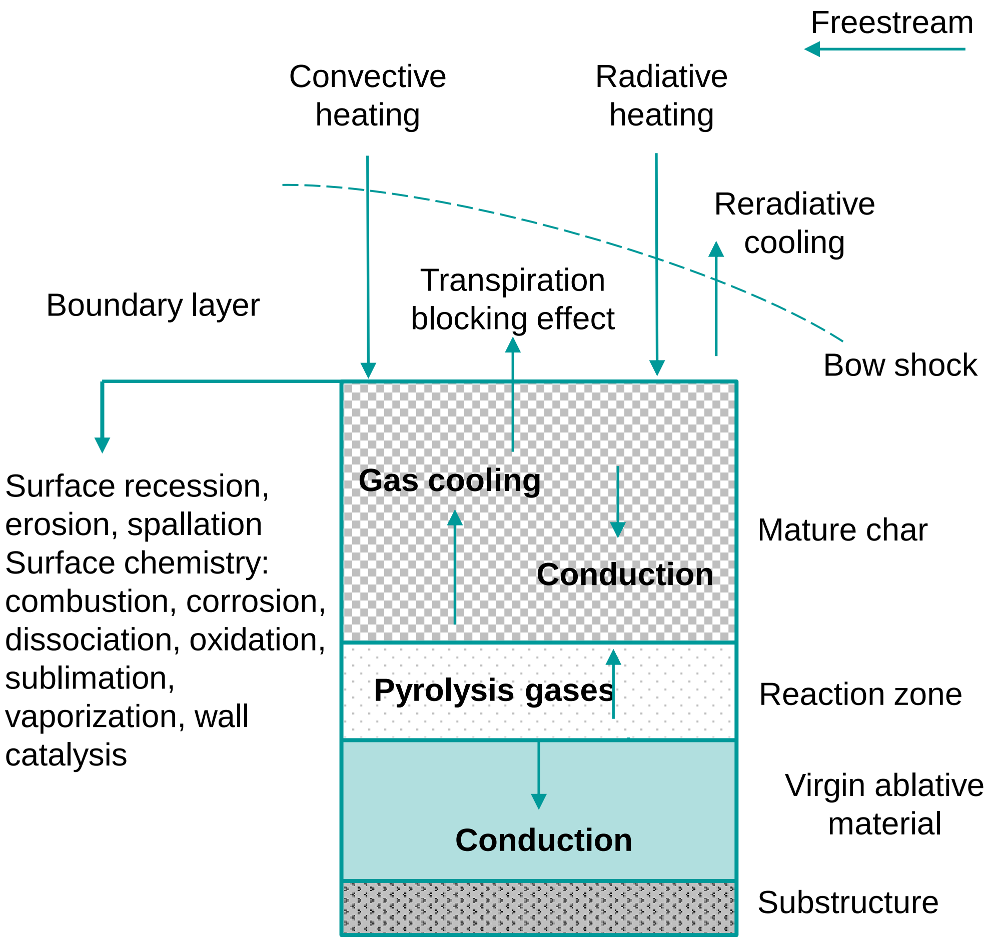
Modeling charring ablative materials

Introducing ablation physics

The ablation process involves:

1. **Atmospheric Hypersonic Flight:** During hypersonic flight, a bow shock forms, raising the surface temperature and interacting with the boundary layer.
2. **Viscous Flow and Heat Transfer:** Viscous flow in the boundary layer increases wall temperature, transferring heat to the heat shield through radiation and convection.
3. **Conduction to Ablative Material:** Heat conducts from the shield's outer surface to the underlying ablative coating layer.
4. **Pyrolysis and Char Formation:** In charring ablative materials, resin undergoes pyrolysis, generating gaseous hydrocarbons and a carbonized char residue.
5. **Gas Generation and Pressure Increase:** Pyrolysis gases pressurize and permeate through the char, reducing porosity and modifying thermal conductivity.
6. **Heat Removal and Blocking Effect:** Gases remove heat by convection and block convective transfer from the boundary layer to the body.
7. **Chemical Reactions and Surface Effects:** Ablation products may chemically react with boundary layer gases, causing surface recession and oxidation.
8. **Mechanical Erosion and Melting:** Mechanical erosion and surface melting reduce the thickness of the ablative layer, influencing heat transfer and aerothermal fields.



