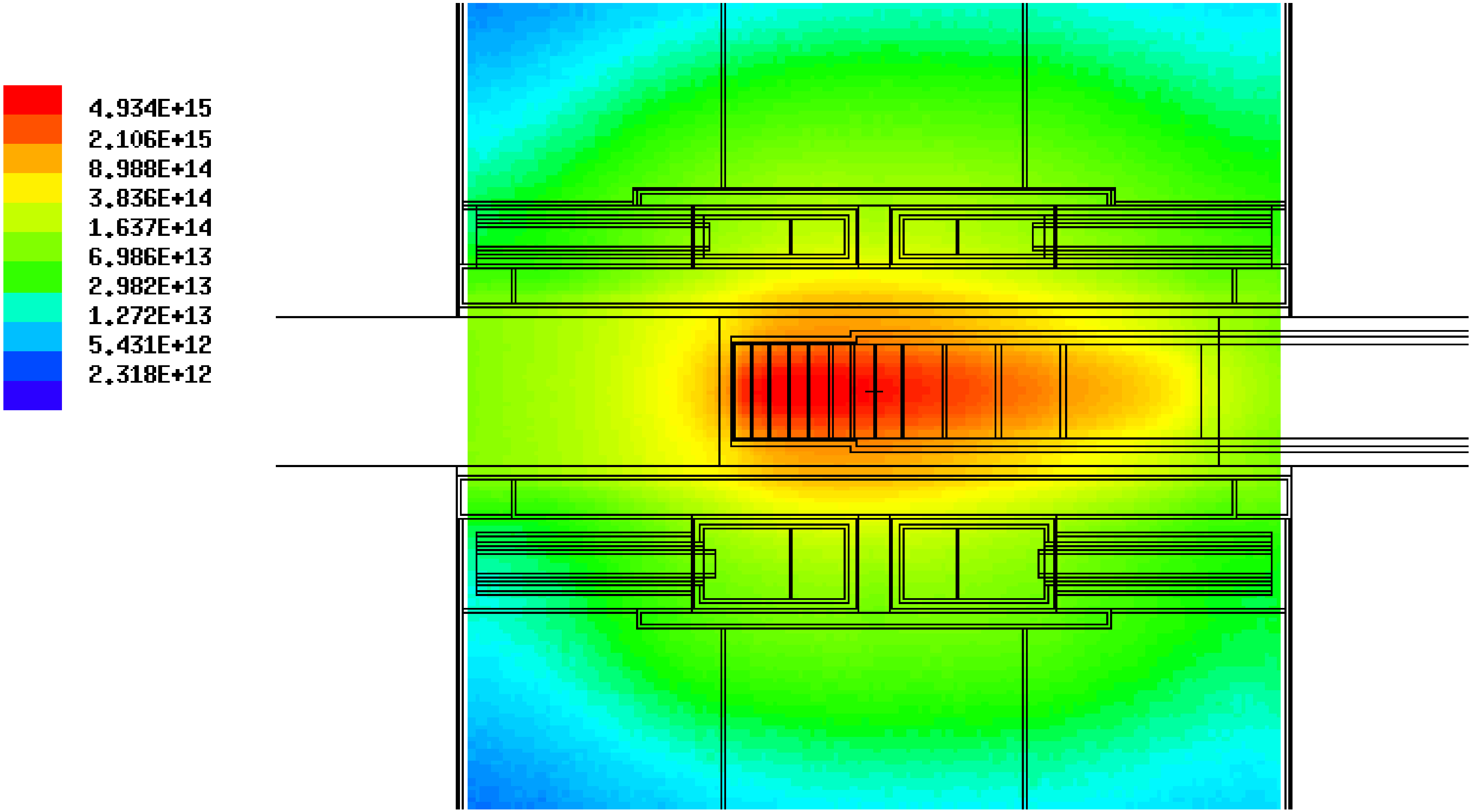


Vision: ESS Spallation Neutron Irradiation Program (ESNIP): Module in Moderator

- ESNIP-I (2019-2024)
  - Proof of Concept Module
  - Passively cooled by pre-moderator water flow
- ESNIP-II (2024 and on): Vision
  - Located at the hot spot position for optimal damage dose
  - Irradiation module with active temperature control
  - Larger Irradiation Volume

