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Thermal Stress Induced in Solid Targets by Electron or Photon beams

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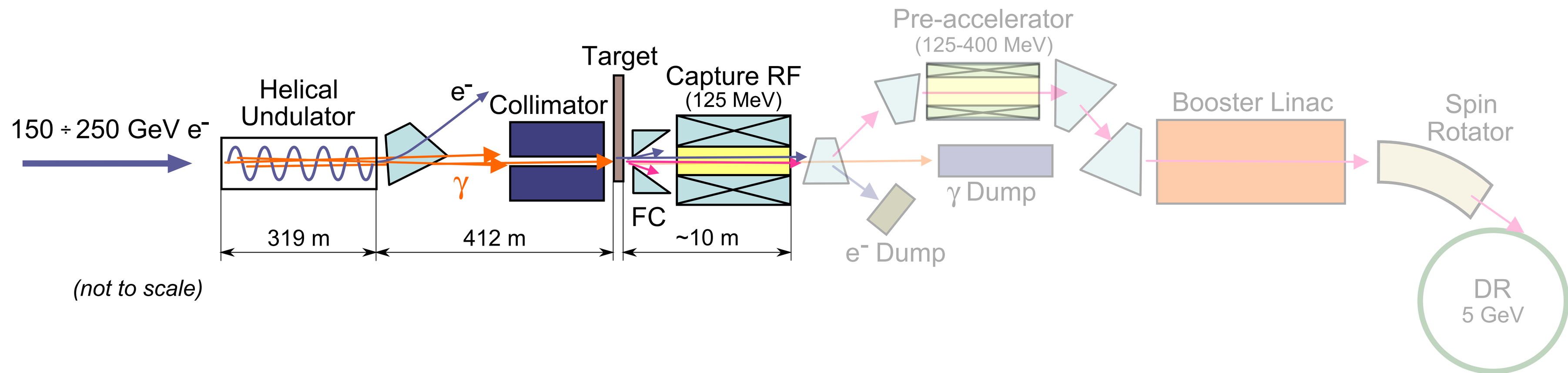
DESY

Solid targets are widely used for particle sources. However, positron sources of future high-energy linear e+e- colliders are very demanding since almost two orders of magnitude more positrons are needed than in past colliders. The e+ production target but also other components of the source experience high peak load as well as high cyclic stress. With ANSYS the static and dynamic load at the target and source components is simulated to develop a reliable design.