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Char/Ablative Thermal Protection System (TPS) Thermal Simulation

- The Simcenter 3D **Ablation-Charring** modeling object simulates the thermal performance of char/ablative TPS.
- If the full physics of char/ablation must be included to predict the complete performance of ablative TPS, user provided subroutine capability is available, see last page of this presentation.

Ablation process in Simcenter 3D

Thermal solver uses a simplified approach to simulate the thermal effects of charring and ablation. It:

- Ignores the pyrolysis, chemical reactions, mechanical erosion and melting.
- Assumes that ablation or charring of a material occurs at the phase change temperature.

Simcenter 3D ablation process includes:

- Virgin material conduction.
- Pyrolysis gas latent heat absorption.
- Char material conduction and char removal.
- Exterior convective and radiative heating.

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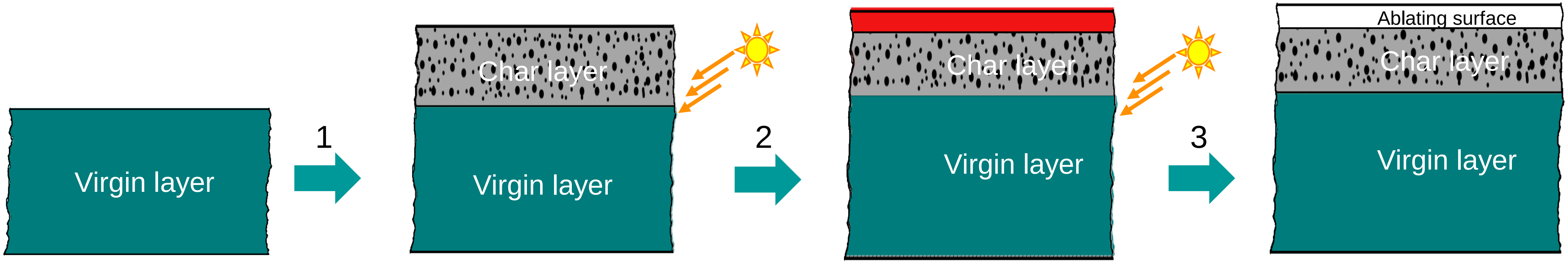
Understanding ablation-charring simulation

- *Charring* is a chemical process that occurs when a solid that is subjected to intense heat is incompletely combusted.
- When a virgin element reaches its defined phase change temperature, the element is transformed into the specified char material and heat is absorbed.
- *Ablation* is the loss of material from the surface of an object by an erosive process such as vaporization, melting, or chipping
- When a char element reaches its defined phase change temperature, the thermal solver increases its thermal conductivity by a factor of 1.0×10^{5} and reduces its capacitance by a factor of 1.0×10^{-6}, thermally eliminating the element.

Schematic of charring ablator



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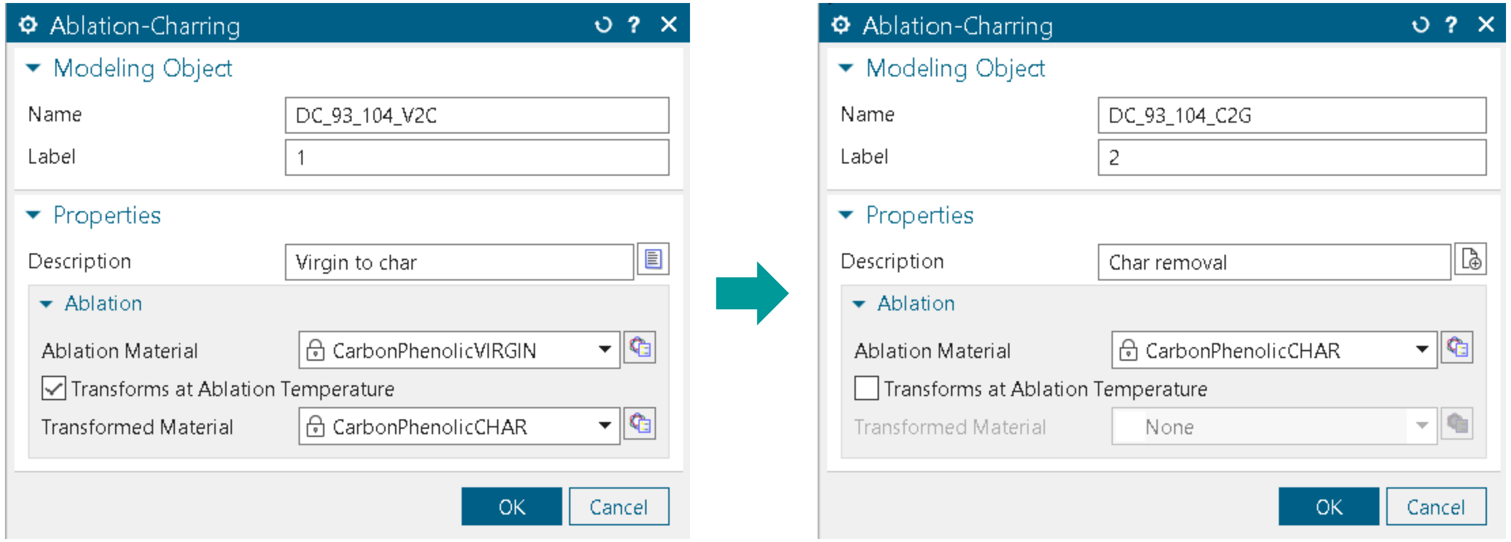
Ablation-charring simulation

