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Conventional and Undulator Beam Target Thermal-Structural Analyses

Workshop on Positron Sources for the ILC Daresbury Laboratory, Warrington, UK
April 11–13, 2005

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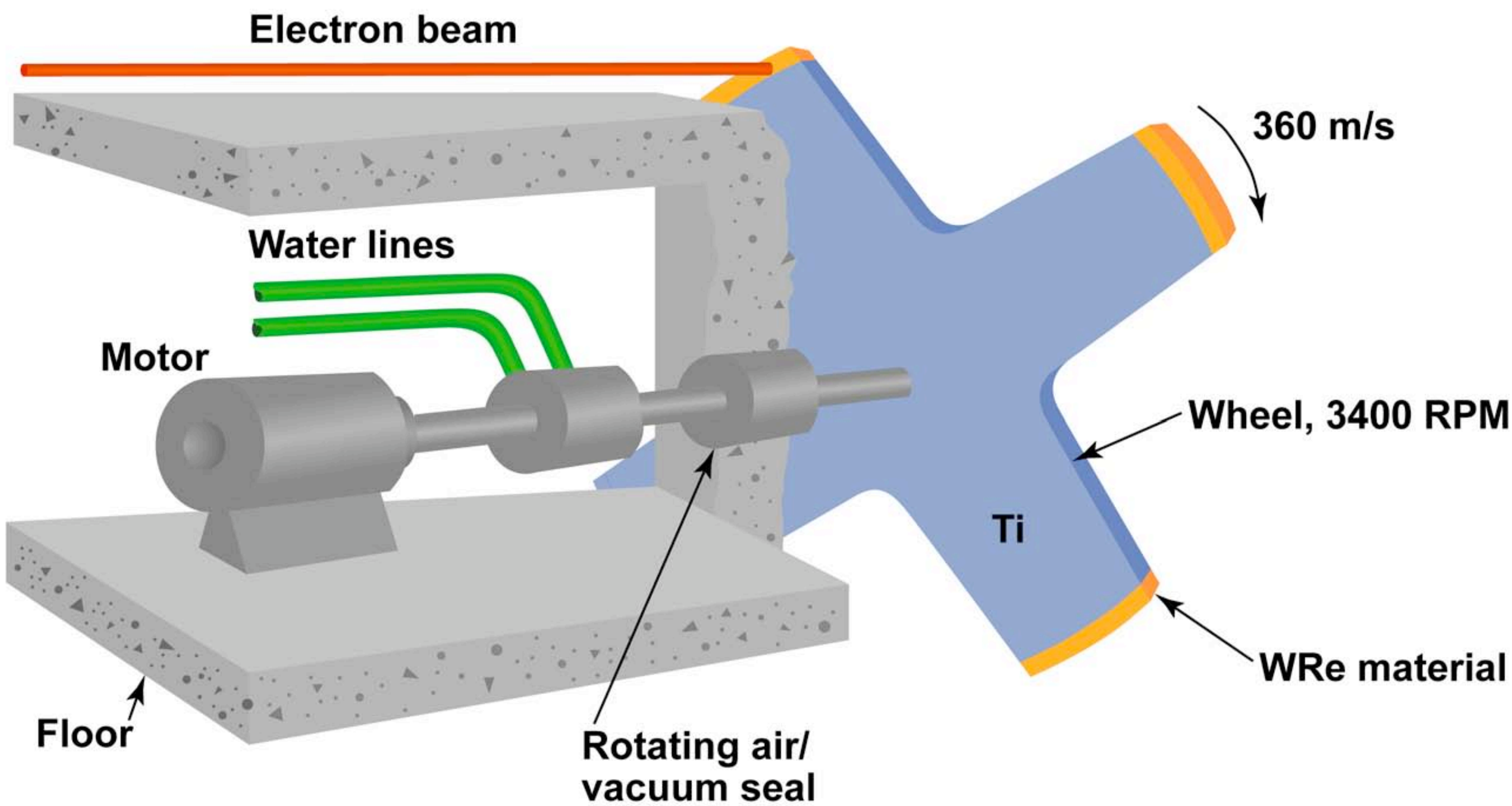
Conventional electron beam target design

- **Target material is W23Re**
- **Target is a wheel that rotates with a tip speed of 360 m/s**
- **Target thickness is 4.5 RL (1.5 cm)**
- **Target is cooled with water in flow channels**
  - **Water enters along a rotating shaft and flows radially to WRe target at perimeter of the wheel**
- **Target wheel shaft penetrates to adjacent air space. A rotating vacuum seal maintains vacuum.**

Conventional source target system layout

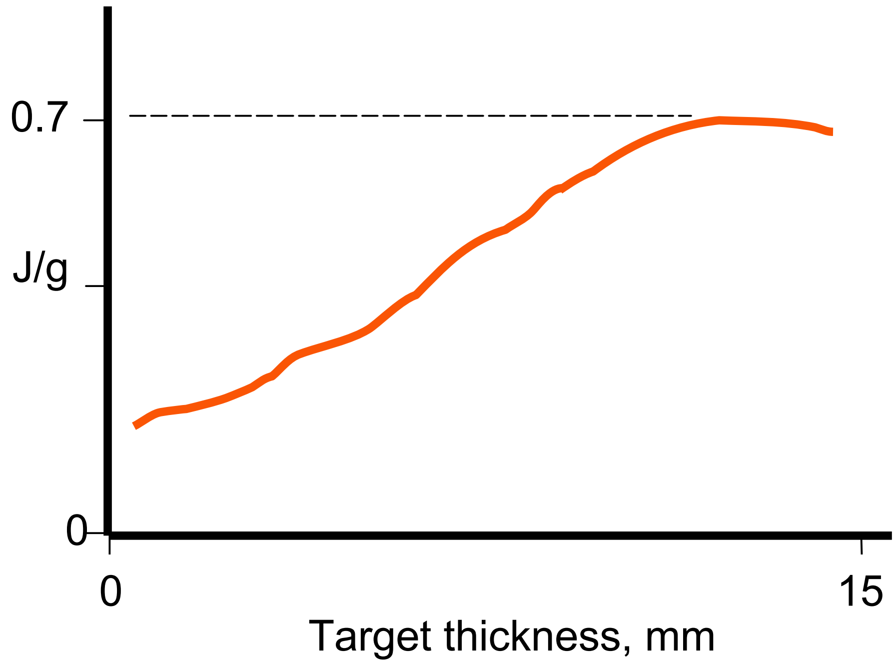


Conventional electron beam parameters

- 5 pulses/second
- 2820 bunches/pulse (337 nano-seconds bunch time separation)
- $2x10^{10}$ electrons/bunch
- Electron energy is 6 Gev
- Beam spot radius is 2.0 mm
- Energy deposition in target is 56 kW
- Peak energy deposition is 0.7 J/g per bunch on back side of the target (Gaussian profile)

