Thermo-Mechanical Simulations for Positron Target

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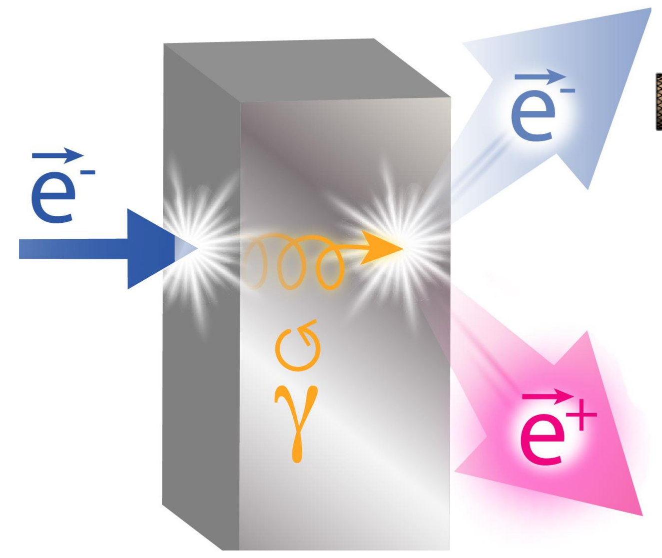
Abstract

Jefferson Lab is currently planning to upgrade the Continuous Electron Beam Accelerator Facility (CEBAF) to support a positron beam through the Ce⁺BAF project, a major component of which is the positron source: a piece of tungsten through which an electron beam is passed. More than half of the energy present in the electron beam is deposited into the target, leading to thermal strains that will result in stresses and fatigue that may cause the target to fail. The energy deposition, resulting temperature increases, the effect of the cooling loop on the target, and the resulting mechanical strains have been evaluated and coupled. A framework to use simulations to evaluate the structural integrity of the target has been developed.

Methodology

FLUKA provided energy deposition profiles. The effects of the energy deposition and the cooling effect were calculated in heat transfer (FEA) and computational fluid dynamics (CFD) codes respectively, and they were coupled to obtain a temperature map. To determine the stress-strain effects of the final temperature profile, structural simulation (FEA) was run on the target, along with a fatigue analysis.



Simulation Parameters

Simulation
Beam energy: 7 MeV
Beam current: 100 μA
Target thickness: 0.75 mm
Pulse rate: 60 hz
Beam size (σ) = 2 mm
Min. mesh cell size: 0.2 mm
Init. temp. of water: 10 °C
Flow rate of water: 0.8 kg/s

Boundary Conditions
Fixed edges on frame
No convection
Radiation neglected

Results
Power deposited: 400 W
Max temp. : 480 °C
Max von Mises stress: 440 MPa
Expected lifetime: 60 days

FEA Equations

$$\frac{\partial}{\partial x}\left(k_{xx}\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial x}\left(k_{xx}\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial x}\left(k_{xx}\frac{\partial T}{\partial x}\right)+\dot{q}=\cancel{\frac{\partial T}{\partial t}}$$

Equation 1: heat equation, time dependent term is 0

$$\epsilon=\alpha T,\qquad \sigma_x=\frac{E}{1-\nu^2}\left(\epsilon_x+\nu\epsilon_y\right)-\frac{E\alpha T}{1-\nu}$$

Equation 2: describing thermal strains and thermal stresses

$$\sigma_v^2=\frac{1}{2}\left((\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right)$$

