NC STATE UNIVERSITY

Course No: NE 533 | Spring 2022

Course Title: Nuclear Fuel Performance

Final Project

Submitted to:

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Part 1:

Steady State:

Simulation in moose has been performed to observe the heat conduction of the fuel rod of the given dimension. The parameters are selected as follows:

Table 1: Material properties

	Fuel	Gap	Cladding
Thermal Conductivity	0.03	0.1	0.17
Specific Heat	0.33	5.19	0.35
Density	10.98	0.00082	6.5

The figure below shows the geometry.Green portion represents the fuel, red portion represents the gap, and the gray portion represents the cladding.

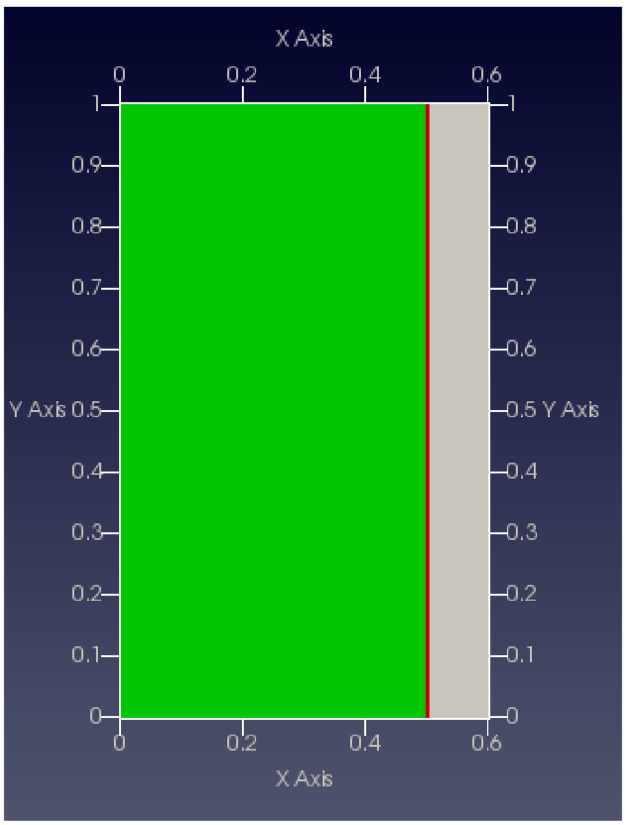


Figure 1: Fuel (0.5mm), Cladding (0.002mm), Gap (0.1mm)

In steady state, the heat conduction is studied. The figure below shows the distribution of heat across the fuel. The graph shows temperature vs radial distance. X-axis represents distance from the centerline, and Y-axis represents temperature in kelvin. The temperature is maximum at the center, and gradually decreases outwards.

