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ICONE-16
Validation of CFD Methods Using Data for a Ventilated Dry Storage Cask

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Introduction

- NRC uses CFD for confirmatory analyses in dry cask applications.
- CFD is used to analyze dry cask for:
  - Normal storage operation (long-term): Steady state analysis
  - Accident analysis (short-term): Transient analysis, e.g. (blocked vents scenario, fire analysis, etc.)
- Dry cask thermal performance should comply with 10CFR72 requirements.
- Thermal evaluation follows the guidelines of NUREG-1536 and Interim Staff Guidance Memorandum No.11 to demonstrate thermal compliance of the dry cask
- Specifically, some of the requirements are:
  - The fuel cladding temperature for long term storage shall be limited to 400 C
  - The system should be passively cooled

Sources of Errors and Uncertainties

- CFD user introduces errors and uncertainties when performing CFD
- CFD is a knowledge-based activity despite the availability of CFD software
- The following seven different source of errors and uncertainties:

1. **Model uncertainties**: Models may not be a good representation of reality
   - e.g. **Turbulence Models** (most published)
2. **Discretization errors**: Difference between exact solution and discretized equations
3. **Iteration errors**: Difference between fully converged solution and not fully converged
4. **Round-off errors**: A computer solves the equation with a finite number of digits
5. **Application uncertainties**: Geometry errors, **BC Uncertainty**, steady vs. transient
6. **User errors**: Oversimplification of the problem and mistakes of the user
7. **Code errors**: Bugs in the software

Error: a recognizable deficiency that is not due to the lack of knowledge

Uncertainty: a potential deficiency that is due to lack of knowledge

Dry Cask Modeling Issues and Validation:

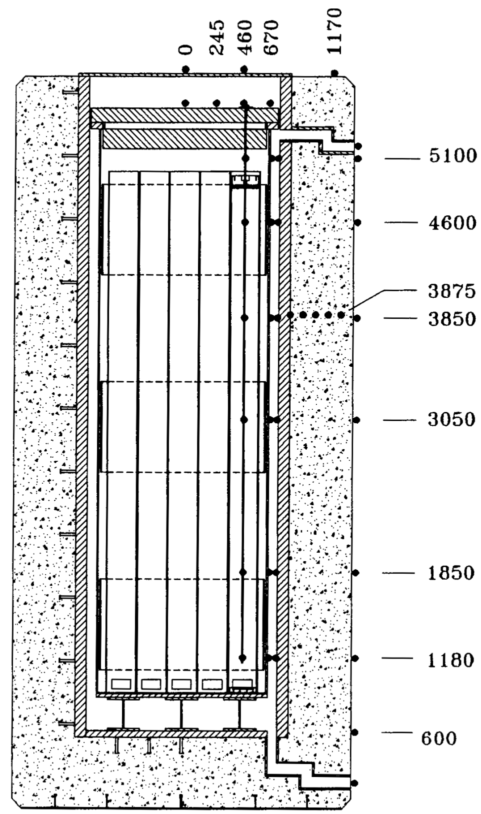
- Porous media is typically used to model flow through fuel rods to save time and effort
  - Effective conductivity representing radiation and conduction in the porous region
  - Porous media modeling uses equivalent frictional and inertial resistances
- Uncertainty in flow regime modeling
  - Turbulent vs. Laminar
  - Uncertainty in turbulence models
- Uncertainty in Boundary condition
  - Buoyancy driven flow
  - Pressure boundaries: What values?
- The Solution is to validate the CFD model before using it

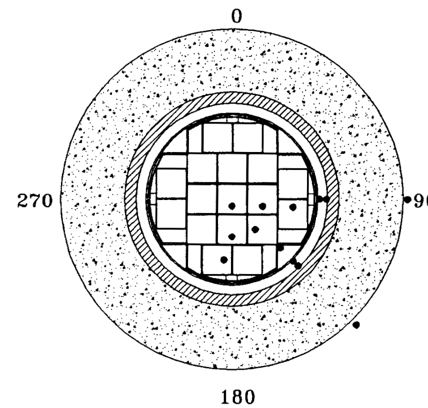
- **Validation**: Procedure to test if the model accurately represents reality

