



# Irradiated T2K Ti alloy materials test plans

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RaDIATE Meeting at BNL

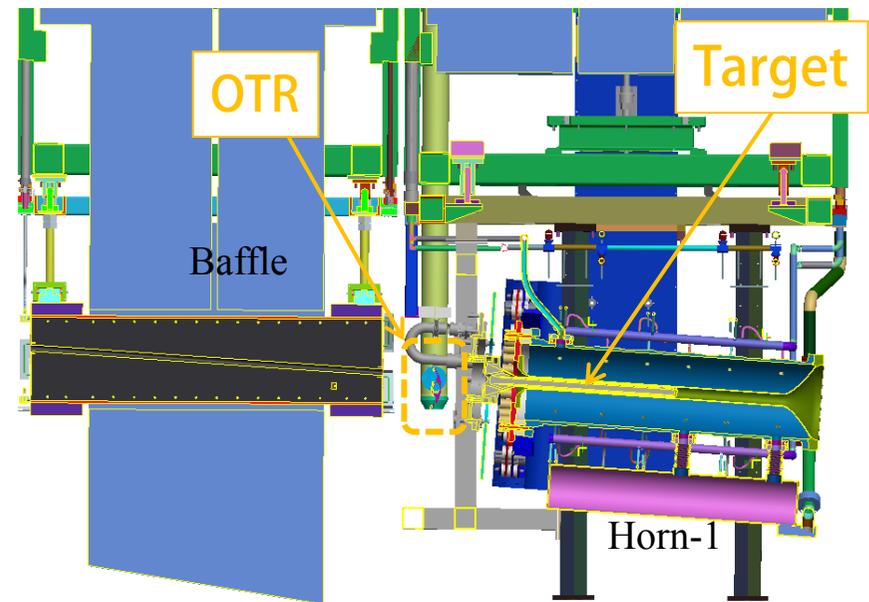
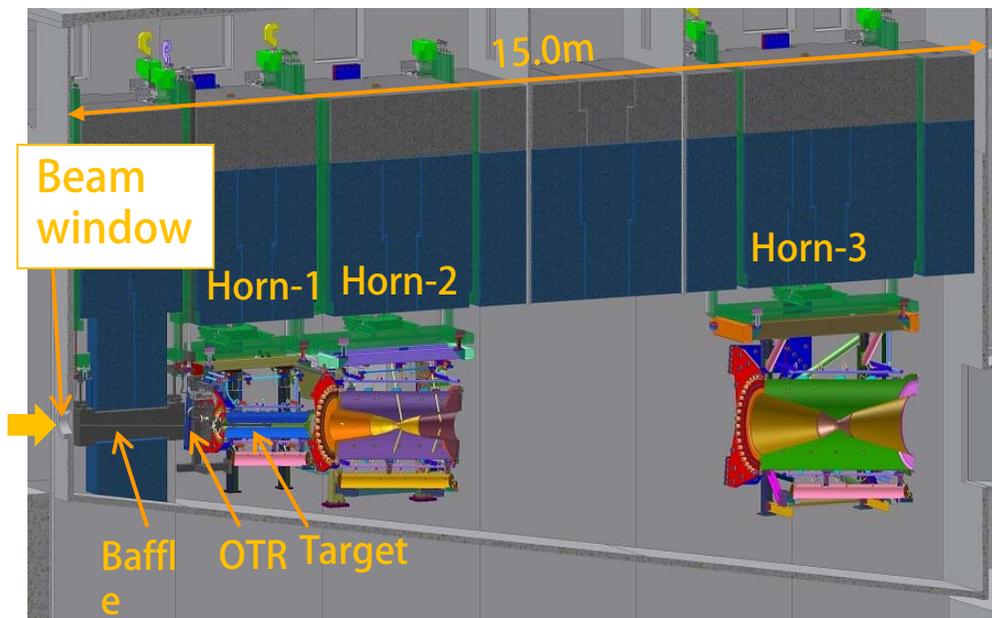
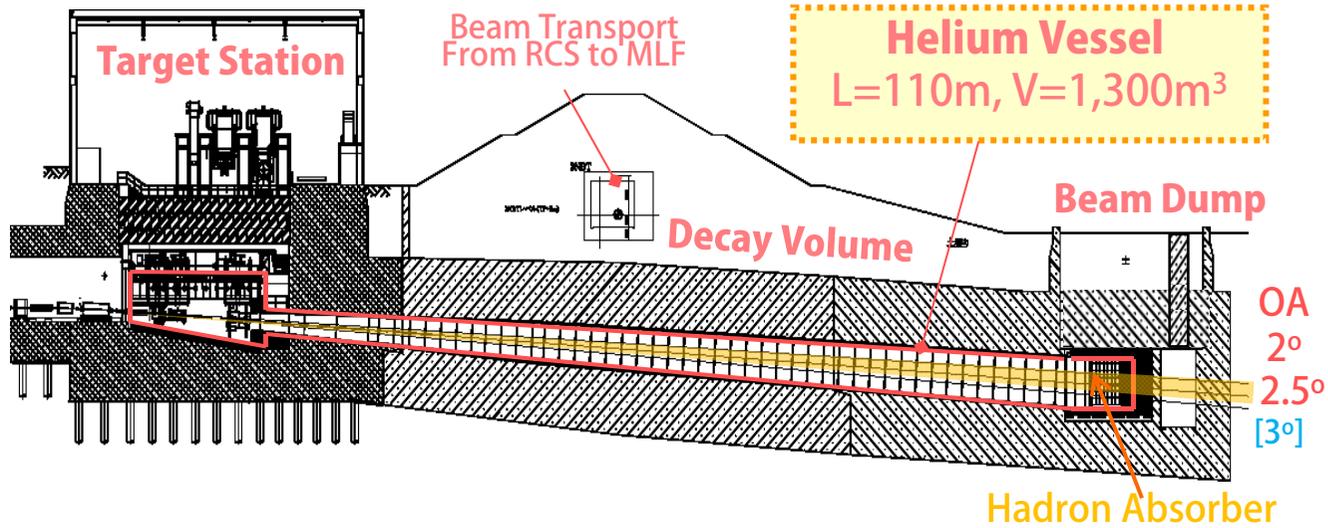
Nov. 24, 2015