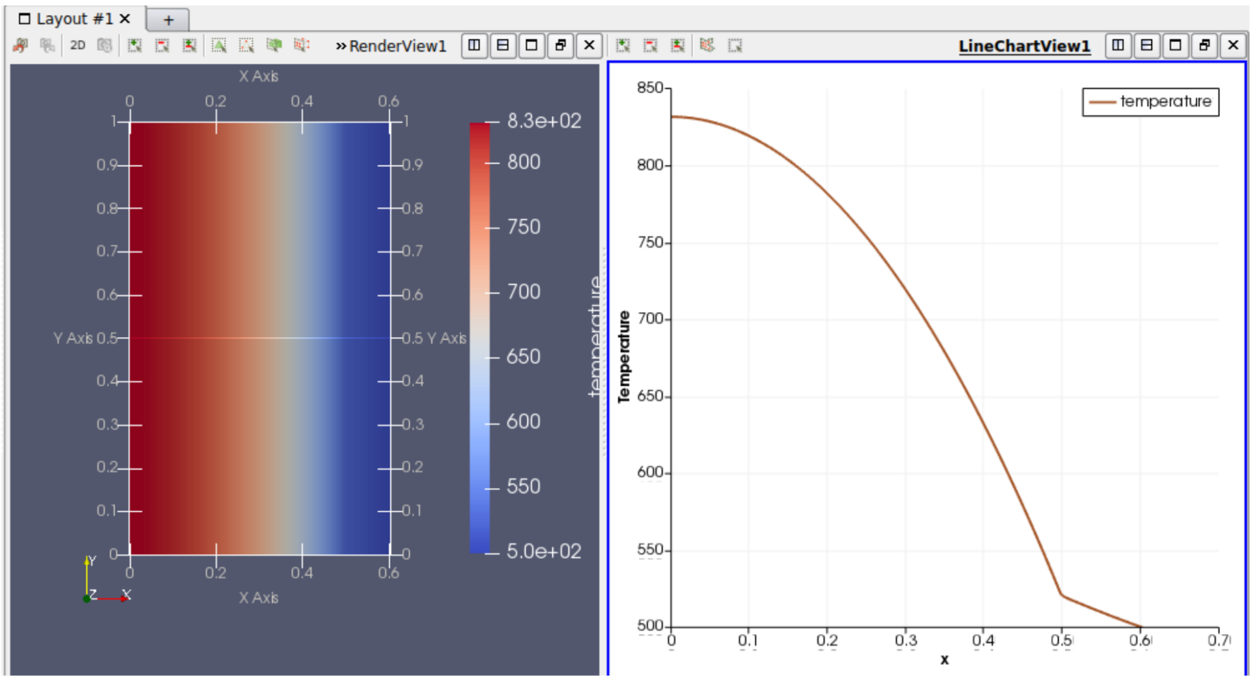


Figure 2: Steady-state analysis (Part 1)

Analytical calculation is also performed. The table below shows the comparison:

Table 2: Difference between simulation and analytical results

	Centerline	Fuel Surface	Inner Cladding
Simulation	831.6	520.5	520
Analytical	927	529.1	528.1
Error	10.3%	1.6%	1.5%

Transient:

The figure 3 below shows the result for transient analysis with t=0 to t=100. The graph shows the centerline temperature over time.

