Thermo-structural analysis on a UHV gate valve
(accidental case LINAC2/4 to PSB)

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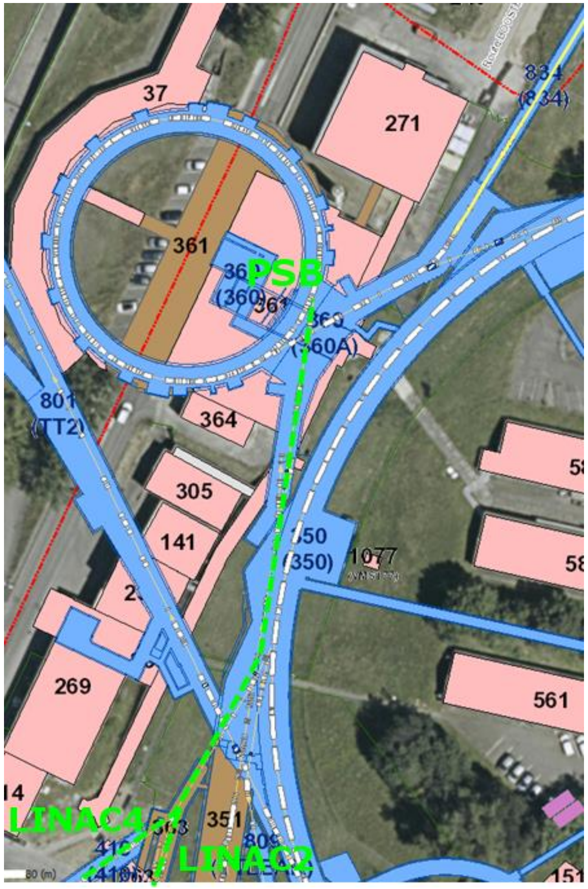
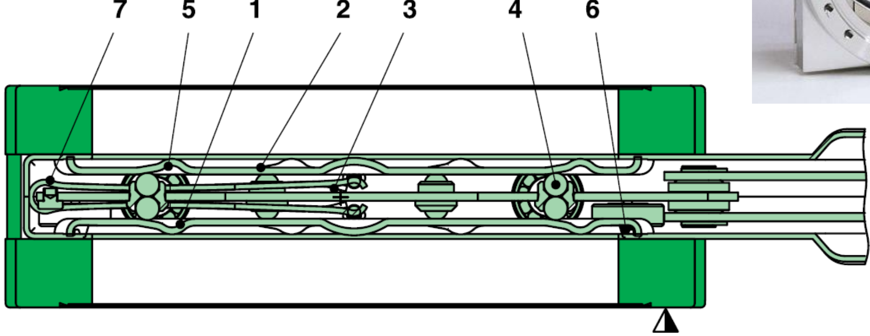
0. Valve type / position

- UHV gate valve with pneumatic actuator
- Series 10.8, DN 63 - 200 (2½" - 8"), VAT Vakuumventile
- Housing / mechanism material: AISI 304 (1.4301)