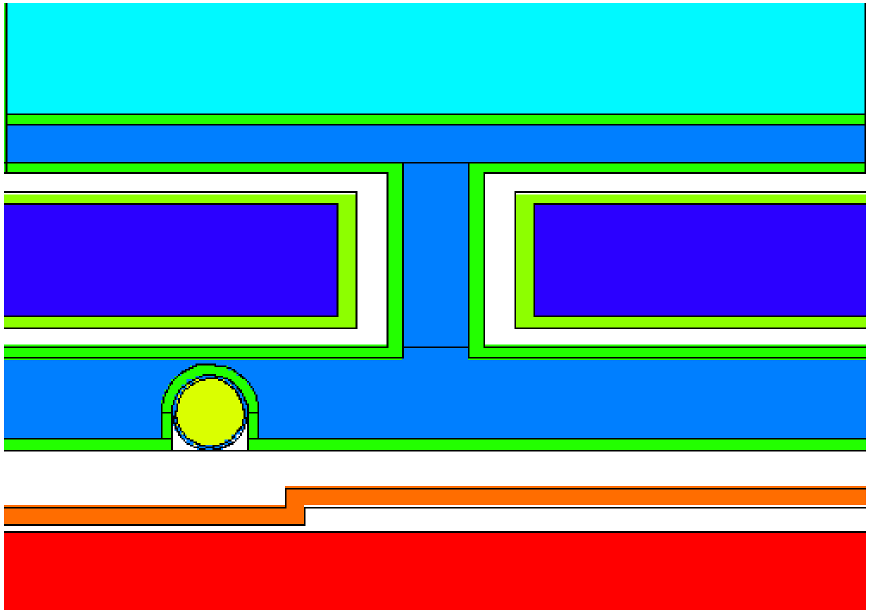
Fast neutron distribution (E > 0.1 MeV)