- The **Ablation-Charring** modeling object is used to simulate the material transformation that an object undergoes when it is exposed to an intense transient heat source.
- The thermal solver models ablation or charring of 3D solids, 2D multi-layer shells, or axisymmetric elements.
- An element that is ablated or charred does not change back to its original state even if its temperature falls below the defined phase change temperature.



The **Ablation-Charring** modeling object is applied twice to elements meshed as virgin.

Defining phase temperature

To simulate ablation-charring, it is necessary to define a phase change temperature of the material.

This example shows how to adjust the char material phase change temperature to match reliable test data.

Experimental data:

Ablation-charring test

At time= 8 min.

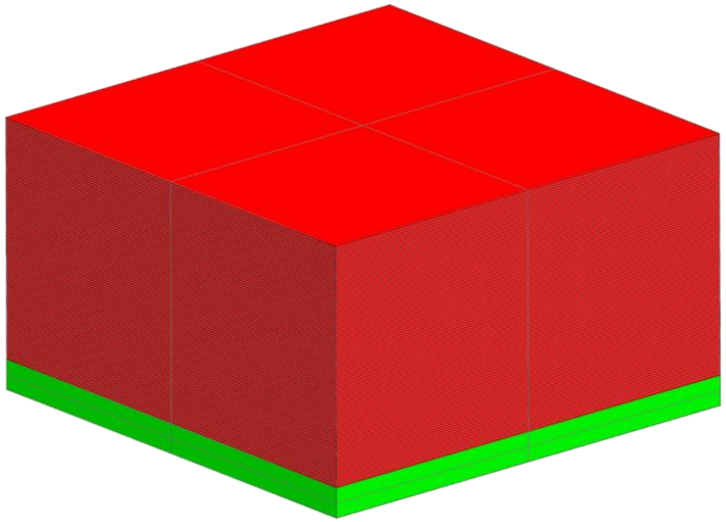
- The plate temperature is 244 F.
- Virgin thickness is 0.125 in.
- Char thickness is 0.072 in.

Simulation:

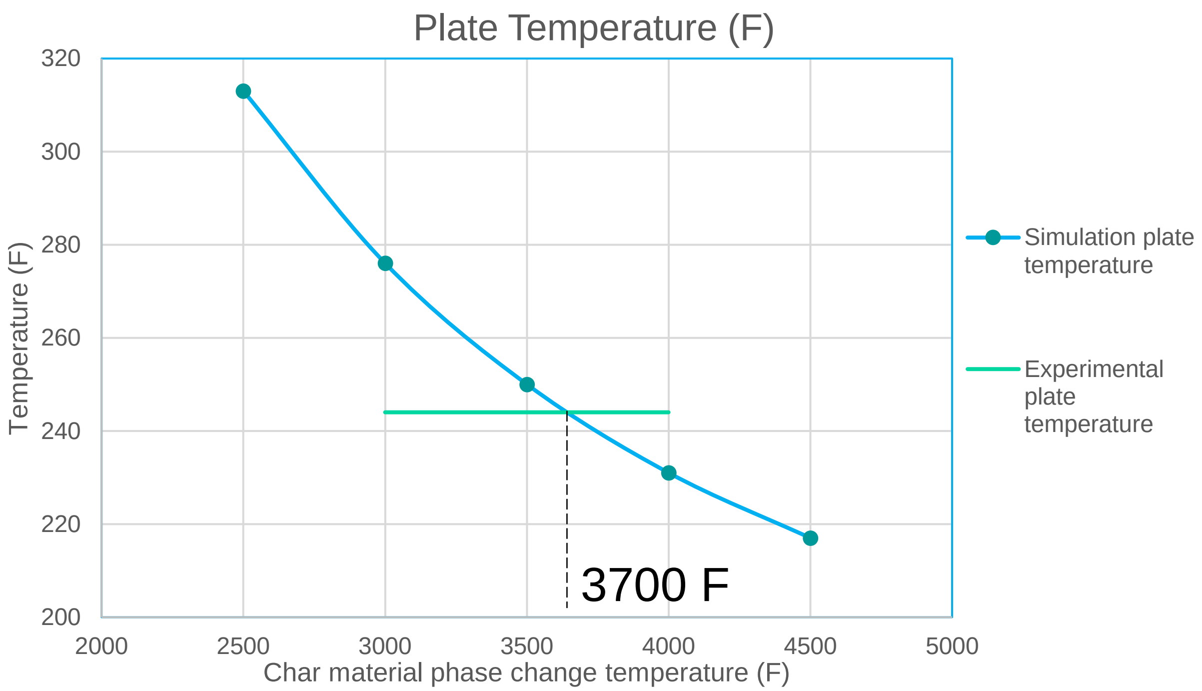
5 runs using different char material phase change temperatures.

