Validation of Dry Cask CFD Models using Recent Dry Cask Simulator Data.

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Agenda

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- Experiment
- CFD Model
- Preliminary Results
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  - Belowground configuration ((2.5kW, 4.5b) and (1kW, 1b))
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- Conclusion

Introduction

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Objective: Perform validation studies for the use of CFD in dry cask applications using newly built dry cask simulator thermal-hydraulic data to assist NMSS/SFM in making regulatory decisions to ensure adequate protection for storage and transportation casks.

Technical Issue:

- CFD is being used by dry cask applicants to cut on safety margins.
- Previous CFD validation studies for dry cask applications demonstrated that modeling uncertainties are still an issue.
- Modeling **uncertainties** which are the difference between the real flow and the exact solution of the modeled equation require validation.
  - **Uncertainty**: a potential deficiency that is due to lack of knowledge.
  - **Error**: a recognizable deficiency that is not due to the lack of knowledge
- Modeling Uncertainty Examples:
  - **Turbulence** to model air flow in the gap between canister and overpack.
  - **Porous media** input to model fuel assemblies. (calculated porous media friction factors were underestimated by as much as 35%).
  - **Boundary and operating conditions** such as heat transfer correlation on the outside surface that can affect the air cooling mass flow rate, heat transfer from the canister wall, and eventually the PCT.

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Introduction (continued)

- Requests for higher heat loads and high burnup fuel continue to be the norm, available margins are reduced to the point that predicted PCT's are very close to the allowable limits.
- Some applications showed almost no-margin in PCT. (no verification, validation and uncertainty quantification (VV&UQ) was used)
- To approve some of the cask designs, NRC staff reduced decay heat to establish design safety margins.
- NRC is using CFD best practice guidelines to appropriately review thermal designs (NUREG-2152).
- After reviews of past validation efforts in VV&UQ of CFD in dry cask applications, and the technical issues in hand, new experimental undertaking was deemed necessary.
- To provide a mean to validate dry cask applications, NRC and DOE are co-chaired and co-sponsored an experimental program with Sandia National Laboratories in Albuquerque NM.
- Regulatory Application: Assist NMSS in making the regulatory determination of adequate protection for storage and transportation casks using analytical methods.

Experiment

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- Purpose: Validate CFD models and approximations in dry cask applications.
- Measure temperature profiles, PCT and induced mass flow rate for a wide range of decay power and helium cask pressures
  - Mimic conditions for above and belowground configurations of vertical dry cask systems.
  - Simplified geometry with well-controlled boundary conditions.
- Use existing prototypic BWR Incoloy-clad test assembly
- BWR Dry Cask Simulator (DCS) system capabilities
  - Power: 0.1 – 20 kW
  - Pressure vessel: 3E-3 – 24 bar
    - Pressure vessel temperatures up to 400 °C
    - ~200 thermocouples throughout system
  - *Test conditions presented here*
    - Power: 0.5 – 5 kW
    - Pressure: 3E-3 – 8 bar
  - Air velocity measurements at inlets
    - Calculate air mass flow rate

