Irradiated T2K Ti alloy materials test plans

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The 2nd RaDIATE collaboration meeting
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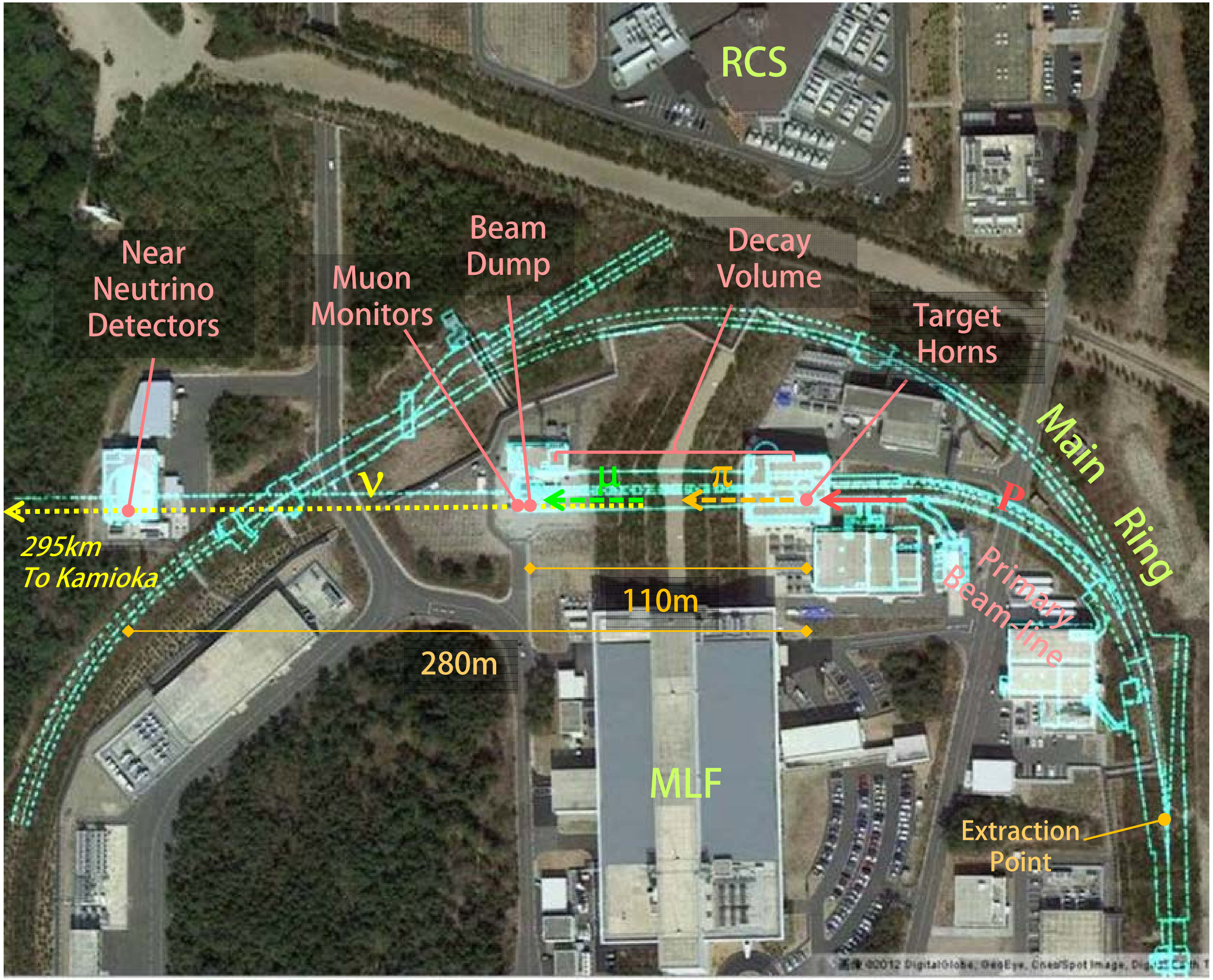
Motivation for the studies on Ti-alloys

- Ti alloys at J-PARC neutrino beam-line
  - Beam window (Ti-6Al-4V)
  - Target window-case, surrounding graphite (Ti-6Al-4V)
  - OTR profile monitor, upstream of the target (Ti-15V-3Cr-3Sn-3Al)

- 1st beam window still in service: 1×10^{21} pot
- The 1st target / OTR replaced during 2013-14 maintenance: 6.6×10^{20} pot, 1.2×10^{7} pulses

- Expected radiation damage > O(1) DPA
  - Larger than the existing data (~0.28DPA@BLIP)

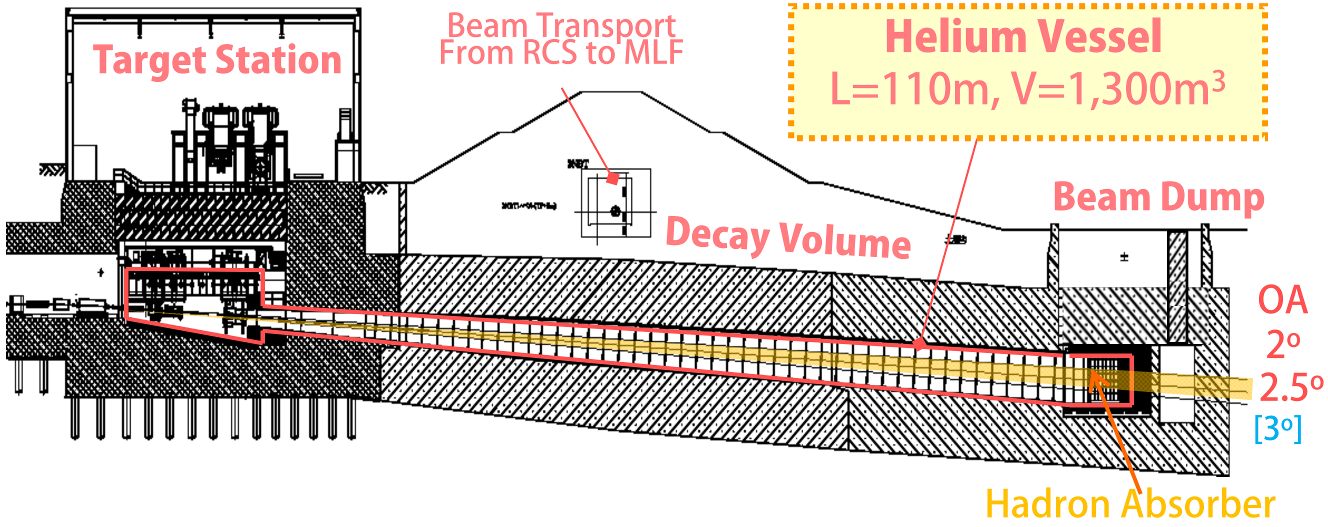
Neutrino experimental facility at J-PARC