Electron beam energy deposition along target centerline

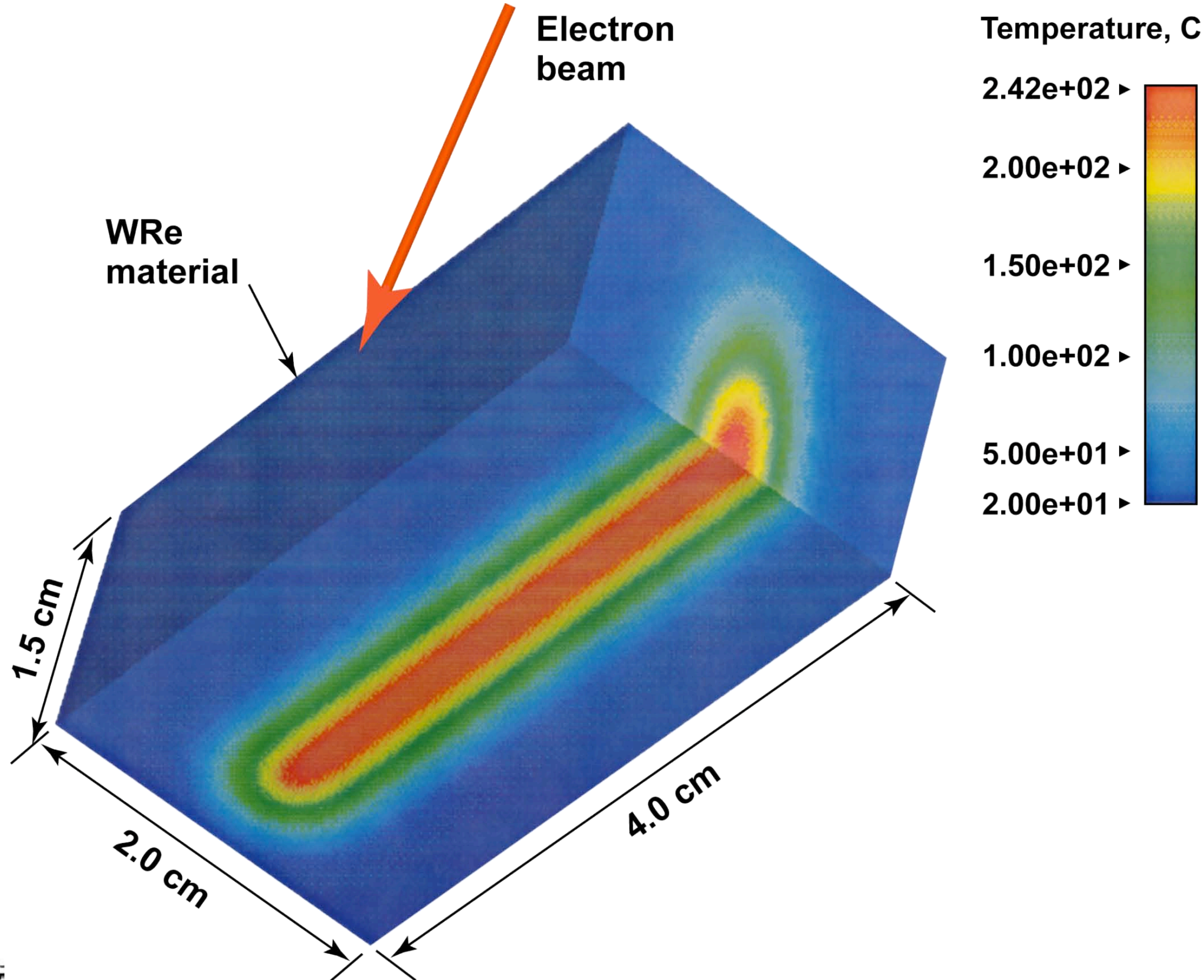
- **EGS-4 calculation**



Thermal structural analyses for WRe target

- EGS-4 code used to obtain energy deposition
- LLNL codes Topaz-3d (thermal conduction code) coupled to Dyna-3d (dynamic structural response code) used to calculate WRe temperature and stress pulse response
- As target rotates and the WRe moves at 360 m/s, the pulse heats up the WRe
  - Each pulse traces out a path 36 cm long along the perimeter of the wheel, with a peak temperature jump of 222 C
  - Figure shows the temperature response of a 4 cm long rectangular section volume of the WRe target material
- Resultant peak stress in the WRe is 90 ksi ($6x10^8$ Pa) at centerline of the beam path

Conventional electron beam target, temperature response, WRe, 1 ms pulse, 2 mm spot, 360 m/s velocity



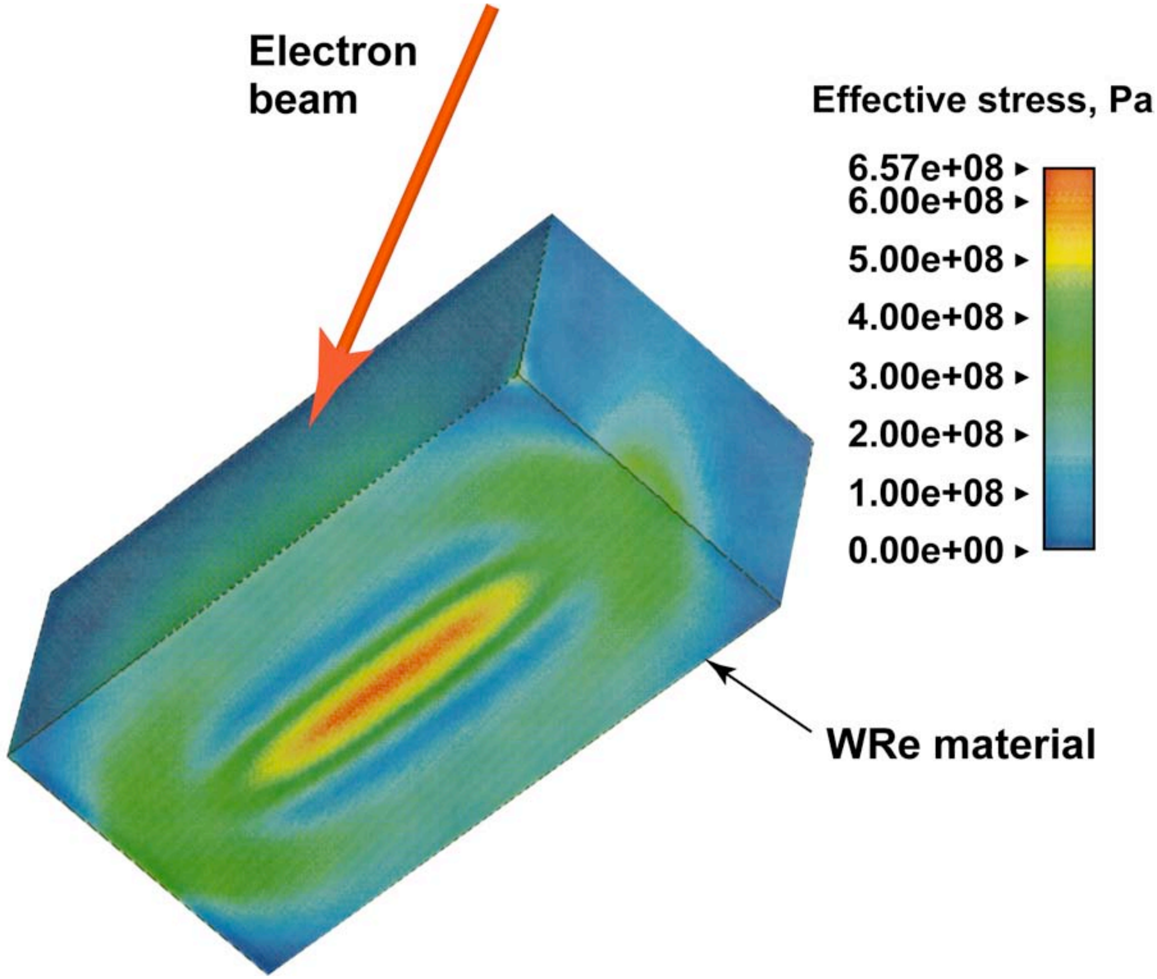
Structural thermal stress response- 90 ksi peak