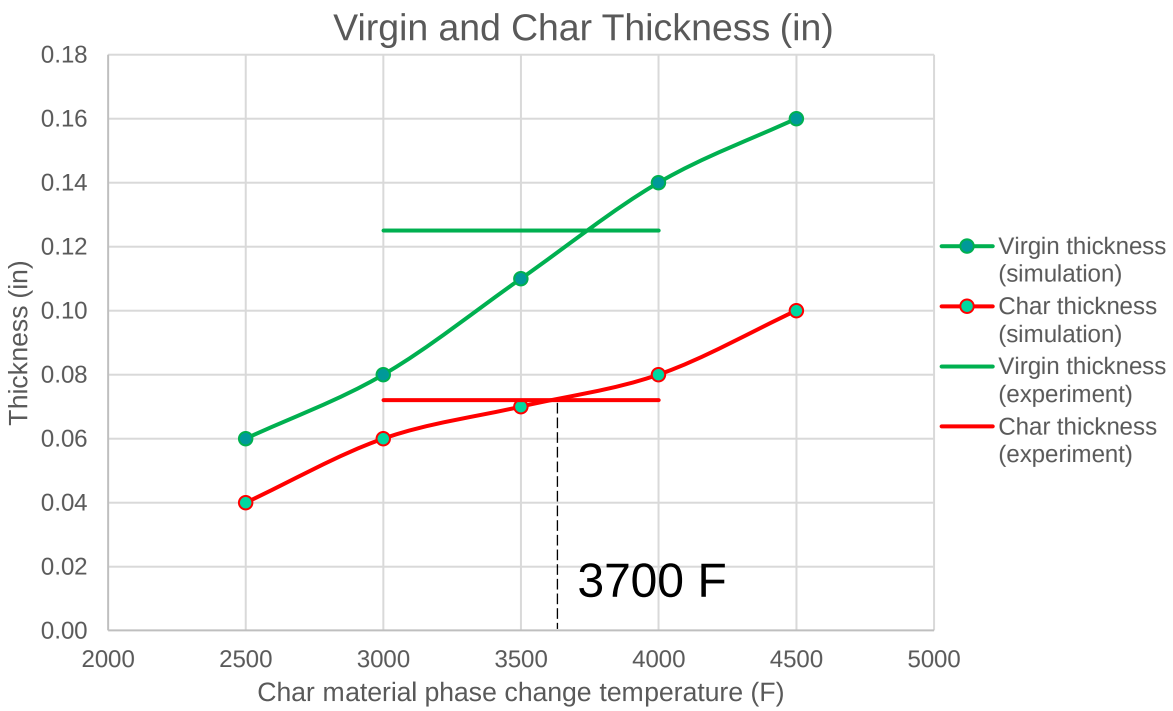
Solution results at time = 8 min.

T(char) F	T(steel) F	t(virgin) in	t(char) in
2500	313	0.06	0.04
3000	276	0.08	0.06
3500	250	0.11	0.07
4000	231	0.14	0.08
4500	217	0.16	0.10



Simulation and experimental results





The experimental plate temperature of 244 F corresponds to the simulation char material phase change temperature of 3700 F.