Scheme of Positron Source



Positron Source Parameters

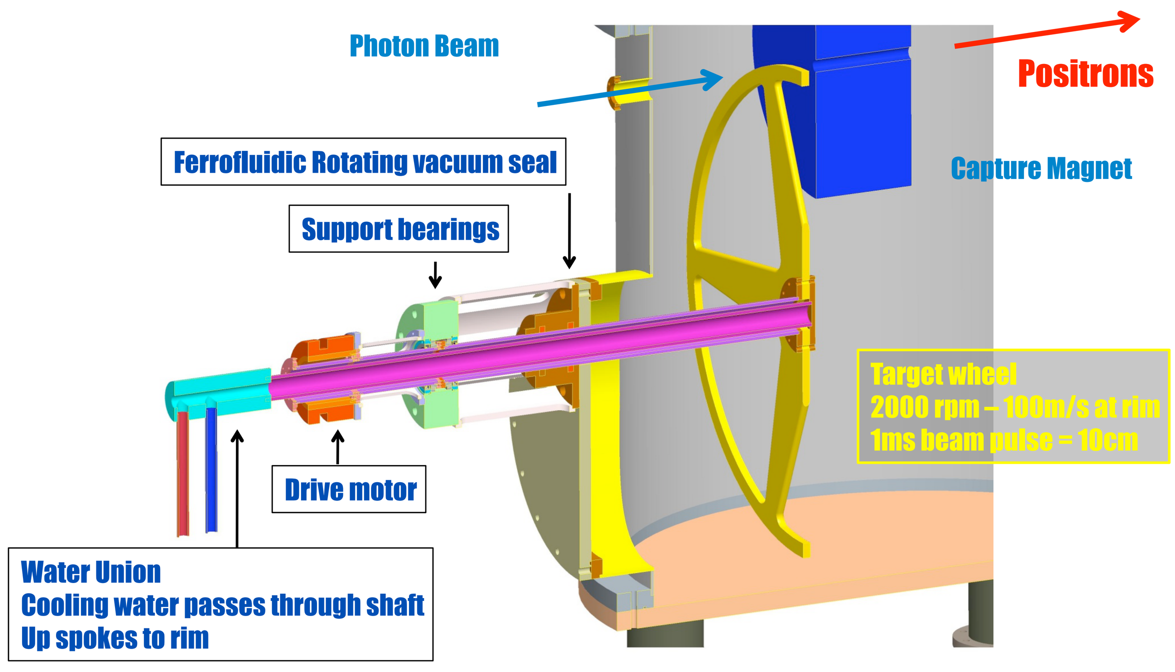
Positron yield (at DR): 1.5 e^+/e^-

Electron Beam
- e^- energy: 120 - 250 GeV
- Number e^- per bunch: $2\cdot10^{10}$
- 1312 bunches/pulse, 5 Hz
- Bunch spacing: 554 ns
- Pulse length: 0.727 ms

Helical SC Undulator & Photons
- Up to 231 m active (magnet) length
- B = 0.86 T, K = 0.92, 11.5 mm period
- Average photon power: up to **~150 kW**
- Photon energy: ~7 - 40 MeV
- rms spot size on target: ~1 mm

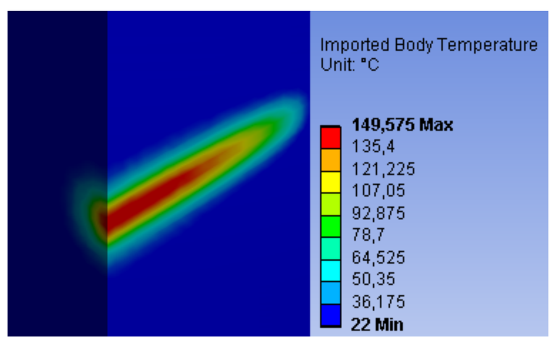
Target
- Ti6Al4V, 0.4 X_0 (1.4 cm) thickness
- Diameter: 1 m
- Rotation speed: 100 m/s (2000 rpm)
- Average heat load: up to **~7 kW**

ILC Target Wheel Experimental Setup (LLNL)

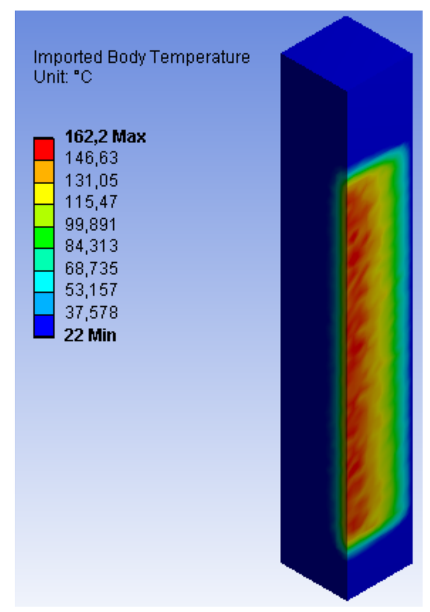


Temperature Distribution in Target after 1 Pulse

Scaled (per Bunch) Temperature Profile



Temperature of Moving Target (100 m/s)



Simulation Workflow

1. Geant4 + Bmad: beam tracking from undulator to Damping Ring (DR) to define the length or field of undulator required for 1.5 e+/e- at DR → **Photon spot size** on target & **number of photons** and their **energy and positions**
2. FLUKA: **energy deposited in target** by primary photon
3. ROOT script: conversion of deposited energy into ANSYS **internal heat generator** format
4. ANSYS Transient Thermal: imported heat generator → **temperature rise** per beam pulse

5a. ANSYS Static Structural: imported body temperature → ***"static" thermal stress***

and

5b. ANSYS Explicit Dynamics: pre-stressed initial conditions (from static structural) → ***dynamic thermal stress***