- Energy deposition from the electron beam into the WRe target results in a quasi-static stress state that relaxes as the material temperature relaxes.
- Figure shows the peak effective stress due to the electron beam in a 4 cm long rectangular volume of the target material. Peak stress is reached after a few cm of beam path travel, as shown in figure.
- Effective stress, $\bar{\sigma}$, given by combination of principal stresses, σ_i, as:

$$\bar{\sigma} = \frac{1}{\sqrt{2}}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2\right]^{1/2}$$

- The peak stress in the WRe is 90 ksi ($6x10^8$ Pa) at centerline of the beam path

Conventional electron beam target structural response, WRe material, 1 ms pulse, 2 mm spot, 360 m/s velocity

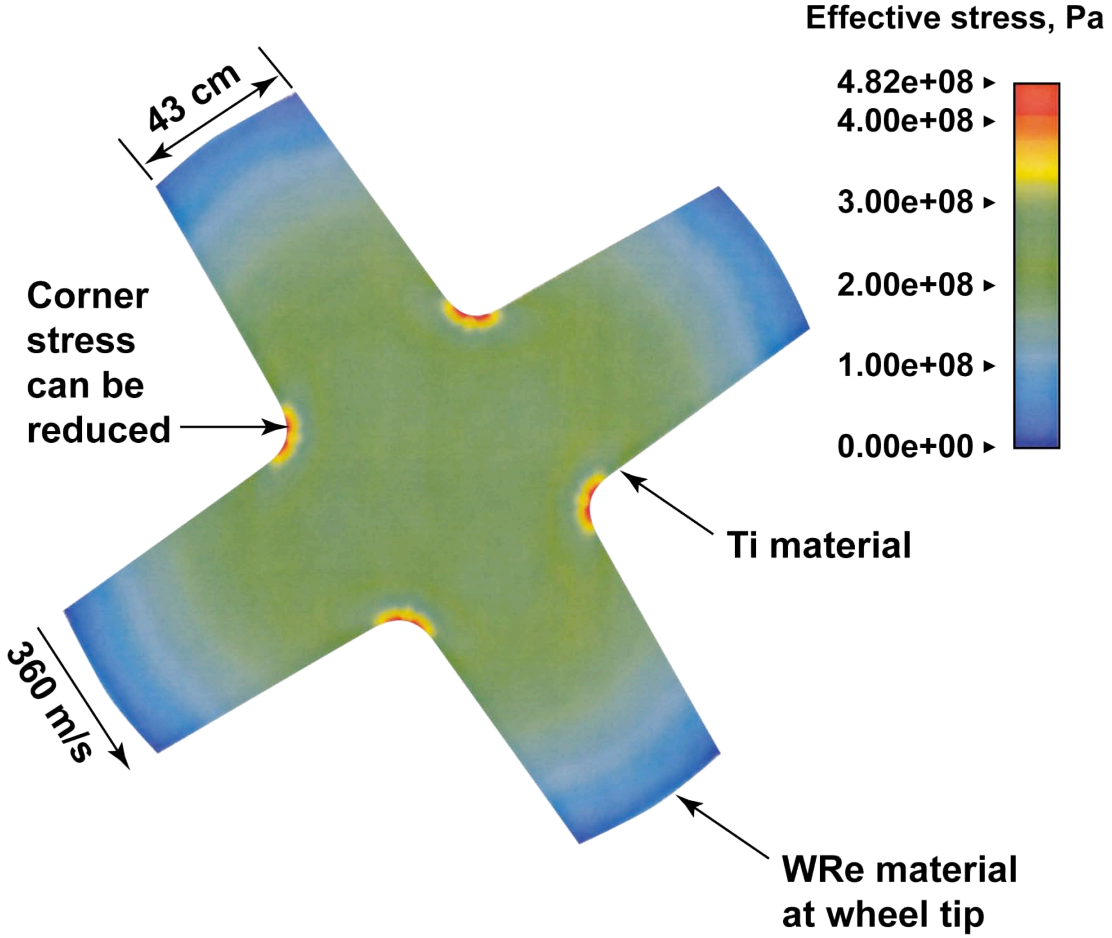


Stress in target due to rotation is acceptable

- Wheel perimeter speed is 360 m/s (3400 RPM)
- Wheel designed to be made of Ti alloy with WRe target material along the perimeter
- Peak stress due to rotation occurs in the Ti material and is low at a value of 69 ksi (4.8×10^8 Pa)
  - Maximum allowable Ti stress is 120 ksi
- Stress due to rotation in the WRe material is low at 5–10 ksi
- The wheel does not have any problems with stress due to the rapid rotation

Effective stress due to rotation of electron beam target wheel (2 m dia.) 3400 rpm

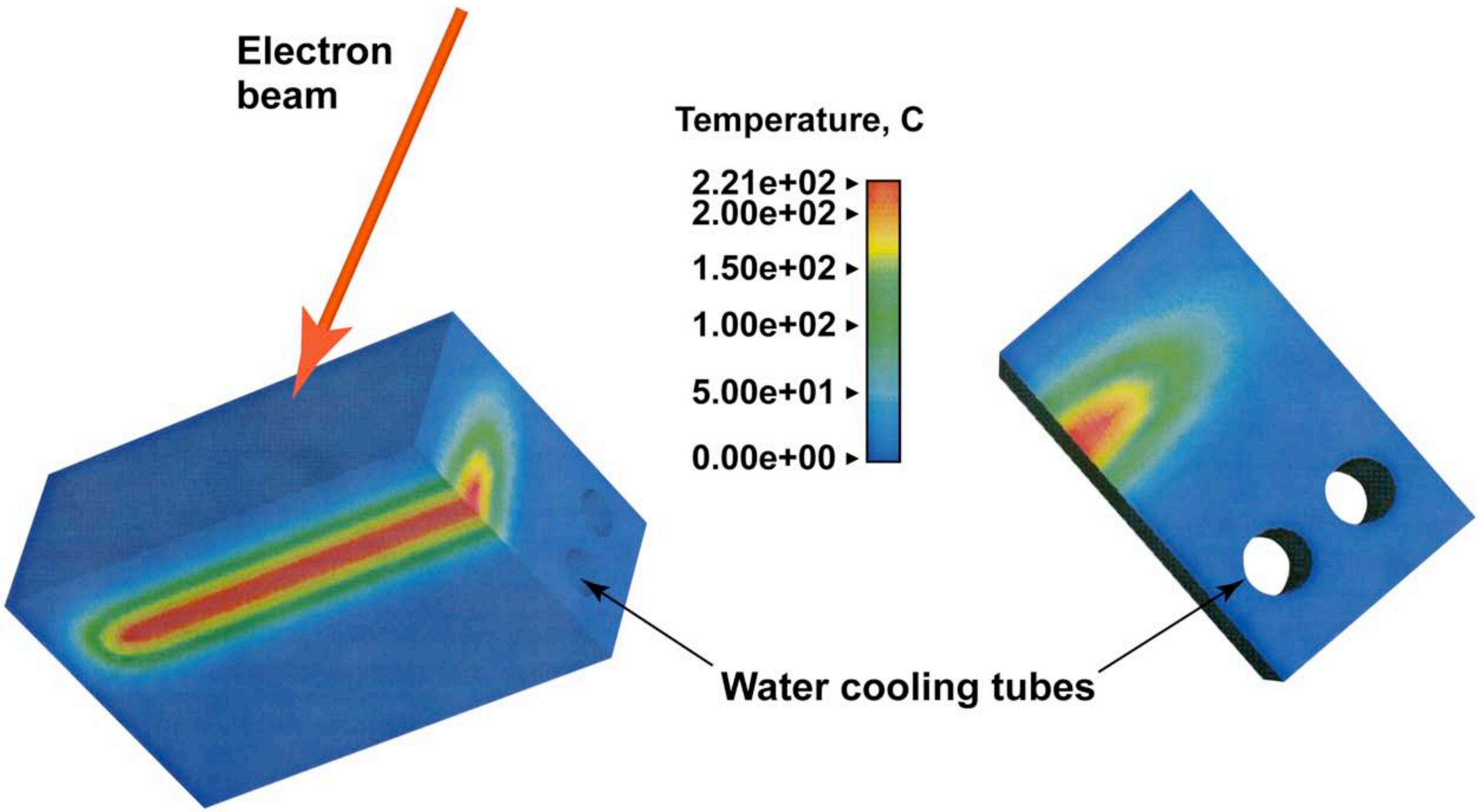
- **Maximum allowable Ti stress is 120 ksi (8.3×10^8 Pa)**



