# THERMAL SIMULATIONS FOR OPTICAL TRANSITION RADIATION SCREEN FOR ELI NP COMPTON GAMMA SOURCE

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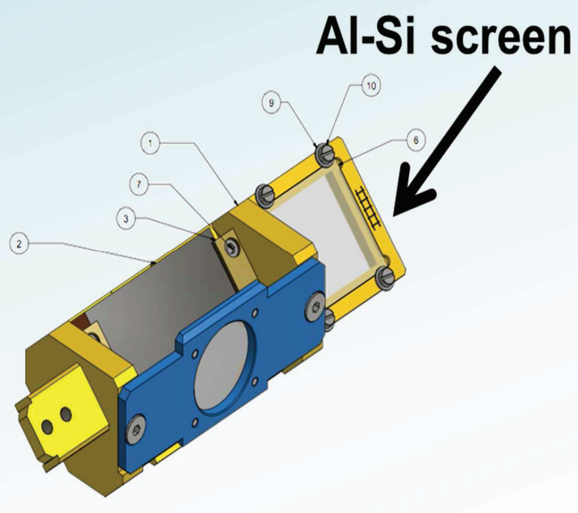
## Abstract

The ELI-NP GBS (Extreme Light Infrastructure-Nuclear Physics Gamma Beam Source) is a high brightness electron LINAC that is being built in Romania. The goal for this facility is to provide high luminosity gamma beam through Compton Backscattering. A train of 32 bunches at 100Hz with a nominal charge of 250pC is accelerated up to 740 MeV. Two interaction points with an IR Laser beam produces the gamma beam at different energies. In order to measure the electron beam spot size and the beam properties along the train, the OTR screens must sustain the thermal and mechanical stress due to the energy deposited by the bunches. This paper is an ANSYS study of the issues due to the high quantity of energy transferred to the OTR screen. They will be shown different analysis, steady-state and thermal transient analysis, where the input loads will be the internal heat generation equivalent to the average power, deposited by the ELI-GBS beam in 512 ns, that is the train duration. Each analyses will be followed by the structural analysis to investigate the performance of the OTR material.

## 1. Optical Transition Radiation (OTR)

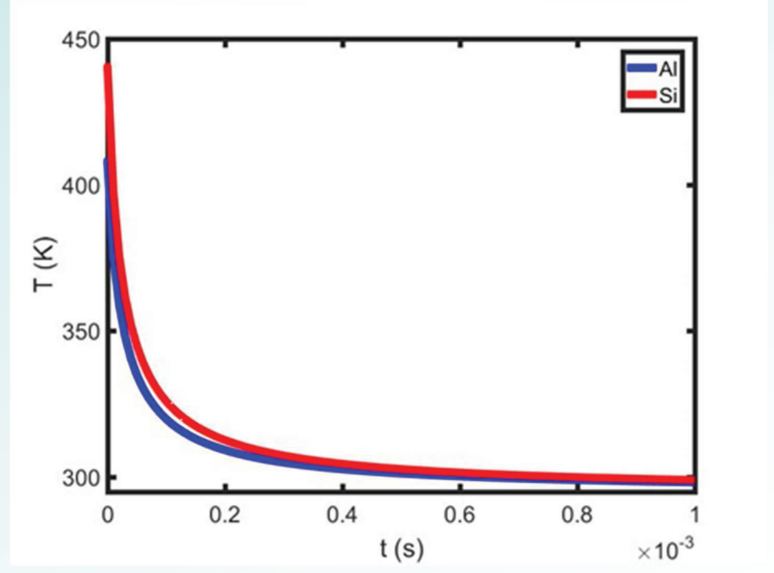
In order to measure the beam profile the Aluminum or Silicon Optical Transition Radiation (OTR) screen are used.This radiation hits the screen for several cycles during the experiments; thus we want to study, with the finite element analysis (Ansys Code), the OTR material behaviour under thermal stress for 512 ns, train duration. After the thermal analysis the scope is to study the performance of the material through structural analysis in order to investigate the deformation and the equivalent stress for each pulse (of 32 bunches).




## 2. Conduction cooling

The ANSYS analysis is in agreement with the theoretical study where was evaluated the conduction cooling after the heating of a ELI-GBS beam train.