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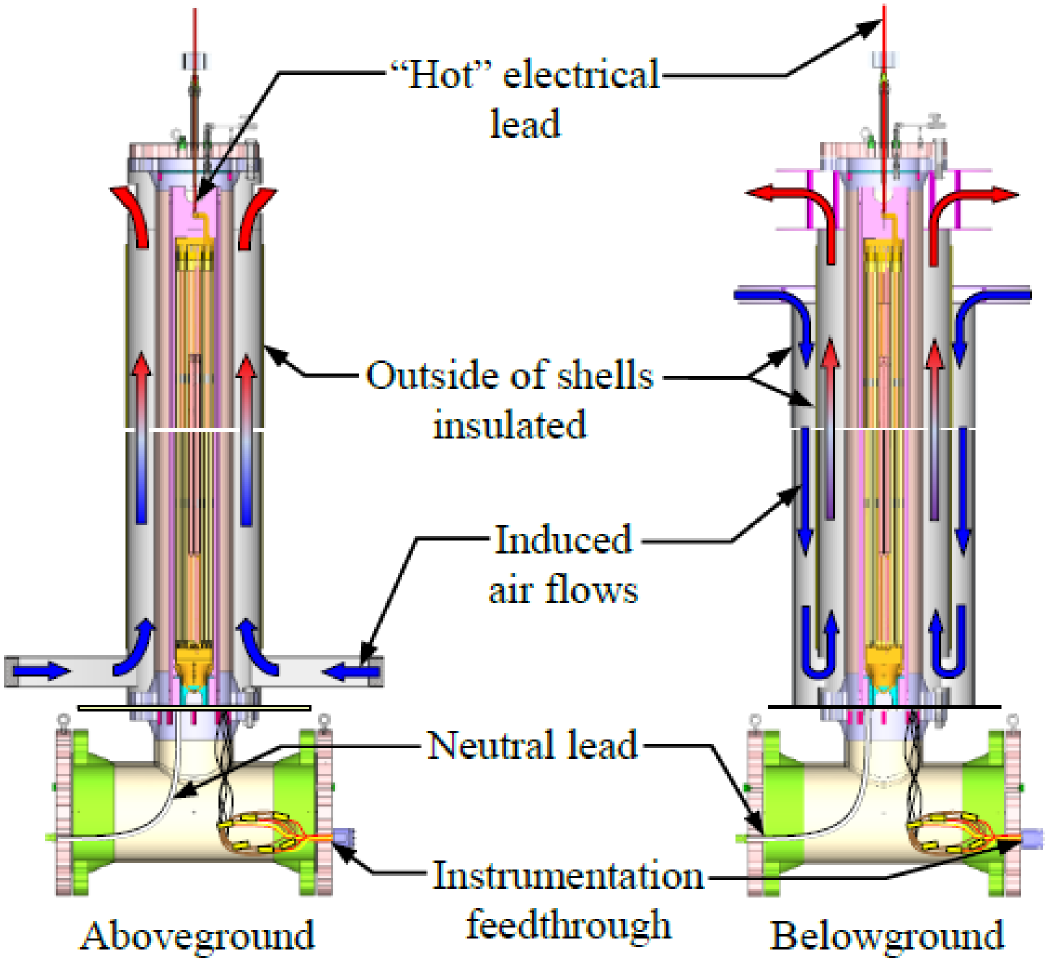
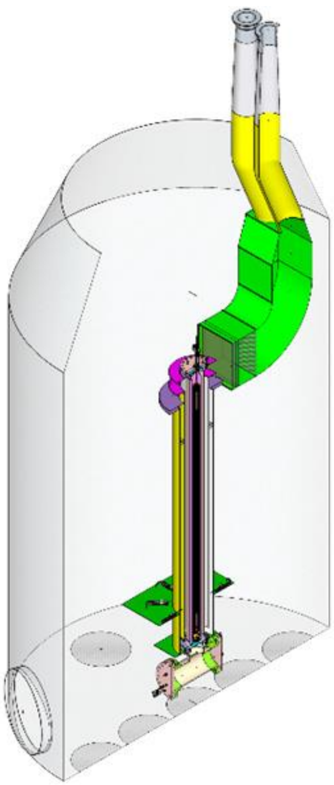
Experiment (continued)



Cross Wind



CFD Model

- ANSYS Fluent 16. was used.
- Pressure based solver was used.
- Second Order upwind discretization scheme was used for: Momentum, turbulence (turbulent kinetic energy and dissipation), energy, and radiation heat transfer.
- Least square cell based was used for the gradient terms.
- Body force weighted was used for interpolation in the pressure equation.
- Discrete ordinates method was used for radiation heat transfer.
- SIMPLE method was used for the velocity-pressure coupling.
- Turbulent regime was used in the air channel.
- Laminar mode inside the canister for Helium flow.