The experimental char thickness of 0.072 in. corresponds to the simulation char material phase change temperature of 3700 F.

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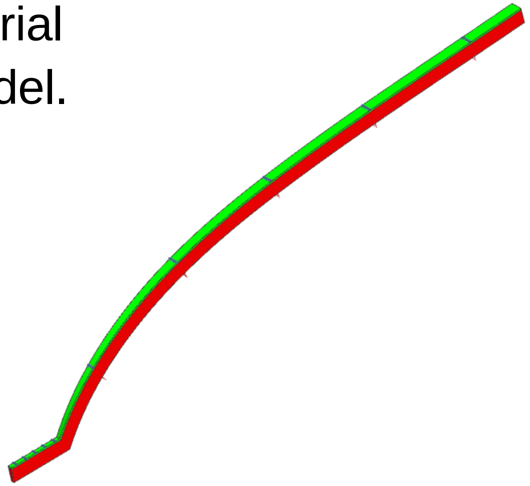
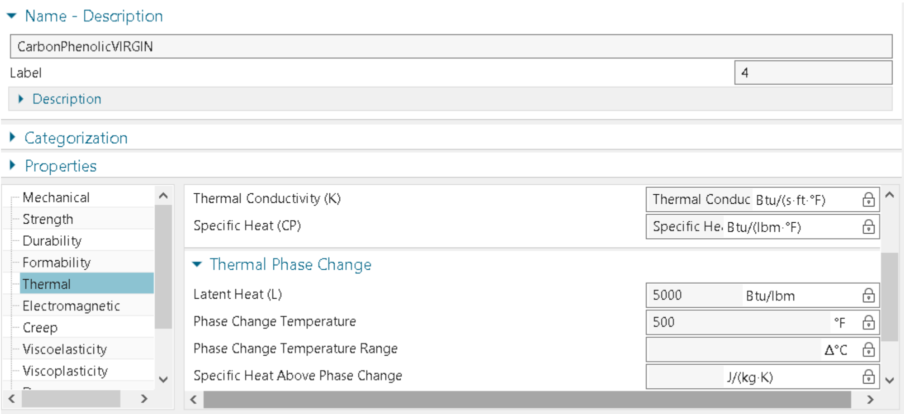
Setting up ablation – charring models

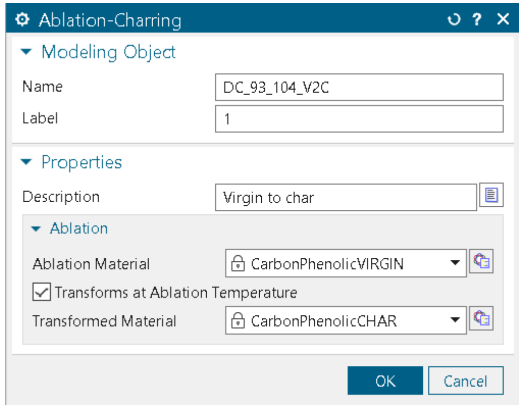
Once the char material phase change temperature is finalized, the virgin and char material definitions and both **Ablation-Charring** modeling objects can be applied to the real model.