Equation 3: von Mises stress with principle stress components

Results – Images

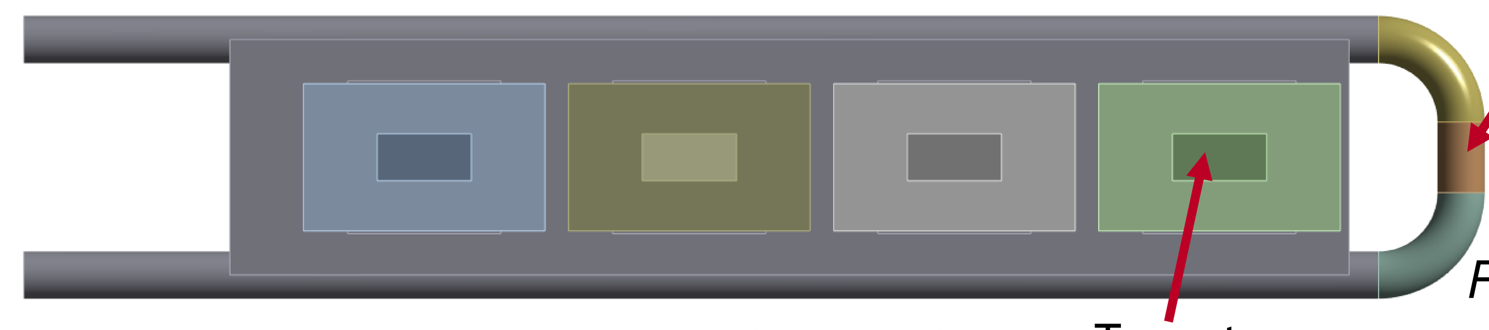


Figure 1 (above): CAD model of target frame

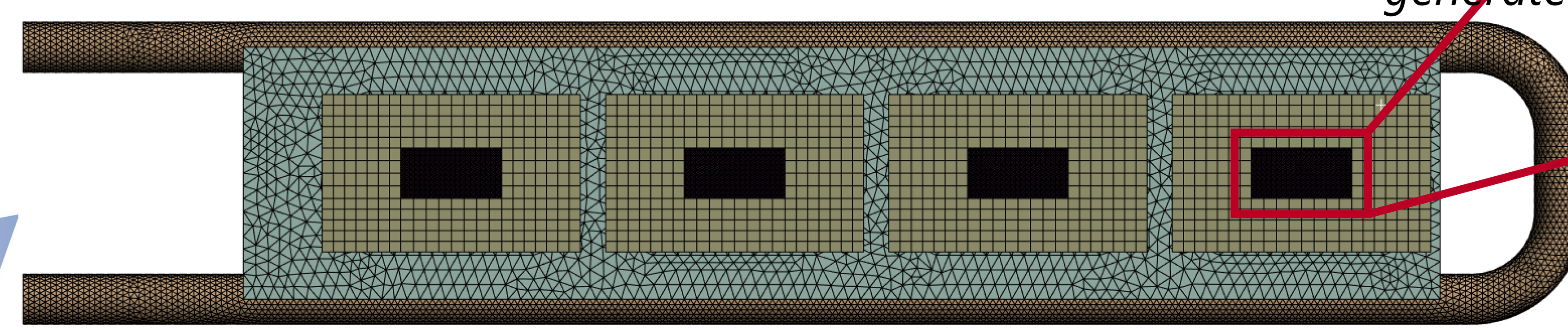


Figure 2 (above): mesh generated in ANSYS Mechanical

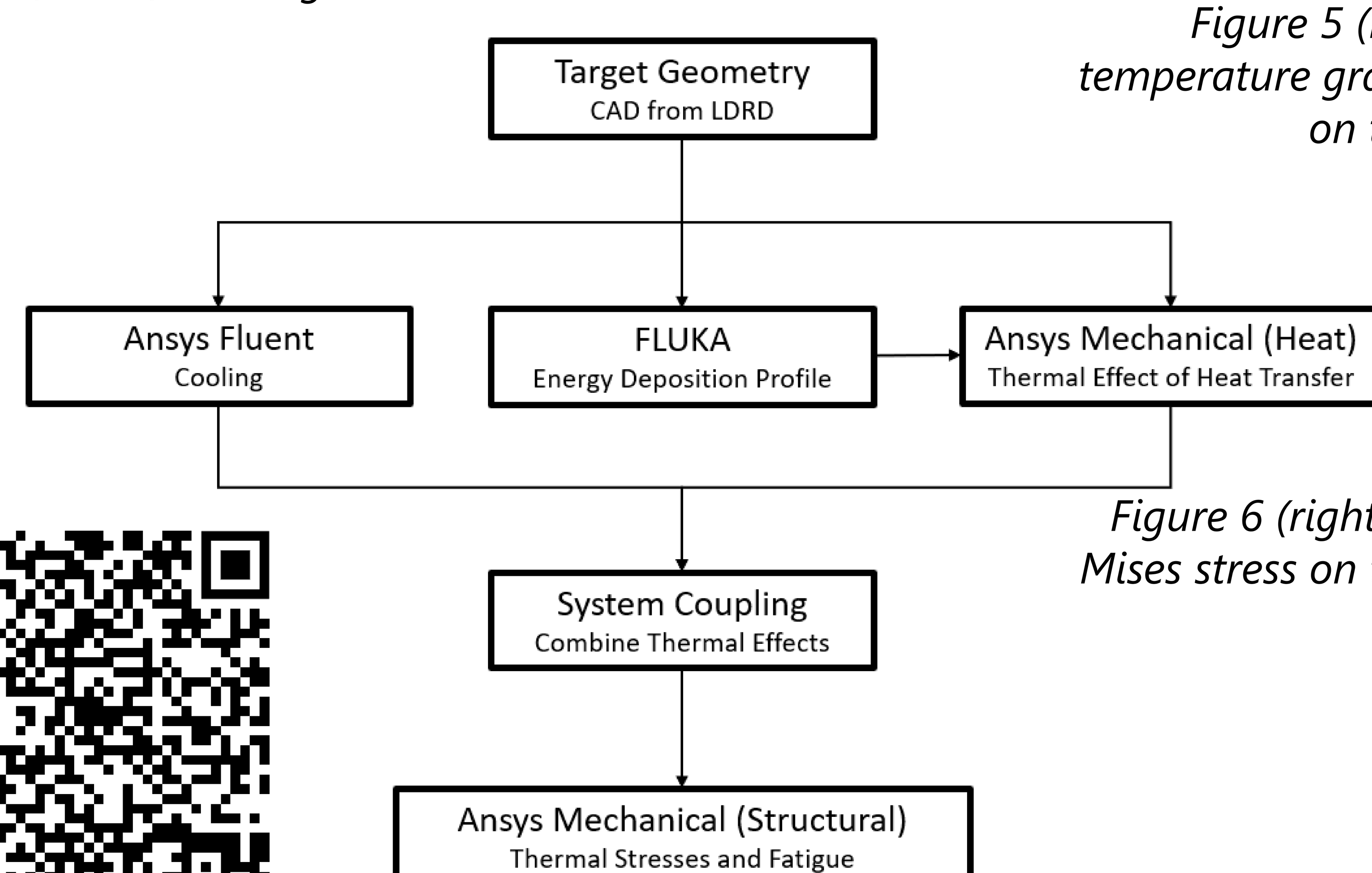


Figure 3 (above): workflow