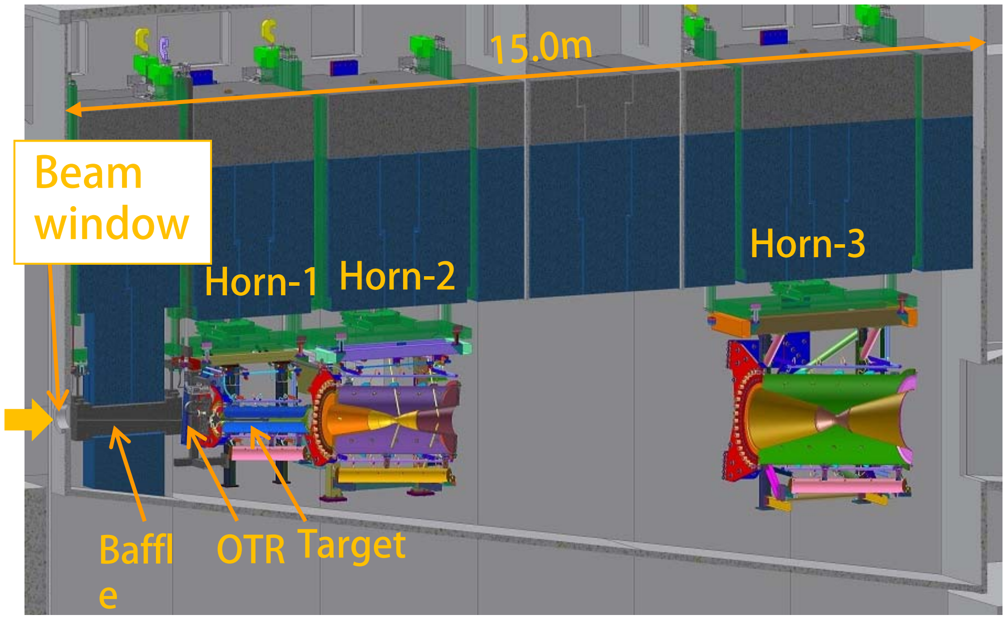


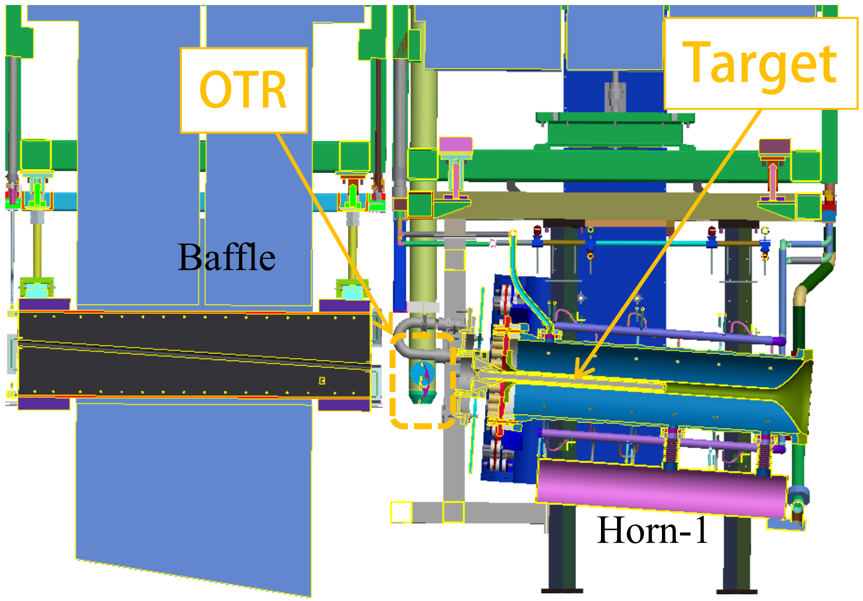
N

J-PARC, Tokai

The secondary beam-line







Parameters of Main Ring operation

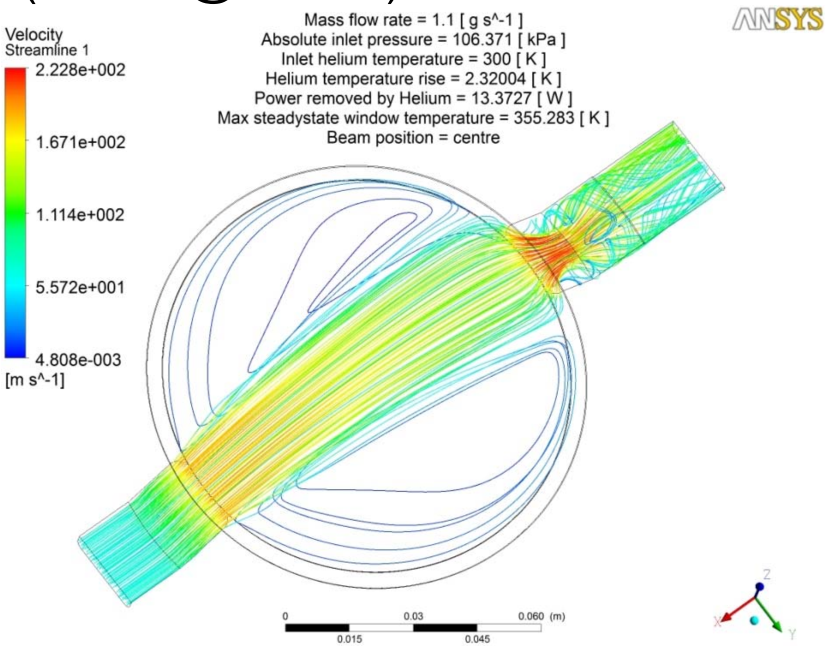
Parameter	Original	Achieved [Mar.2015]	Doubled rep rate
circumference	1567.5m		
beam kinetic energy	30 GeV		
beam intensity	3.3×10^{14}ppp	1.66×10^{14}ppp	2.0×10^{14}ppp
	4.1×10^{13}ppb	2.12×10^{13}ppb	2.5×10^{13}ppb
[RCS equivalent power]	[1MW]	[505kW]	[610kW]
harmonic number	9		
number of bunches	8 / spill		
spill width	~5us		
bunch full width (at extraction)	~50ns		
maximum RF voltage		280kV	560kV
repetition period	2.1sec	2.48 sec	1.28 sec
beam power	750kW	320kW	750kW~

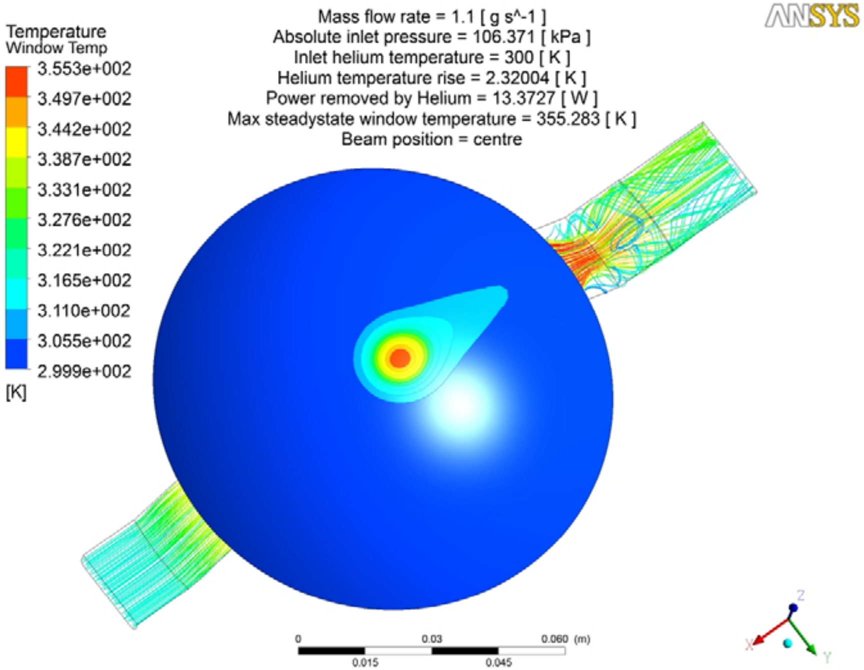
- Original (old) planed parameters for 750kW was MR cycle: 2.1s, PPP: 3.3×10^{14}
  - Components of the neutrino facility (target/beam window) were designed
- Present expected parameters: Doubled rep-rate, MR cycle: 1.3 s, PPP: 2.0×10^{14}
  - Instantaneous temperature rise / pulse (thermal shock) will be reduced by 60%

Beam window

M.Fitton

Design: 2 x 0.3mm thick titanium domes cooled by helium flow
Material: Titanium alloy bar Ti6Al-4V (Grade 5) (Windows I & II)
Proton beam : 30GeV, 4.2mm sigma
Beam power: 345kW (750kW window design power)
Number of protons to date: 1.04×10^{21} (May 2015 and still in service)
Max temp (at beam centre): 52° C estimate at current beam power (82° C @750kW)