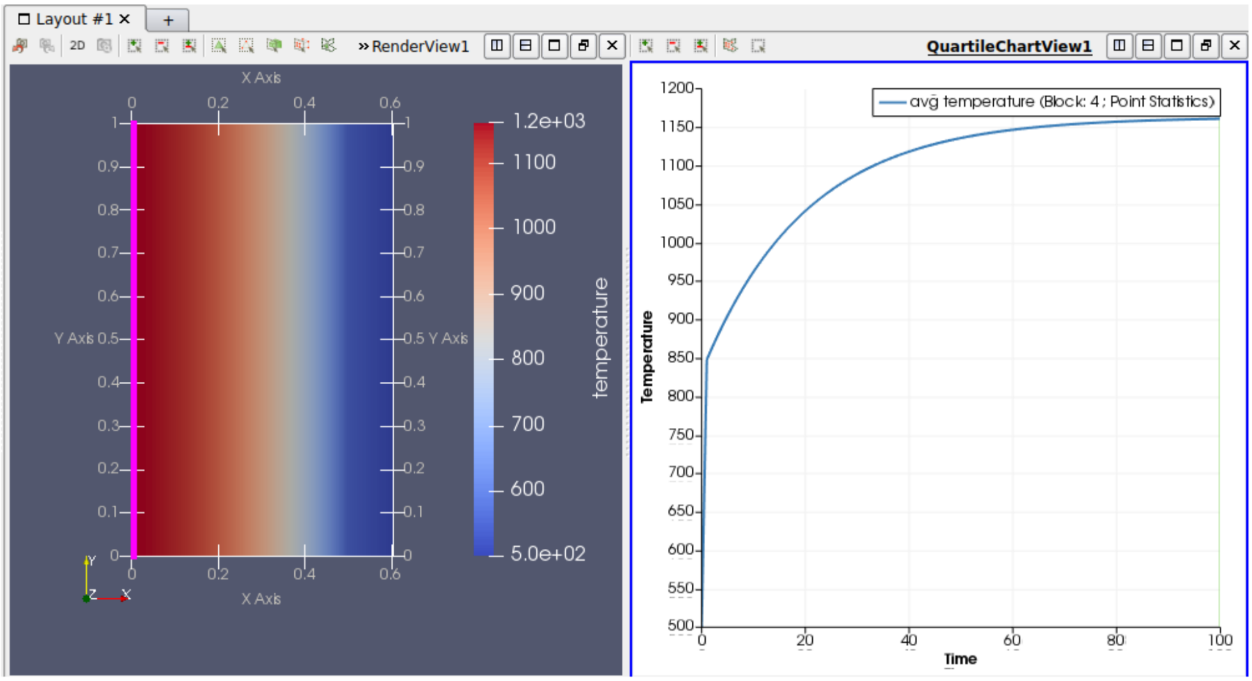


Figure 3: Transient analysis (Part 1)

Part 2:

2D RZ mesh is configured as per the parameters similar to part 1 and the given dimension. In this analysis, the temperature is not the same for all axial positions.

Steady State:

The steady state behavior is shown in the figure below. As shown in the figure, the temperature is maximum at Z_0 and decreases in all other directions. The figure shows the temperature variation in different axial positions. The table below shows the temperature at z=1,0.5,and 1.

Table 3: Temperature profile at z=0, z=0.5 and z=1

	z=0	z=0.5	z=1
Centerline Temperature (x=0)	403.6	571.99	403.6
Fuel Surface (X=0.5)	398	412	398
Cladding(X=0.502)	398.16	411	398.16