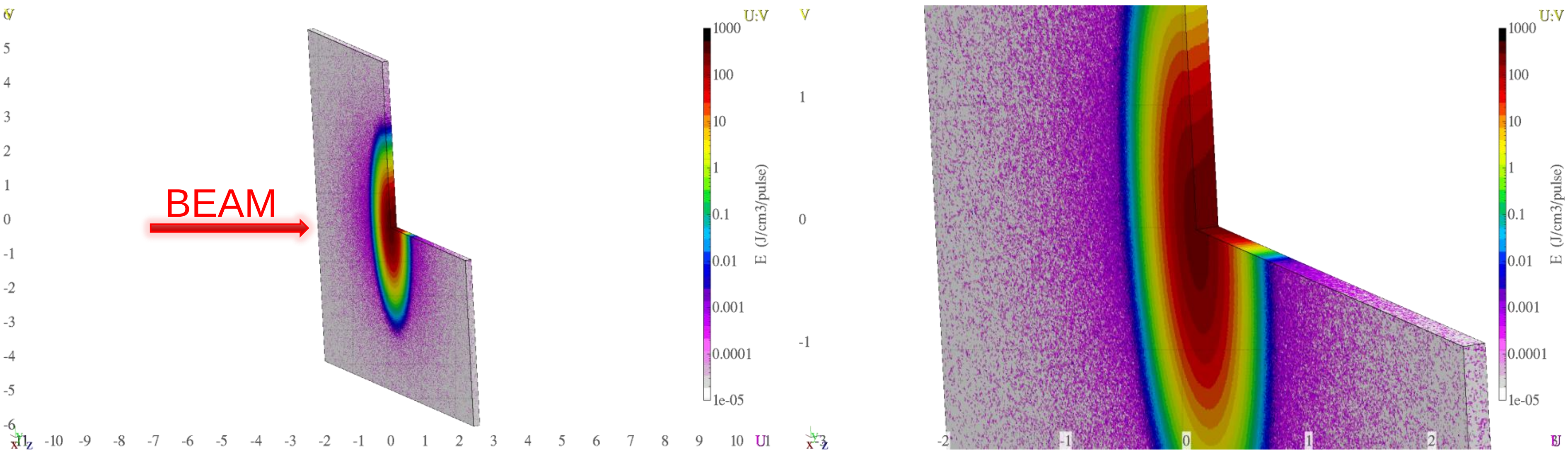


1 Gate
2 Counter-plate
3 Leaf springs
4 Ball pairs
5 Ball detents
6 Gate seal
7 Spring stop
▽ Valve seat side

1. Simulation conditions

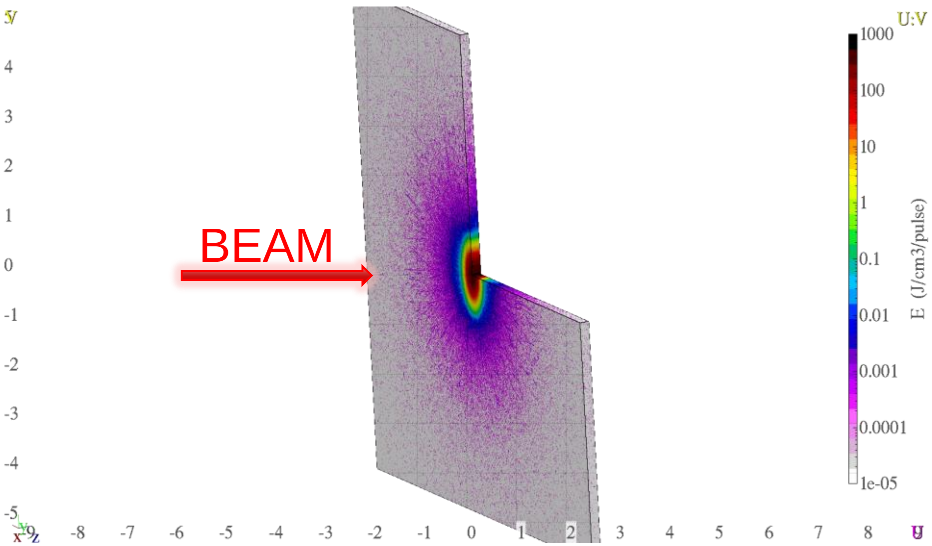
- Proton beam properties:
  - Case 1:
    - Energy: 50 MeV
    - Size: σ_x = 2.9 mm, σ_y=6.4 mm
    - Intensity: 2.3×10^{13} p^+/pulse
    - Pulse: 21.7 µs
  - Case 2:
    - Energy: 160 MeV
    - Size: σ_x = 1.2 mm, σ_y=1.9 mm
    - Intensity: 1.6×10^{13} p^+/pulse
    - Pulse: 100 µs
- Plate properties:
  - Size: 10 cm x 10 cm x 2 mm
  - Material: SS304L (ρ=8.02 g/cm^3)