The screen cannot completely cool down in the time between two subsequent pulses; therefore, for each bunch there is an increase of temperature of 0.3° C for Al and 0.4° C for Si. However after few cycles, an equilibrium is reached and the cumulative temperature effect is negligible.[1]



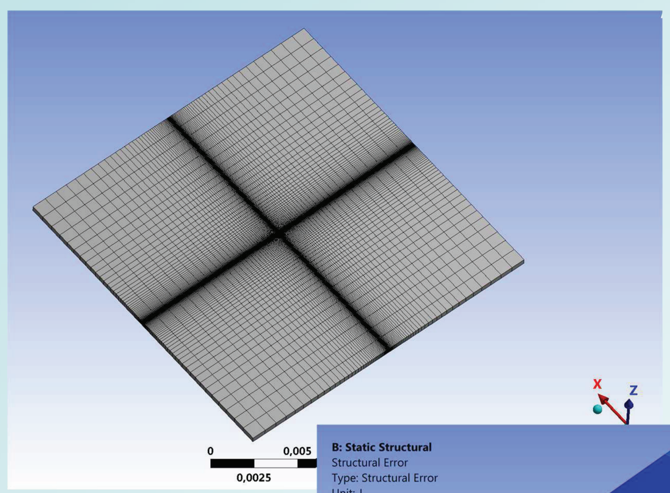

The cooling mechanism considered is the only conduction from the heated area to the screen flange; the temperature of the flange is independent from the temperature of the heated area and equal to the machine working temperature that corresponds to the room temperature in our case, 22°C: indeed, the site is located in an oversized conditioned environment to remove heat to an extent greater than that emitted by the accelerator. [2].

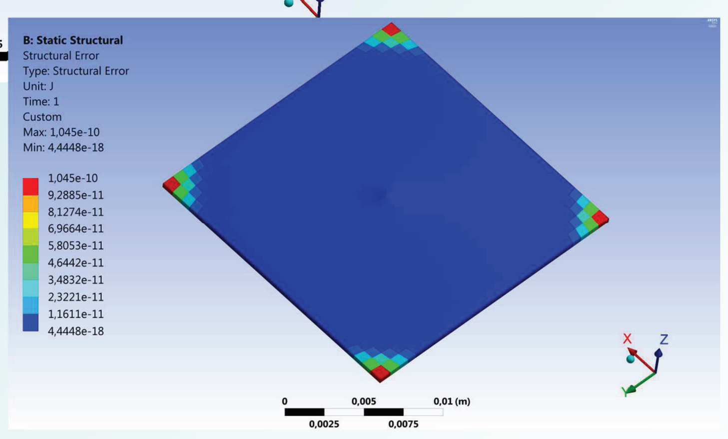
## 3. Ansys Analysis

The first step is to build a 3D solid model of the item we are analysing and define the material properties. The target has been modelled with 20x20x1 mm Aluminum plate and the worst case of the dimensions of the area hit by the beam are.

| $\sigma_x$ ($\sigma_y$)[μm] | $\Delta T^+$ Al [K] | $\Delta T^+$ Si [K] |
|---|---|---|
| 298(298) | 6 | 8 |
| 251(252) | 9 | 12 |
| 211(213) | 12 | 16 |
| 184(184) | 17 | 21 |
| **47.5(109)** | **109** | **141** |
| 241(27.4) | 85 | 110 |
| 106(70) | 76 | 99 |

After the 3D model generation, the OTR has been meshed using hexagonal elements, with size decreasing from the border to the centre.






This mapping is crucial to finely impose the energy releasing, concentrating elements only in the target volume that the beam hits. The structural error confirmed the bias strategy used to define target meshing; the regions where the result can be affected by a computational error (due to for example at the size or shape of the mesh), are on the border and in any case by negligible values.

## 4. Thermal Analysis

Assuming an electron beam with a Gaussian spatial distribution, the OTR profiles have as boundary condition the room temperature 22°C and a Gaussian distribution of the power released on the OTR screen as body load. The power is implemented trough a dedicated command APDL in Ansys, associating the correct Gaussian load to all the target nodes, including those belonging to the elliptic beam section.

### STEADY-STATE

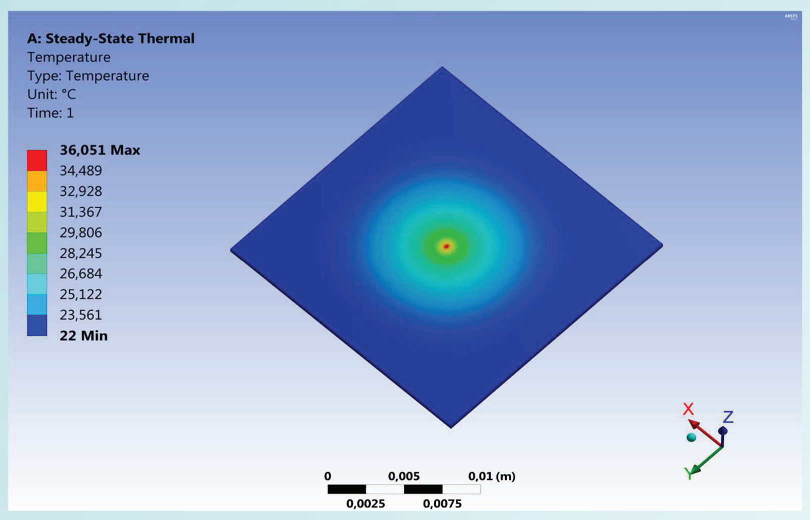
Represents, with a good approximation, the maximum value of temperature increase reaching the equilibrium after a certain amount of thermal stress cycles.