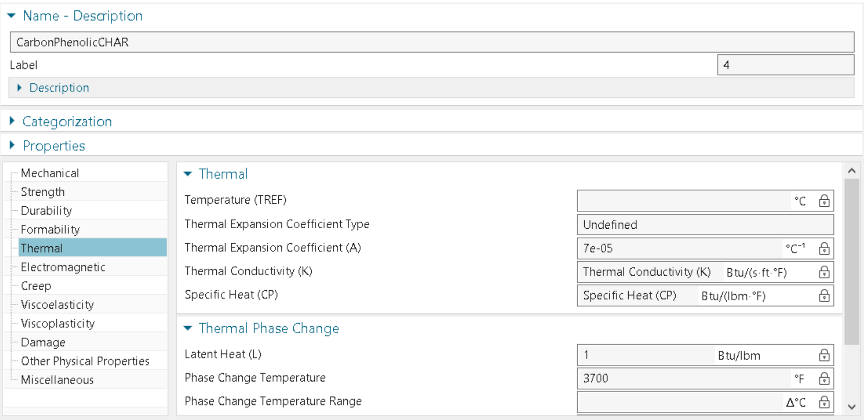
For example,
Solid Booster Rocket

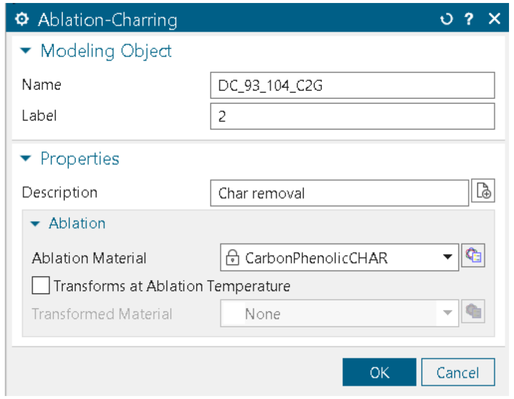
Virgin material





Char material





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