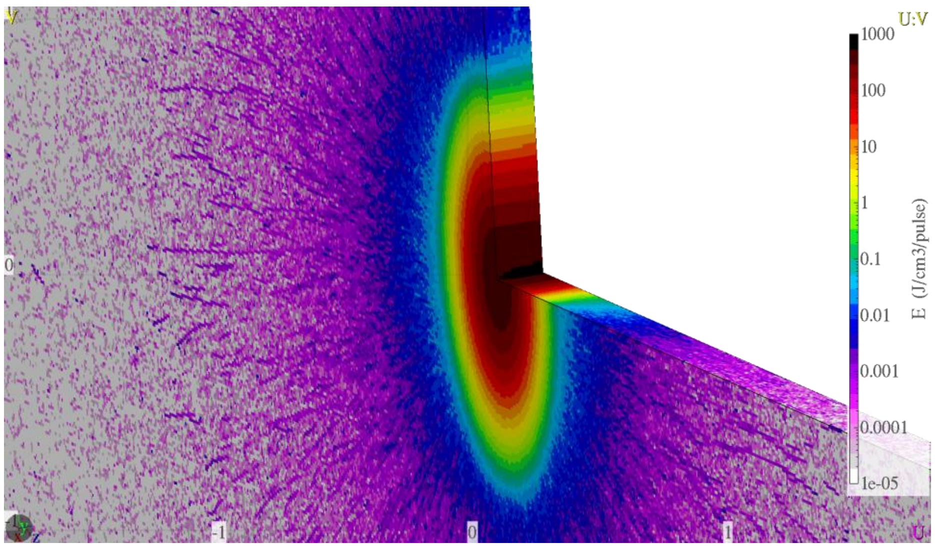
1.1 50 MeV proton beam



Case 1: 50 MeV, σ_x = 2.9 mm, σ_y=6.4 mm, I=2.3x10^{13} p^+/pulse

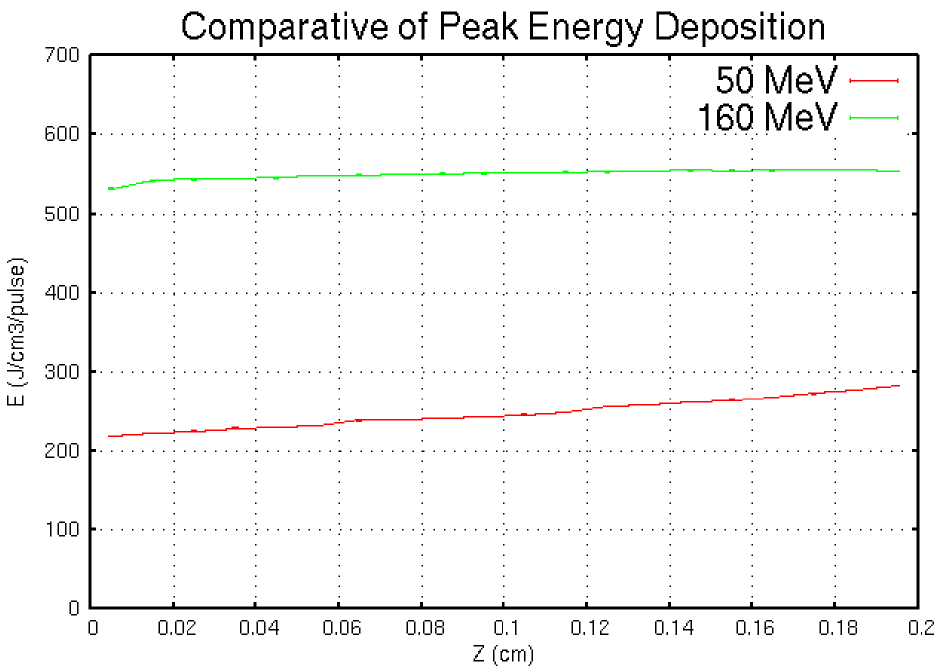
1.2 160 MeV proton beam

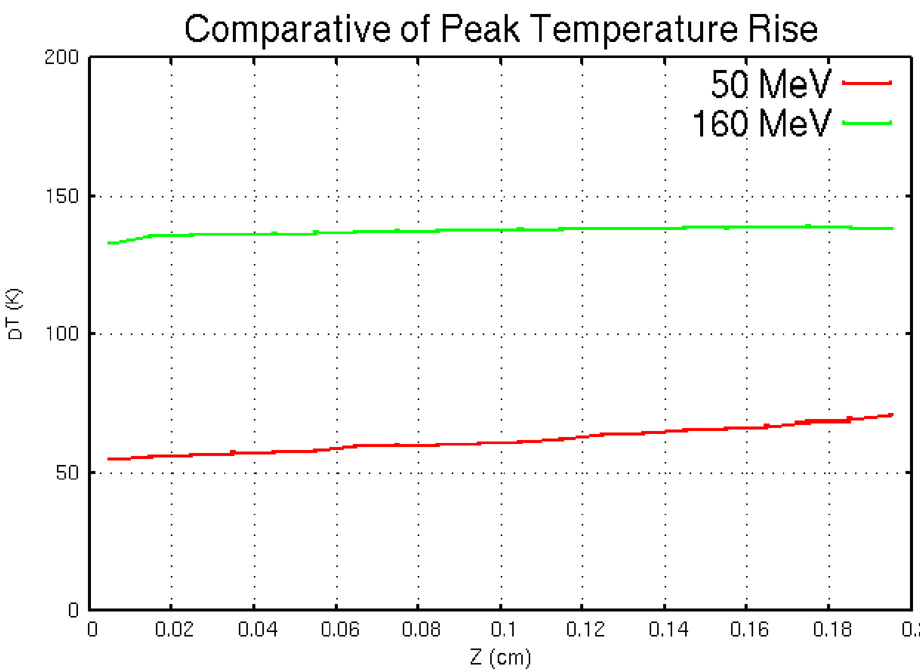




Case 2: 160 MeV, σ_x = 1.2 mm, σ_y=1.9 mm, I=1.6x10^{13} p^+/pulse

1.3 Results





~560 J/cm^3/pulse and ~140 K/pulse are peak values (obtained for 160 MeV)

Adiabatic temperature rise is roughly estimated under the assumption of constant specific heat:

$$\Delta T\left(\frac{\mathrm{K}}{\mathrm{pulse}}\right) = \frac{E\left(\frac{\frac{J}{cm^3}}{pulse}\right)}{c\left(\frac{J}{g}/K\right) * \rho\left(\frac{g}{cm^3}\right)}$$ with c_{SS304L}= 0.5 J/(g x K) and ρ=8.02 g/cm3

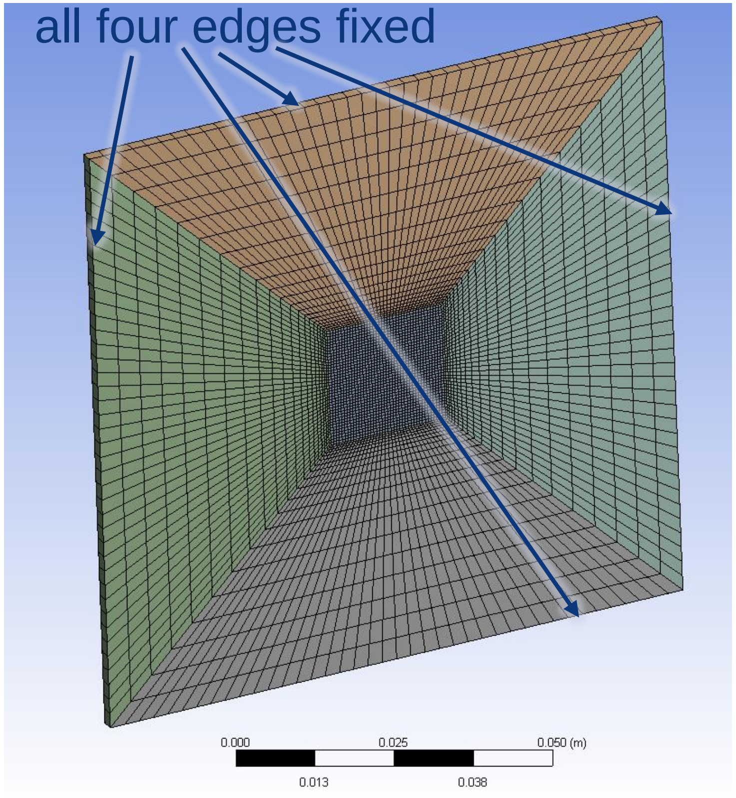
1.4 Energy balance

Beam type	Energy deposited (MeV/proton)	Energy deposited (% of incoming energy)	Energy deposited (J/pulse)	Absorbed power (W)
50 MeV	15.7	31.4 %	57.8	48.2
160 MeV	6.2	3.9 %	15.9	13.3

Beam intensities considered:
2.3e13 p/pulse for 50 MeV
1.6e13 p/pulse for 160 MeV