- Ventilated Storage Cask (VSC-17) experimental data, collected by INEEL was used

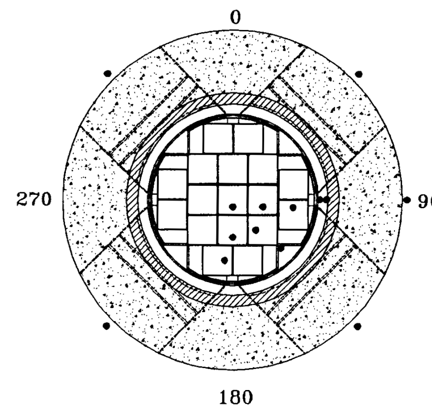
- Similar flow structure and geometry as the casks presented to NRC for certification

Dry Cask VSC-17

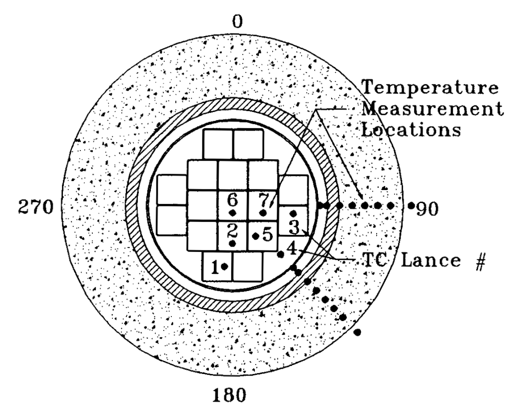




ELEVATIONS 3050 & 4600



ELEVATIONS 1180, 1850, & 5100
PLUS BOTTOM VENTS



ELEVATIONS 3850/3875

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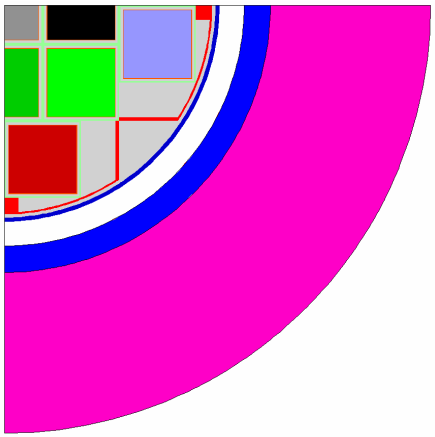
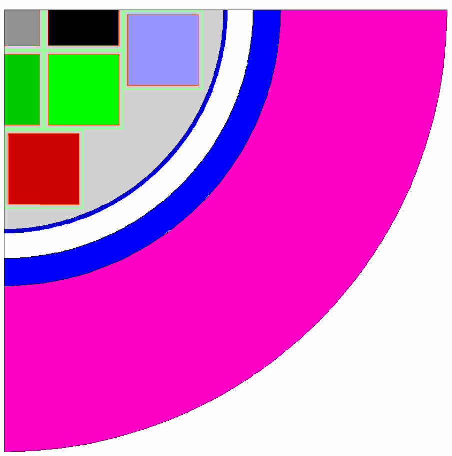
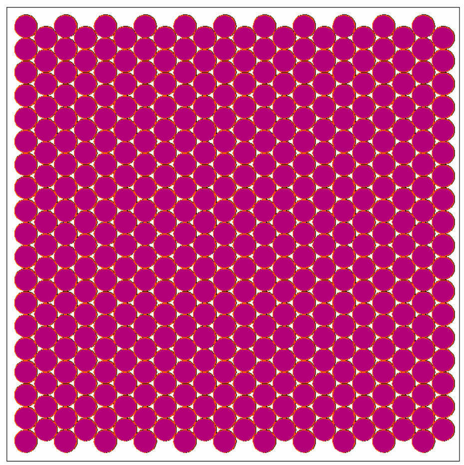
VSC-17 Modeling