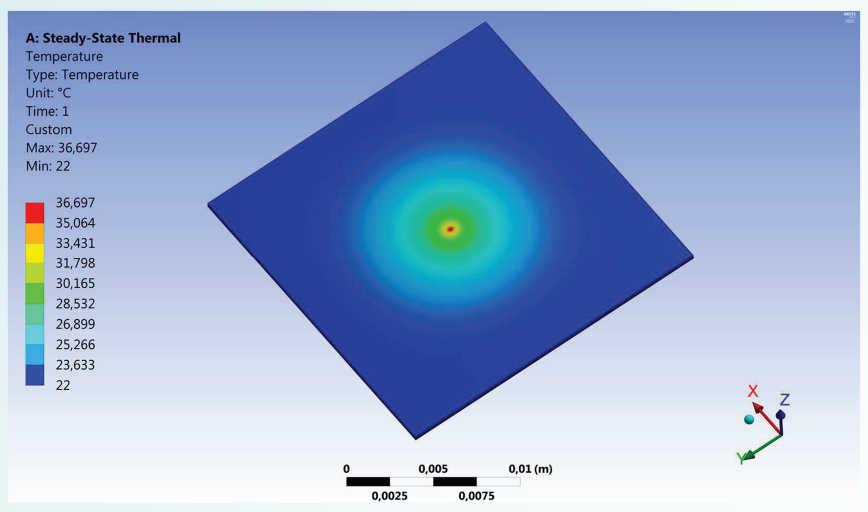
*Aluminum Gaussian Distribution*

The temperature increase calculated is about 14 °C respect to the initial temperature (22°C). This result is due to at the thermal inertial of the material and its physics property.

*Silicon Gaussian Distribution*

The temperature increase calculated, is 14.6 °C respect to the initial temperature. Hence, the two materials have comparable thermal behavior considering the similar final temperature.

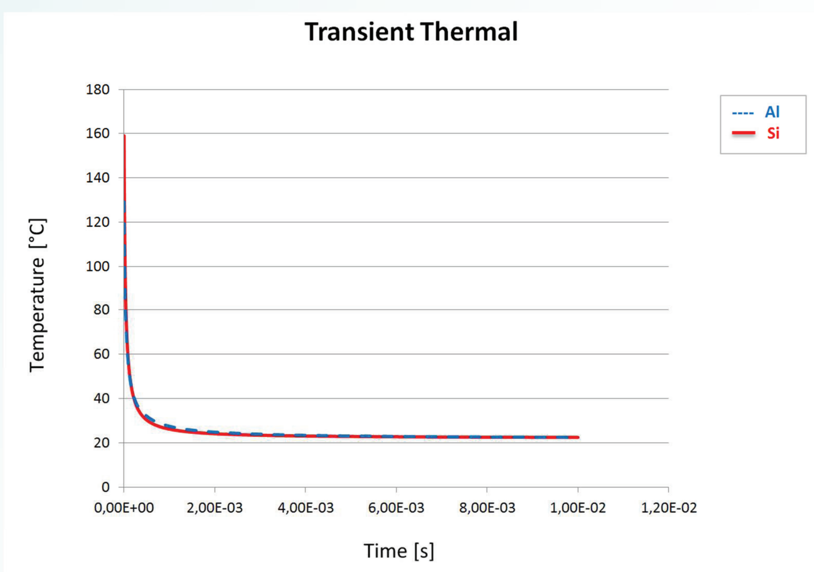



### TRANSIENT ANALYSIS

Allows to evaluate the temperature evolution for each pulse along the transient.

| Material | T min [°C] | T max[°C] |
|---|---|---|
| Aluminum | 22.5 | 129 |
| Silicon | 22.4 | 159 |




OTR screen cannot completely cool down in the time between two subsequent pulses, and temperature increases by 0.5°C after first. With the previous steady-state analysis, imposing the average power, it has been verified that temperature increase reaches the equilibrium.