Beam repetition period: 1.2 seconds for both beams

2. Thermal-structural analysis

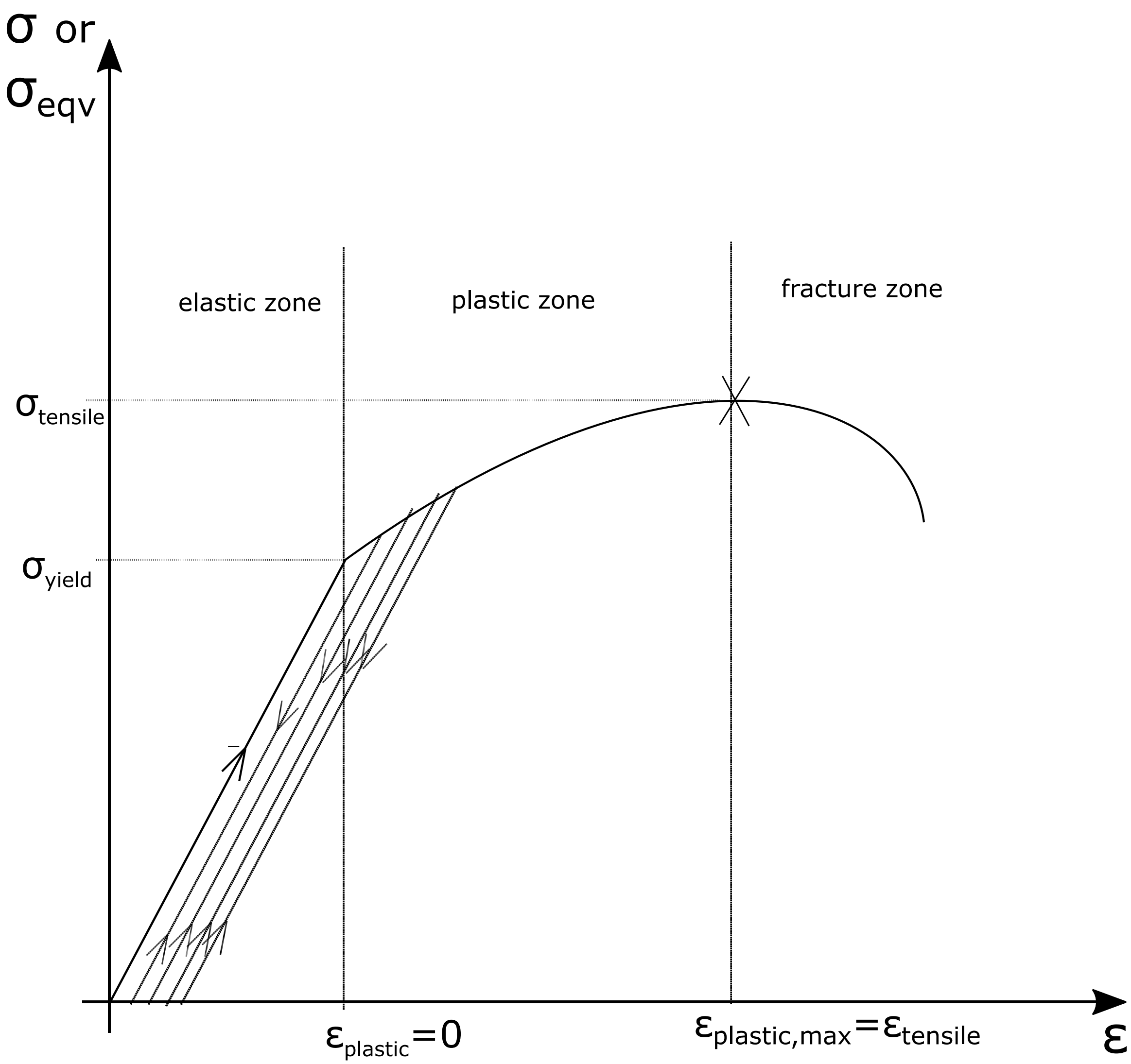


- Repetition rate: 1.2s
- Initial temperature: 22^{o}C

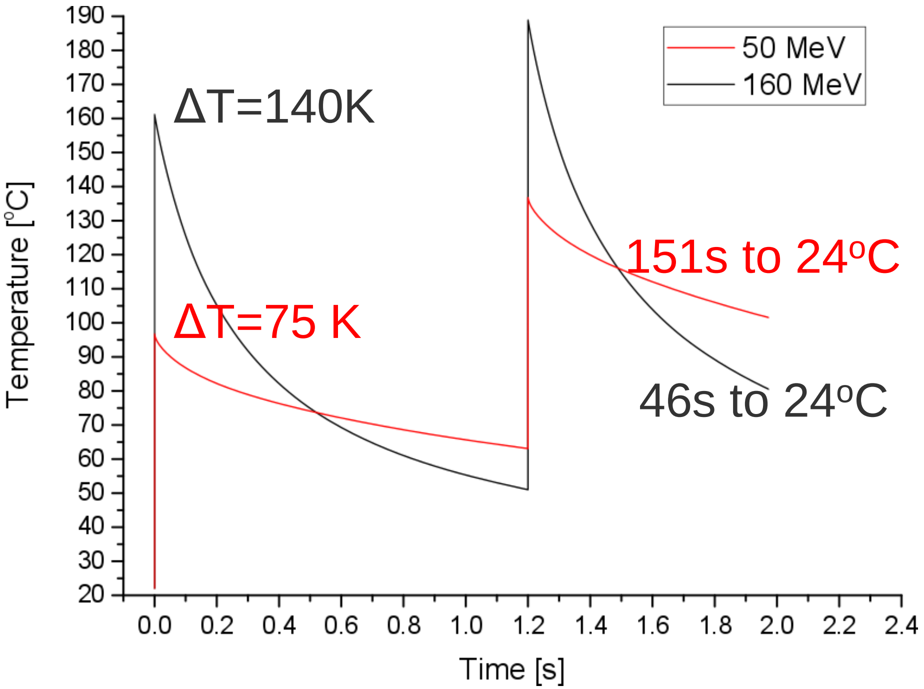
- FEM simulation (Ansys 17.1)
- SHELL131/181 layered elements
  - 20 layers (see EDMS 1610806)
- Boundary conditions:
  - Thermal: conduction through matter (neither convection nor radiation considered)
  - Mechanical: four edges fixed / bilinear isotropic hardening material model*