# Motivation for the studies on Ti-alloys



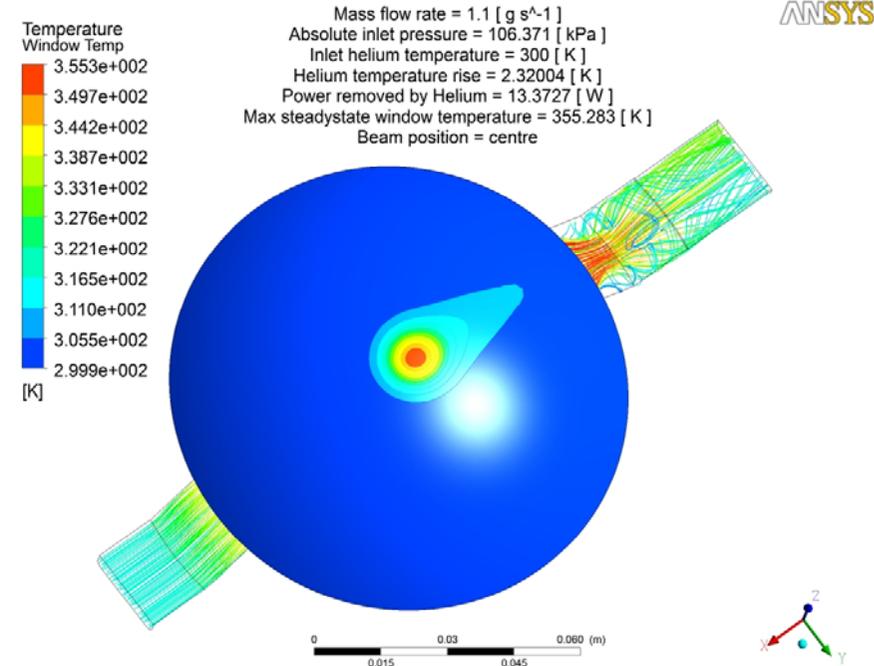
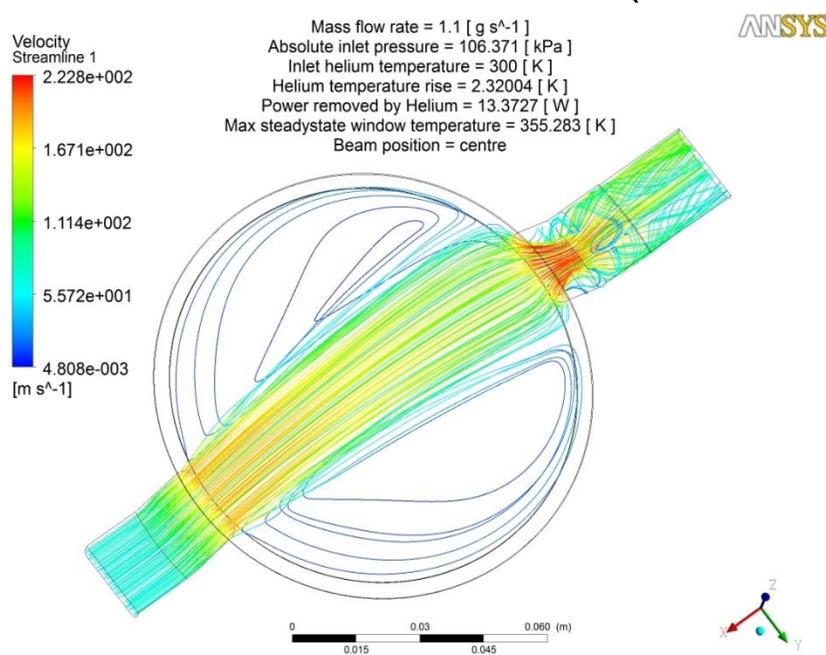
- Ti alloys at J-PARC neutrino beam-line
  - ◆ Beam window (Ti-6Al-4V Grade-5 → 23)
  - ◆ Target window-case: surrounding graphite (Ti-6Al-4V)
  - ◆ OTR profile monitor: upstream of the target (Ti-15V-3Cr-3Sn-3Al)
- 1<sup>st</sup> beam window still in service:  $1.1 \times 10^{21}$  pot
- The 1<sup>st</sup> target / OTR replaced during 2013-14 maintenance:  $6.6 \times 10^{20}$  pot,  $1.2 \times 10^7$  pulses
  - ◆ World-most irradiated Titanium alloy
- Expected radiation damage  $> O(1)$  DPA
  - ◆ Larger than the existing data ( $\sim 0.28$  DPA @ BLIP)