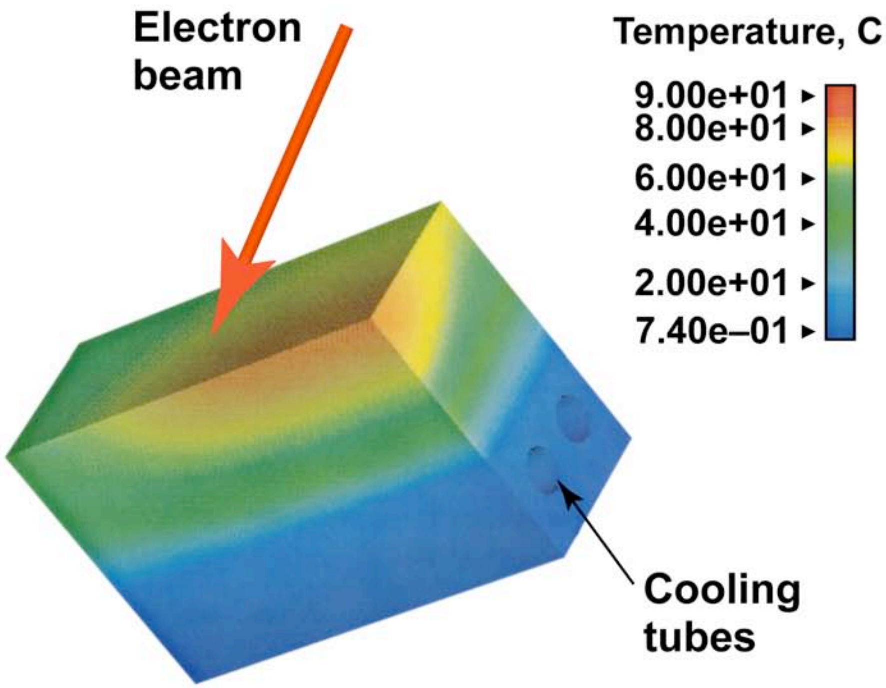
WRe target cooled by adjacent cooling tubes

- The 1 ms long electron beam pulse heats up the WRe target by 211 C and this temperature relaxes to 50 C (see figure) before another pulse strikes this part of the target again
  - Total power deposited is 18 kW
- The target is cooled with water flowing in two water channels. The water enters the target along the shaft and flows out toward the wheel perimeter.
- Water flow pressure drop along the channels is low (10 m/s water velocity)
- Water heat up flowing through the target channels is minimal (15 C)
  - Convective flow heat transfer coefficient is 20,000 W/m^2 C

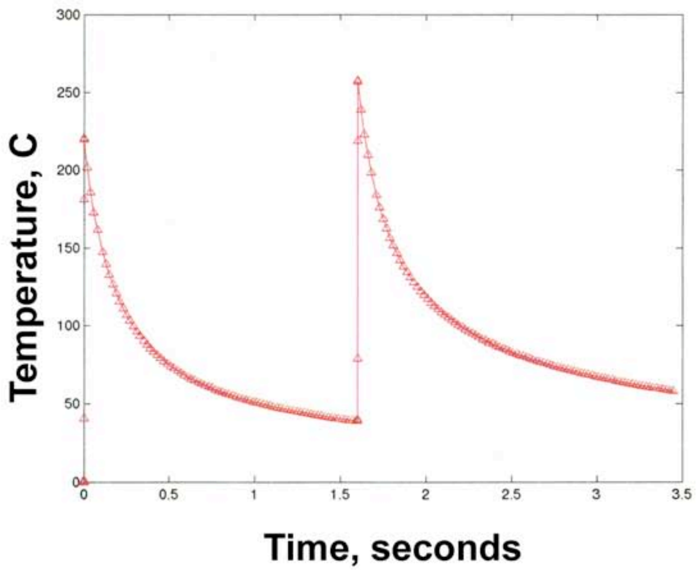
Conventional electron beam WRe target cooled by two water tubes, initial temperature due to one pulse



WRe target thermal response after two pulses



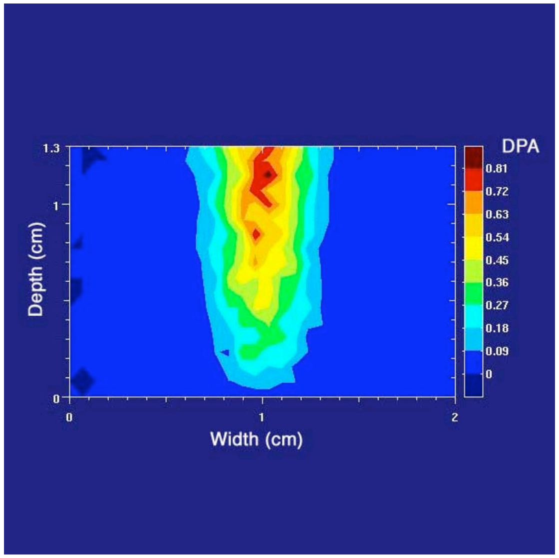
Temperature profile in WRe after two pulses.



Temperature plot of WRe for two pulses.

Radiation damage calculations in WRe wheel made

- **An acceptable damage limit is assumed to be 0.5 DPA (number of displacements per atom of material)**
- **Calculations using the FLUKA and SPECTER codes give values of 0.5 DPA after 3 years operation**



DPA profile in WRe after 5 years of operation.