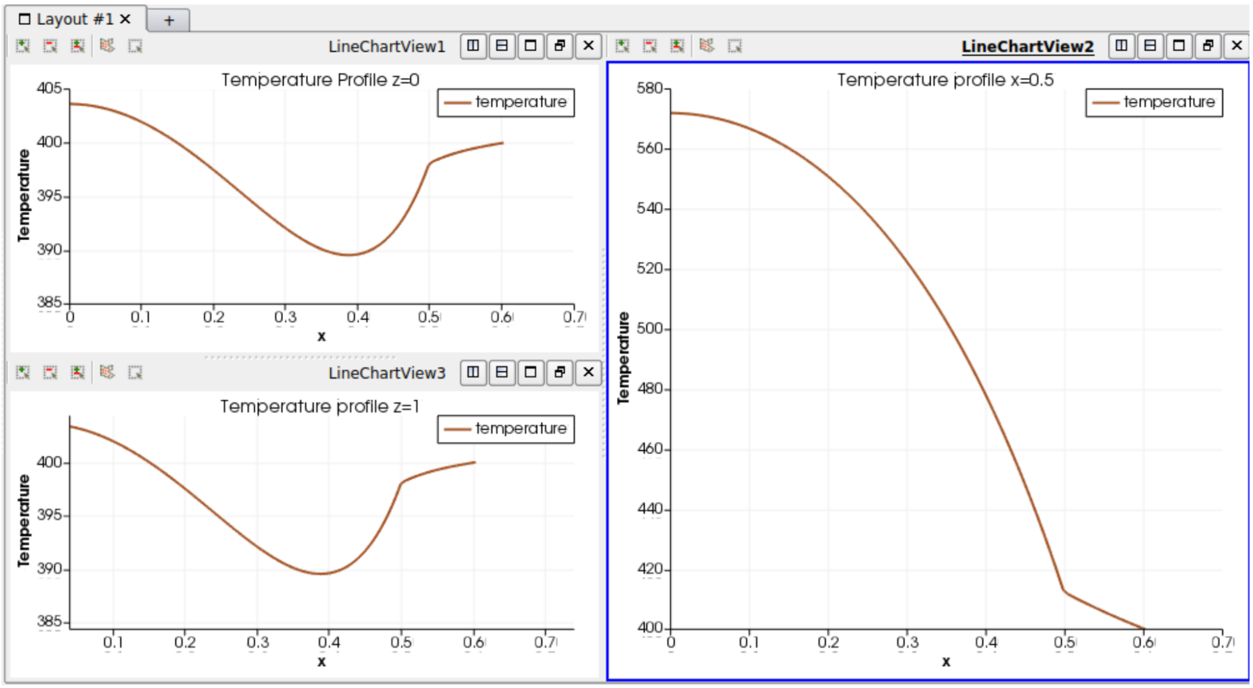


Figure 4: Temperature vs x at z=0,z=0.5, and z=1

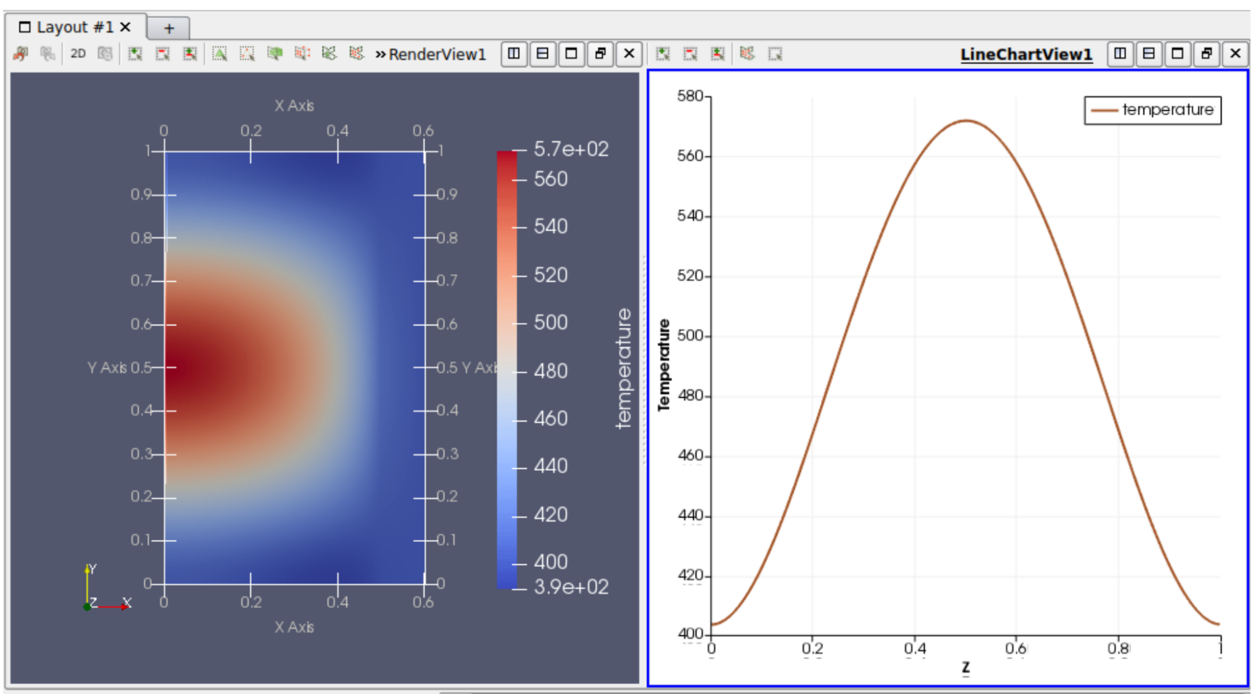


Figure 5: Temperature vs axial position (Part 2)

Transient:

The figure below (Figure 6) shows transient analysis of part 2. The graph shows how centerline temperature changes over time and its range as the blue area.