# The secondary beam-line

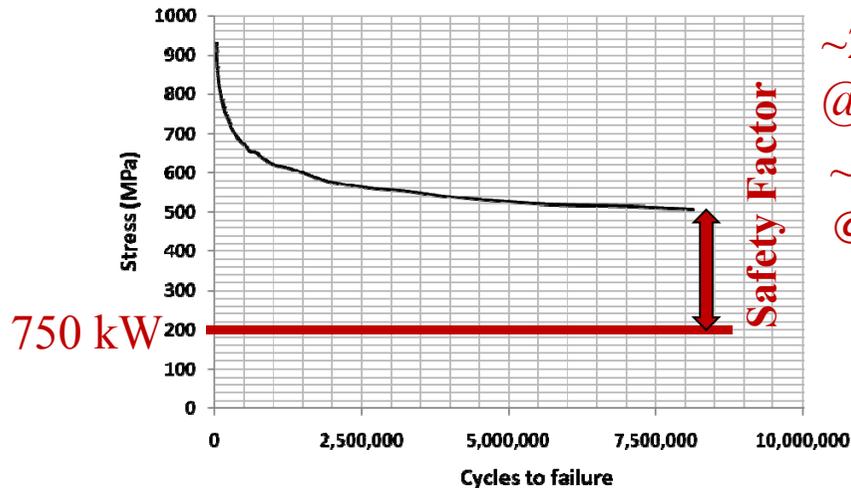
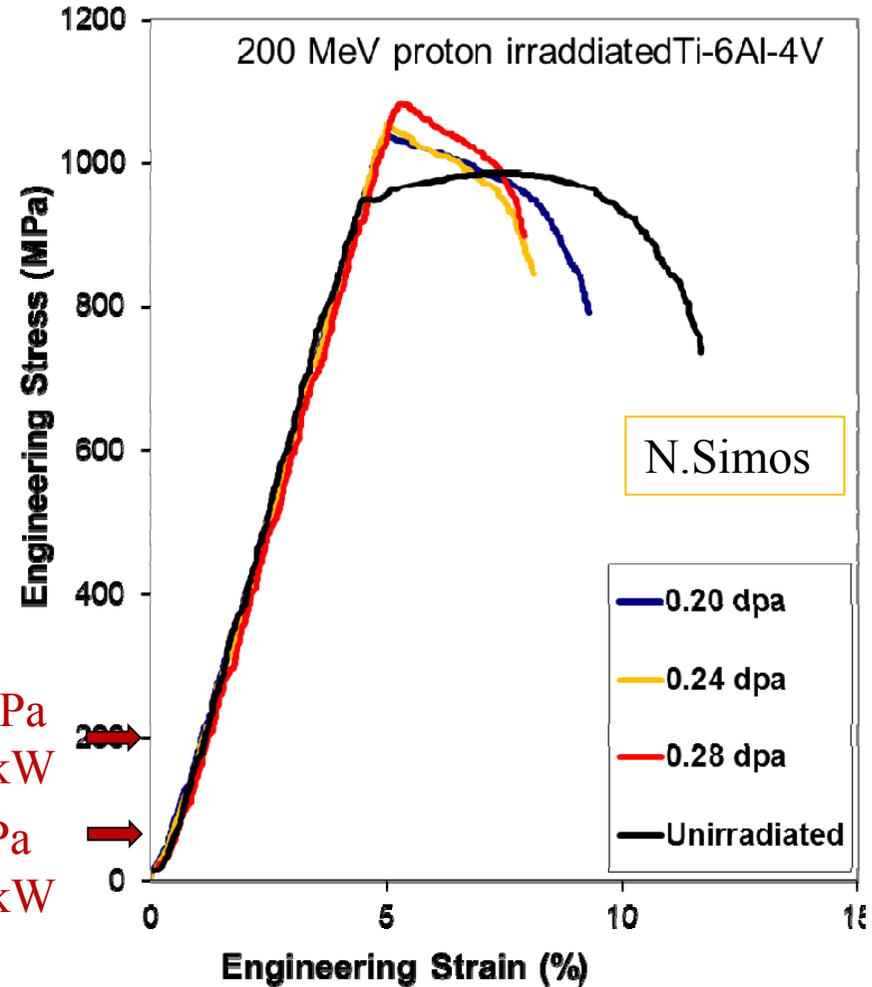
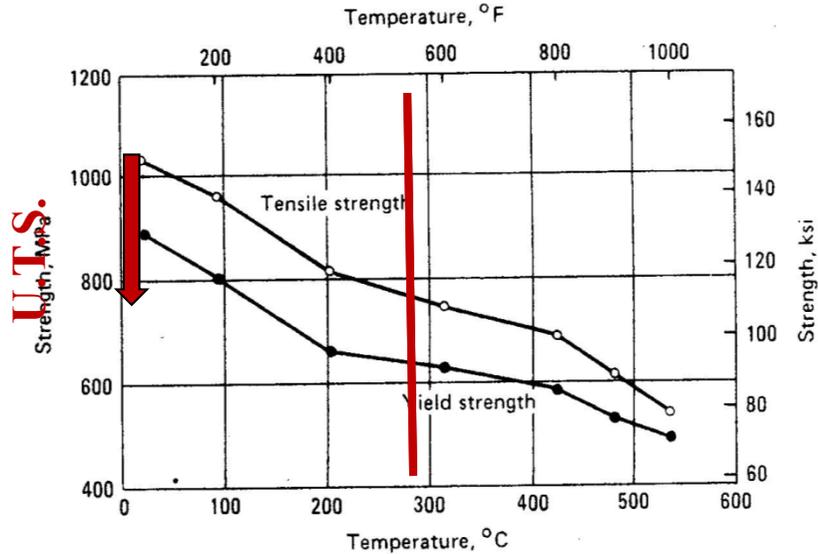


# Beam window

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:  $1.04 \times 10^{21}$  (May 2015 and still in service)  
Max temp (at beam centre): 52° C estimate at current beam power  
(82° C @750kW)  
Estimate of current conditions at 345kW : Peak stress ~ 50MPa  
(750kW- $3.3 \times 10^{14}$  ppp → 200MPa)