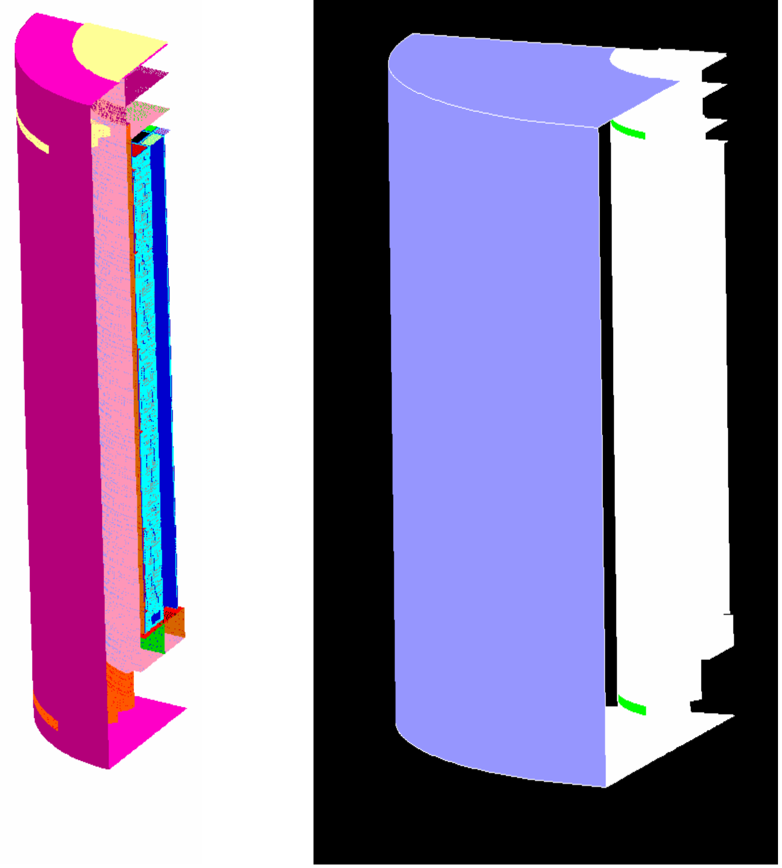
- Inert gas (He) inside the canister. Laminar flow based on the Rayleigh Number
- Air flows in an open system to cool the canister: issues of flow regime
- **Pressure Boundaries** were used at the inlet and outlet air ducts
- **Regime of the flow**: can under-predict the Peak Cladding Temperature (PCT)
- Four turbulence models were used:
  - Low Reynolds std k-ε: requires fine mesh near the wall (y+ ~1)
  - Transitional k-ω SST: requires fine mesh near the wall (y+ ~1)
  - Standard k-ε: requires a mesh near the wall (y+ ~ 30), uses Std wall functions
  - Laminar flow regime: requires fine mesh
- Consolidated Fuel (410 rods): fuel was modeled by a solid volume with an energy source of 14.9 kW.
- Equivalent effective thermal conductivity was found using 2-D CFD analysis
- Grid independent solution was found first

VSC-17 Modeling (Cont)