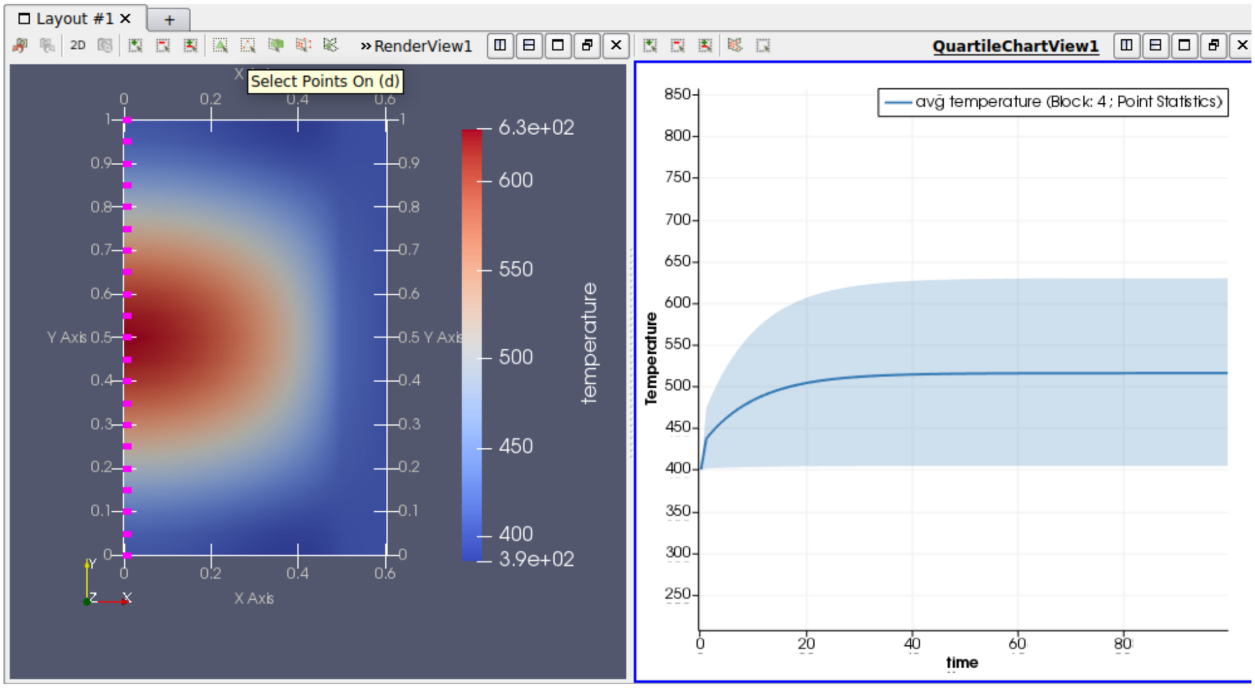


Figure 6: Transient analysis, temperature vs time (Part 2)

Part 3:

In this simulation, the stress due to temperature is computed with LHR=175W/cm. Both heat conduction and tensor mechanics modules have been utilized. Thermal expansion coefficient value is obtained from the manuscript from Argonne National Laboratory [1]. Young's modulus and poisson's ratio is obtained from the paper by Kurt et al.[2] In this first part (Figure 8), a constant thermal conductivity of 0.03 is used. Figure 7 shows the temperature profile, which is the same for both analyses.

In the second part of the analysis, the thermal conductivity is varied as per the empirical data obtained from the paper [3] by Steven et al. In this experimental data, the conductivity values vary from 0.06 to 0.02 in different temperatures analyzed in the simulation. The observation I have made is that with such small variance of thermal conductivity, the variation in temperature dependent stress is less noticeable (Figure 9a). However, to confirm the change of stress due to temperature dependent thermal conductivity, I have increased the range for additional test (Figure 9b)