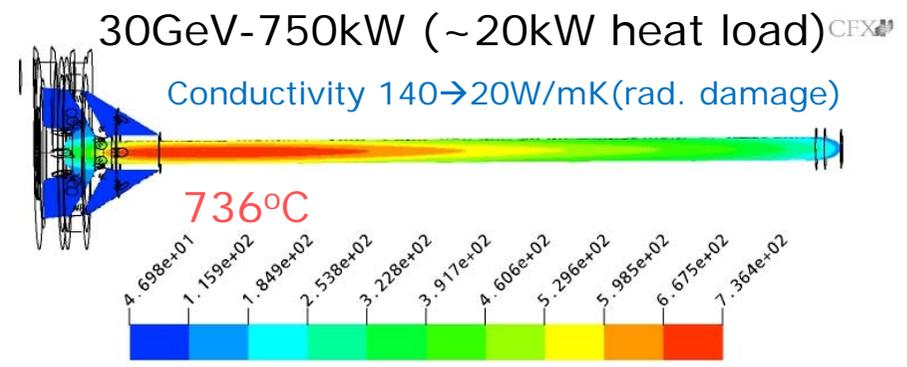
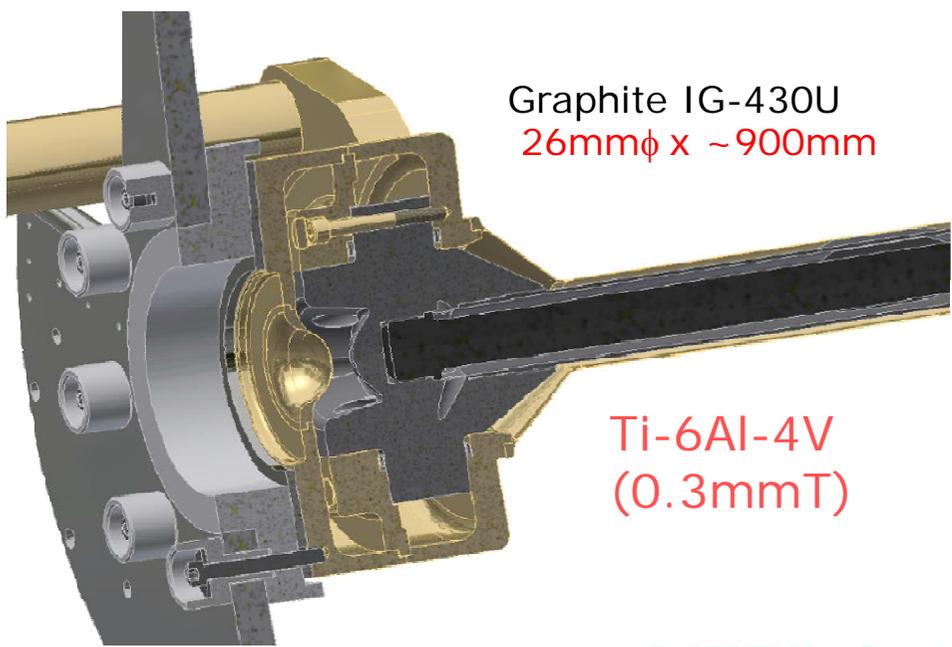
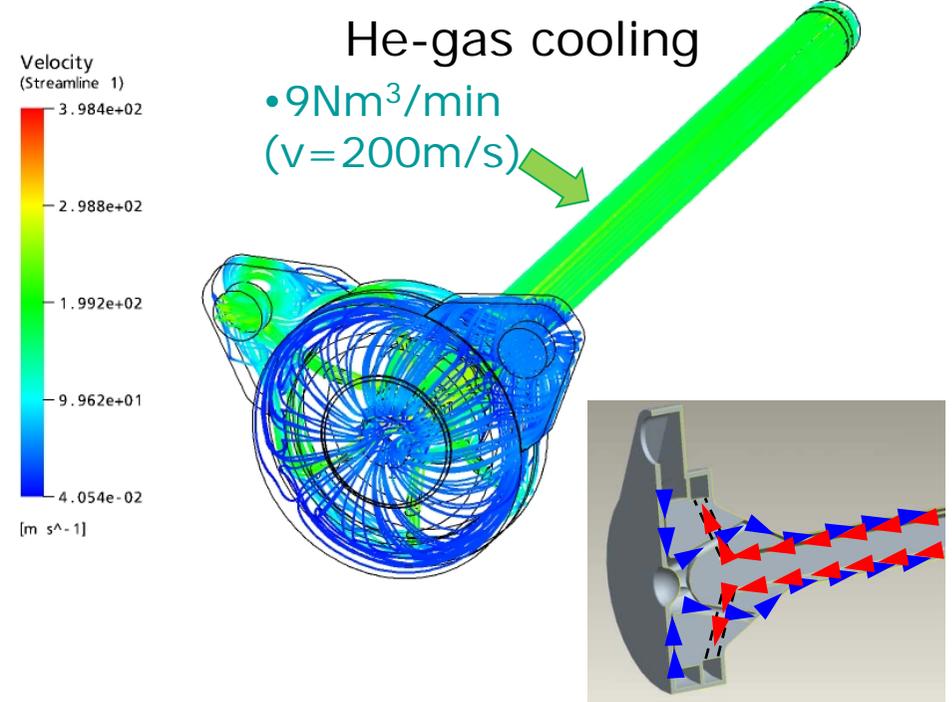
# Effects of elevated temperature, fatigue & radiation damage



~200MPa  
@750 kW  
~50MPa  
@320kW

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)



$\Delta T \sim 200K$   $\sim 7MPa$  (Tensile strength 37MPa)

# Proposed new study items

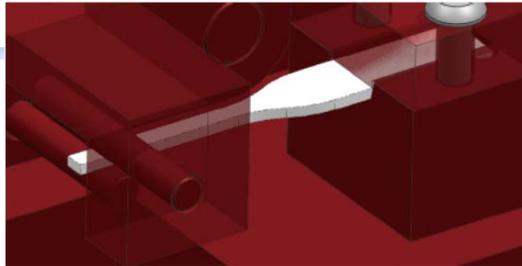


- Studies on high-energy proton irradiation on Titanium alloy up to a few “DPA”
  - Material: Ti-6Al-4V Grade-5 / Grade 23 ELI
  - Environment: Helium (Vacuum )
  - Temperature : ~80°C (Beam window) 150°C (Target)
- 1. Design new irradiation run at BLIP in US-FY2016~2017
- 2. Develop a compact Fatigue Testing Machine (FTM), to study fatigue effect for irradiated specimens in a hot-cell (BLIP beam-line)
- 3. PIE for the OTR foils (PNNL for micro-optical studies + UK for micro-mechanical studies)
- ✓ Activities supported as one of KEK’s US-Japan cooperative research programs, since JFY2014