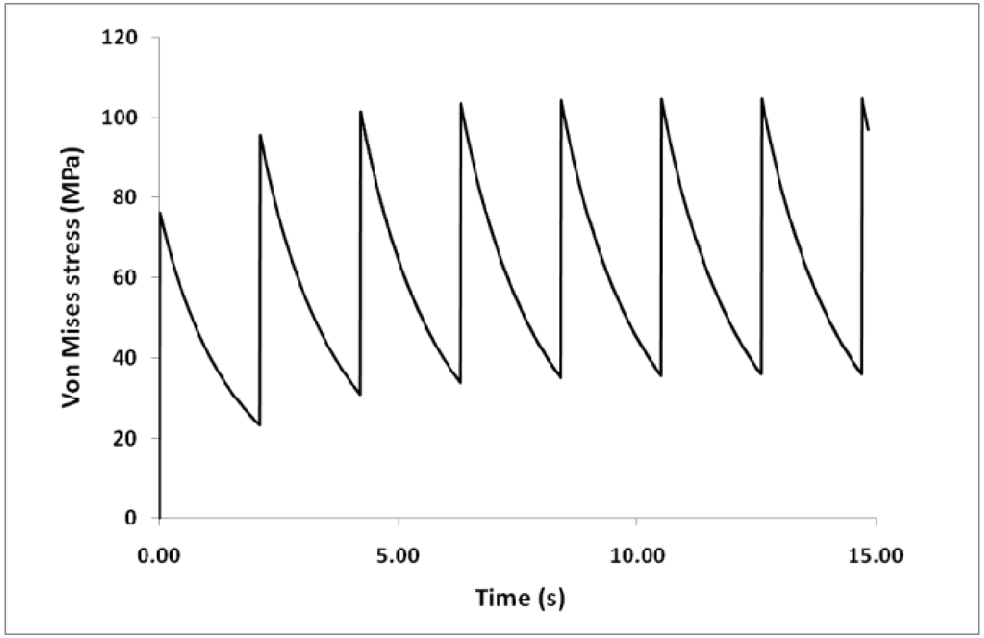




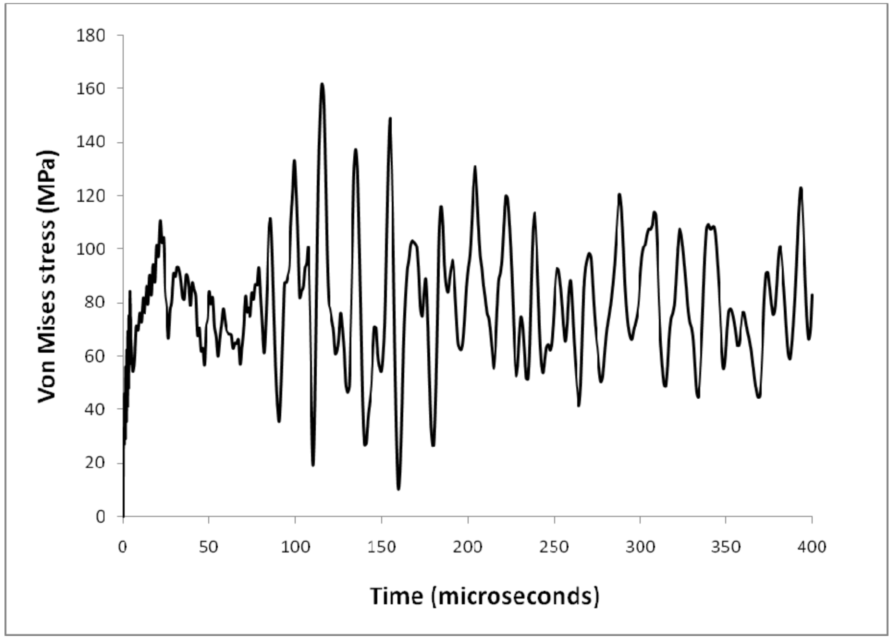
Results for 750kW simulations

M.Fitton

Thermal stress cycling



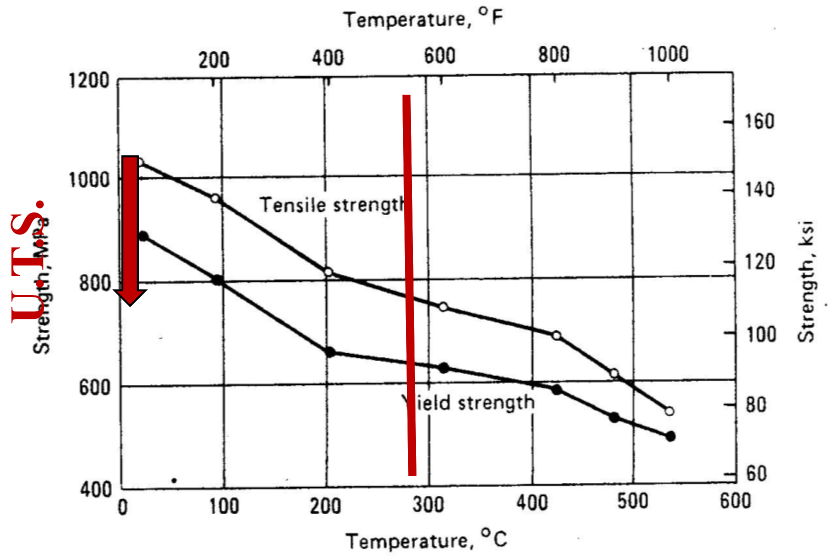
Dynamic stress waves due to rapid beam heating