Link to supplementary material

Figure 4 (right): energy deposition profile generated by FLUKA

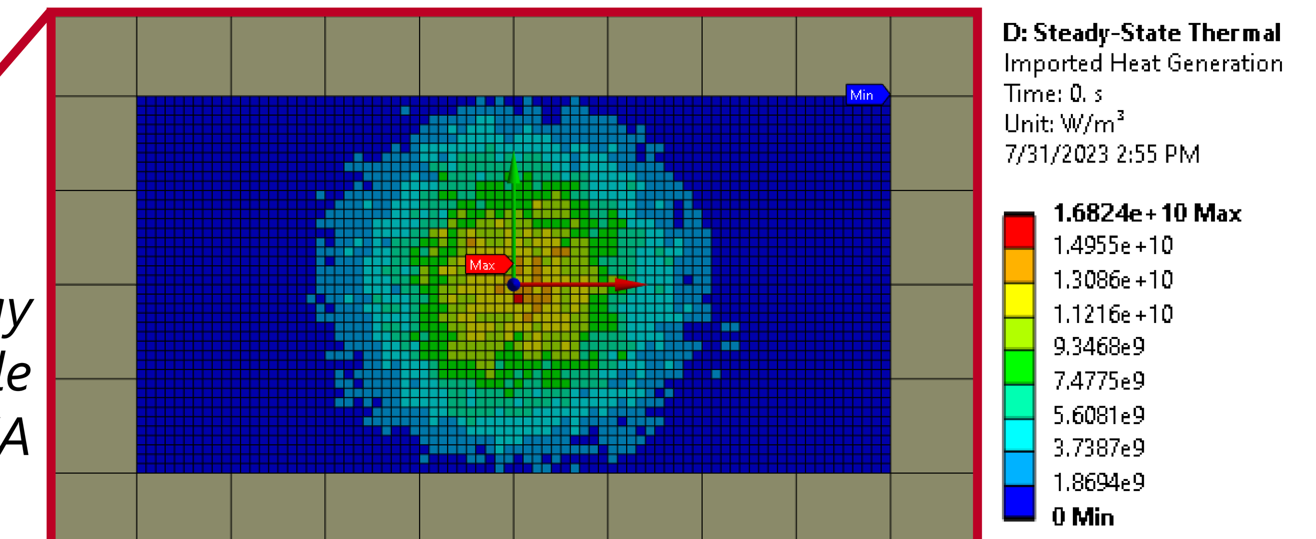


Figure 5 (right): temperature gradient on target

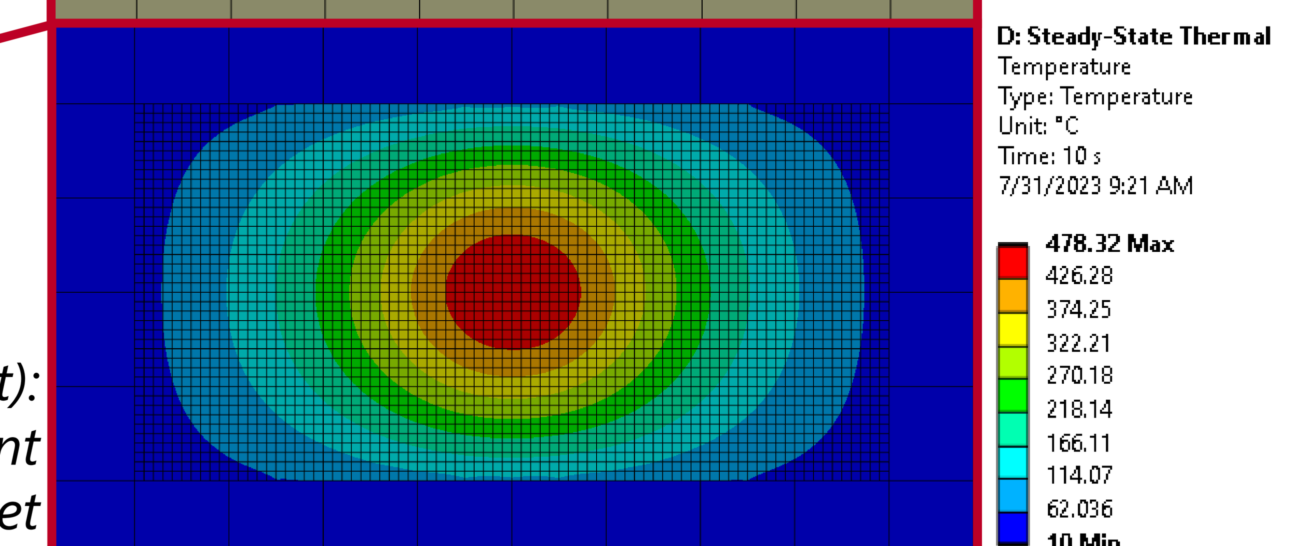


Figure 6 (right): von Mises stress on target

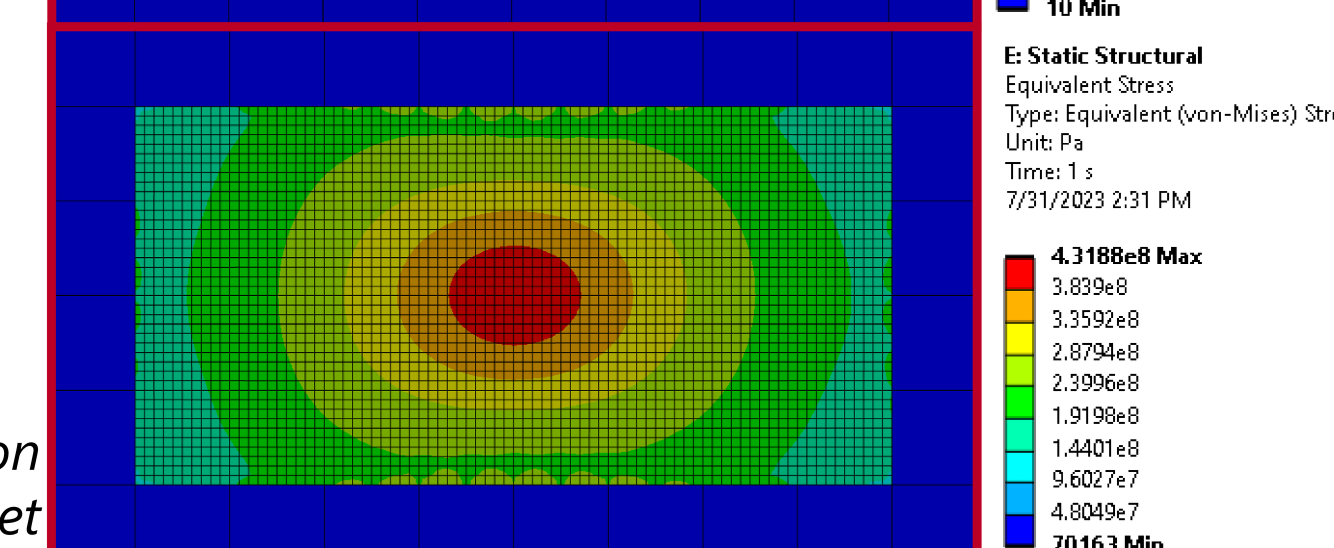