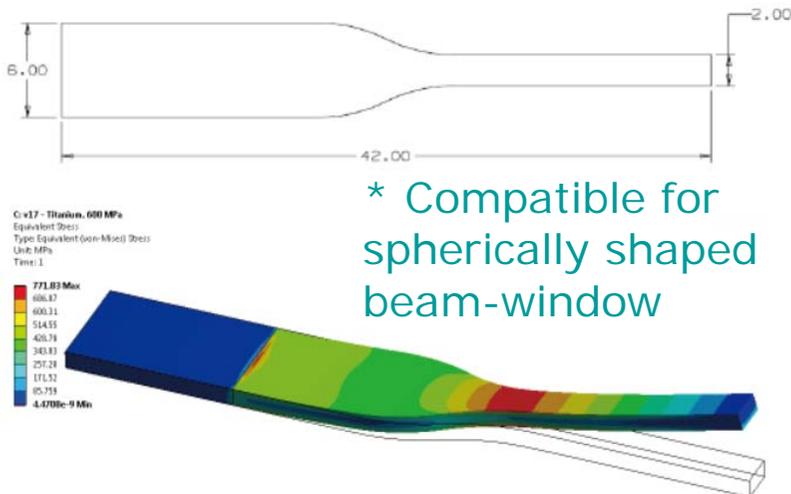
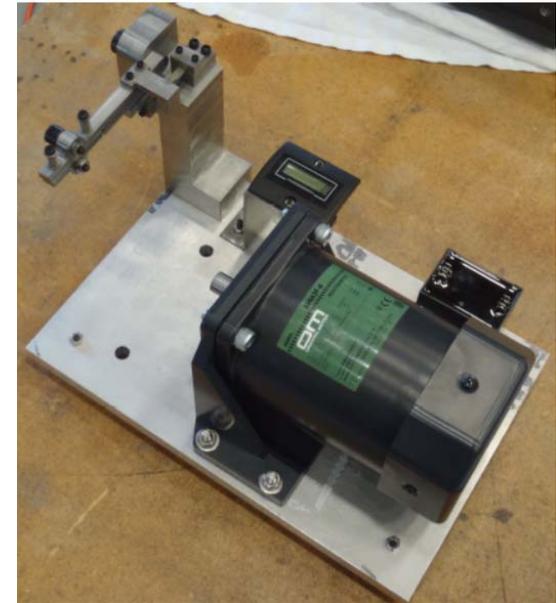
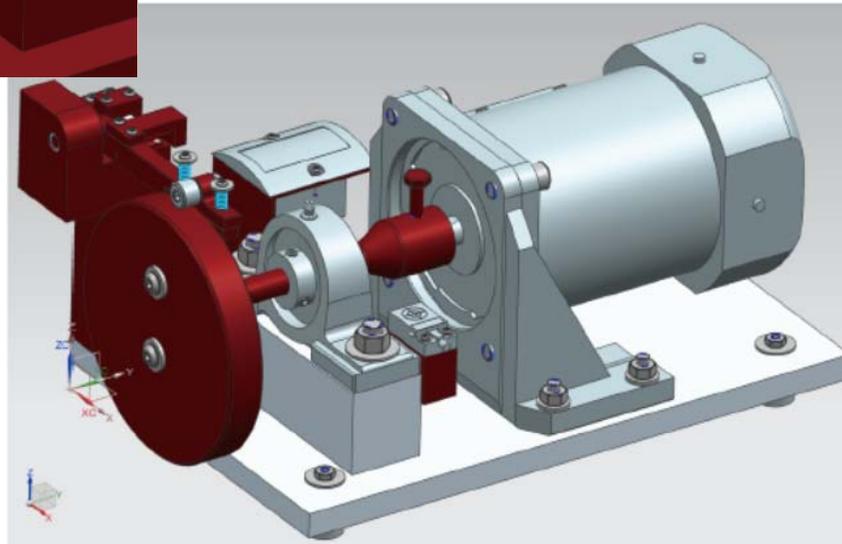
# Fatigue Testing Machine (FTM)