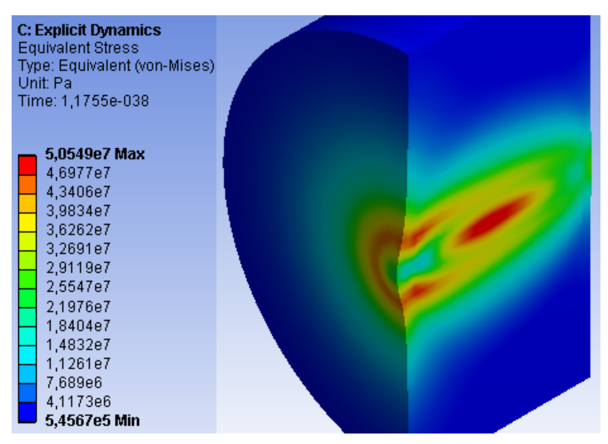
or

5c. ANSYS Transient Structural: imported body temperature → **dynamic thermal stress**

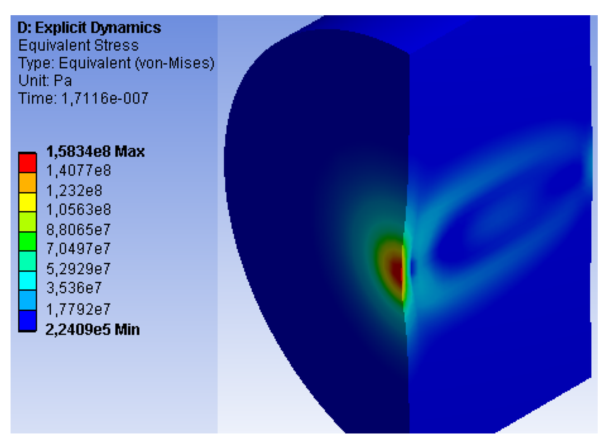
6. ANSYS Fatigue Analysis: safety factor estimations for aging material due to alternating temperature/stress and radiation damage (to be done)

Thermal Stress Induced in ILC e^+ Target by Undulator Photons

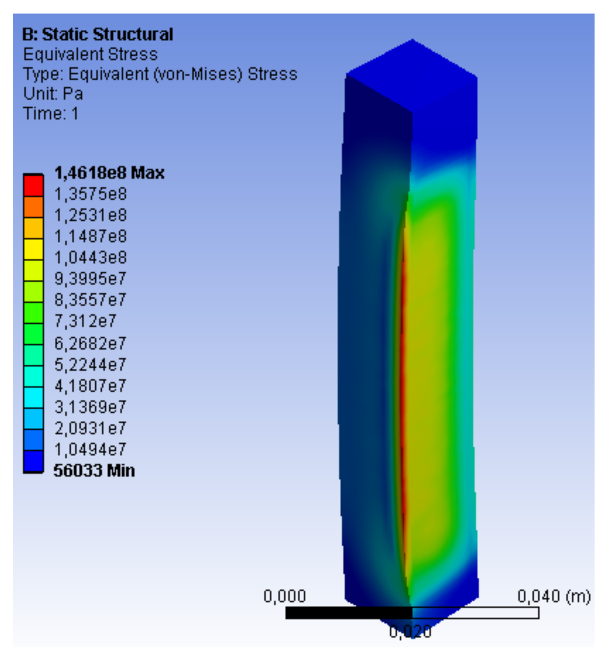
Dynamic Stress at t = 0 (Pulse End)