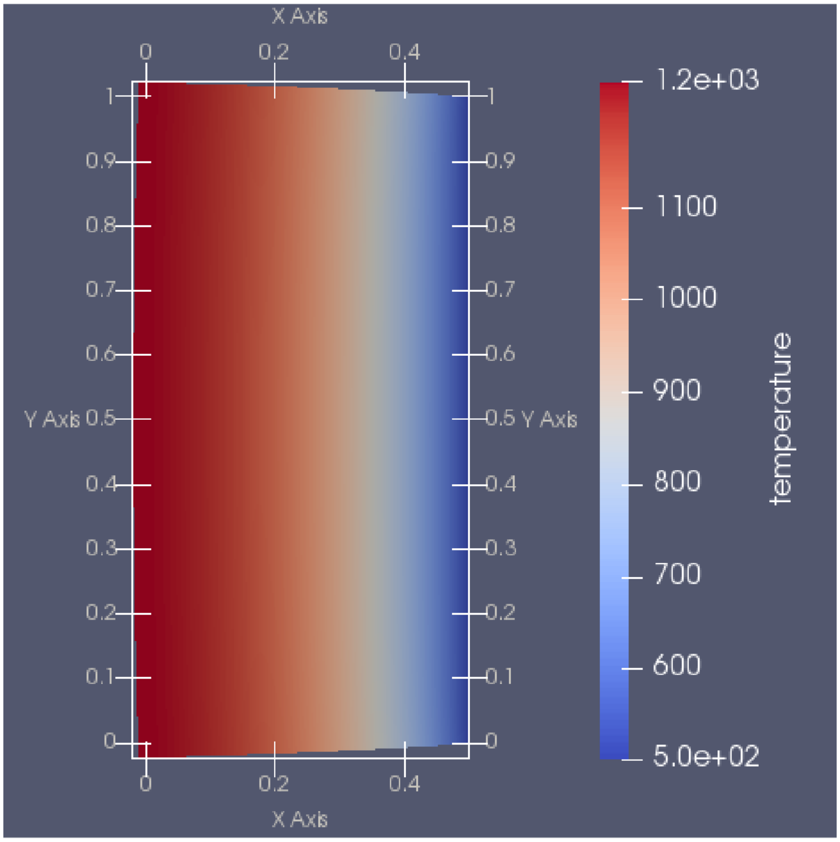


Figure 7: Temperature distribution (part 3)