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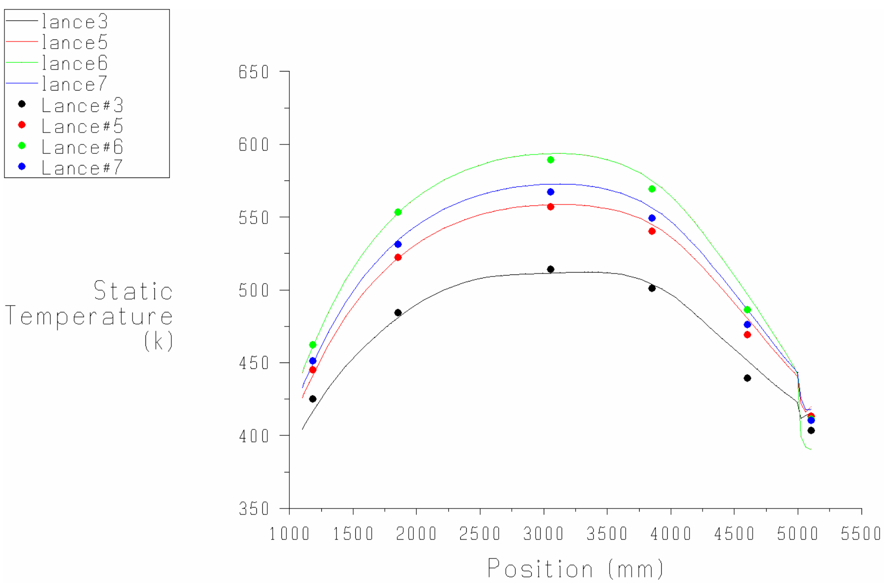
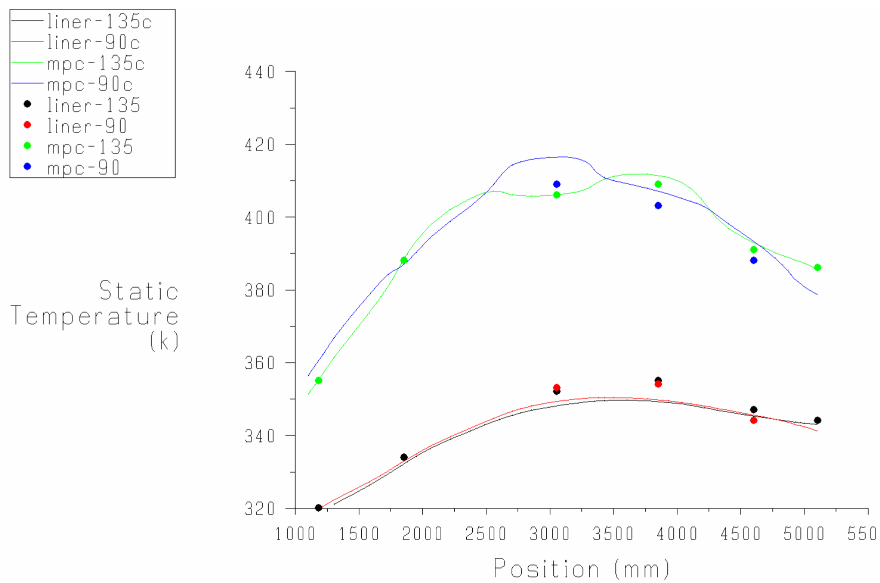
VSC-17 Results (Comparison)