*to account for permanent deformations

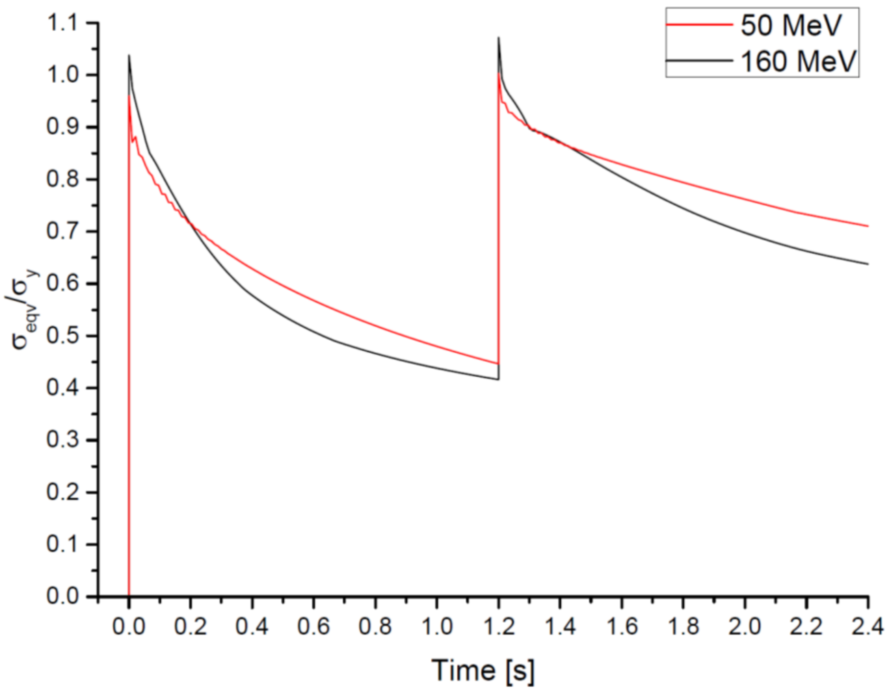
Stress strain curve



Results for two repeated pulses



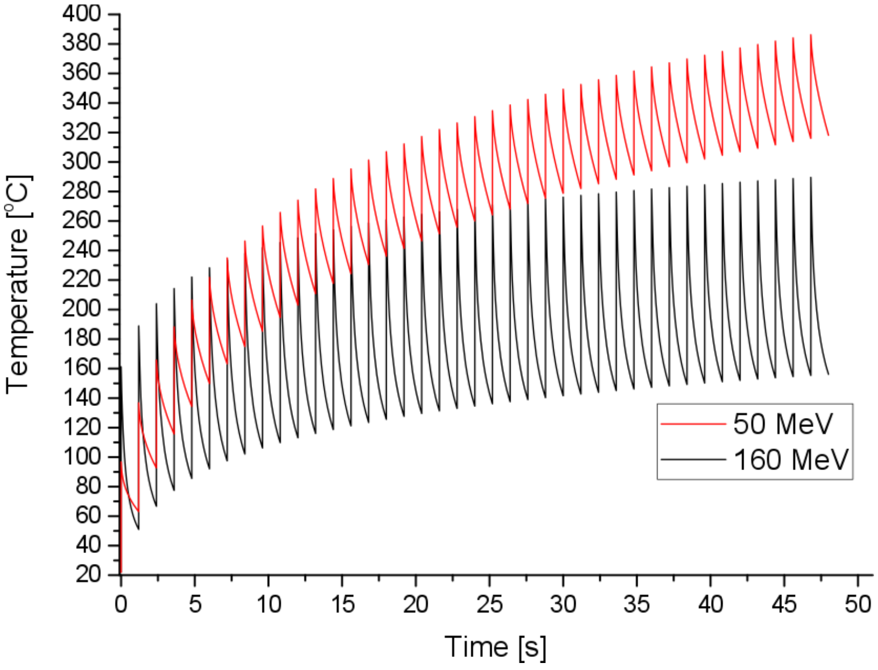
Maximum temperatures reached

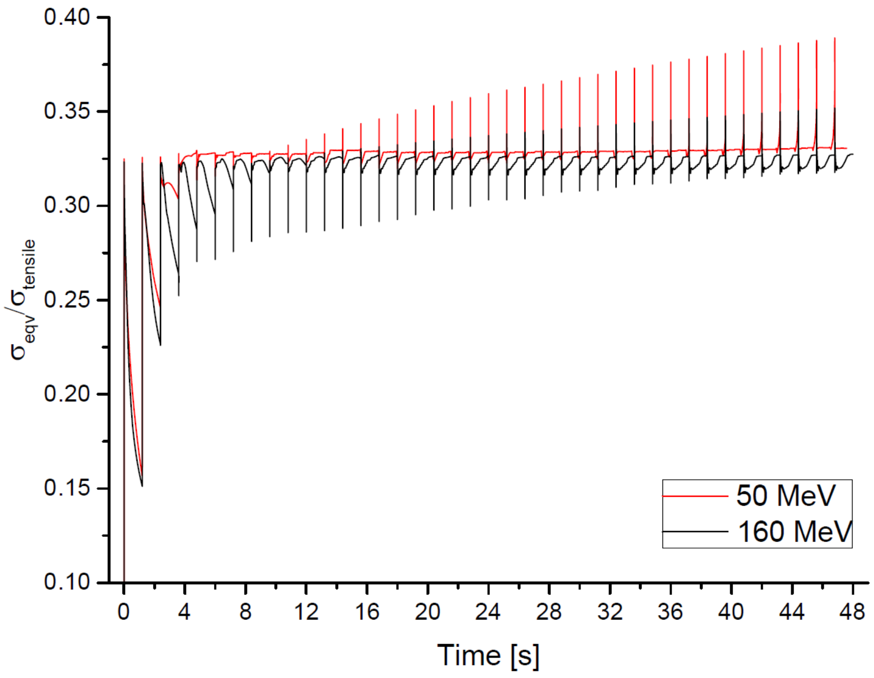


$\sigma_{eqv}/\sigma_{yield} > 1$: plastic deformation

Multiple repeated pulses

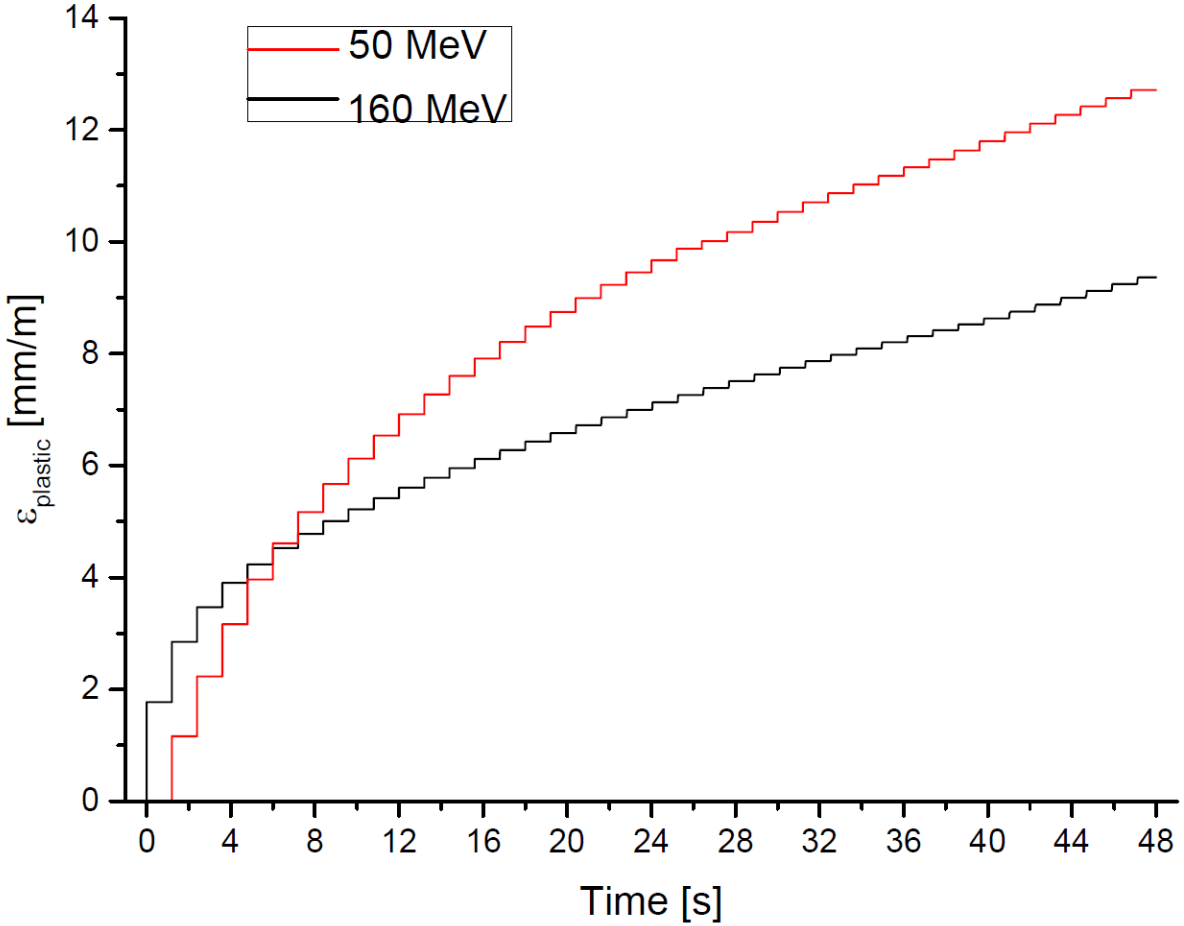