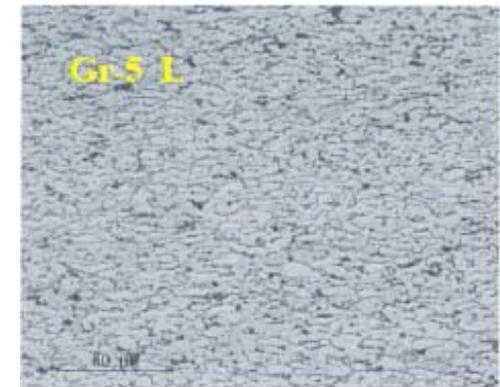
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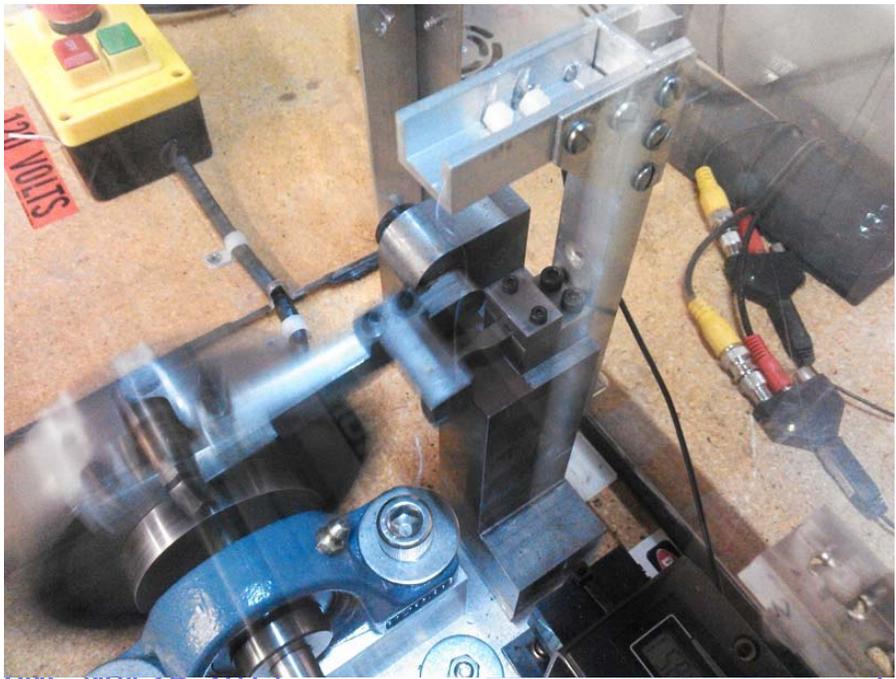
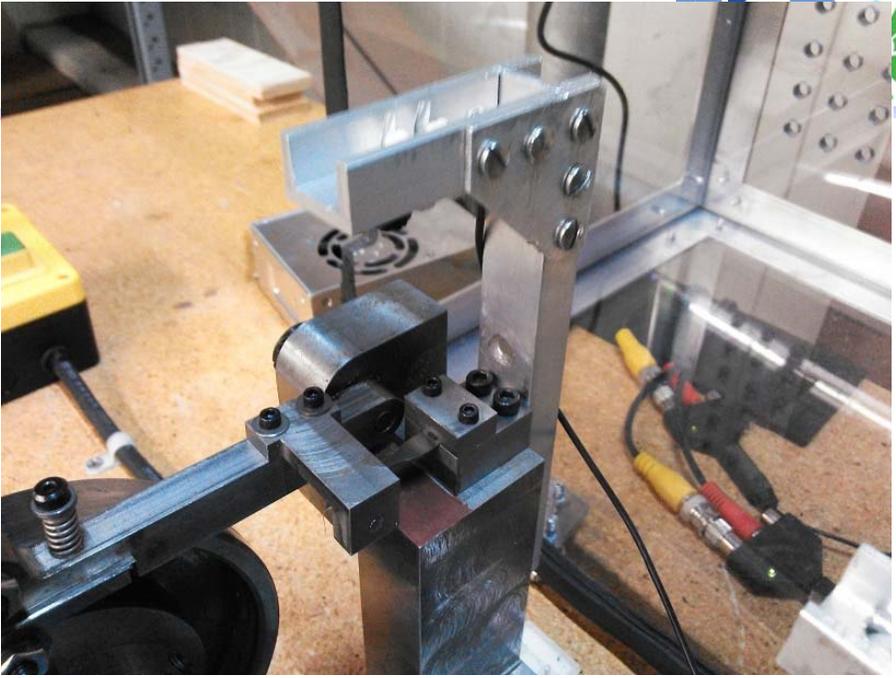
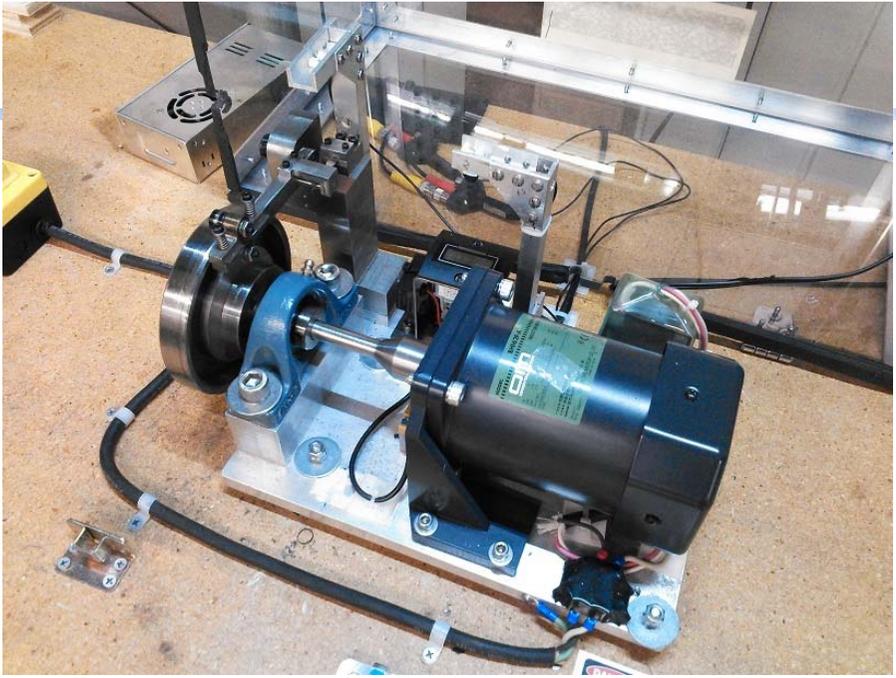