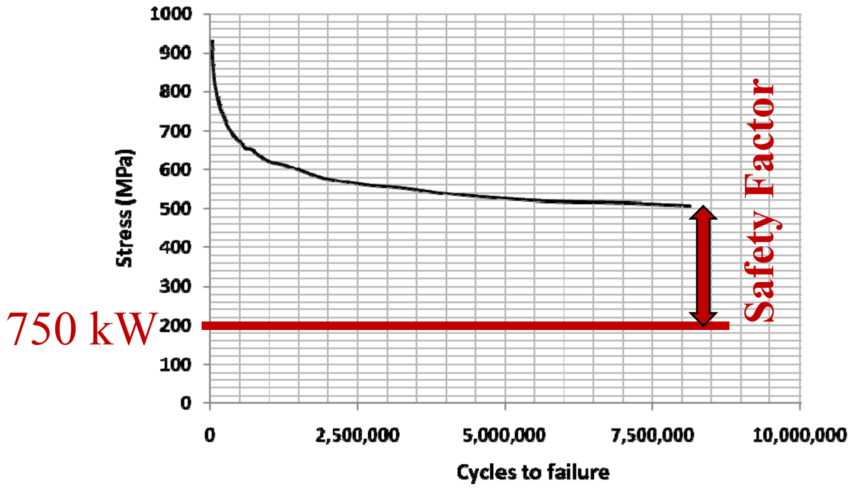


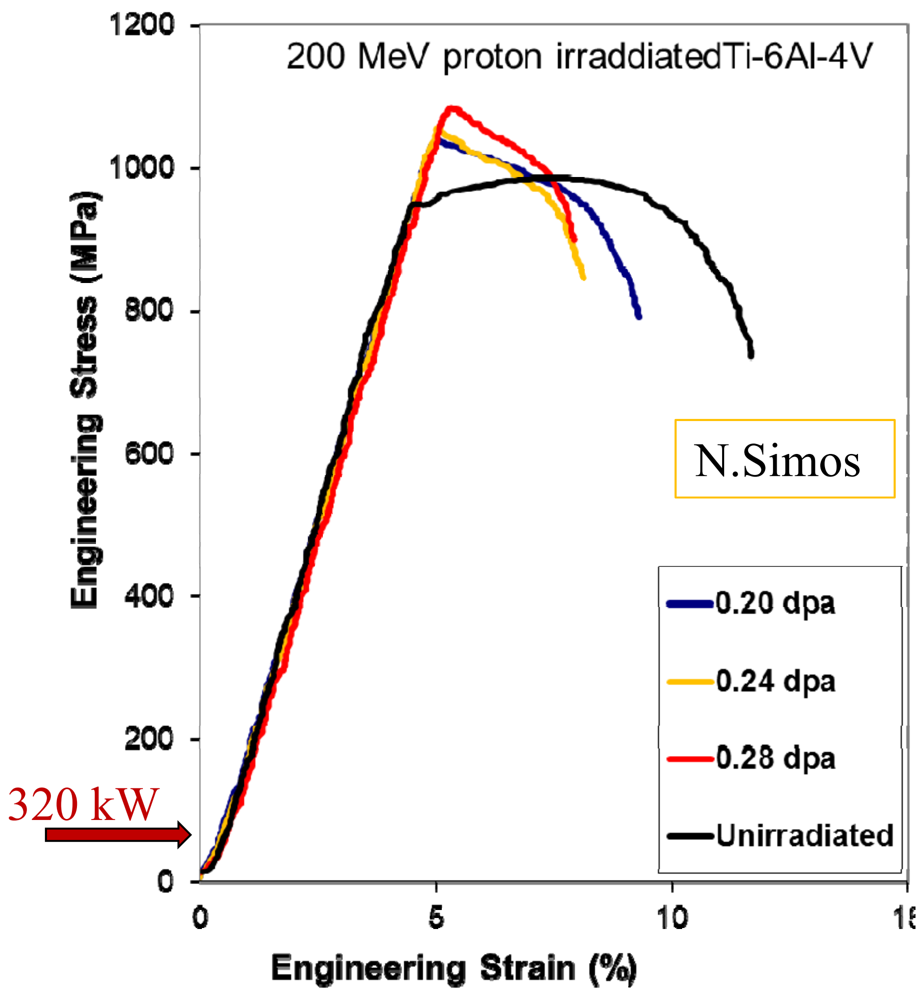
- Estimate of current conditions at 345kW
- Peak stress ~ 50MPa
- Fatigue cycles ~ 0.5×10^6 @ 0.5Hz

Effects of elevated temperature, fatigue & radiation damage

C.Densham

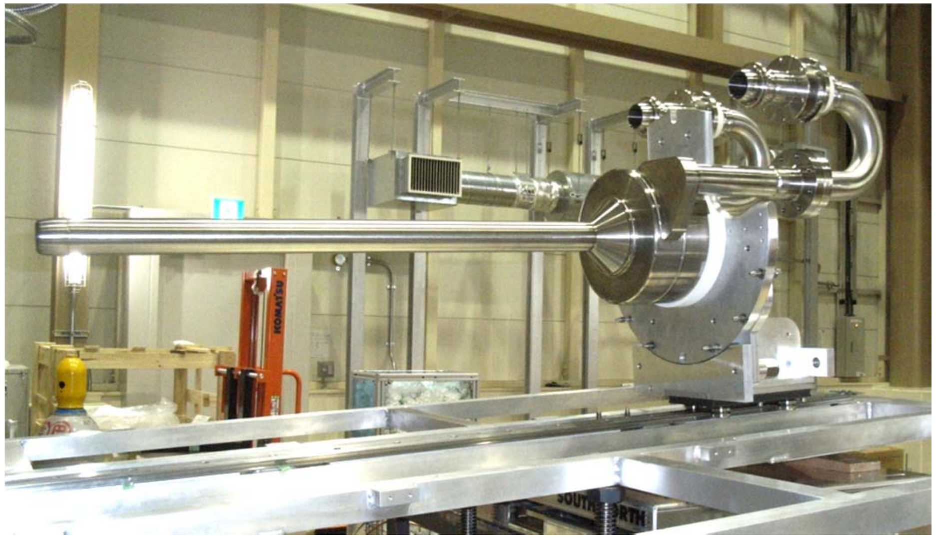


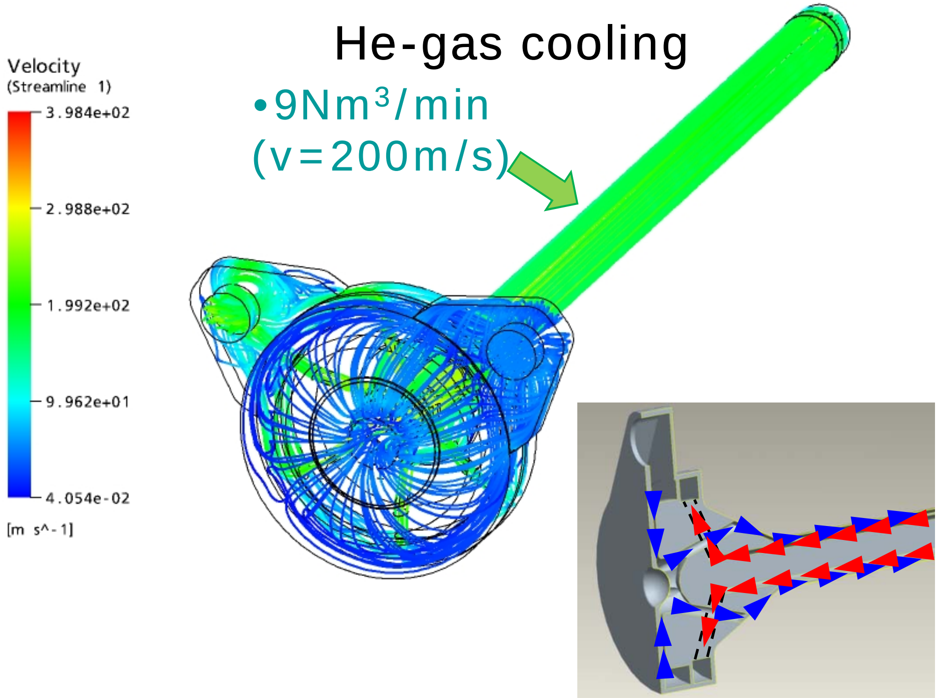




Significant loss of ductility at 0.2~0.28 dpa
Now likely to be entirely brittle at 1~2 dpa
Does it matter ? (Low stress at moment)