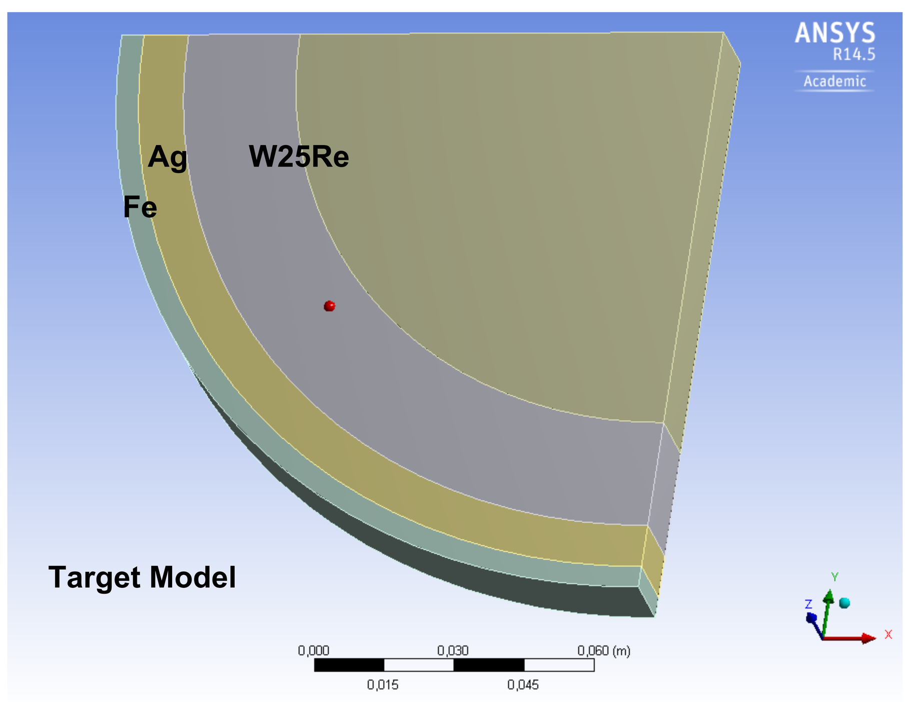
Maximal Dynamic Stress



"Static" Stress at Pulse End



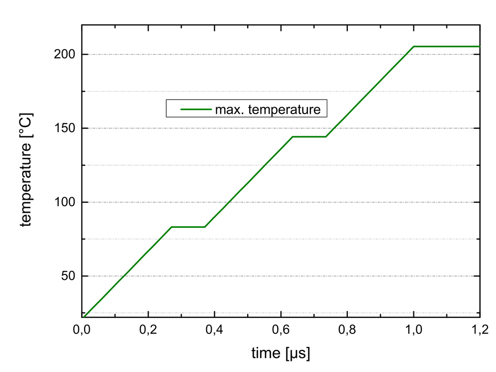
Stress evolution and load cycles in a conventional e+ target for the ILC



Target Material: 4 X0 W25Re (1.4 cm)
e^- beam spot size: r = 4mm (σ)
Time structure:
- 1 pulse <=> 2640 bunches
- Pulse stretched to 63 ms
- 1 mini-train = bunches
- 1 triplet = 3 mini-trains
- 1 pulse = 20 triplets