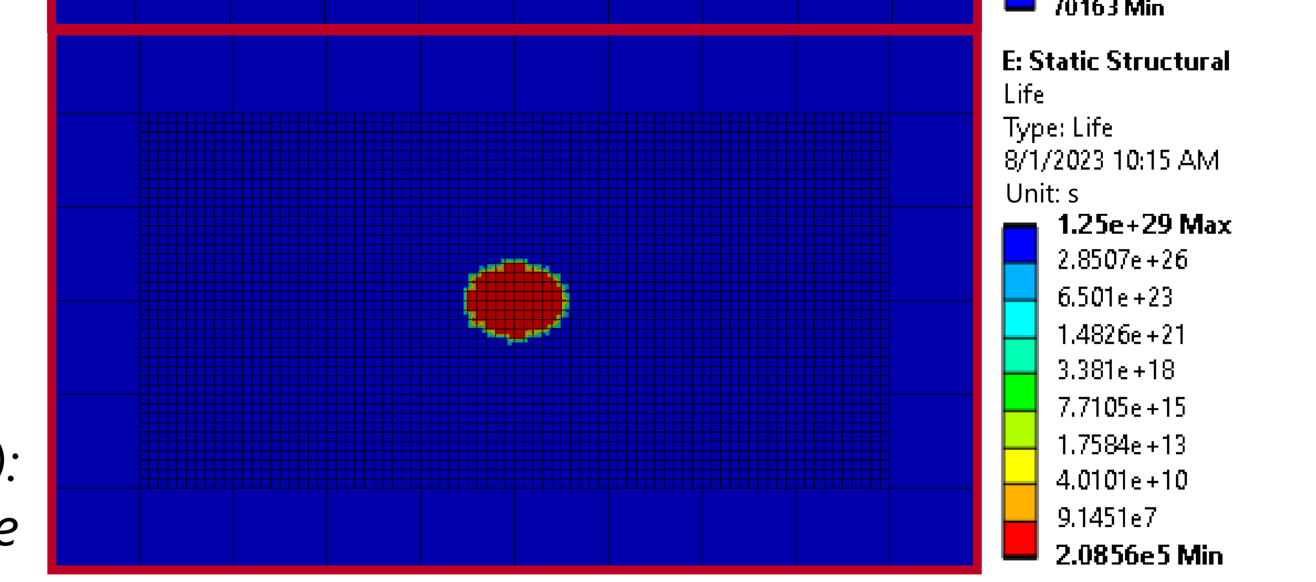


Figure 7 (right): fatigue damage



Conclusion

The simulations pointed out areas of high stresses, which can be addressed with design changes. The cooling loop is essential, not only to keep temperatures low, but to also keep stresses low. The maximum temperature does not exceed the melting point of tungsten, and the maximum stress does not exceed the tensile yield strength of tungsten. The fatigue analysis showed that the target can sustain approximately 60 days of continuous operation without failing. An experiment should be conducted to validate simulation results.

Acknowledgements

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