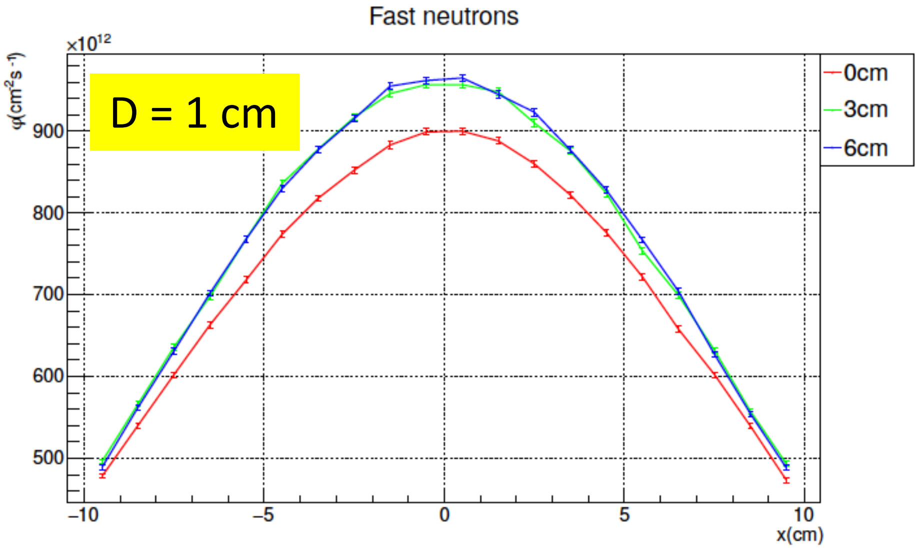
- Maximum flux: 4.0e15 n/cm^2/s

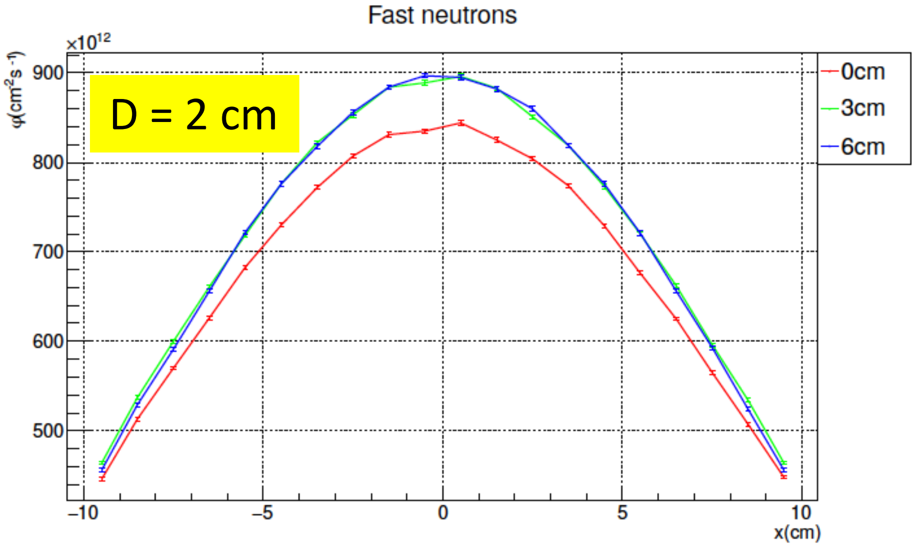


Irradiation Module in Pre-Moderator

- Flux calculated for three different horizontal positions:
  - 0 cm, 3 cm, 6 cm from the moderator center in the beam upstream direction
  - Module radii with 1 cm and 2 cm are considered
  - Fast neutron flux: up to 9.0E14 n/cm²/s