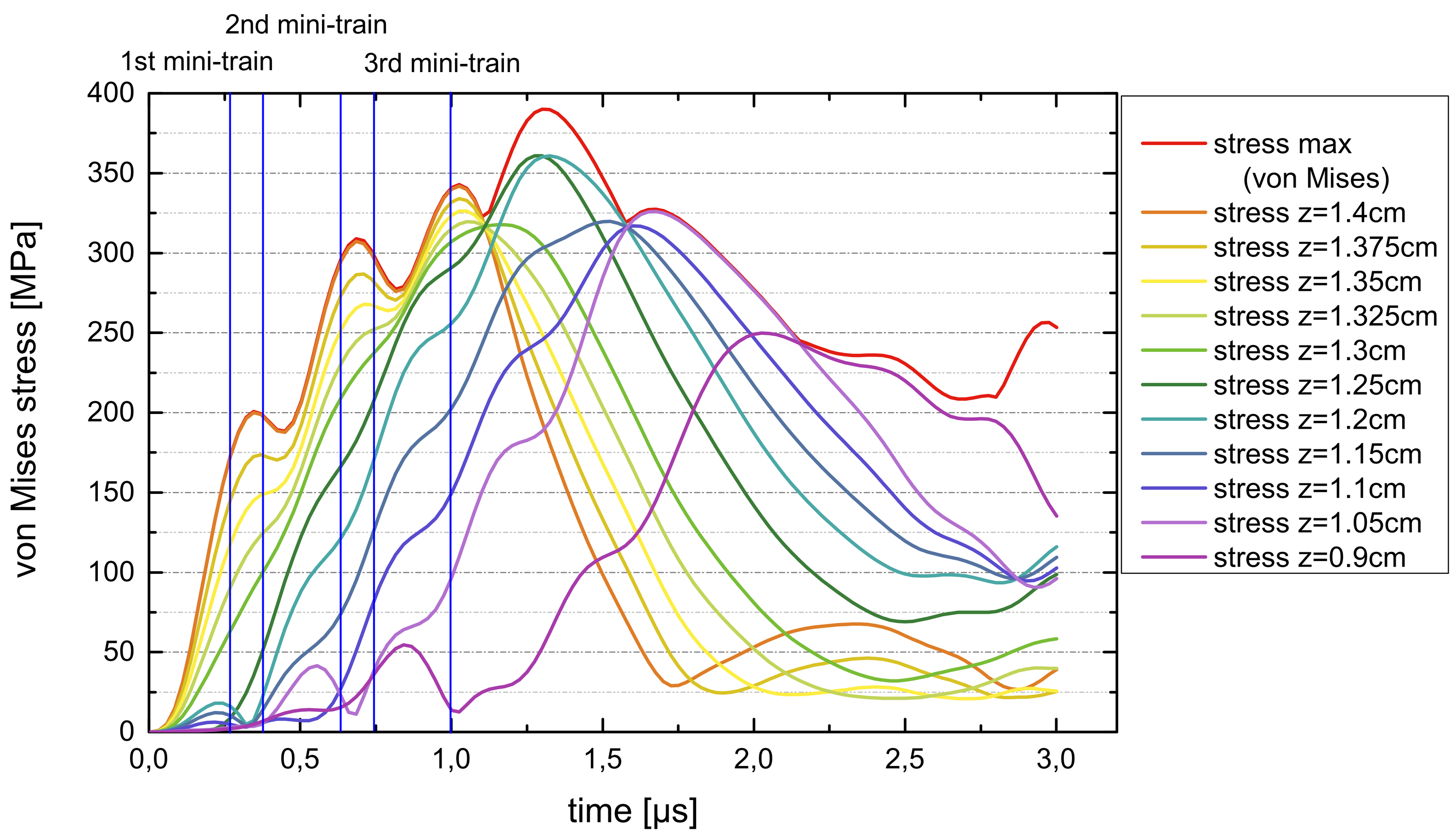
Target wheel
- Radius = 13.5 cm
- Rotation speed = 5 m/s

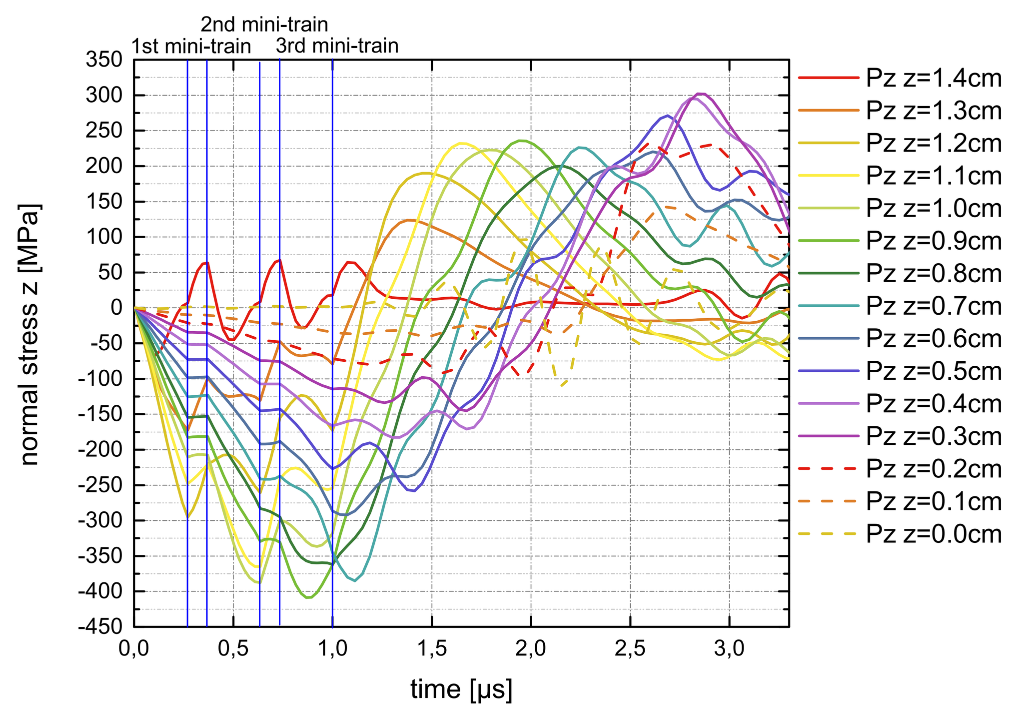
Energy deposition in target: 35 kW
(see Omori et al., NIMA A672 (2012) 52)