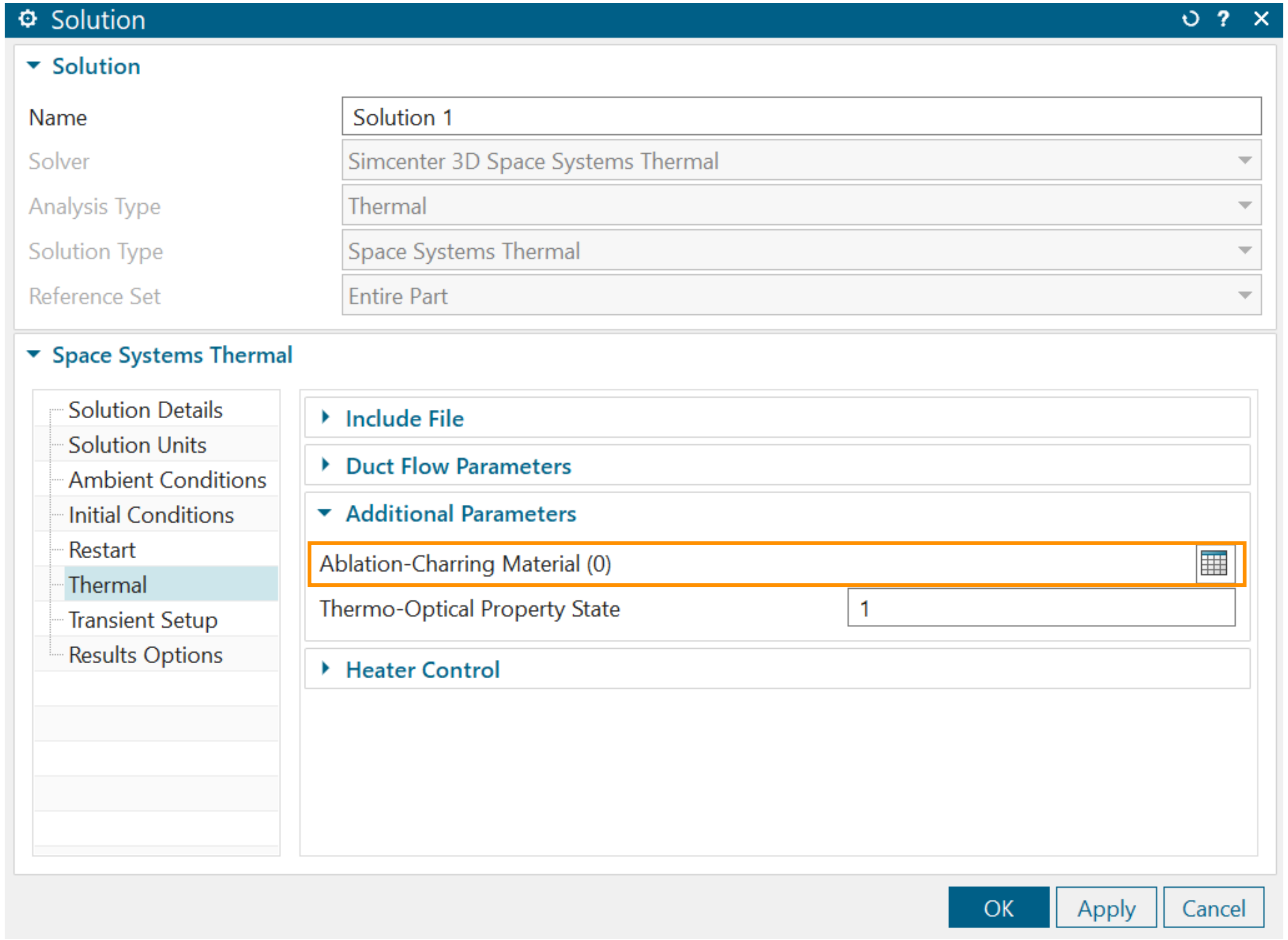
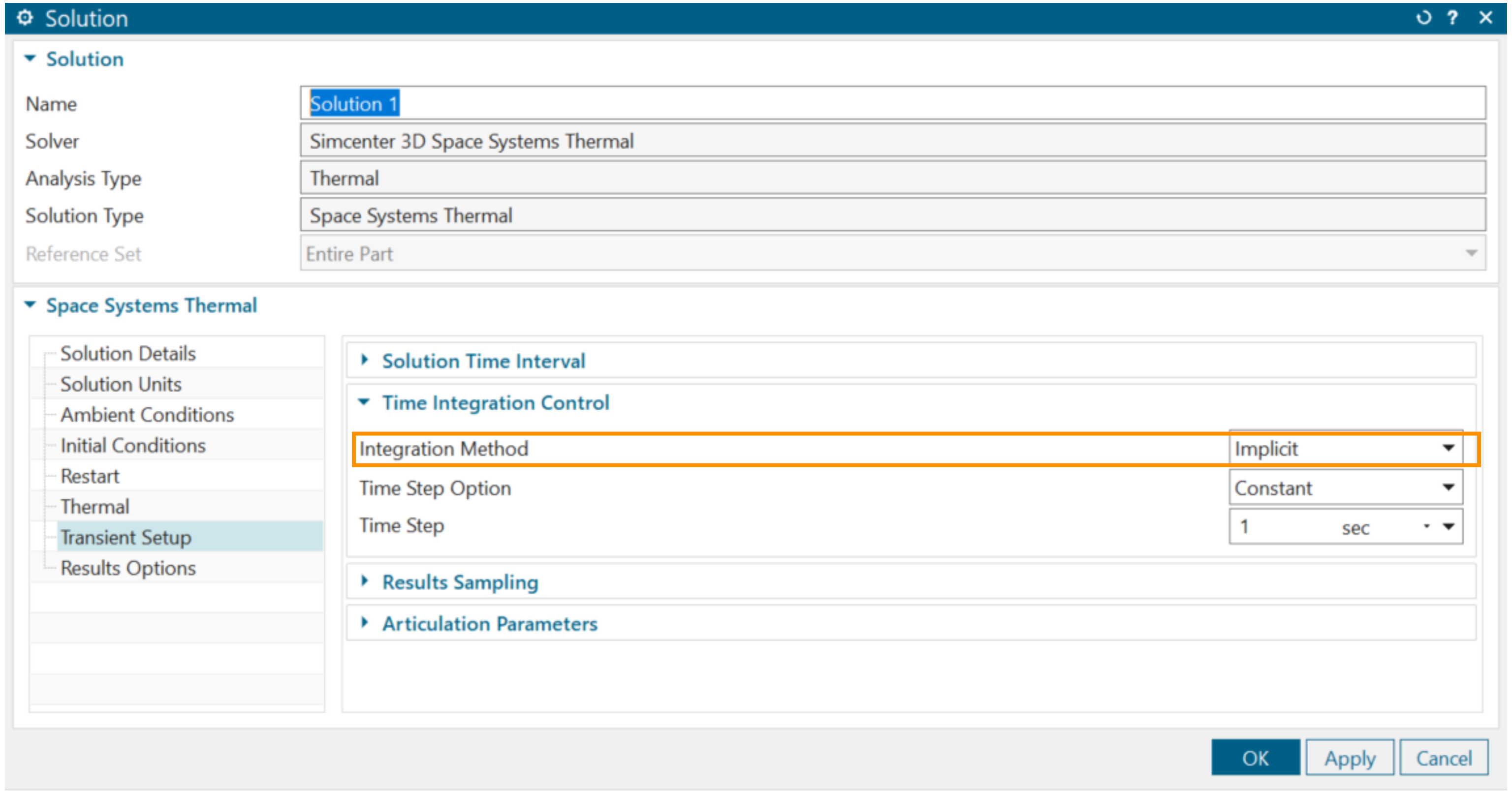
Setting up ablation – charring models

Add the **Ablation-Charring** modeling objects to the additional parameters of the thermal solver.