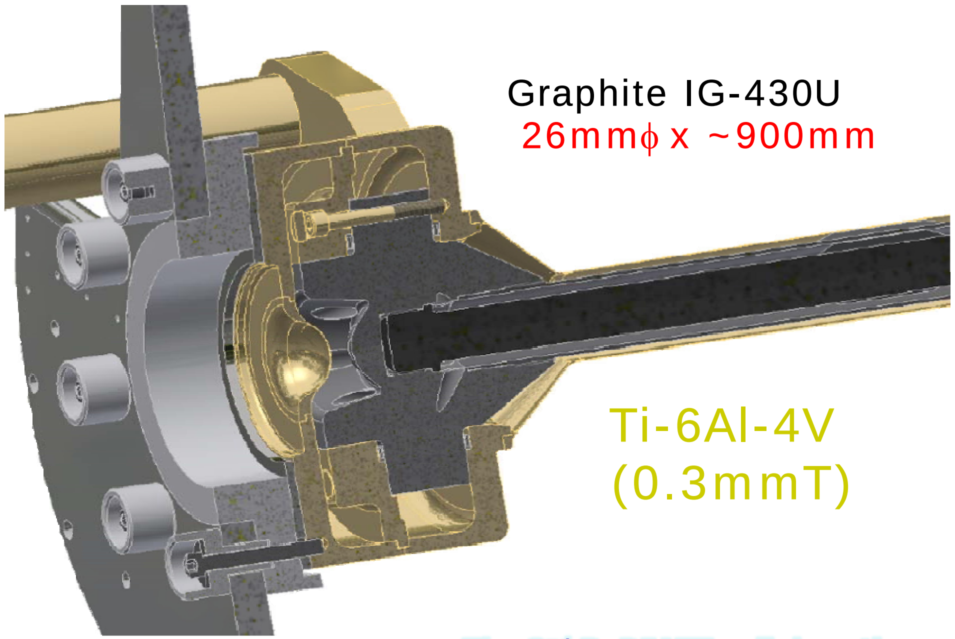
Target (He-cooled graphite)





He-gas cooling

- $9Nm^3/min$ (v=200m/s)



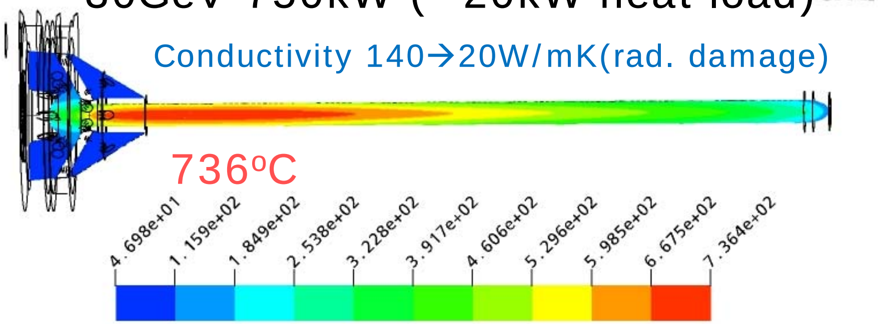
Graphite IG-430U

26mmϕ x ~900mm

Ti-6Al-4V (0.3mmT)

30GeV-750kW (~20kW heat load)

Conductivity 140→20W/mK(rad. damage)



736°C

ΔT~200K ~7MPa (Tensile strength 37MPa)

Proposed new study items

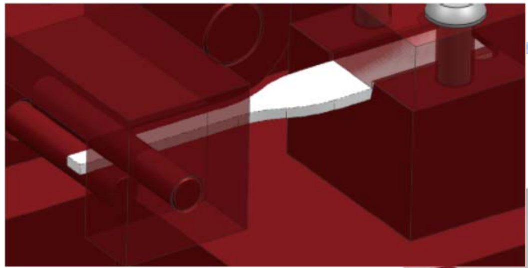
- We are proposing new studies:

1. Develop a compact Fatigue Testing Machine (FTM), to study fatigue effect for irradiated specimens in a hot-cell.
2. Design new irradiation run at BLIP, hopefully in US-FY2016
3. PIE for the OTR foils (PNNL + UK for micro-mechanical studies)

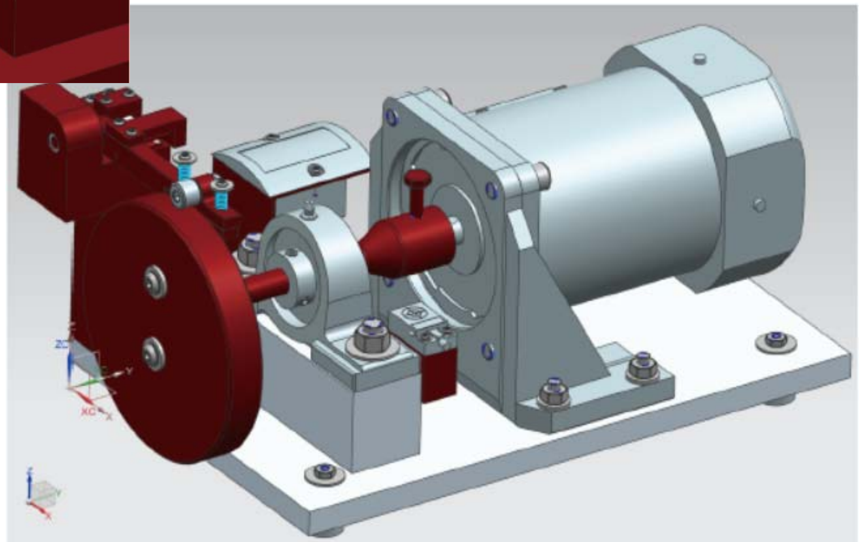
✓ Activities supported as one of KEK's US-Japan cooperative research programs, since JFY2014