Undulator Beam Target Thermal-Structural Analyses

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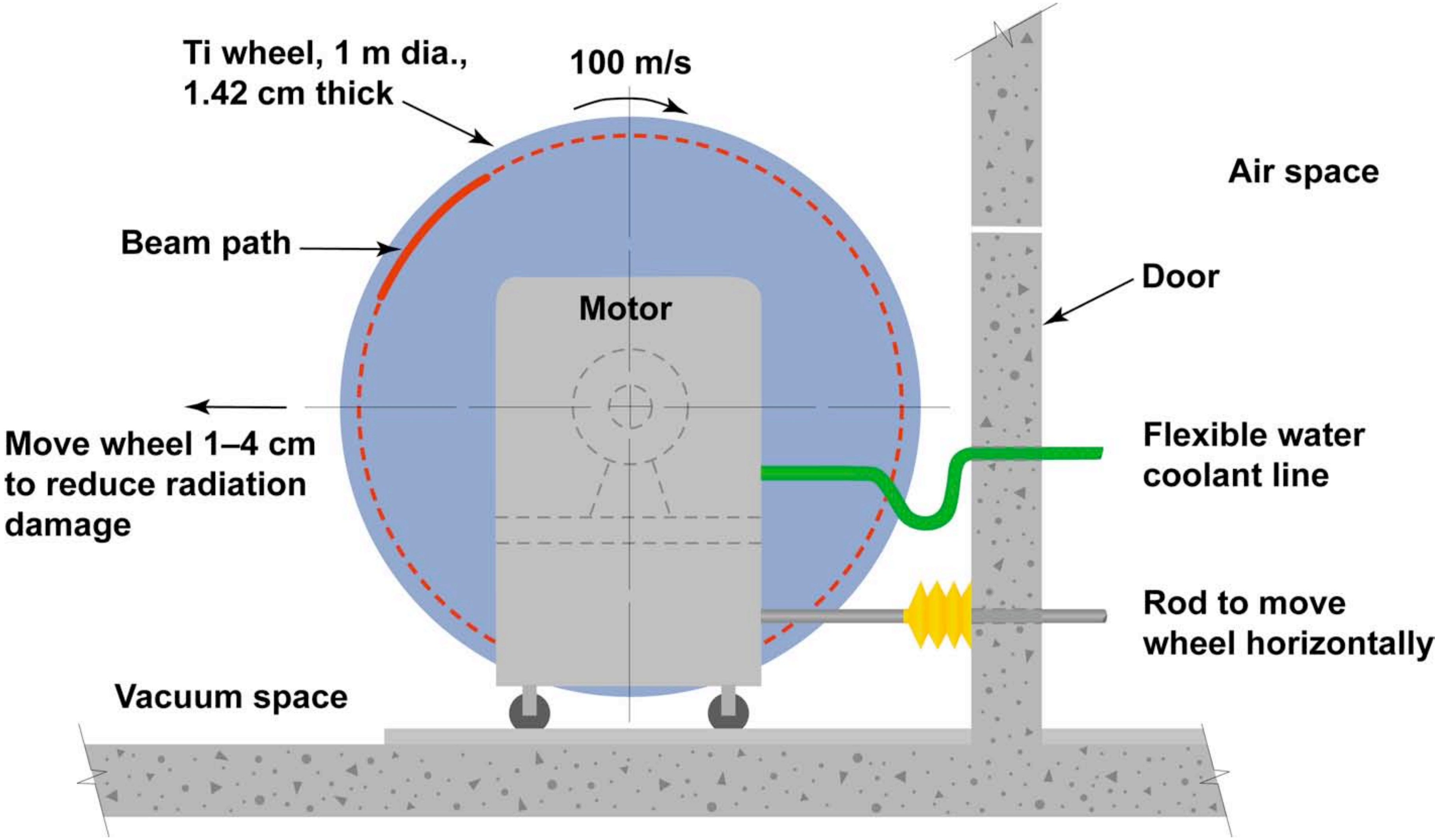
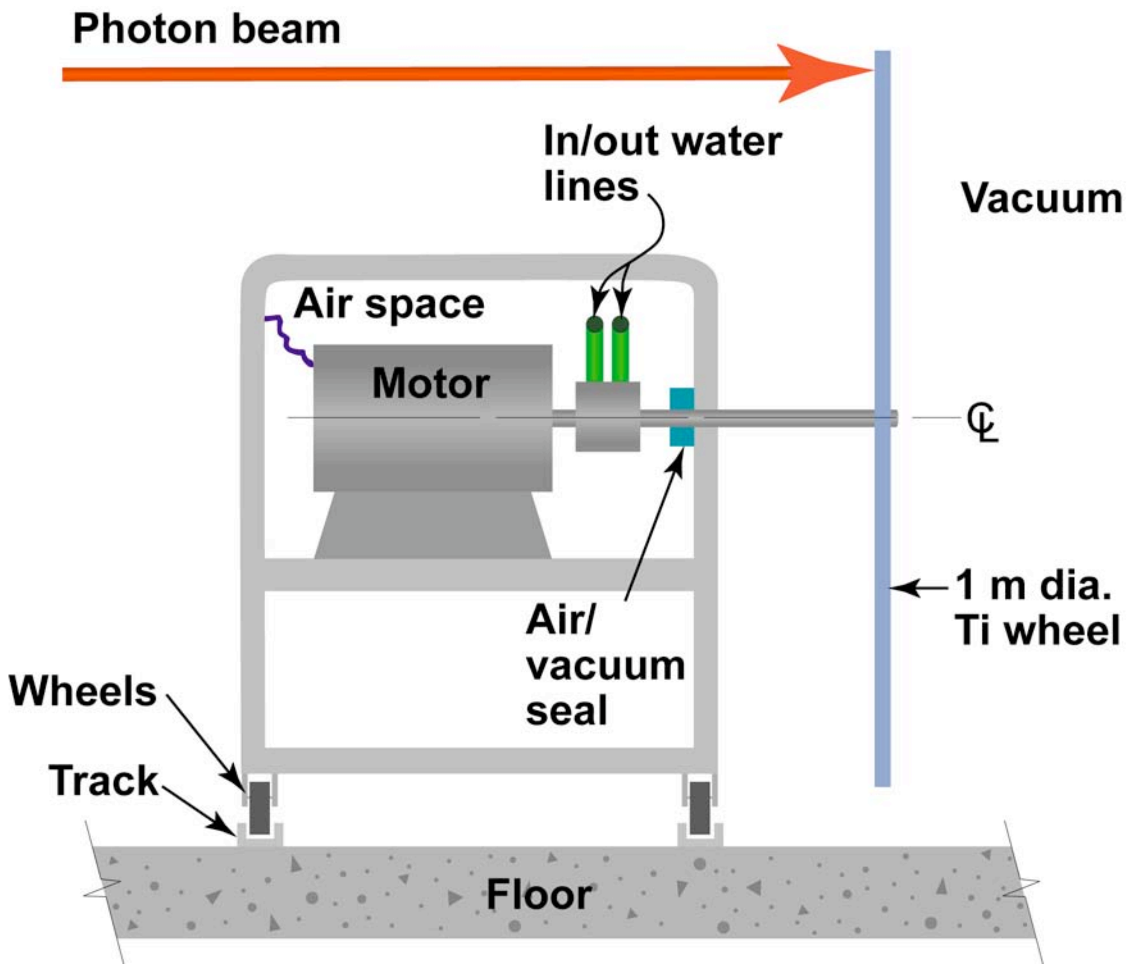
Undulator photon beam target design

- Target material is Ti alloy
- Target is a 1 m diameter wheel that rotates with a tip speed of 100 m/s (1800 RPM)
- Target thickness is 0.4 RL (1.4 cm)
- Target is cooled with water in flow channels
  - Water enters along the rotating shaft and flows radially to the perimeter of the wheel near the beam impact location
- Target wheel shaft penetrates to an adjacent air space. A rotating vacuum/air seal on the shaft maintains the target space vacuum.
- Target wheel could be 2 m diameter, with 100 m/s tip velocity. Temperatures, stress, and radiation damage would be proportionally lower.