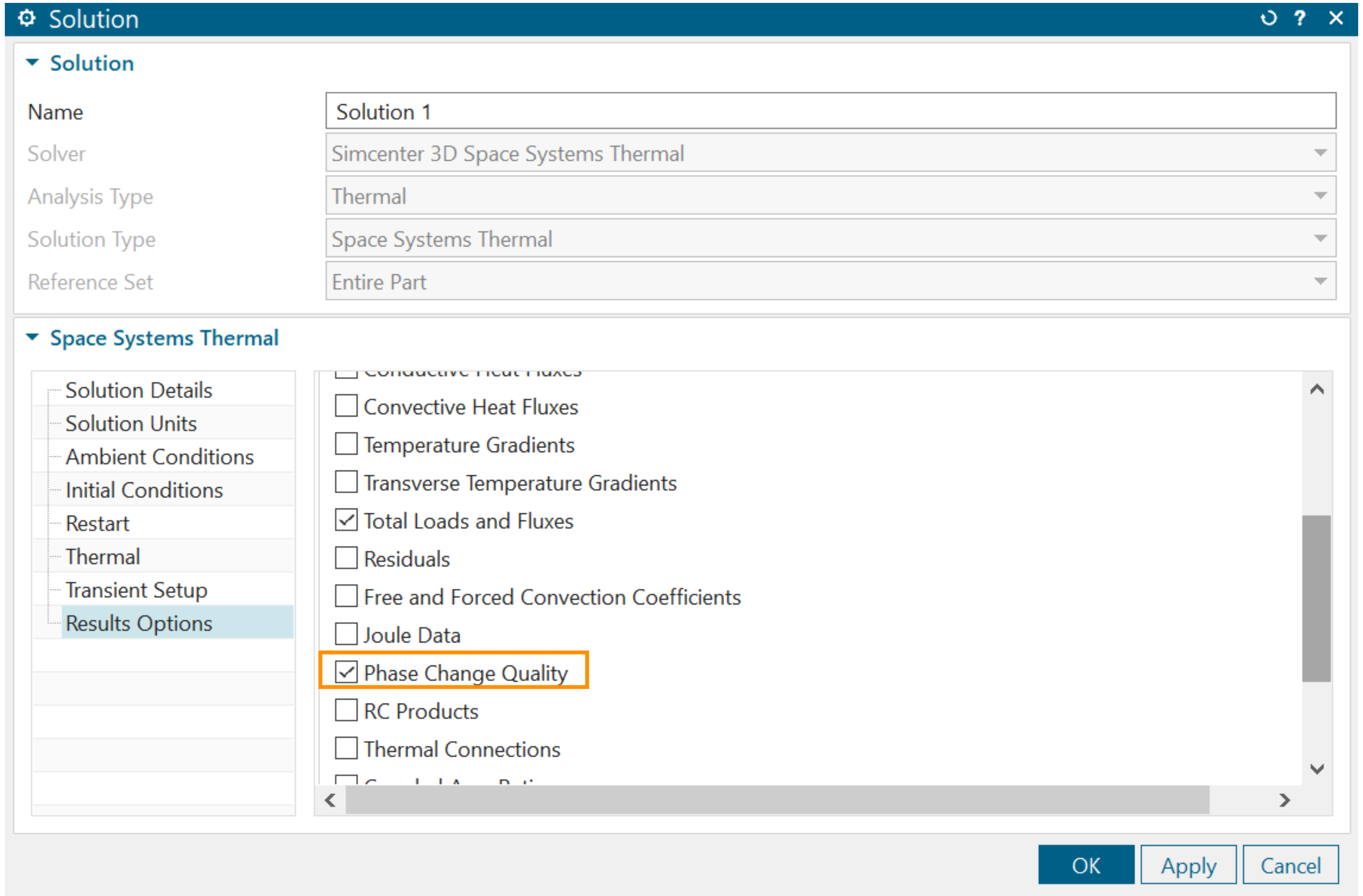
Setting up ablation – charring models

You must select only implicit time integration methods when you model the material ablation.



Identifying ablated mesh elements

Enable the option to identify ablated mesh elements in post after the solve by editing the solution, and selecting **Phase Change Quality**.



Using the user written subroutine to model the complete physics

To include the full physics of char/ablation to predict the complete performance of ablative thermal protective systems, you can use the user written subroutine.

- With user-written subroutine, you can:
  - Retrieve element IDs, coordinates, etc. for the ablation model.
  - Access to conductances, density, conductivity and capacitance of the element.

- ➢ User-supplied ablation model should calculate new average material properties in the element based on solver computed temperatures and any dependent variables tracked in the ablation model.
- ➢ New material properties are used to update new conductances and capacitance in the element.