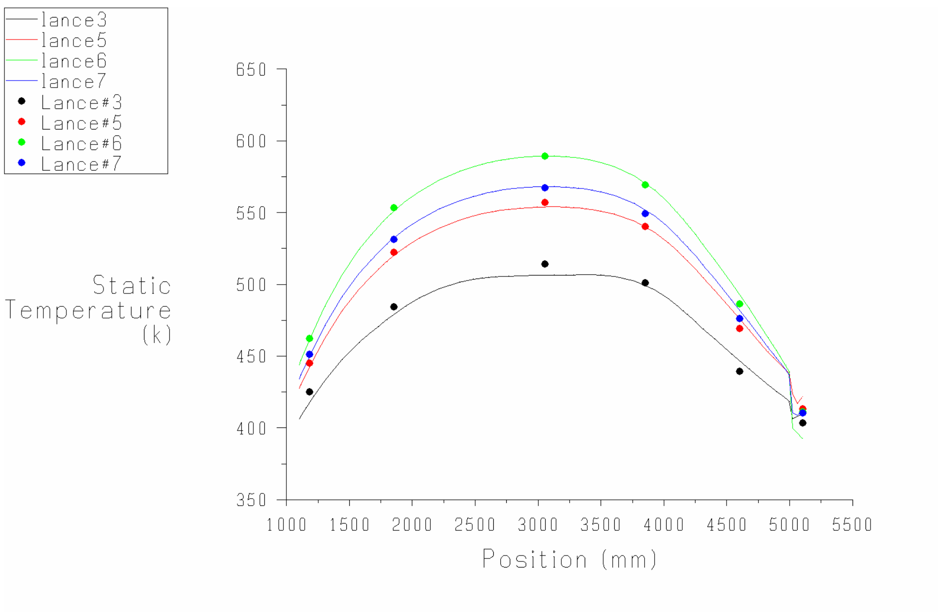


Fuel axial temperature using low Reynolds k-ε turbulence model

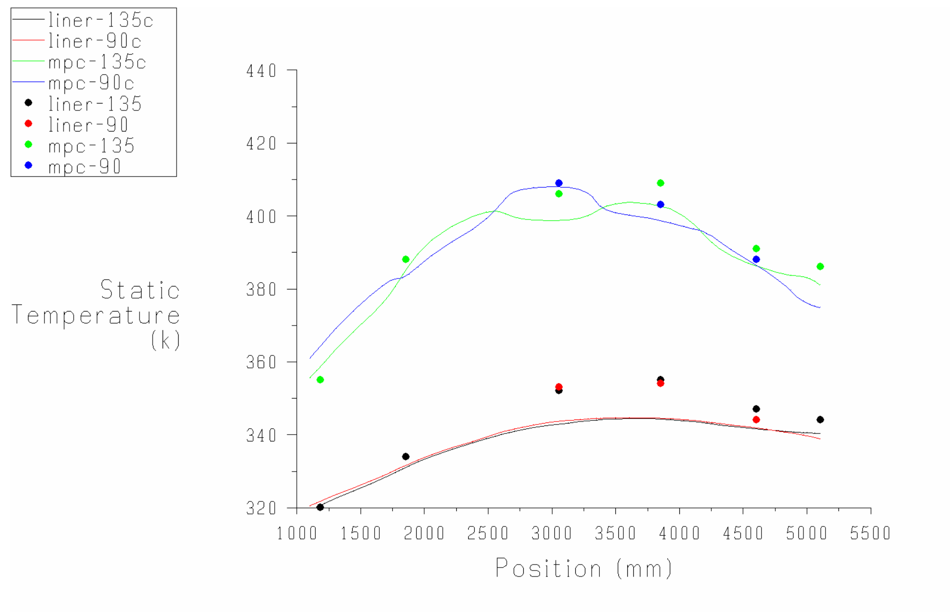


Liner and MPC walls axial temperature using low Reynolds k-εturbulence model

<u>VSC-17 Results</u> (Comparison)