- No fracture for 40 repeated pulses ($\sigma_{eqv} < \sigma_{tensile}$)





- Tensile strength is not reached after 40 repeated pulses ($\sigma_{eqv}<\sigma_{tensile}$)

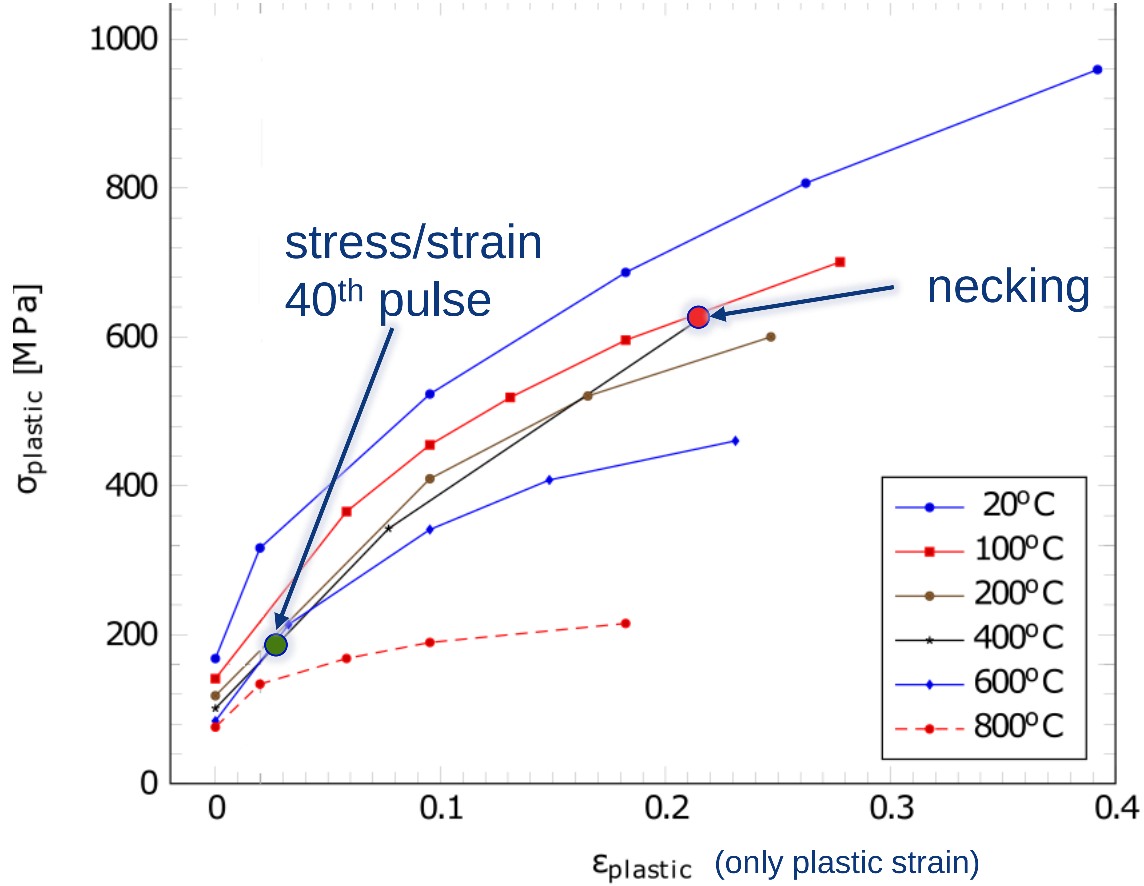
Plastic deformation



- $\varepsilon_{plastic,max}$ ~ 200 mm/m
- Rough prediction: between 900* and 1300** pulses until fracture starts