Undulator-based photon beam target (front view)



Undulator-based photon beam target (side view)

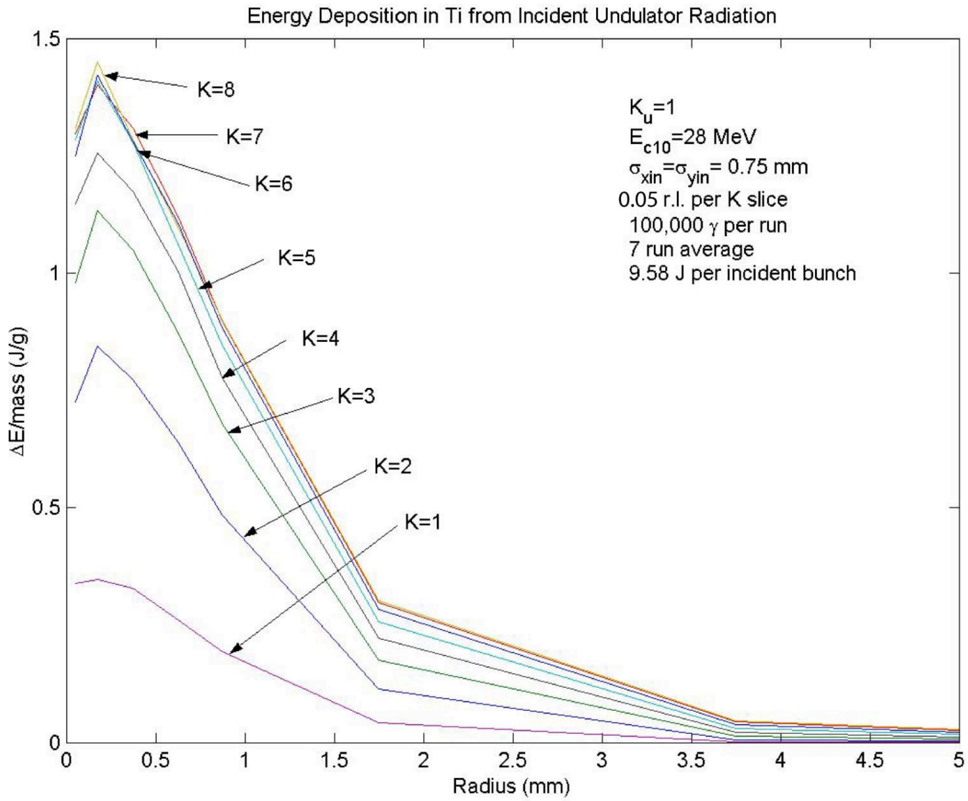


Undulator photon beam target parameters

- 5 pulses/second
- 2820 bunches/pulse (337 nano-seconds bunch time separation)
- $8x10^{12}$ photons/bunch
- photon energy is 22 Mev
- Beam spot radius is 0.75 mm
- Beam power is 220 kW
- Energy deposition in target is 18 kW
- Peak energy deposition is 1.45 J/g per bunch (9.58 J per incident bunch) on back side of the target (Gaussian profile)

Photon beam energy deposition profile in Ti target

- **EGS-4 used to make energy deposition calculation**

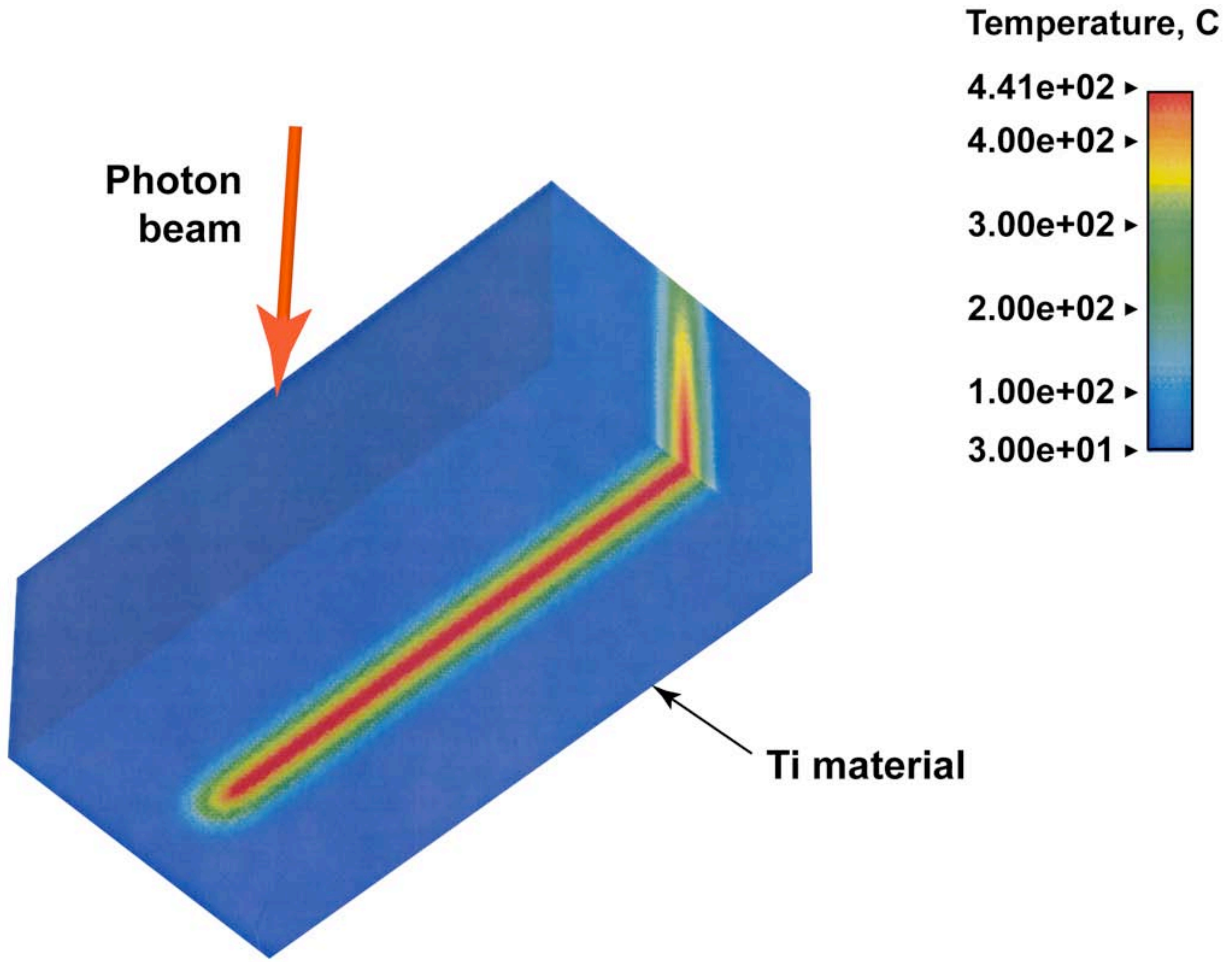


Photon beam energy deposition

Thermal structural analyses for Ti target

- EGS-4 code used to obtain energy deposition
- LLNL codes Topaz-3d (thermal conduction code) coupled to Dyna-3d (dynamic structural response code) used to calculate Ti temperature and stress pulse response
- As target rotates and the Ti at the beam location moves at 100 m/s, the pulse heats up the Ti
  - Each pulse traces out a path 10 cm long along the perimeter of the wheel, with a peak temperature jump of 411 C
  - Figure shows the temperature response of a rectangular volume of the Ti target material