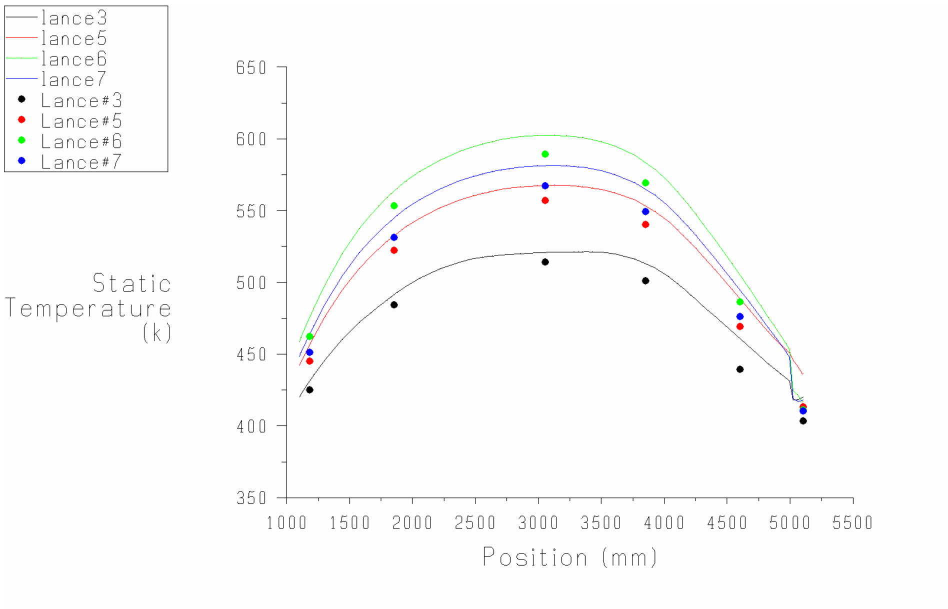


Fuel axial temperature using standard k-ε turbulence model

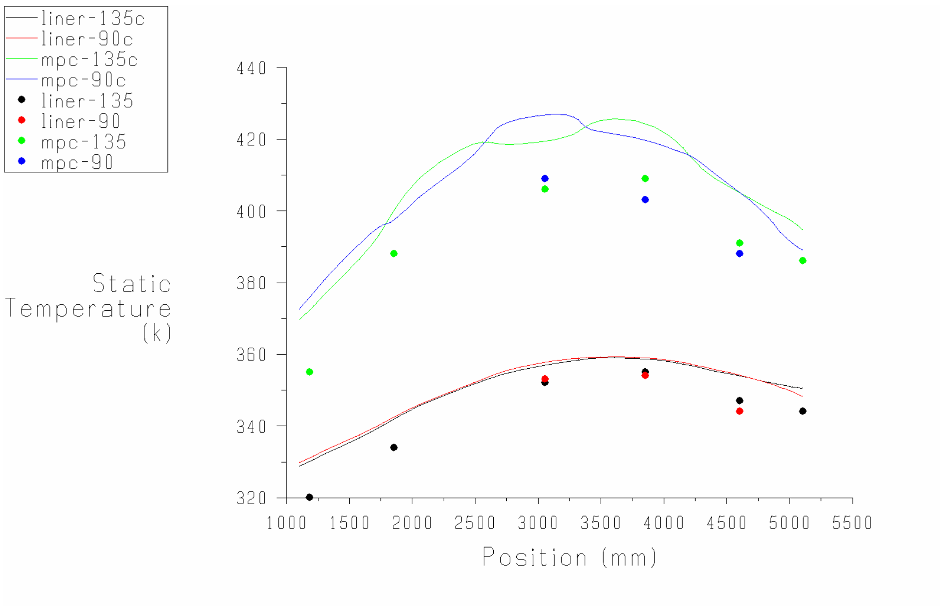


Liner and MPC walls axial temperature using standard k-εturbulence model

VSC-17 Results (Comparison)