  * thermo-mechanical fatigue (model needs to be better studied) / ** linear extrapolation from results

Stress-strain curve (true stress)

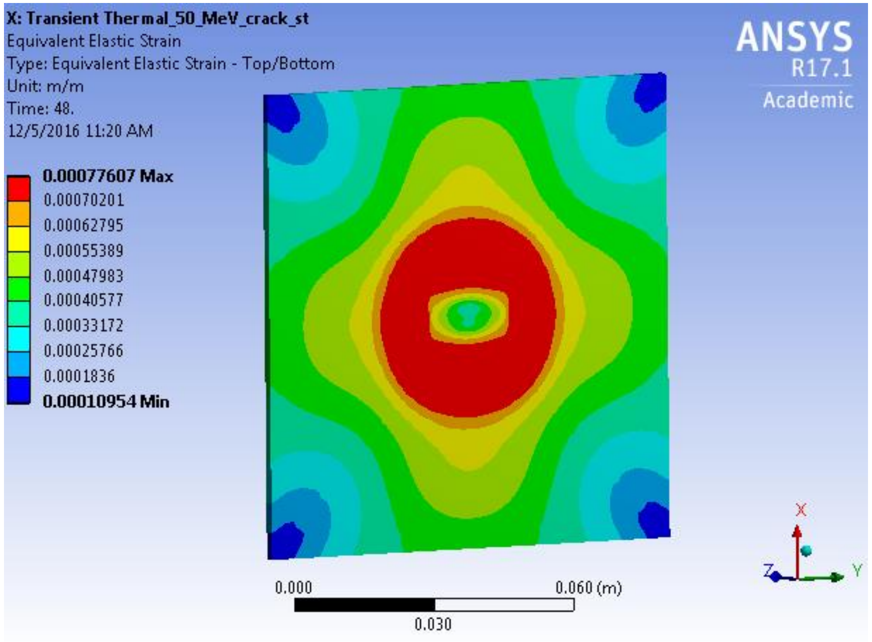


Multilinear model

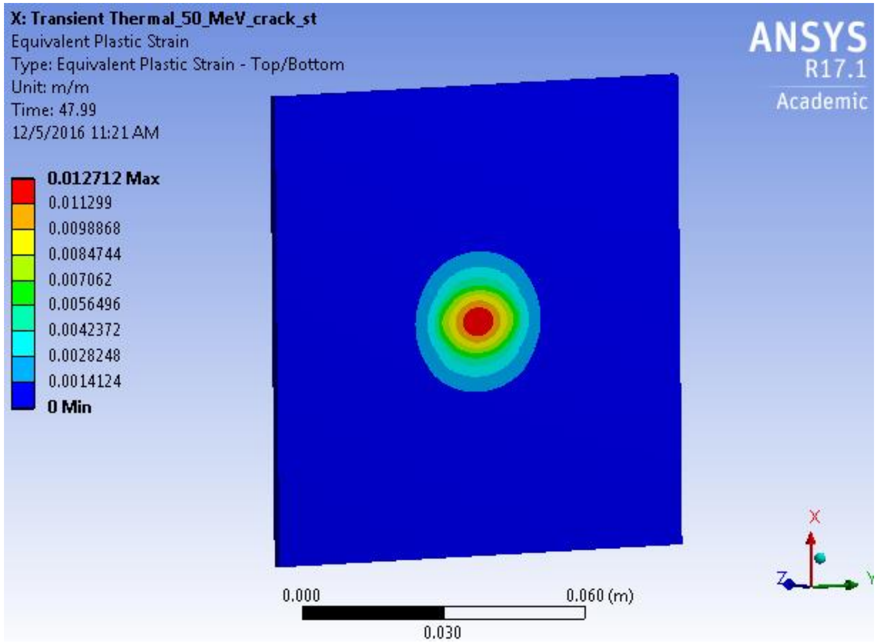
Curves from: Dempsey, J. Franklin, et al. "Temperature dependent ductile material failure constitutive modeling with validation experiments." Challenges in Mechanics of Time-Dependent Materials and Processes in Conventional and Multifunctional Materials, Volume 2. Springer New York, 2013. 7-15.