Undulator photon beam target temperature, C, 100 m/s wheel rim velocity



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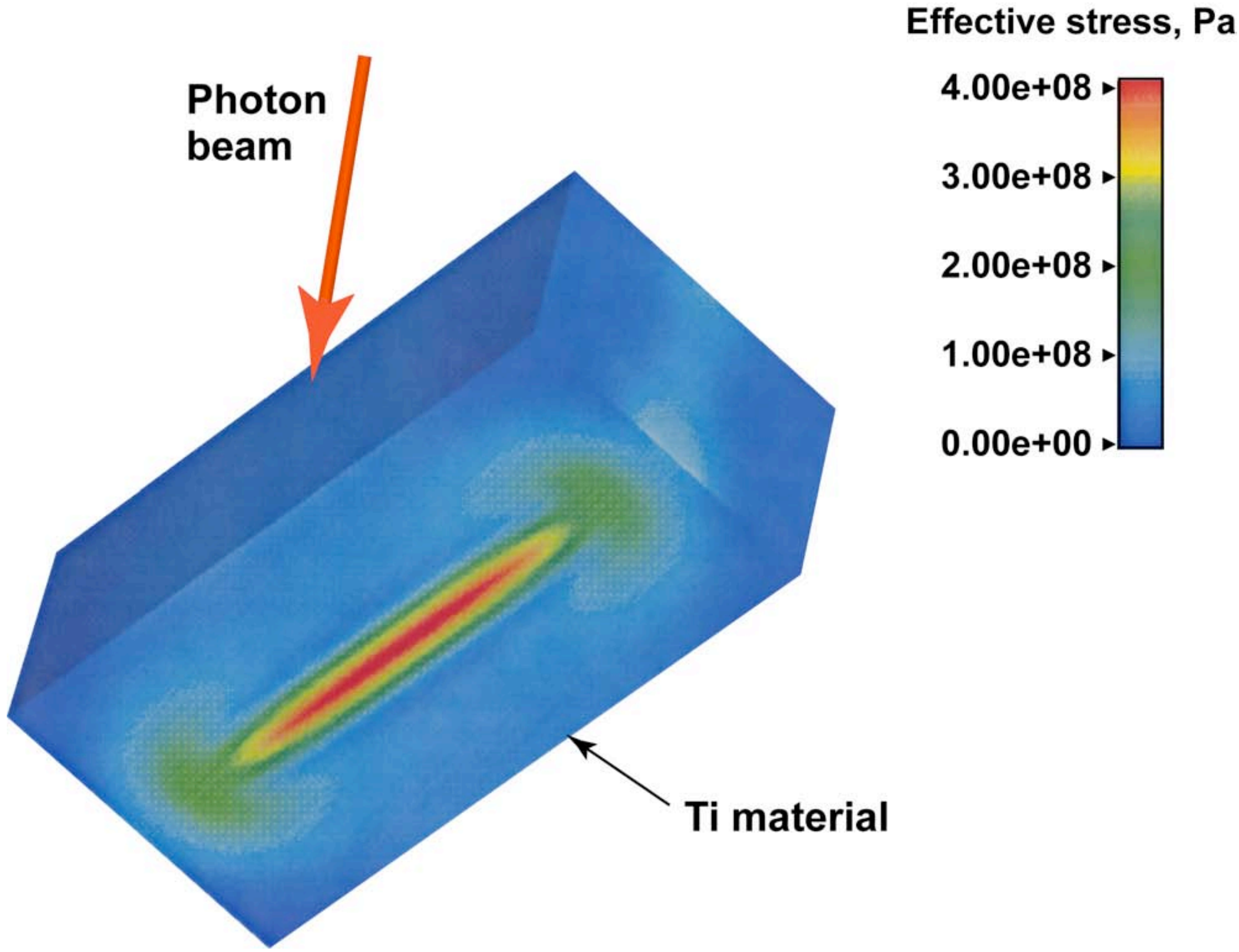
Structural thermal stress response- 58 ksi peak

- Energy deposition from the photon beam into the Ti target results in a quasi-static stress state that relaxes as the material temperature relaxes
- Figure shows the peak stress due to the photon beam in a rectangular volume of the target material
- The peak stress in the Ti is 58 ksi ($4x10^8$ Pa) at centerline of the beam path

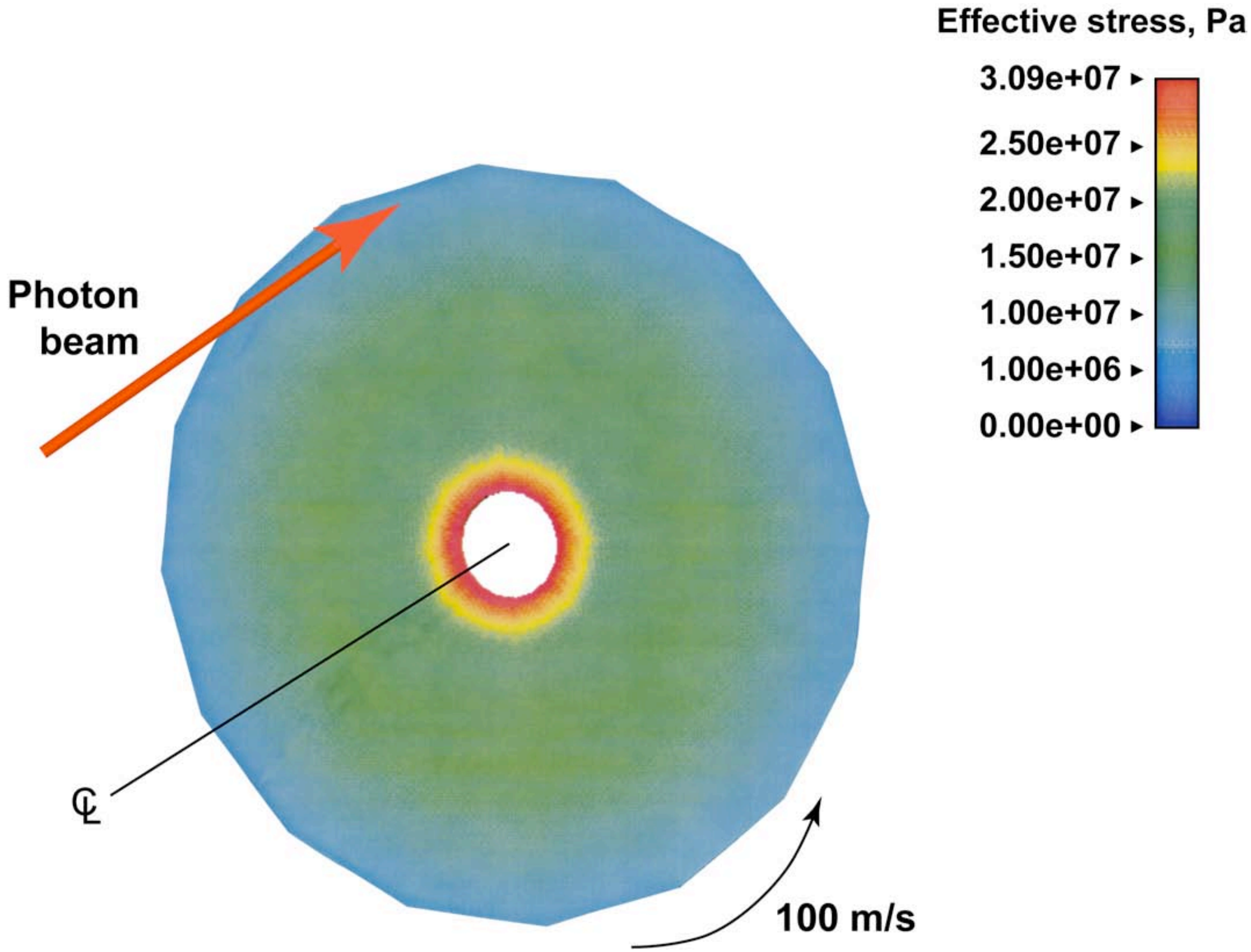
Undulator photon beam Ti target, thermal stress response, Pa, 100 m/s target velocity