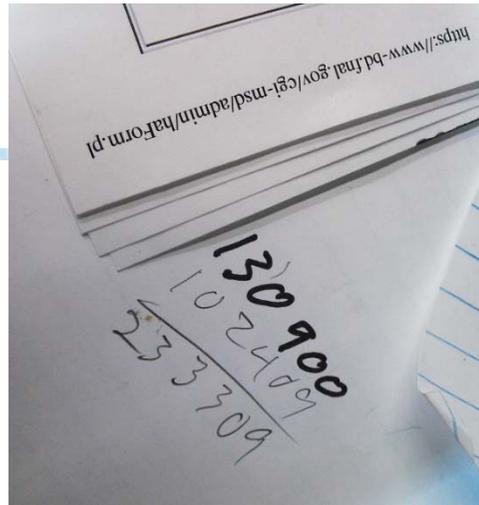
1,500 rpm,  $10^7$  cycles / 4.6 days



Specimen production & a few pre-irradiated tests



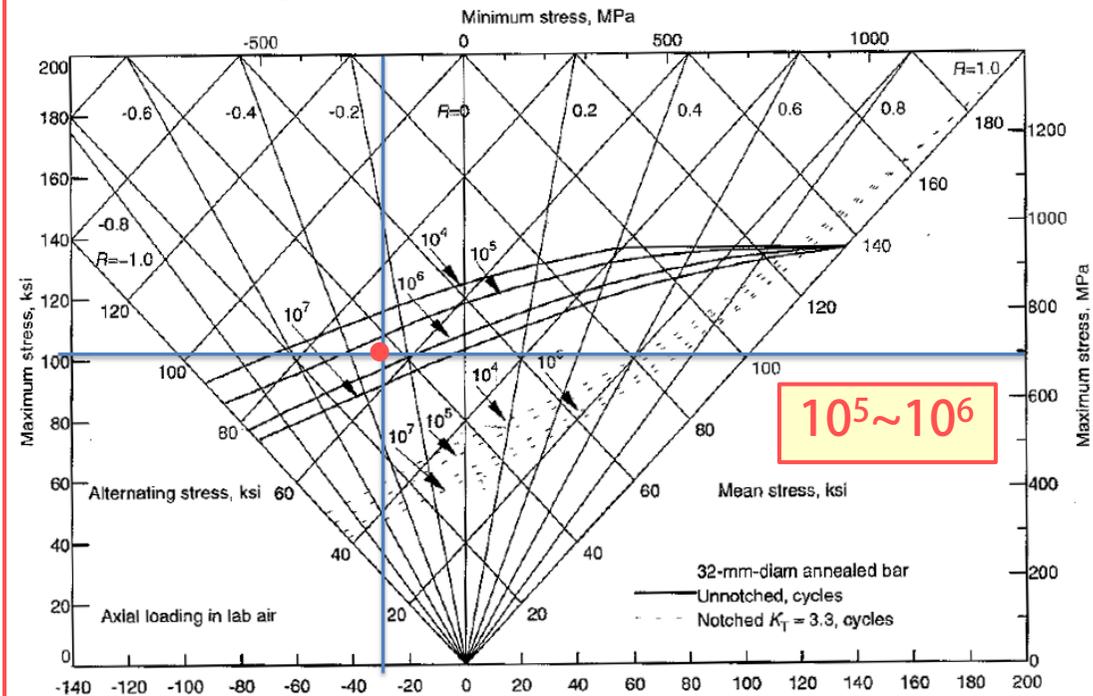


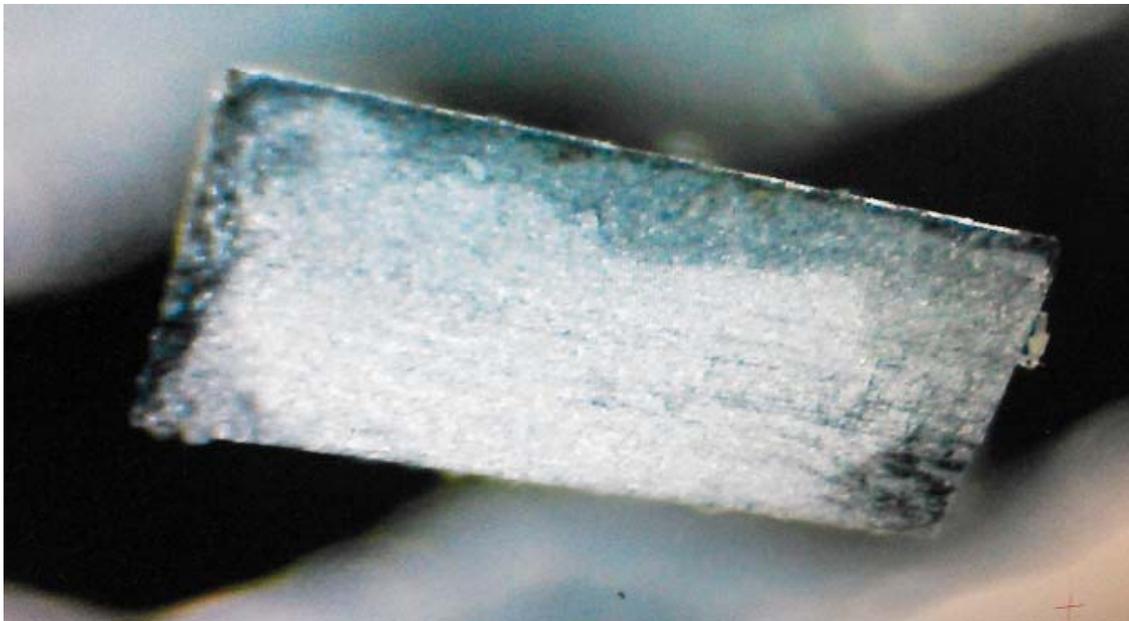
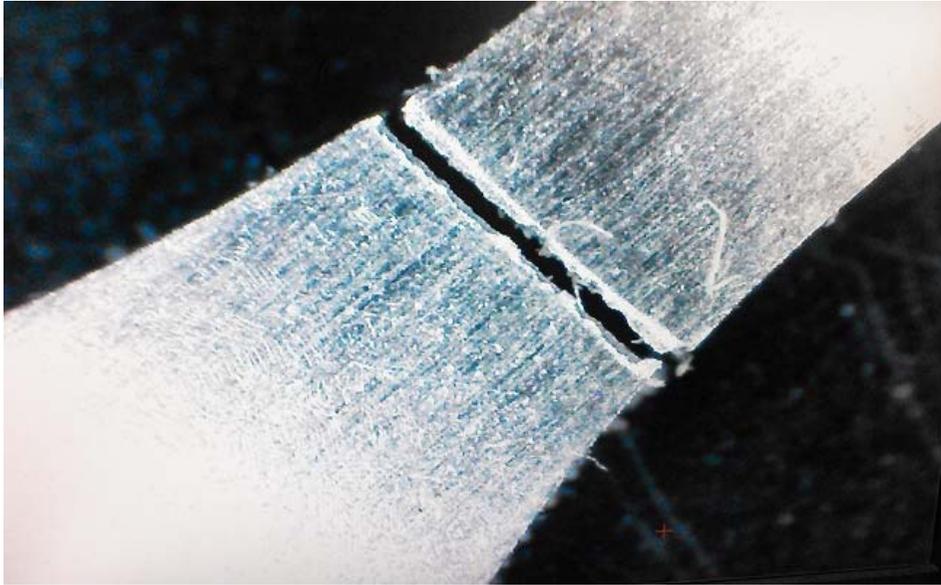