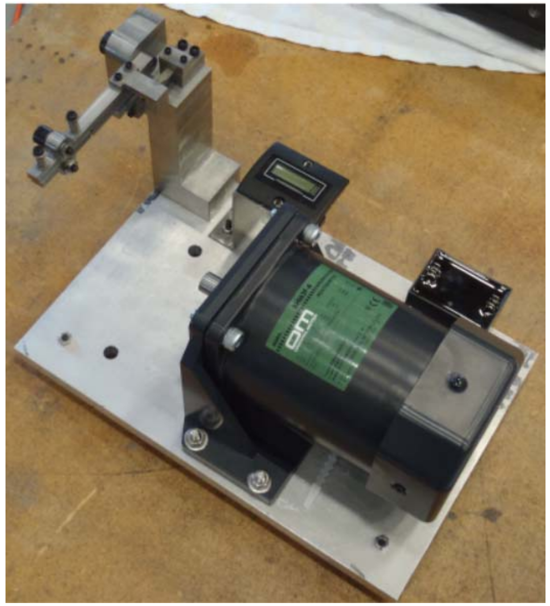
Fatigue Testing Machine (FTM)

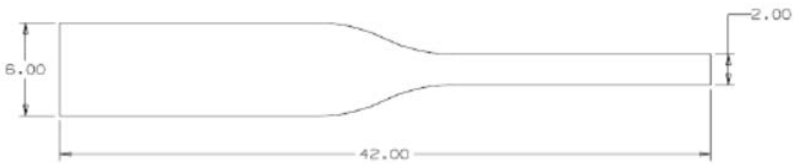
B.Hartsell et al

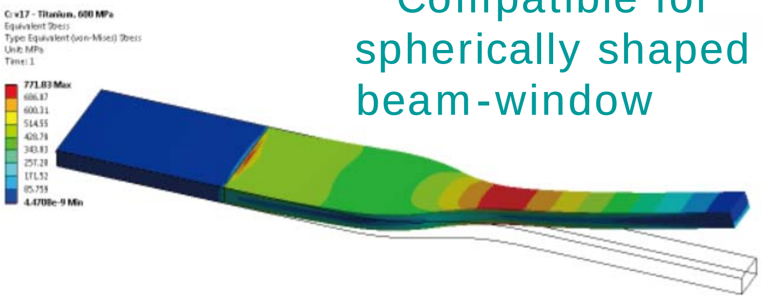


1,500 rpm, 10^7 cycles / 4.6 days





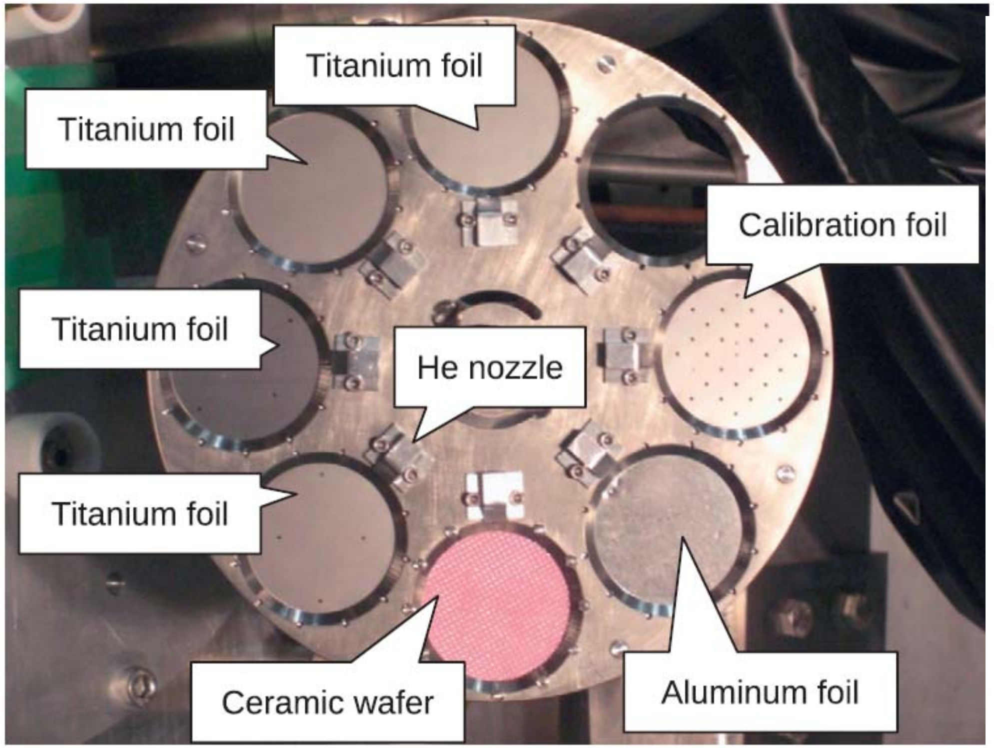




* Compatible for spherically shaped beam-window

Specimen production & a few pre-irradiated tests

OTR (Ti-15V-3Cr-3Sn-3Al)