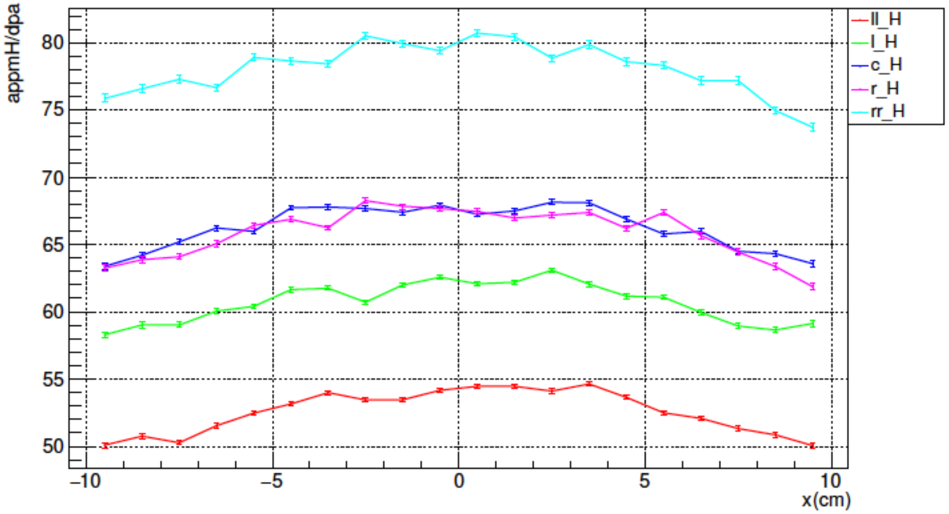


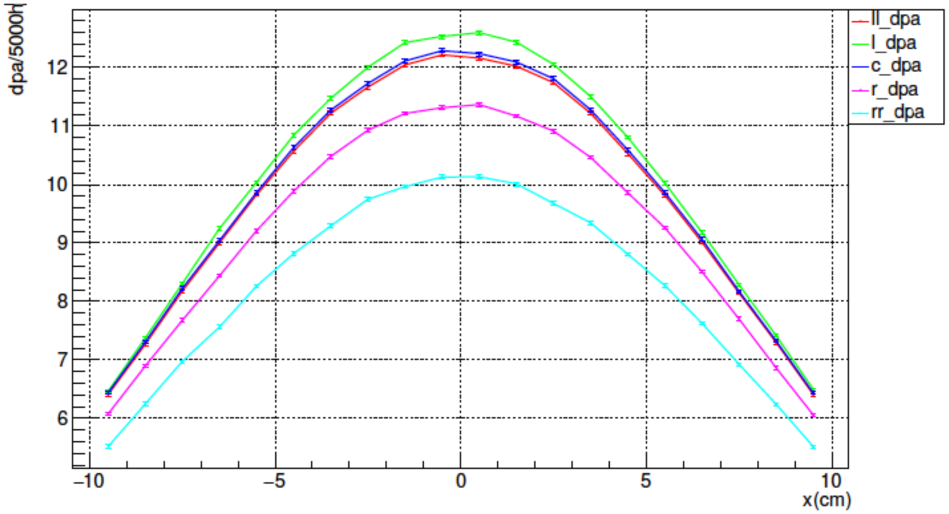


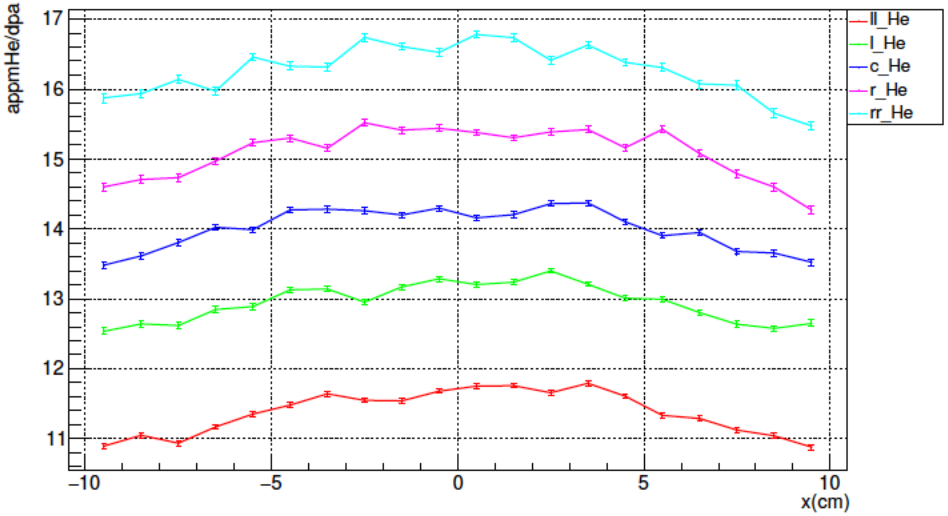


Irradiation Module in Pre-Moderator

- The dpa and gas production rates are calculated for five different horizontal locations along the beam (= +ŷ):
  - y = -6 cm (ll), -3 cm (l), 0 cm (c: moderator center), 3 cm (r), 6 cm (rr)