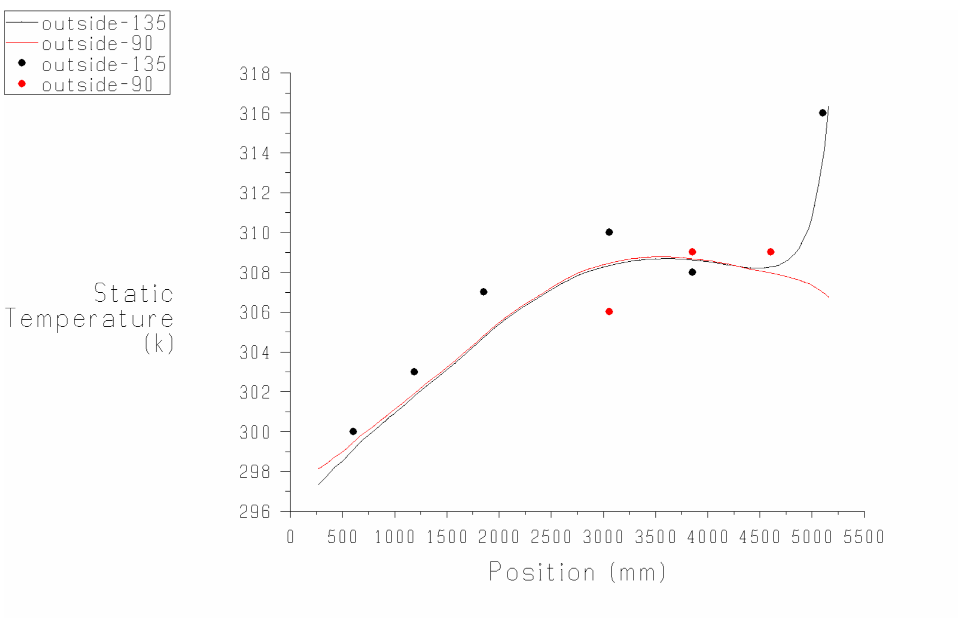


Fuel axial temperature using laminar flow regime

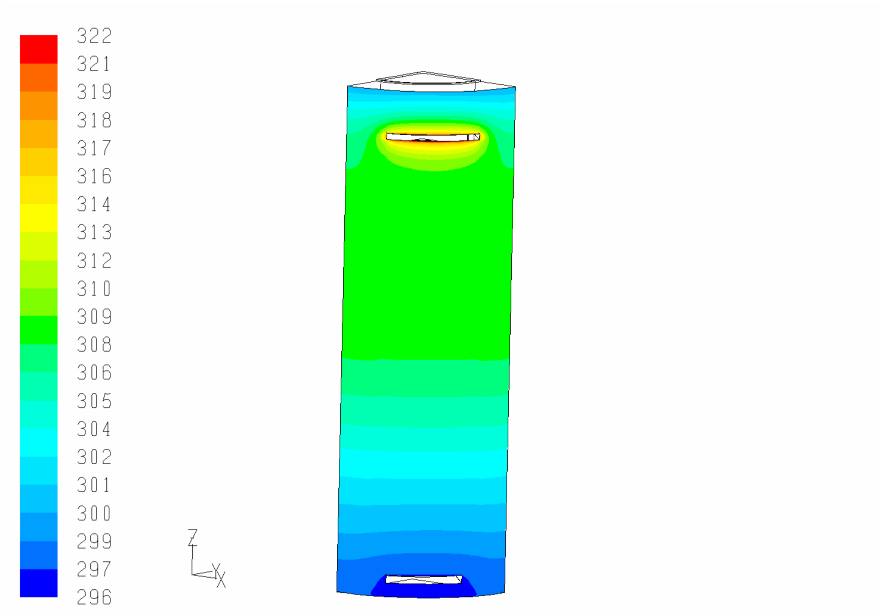


Liner and MPC walls axial temperature using laminar flow regime

VSC-17 Results (outside surface)



Outside surface temperature using low Re k-ε turbulence model



Outside surface temperature contours using low Re k-εturbulence model

Boundary Conditions:

- Buoyancy driven flow
- Pressure Boundaries were used
- Operating density is needed

$$P' = P - \rho_0 g x \qquad \frac{\partial P}{\partial x} = \frac{\partial P'}{\partial x} + \rho_0 g \qquad -\frac{\partial P}{\partial x} + \rho g = -\frac{\partial P'}{\partial x} + (\rho - \rho_0) g$$

Control Volume	Operating density (kg/m3)	Peak cladding Temperature (Kelvin)	Air mass flow rate (kg/s)	Heat absorbed by air (Watts)	Air exit temperature (Kelvin)
Dry Cask	1 (inlet)	598	0.238	9284	339
Dry cask	0.92 (avg)	607	0.1272	7816	351
Dry cask + Ambient	1 (inlet, avg, ambient)	599	0.237	9300	338

Summary

- The developed CFD model was validated to minimize modeling and applications uncertainties
- Temperature measurements from the VSC-17 spent fuel storage cask were used to validate a 3-D CFD model
- The flow in the air channel was found to be in the transitional region of turbulence
- The transitional k-ωSST and low Re k-εmodels were able to predict the experimental data
- Flow inside the MSB is laminar
- For ventilated dry storage casks like the VSC-17, where pressure boundaries are used at the ducts, operating density should be evaluated at the inlet duct conditions of pressure and temperature