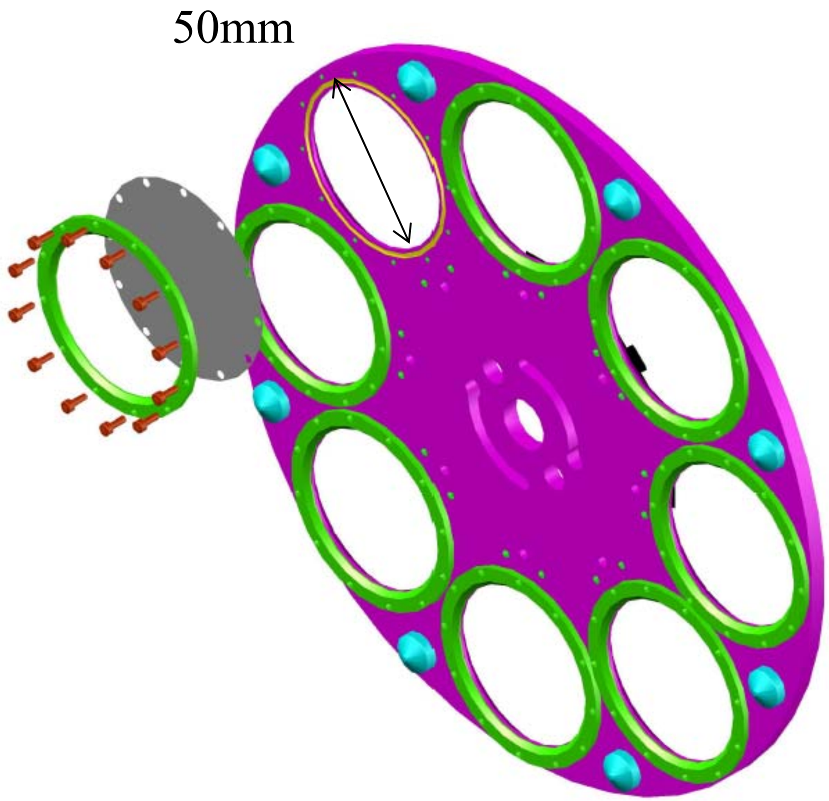


Table 1
The foils used in the OTR system.

Material (number of foils)	Thickness (μm)	Operation
AF995R (1)	100	< 1 kW beam power
Al 1100 (1)		1–40 kW beam power
Ti 15-3-3-3 (4)	50	> 8 kW beam power
Ti 15-3-3-3 (1)		Calibration with no beam

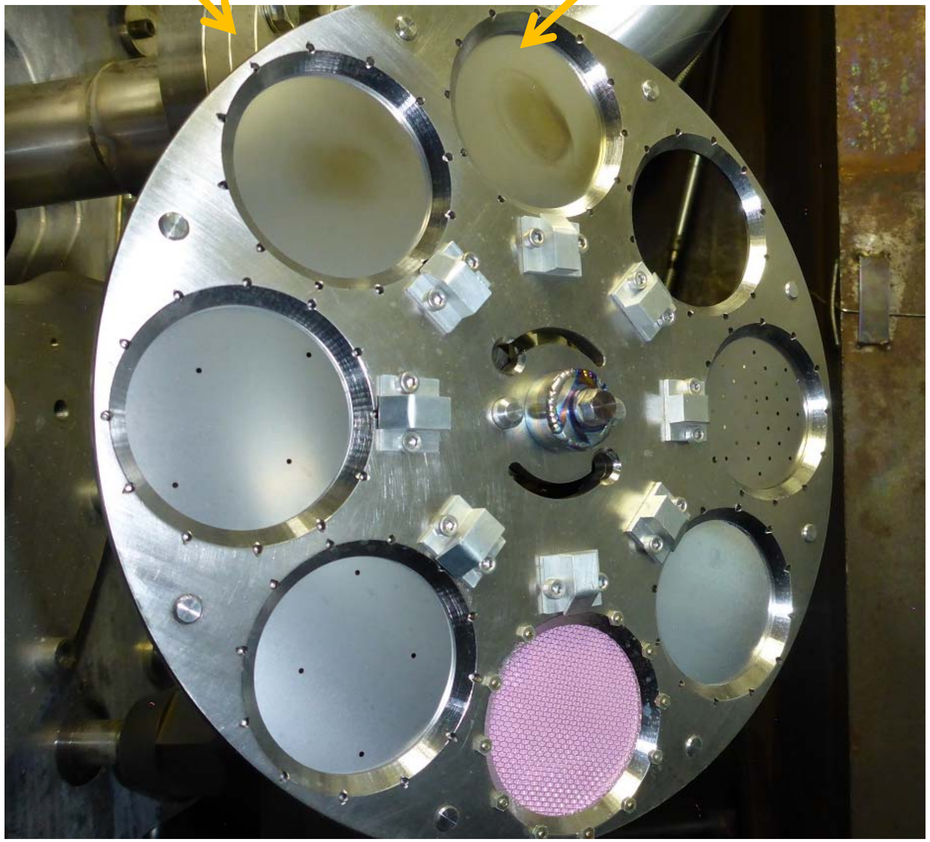
S. Bhadra et al., NIM A 703 (2013) 45–58

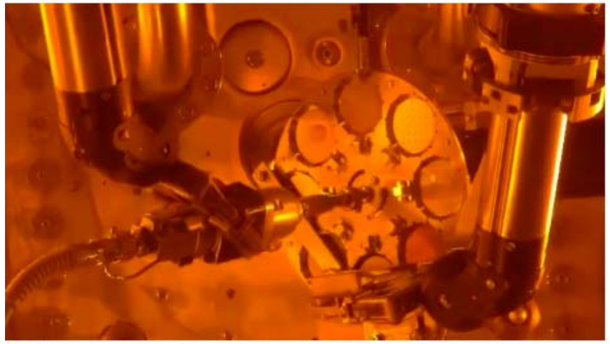
OTR PIEs ?

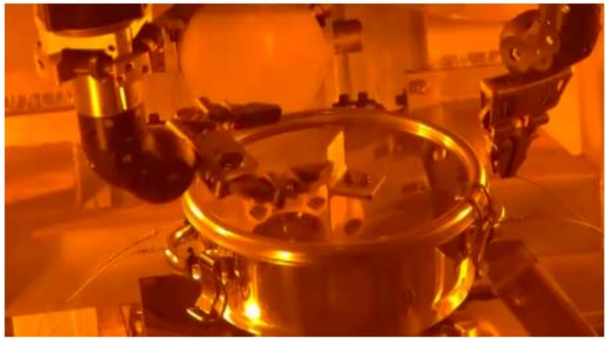
- Two Ti foils receive most of the beam.
- The damage localized within beam-spot size (a few mm)
- PIE as func. of **distance from beam center**

Ti2: 5.0e20

Ti1: 1.6e20







- Optical microscopy at PNNL
  (SEM/EDS/EBSD, TEM, XRD)
- Under discussion:
  - Micro hardness test
  - Michro-mechanical studies w FIB
- We need your expertise !