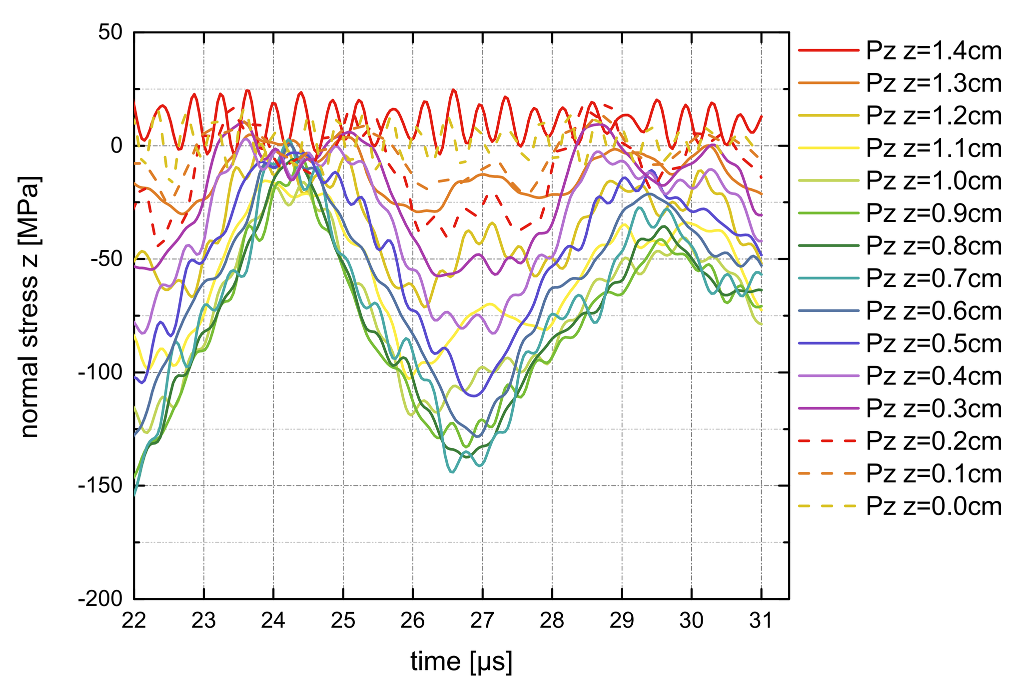


Temperature rise per triplet (1µs): 210K
Stress waves in target:
- Δσ (v.Mises) ~ 400 MPa
- Δσ (normal) ~ 630 MPa

Load cycles with Δσ (normal) ≤ 150 MPa remain after one triplet and will effect fatigue behavior







Limits for material load

Important: cyclic long-term load limit
short-term load limit (immediate)
} **To avoid damage limits must not be exceeded**

Reliable benchmarks under beam irradiation required
Depending on beam spot size, intensity, energy, target thickness

W25Re:
SLC e+ target, long-term operation
[Stein et al., Conf.Proc. C0106181 (2001) 2111
Sunwoo et al., SLAC-TN-03-036]
- **ΔE ≤ 35J/g**
- **ΔT ≤ 210K**
- **Δσ (v.Mises) ≤ 550MPa**

Ti, Ti alloy:
long-term tests with cyclic load still missing
Short-term (15µs):
KEKB exit window test experiment
[Mimashi et al., IPAC2014, MOPRO024]
Damage of 1mm plate obtained for
ΔT ≥ 600K

Future plan:
Simulation studies of peak stress, dynamic stress evolution and long-term behavior are started and ongoing.
Experimental tests are planned.

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