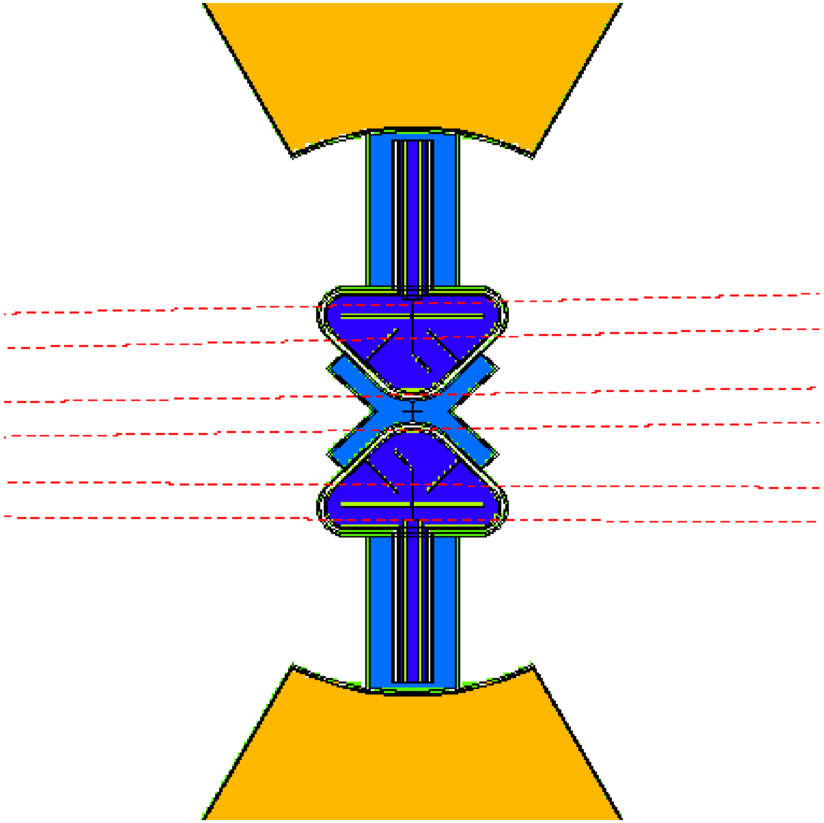


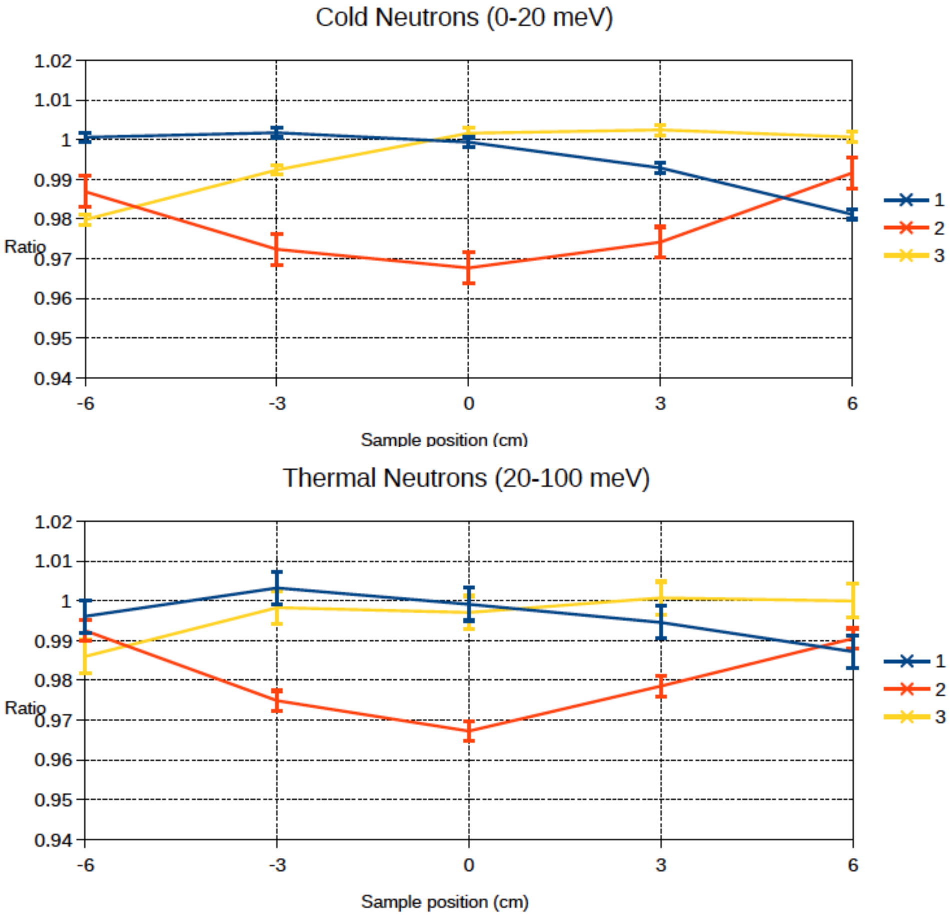




Irradiation Module in Pre-Moderator

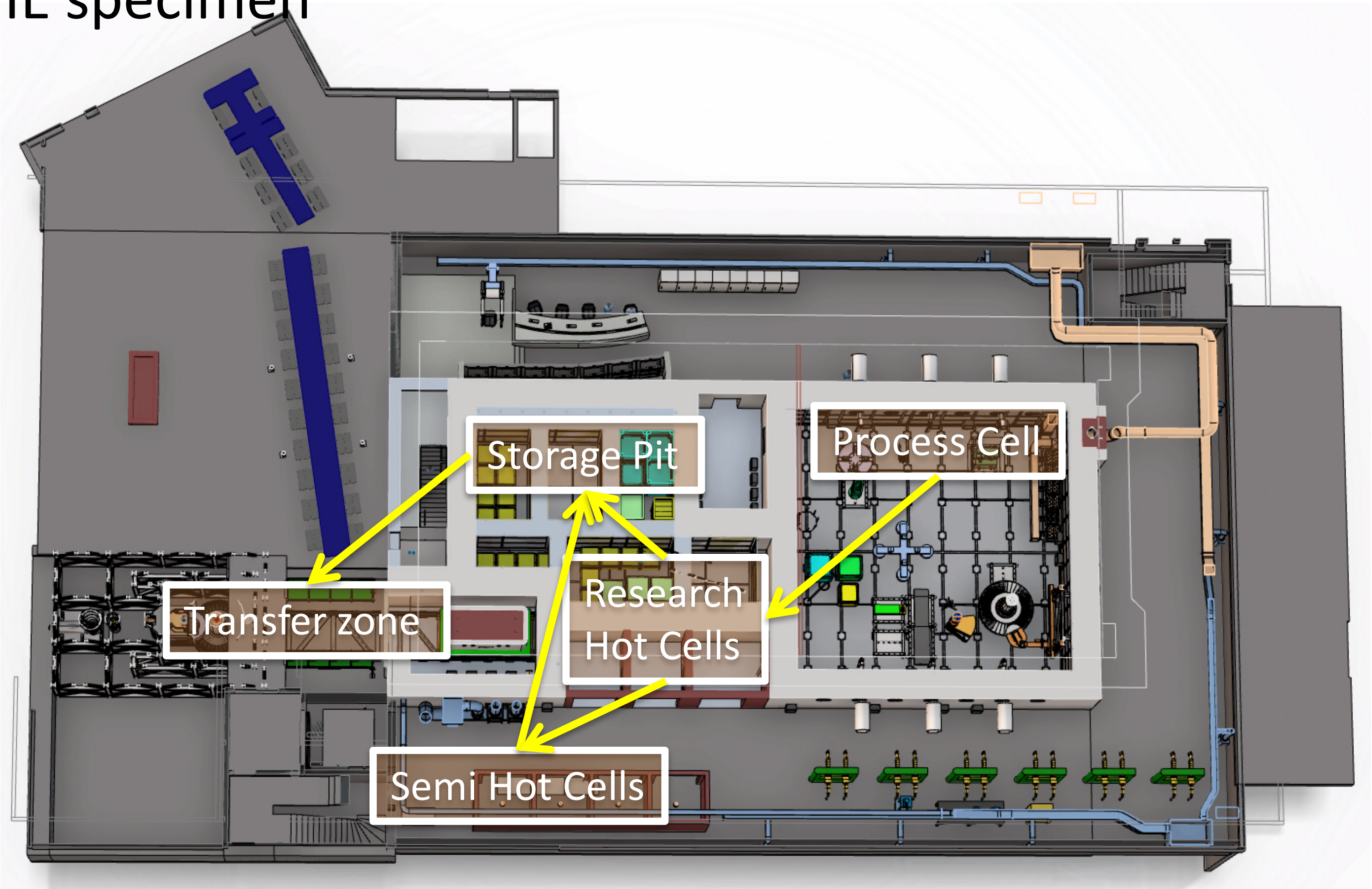
- Neutronic Penalty: Up to 3% per module





Vision: PIECE (PIE Cells at ESS: Vision)

- Allocated Function: Scientifically investigate the activated PIE specimen



Summary

- Materials Knowledge in Target Environment Provides Support for Target Project
- External Materials R&D 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 studied.

Thank you for your attention!