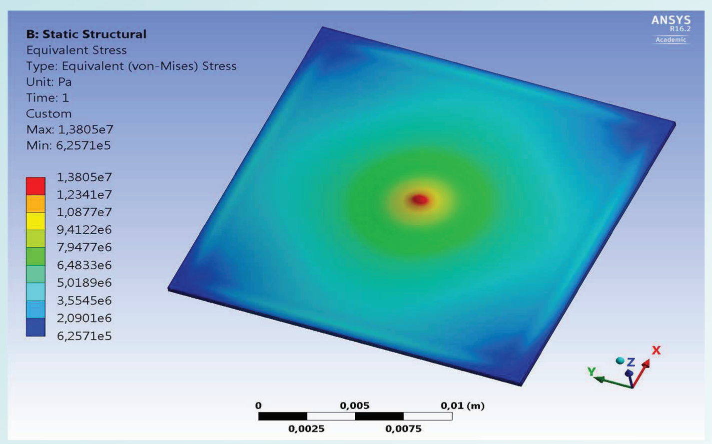
## 5. Structural Analysis

Physics and structural properties of Material OTR [3]

| | | Al | Si |
|---|---|---|---|
| Specific heat ($J * kg^{-1} * K^{-1}$) | $c_p$ | 900 | 700 |
| Density ($kg * m^{-3}$) | $\rho$ | 2700 | 2330 |
| Melting temperature (K) | $T_{melt}$ | 933 | 1687 |
| Thickness (μm) | $\Delta x$ | 0.05 | 380 |
| Emissivity | $\varepsilon$ | 0.18 | 0.67 |
| Thermal conductivity ($W * m^{-1} * K^{-1}$) | $k$ | 204.5 | 143.5 |
| Thermal diffusivity ($m^2 * s^{-1}$) | $\alpha_d$ | $8.418 \times 10^{-5}$ | $8.8 \times 10^{-5}$ |
| Tensile strength (MPa) | $\sigma_{ten}$ | 110 | 225 |
| Coeff. Thermal lin. expansion ($K^{-1}$) | $\alpha$ | $23.9 \times 10^{-6}$ | $2.5 \times 10^{-6}$ |
| Young's Modulus (GPa) | $E_y$ | 70 | 150 |
| Yield Strength (MPa) | $\sigma_{0.2}$ | 320 | |

### STEADY-STATE

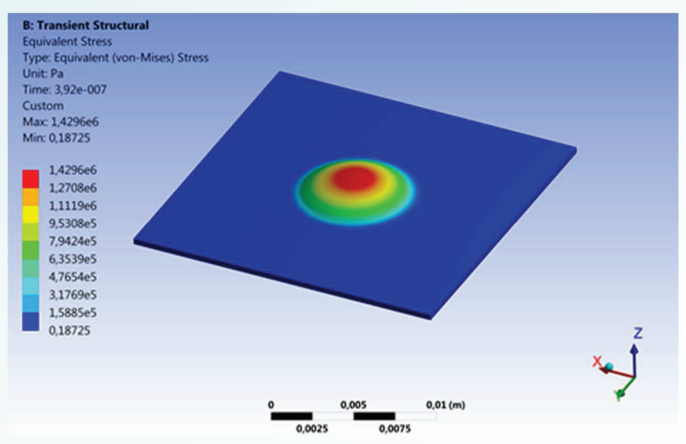
| Material | Maximum Deformation [nm] | Maximum Von Mises [MPa] |
|---|---|---|
| Aluminum | 180 | 13.8 |
| Silicon | 20 | 3.25 |




*Aluminum Stress equivalent (Von Mises)*

### TRANSIENT ANALYSIS

| Material | Maximum Deformation [nm] | Maximum Von Mises [MPa] |
|---|---|---|
| Aluminum | 10 | 1.4 |
| Silicon | 1.07 | 0.45 |




*Aluminum Stress equivalent (Von Mises)*

Silicon is the material chosen for the OTR, transient analysis shows a better thermo-mechanical behavior for a single cycle

## 5. Conclusions

The next step of the FEM study will be an optimization of the time-stepping imposed in the transient, in order to reduce the necessary computational time and memory to simulate a number of cycles up to the equilibrium. The consequent resulting stress will be used to evaluate the fatigue life of the OTR. Then the final step will be the implementation of all brackets and mechanical support components of the OTR, evaluating the whole system dissipation. The expected result of the last analysis is to confirm that the additional mechanical sup-ports and brackets do not induce further thermal dissipation and hence they do not degrade the thermal-mechanical features of the whole OTR system.

## References

[1] M. Marongiu et al, "Design issues for the optical transition radiation screens for the ELI-NP Compton Gamma source", Nuclear Instruments and Methods in Physics Research (2016) 1–4.
[2] V. Balandin and N. Golubeva, "Survival and thermal heat-ing of materials for the OTR screens at the TTF2", 2001, unpublished.
[3] Material parameters taken by: http://www.matweb.com/

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