## Ti 6-4 fatigue behavior

688 MPa  
-190 MPa

Ti-6Al-4V: Constant-life diagram for ( $\alpha + \beta$ ) annealed bar

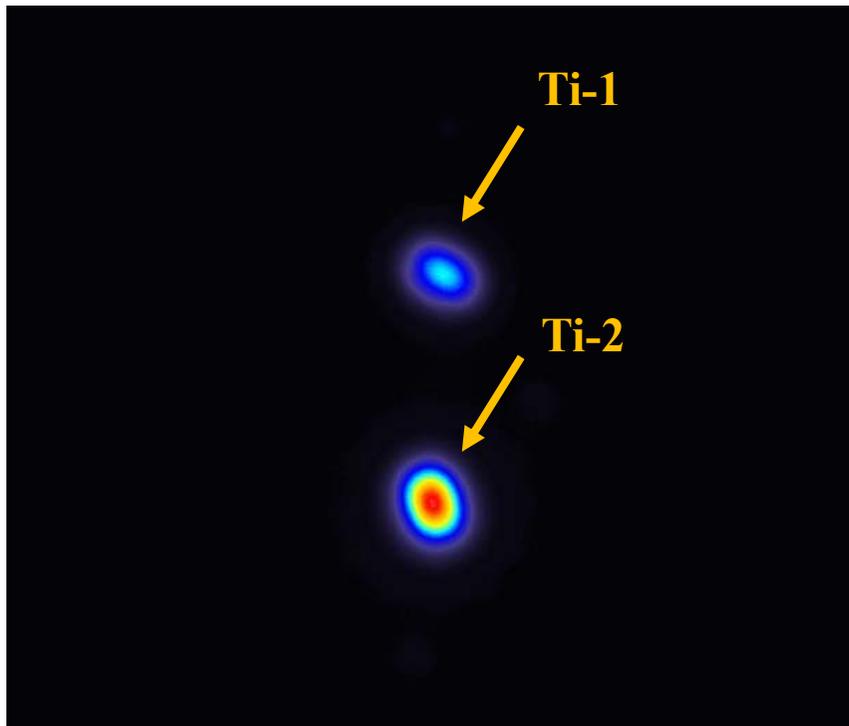




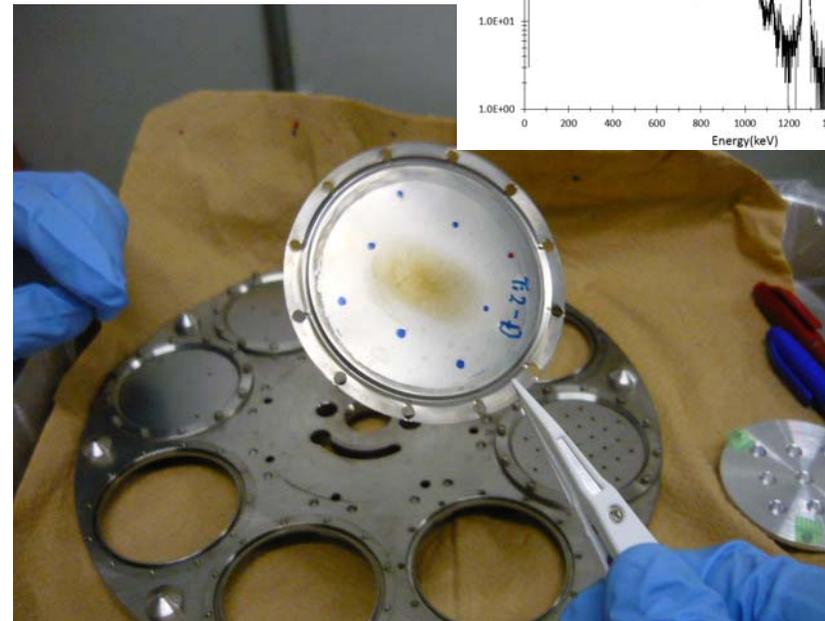
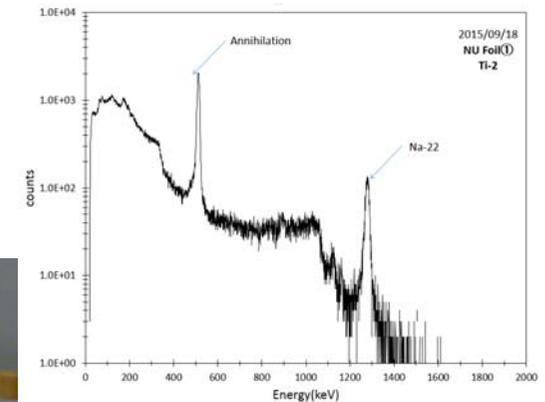


# Disassembly of 1<sup>st</sup> OTR foils for Post Irradiation Examination at PNNL

- World-most irradiated Titanium alloy ( up to a few DPA )
- Disassembly work has been done successfully on Sep.10
- Arranging shipment of irradiated material (level is low)



Dosimetry : Na22  
A few MBq



# PIE Activities in J-PARC



- There was a target/window session at HINT WS at J-PARC, where PIE issue caused hot discussion. <http://j-parc.jp/pn/HINT2015/>
  - ◆ J-PARC director asks us (Chris/Ishida) to organize VC meeting to introduce the RaDIATE activity to him
- Oct.21 VC at director's room connecting to Patrick
  - ◆ We all understand the importance and uniqueness on of the RaDIATE activities, to start discussion as whole J-PARC.
  - ◆ To make immediate budget application to MEXT (?)
- Oct.22 1<sup>st</sup> J-PARC inter-facility meeting:
  - ◆ MLF + MUON + Neutrino + hadron + Safety + director
  - ◆ Contact: Makimura + Ishida
  - ◆ Named as J-PARC "PIE club" by Makimura-san

# PIE club discussions and scopes



- Promote RaDIATE activities at J-PARC
  - ◆ BLIP beam tests
  - ◆ OTR / Beam window PIE at PNNL/UK
- Possible activity items at J-PARC:
  - ◆ Obtain license to produce RI at J-PARC
    - ▶ Transp. from MLF to RFEF
    - ▶ Transp. from J-PARC to PNNL/UK
  - ◆ PIE MLF target / window samples at Reactor Fuel Experimental Facility (RFEF)
  - ◆ Non-destructive thermal conductivity measurement
  - ◆ Make new irradiation facility at LINAC before dump
  - ◆ TIARA (Ion irradiation facility at JAEA Takasaki)
- PIE at IMR Oarai w help of Prof. Kohyama (?)

# PIE club budget requests



- US-JP cooperative program + application to other sources
- 2 primary applications to MEXT for JFY2016 budget (Apr.2016~)
  - ◆ RaDIATE Ti-alloy studies (0.5oku/3years)
  - ◆ SiC/SiC composite
- Need to make good organization through inter-facility basis (PIE club)
  - ◆ Application in Oct. 2016 for JFY2017
  - ◆ UK-Japan Civil Nuclear Research Programme
    - ▶ EPSRC(UK) – MEXT(Japan)
    - ▶ Good to promote micro-mechanical studies ?
  - ◆ Ask involvement of IMR Oarai ?