Stress in Ti target due to rotation is low

- Wheel perimeter speed is 100 m/s (1800 RPM)
- Wheel material is a Ti alloy
- Peak stress in the Ti wheel due to rotation is 4 ksi (3.1×10^7 Pa)
  - Maximum allowable Ti stress is 120 ksi
- The wheel rotation stress is low

Undulator photon beam Ti target stress, Pa, due to rotation, 1 m dia. wheel, 100 m/s velocity (1800 RPM)



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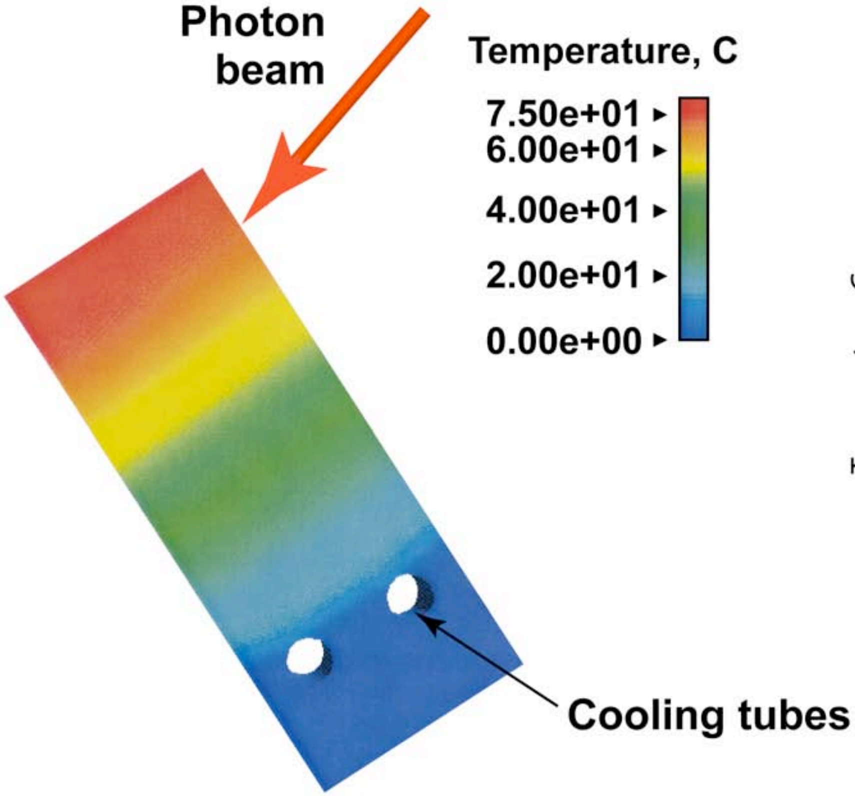
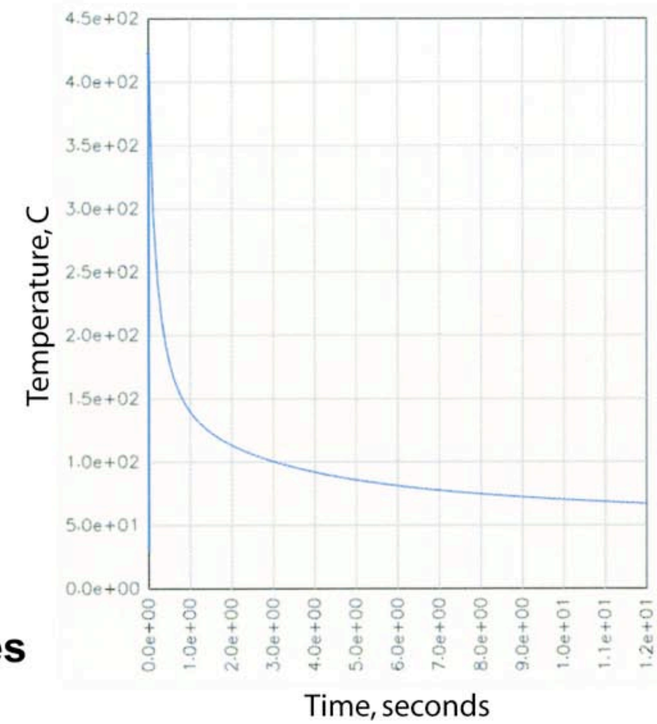
Ti target cooled by adjacent cooling tubes

- The 1 ms long photon beam pulse heats up the Ti target by 411 C and this temperature relaxes to 60 C (see figure) until after 6–12 seconds another pulse strikes this part of the target again
  - Total power deposited is 18 kW
- The target is cooled with water flowing in two water channels. The water enters the target along the shaft and flows out toward the wheel perimeter.
- Water flow pressure drop along the channels is low (10 m/s water velocity)
- Water heat up flowing through the target channels is minimal (5 C)
  - Convective flow heat transfer coefficient is 20,000 W/m^2 C

Ti target thermal response after one pulse



Temperature profile in Ti after one pulse.



Temperature plot of Ti after one pulse.

Radiation damage calculations in Ti wheel made

- An acceptable damage limit is assumed to be 0.5 DPA (number of displacements per atom of material)
- Calculations using the FLUKA and SPECTER codes give values of 5 DPA in the circular path traced out by the beam on the rotating Ti wheel after one year of operation
- To reduce the 5 DPA value, the target wheel is moved horizontally by 0.3 cm once a month and the beam impinges on a different path of target material and the DPA value is reduced to 0.5 DPA over one year of operation