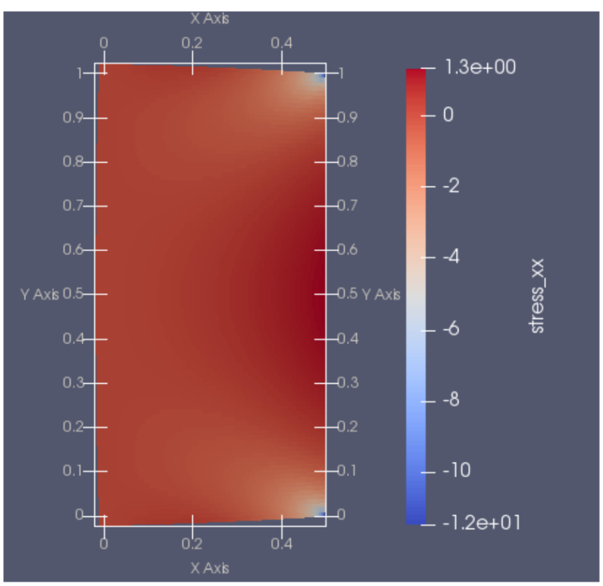
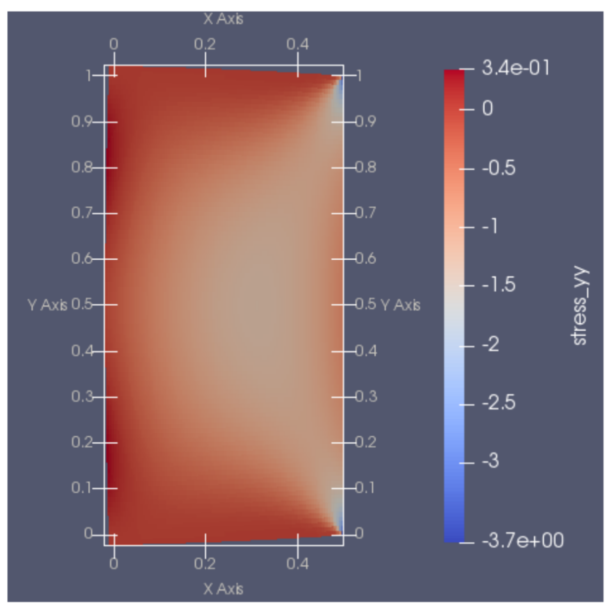
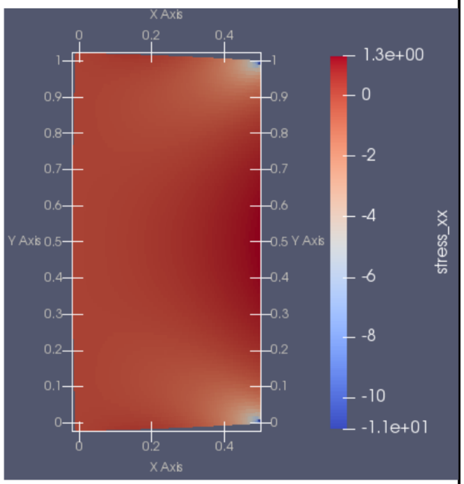
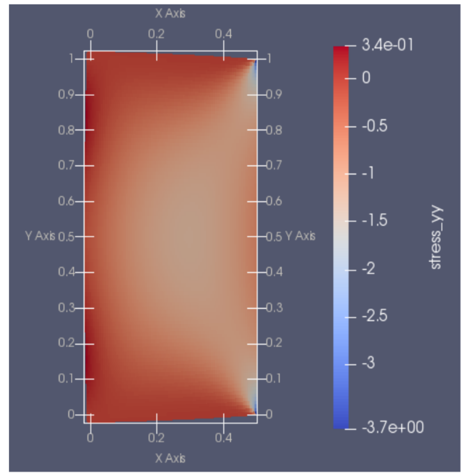
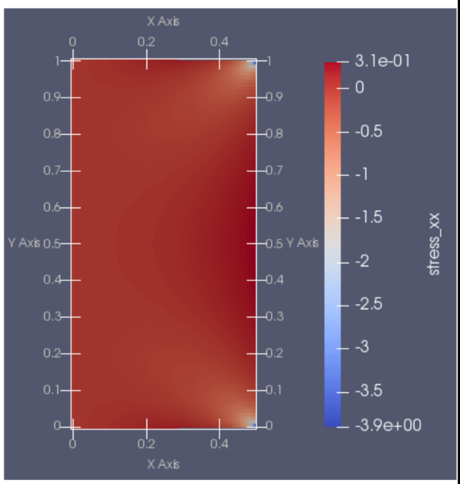
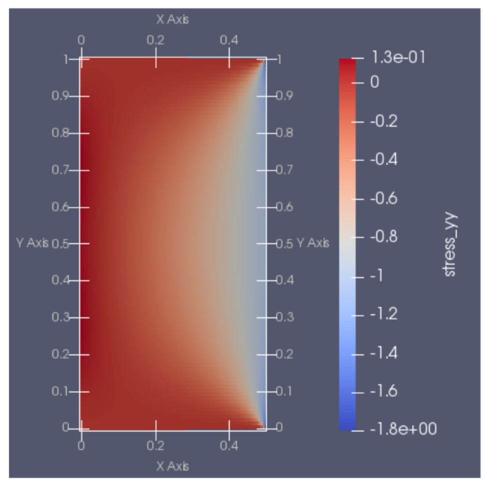
Stress_XX	Stress_YY
	

Figure 8: Stress distribution with constant thermal conductivity

<table>
<tr><td></td><td>Stress_XX</td><td>Stress_YY</td></tr>
<tr><td>Figure 9a: Stresses with thermal conductivity from [3] (from 0.0627 to 0.0262).</td><td></td><td></td></tr>
<tr><td>Figure 9b: Stresses with wider range of thermal conductivity (10 to 0.0005).</td><td></td><td></td></tr>
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Video Links:
(Transient Part 1)
(Transient Part 2)

References:

[1] Fink, Joanne K., Martin G. Chasanov, and L. Leibowitz. *Thermophysical properties of thorium and uranium systems for use in reactor safety analysis*. No. ANL-CEN-RSD-77-1. Argonne National Lab., Ill.(USA), 1977.

[2] Terrani, Kurt A., et al. "Young's modulus evaluation of high burnup structure in UO2 with nanometer resolution." *Journal of Nuclear Materials* 508 (2018): 33-39.

[3] Ross, Steven B., Mohamed S. El-Genk, and R. Bruce Matthews. "Thermal conductivity correlation for uranium nitride fuel between 10 and 1923 K." *Journal of nuclear materials* 151.3 (1988): 318-326.