Border deformation

Elastic strain after 40 pulses

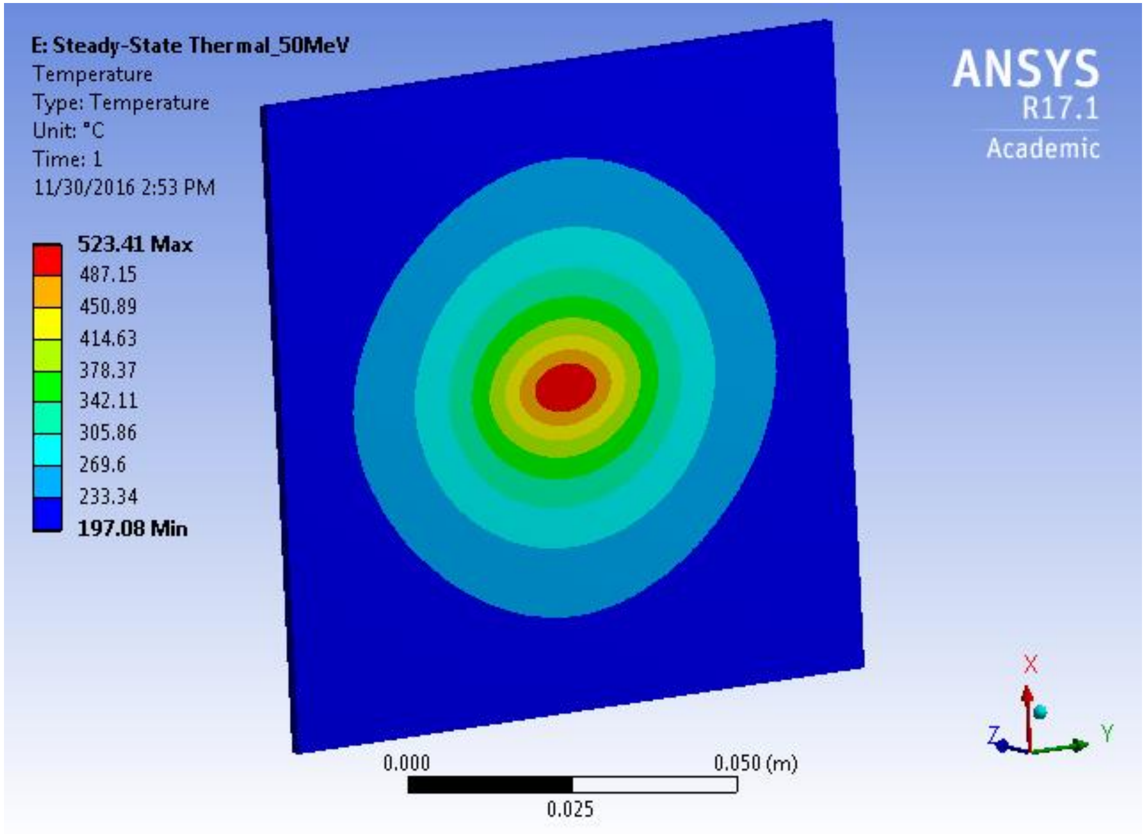


Plastic strain after 40 pulses



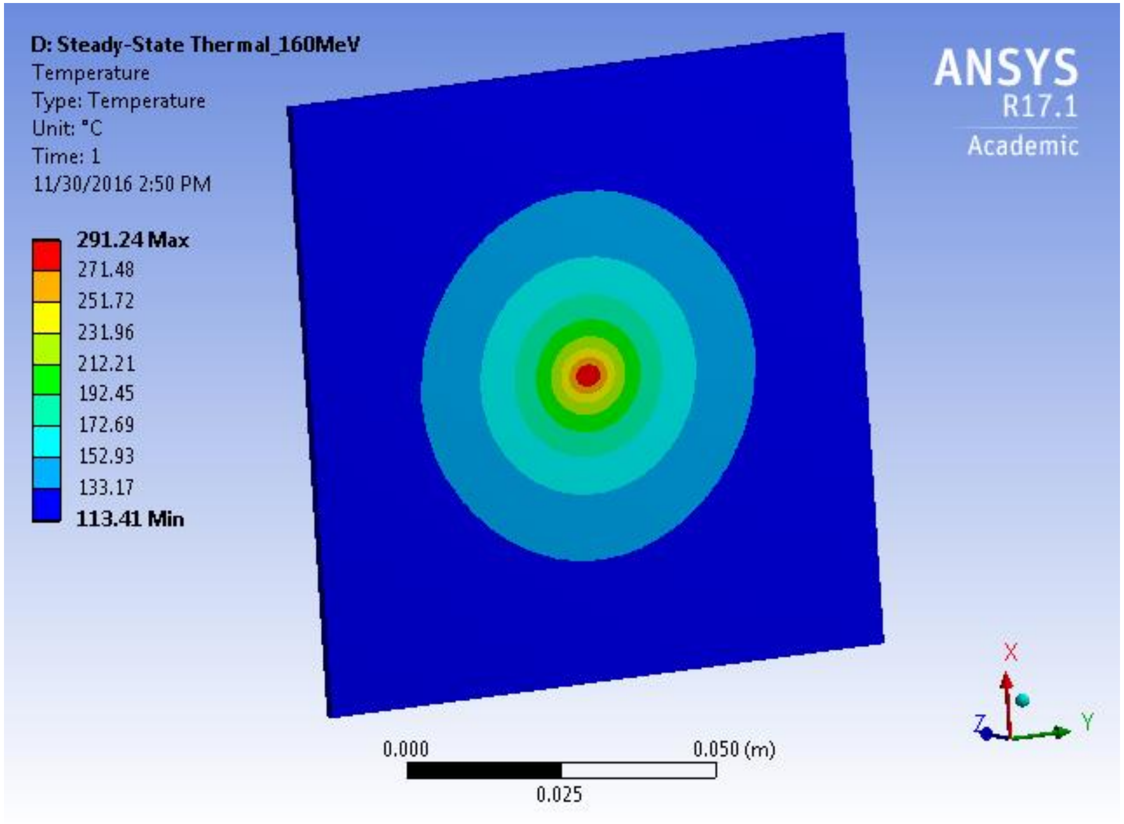
- No plastic deformation on the border for 40 pulses
- Plastic strain in the plate center: 13 mm/m -> 30 µm thru-thickness deformation
- However steady-state temperature must be considered for irradiation over longer time

Steady-state results (50 MeV)



- Heat sink: radiation from the plate (ε=0.6 to the environment) only
  - No convection
  - Conduction to the plate supports implemented
- Maximum temperature: 523°C (operational limit at T_{creep}=550°C)

Steady-state results (160 MeV)



- Heat sink: radiation from the plate (ε=0.6 to the environment) only
  - No convection
  - Conduction to the plate supports implemented
- Maximum temperature: 291^{o}C (operational limit at T_{creep}=550^{o}C)

3. Conclusion

- 2 repeated pulses:
  - $\Delta T_{50MeV,max}$=75ºC $\Delta T_{160MeV,max}$=140ºC
- Plastic deformation after 1 pulse
  - However no permanent deformation on plate borders for 40 pulses
- Structural limits for the plate:
  - $T_{max,50\ MeV}$=523ºC (steady-state)
  - $T_{max,160\ MeV}$=291ºC (steady-state)
- Unclear how the material will behave over hundreds of pulses:
  - Further studies would be needed
- For more information: EDMS 1758139

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