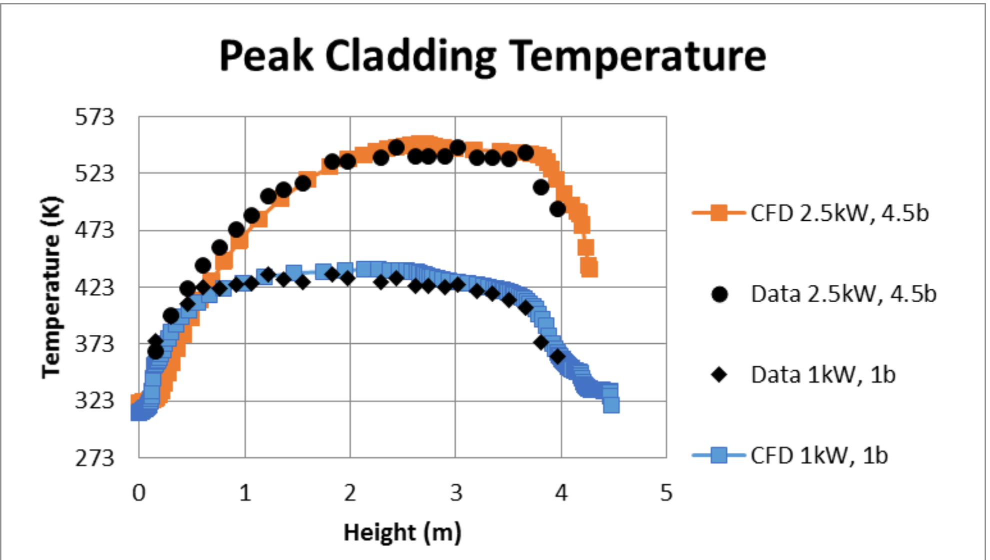
CFD Model (continued)

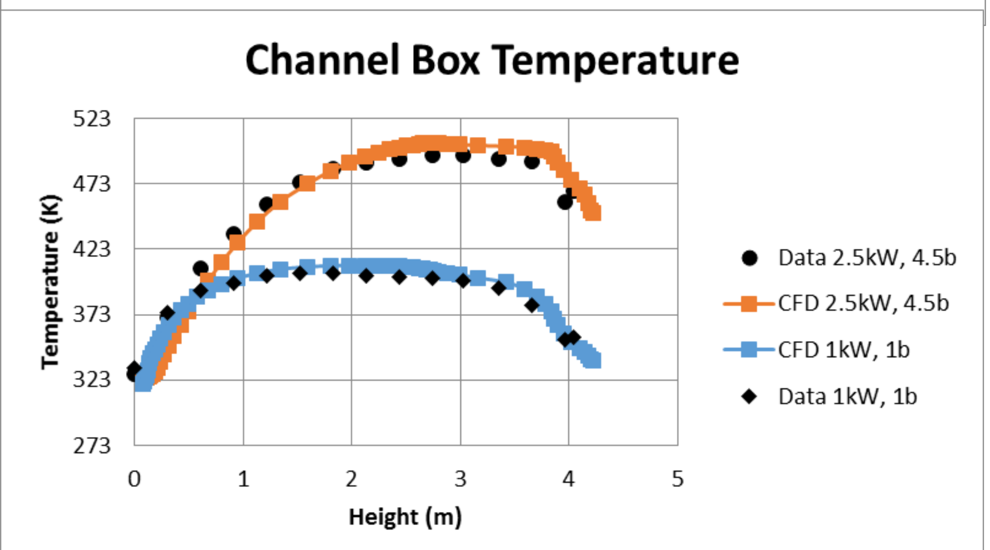
- Low Reynolds k-epsilon model was used to model turbulence (Best Practice Guidelines).
- Ideal gas was used to model both air and Helium.
- Full buoyancy effect was used in the momentum equations (no boussinesq model).
- Buoyancy effect was considered in the modeling of both the turbulent kinetic energy as well as its dissipation.
- Thermo-physical properties as function of temperature was used for the fluids and solids.
- Porous media was used to model fuel rods inside the assembly surrounded by the channel box.
- Flow of helium between the channel box and basket was modeled explicitly (not part of the porous media model).

CFD Model (continued)

- An equivalent frictional and inertial resistances was used for the fuel.
- These resistances were obtained from and earlier experimental data performed by Sandia (NURE/CR-7144).
- Porous media was used to model honeycomb at the entry of the air channel.
- An orthotropic equivalent thermal conductivity was used in the fuel region. see NUREG-2208 and NUREG-2152.
- Mesh was very fine close to the walls
- Best practice guidelines were used for mesh generation. (NUREG-2152)

Aboveground Preliminary Results





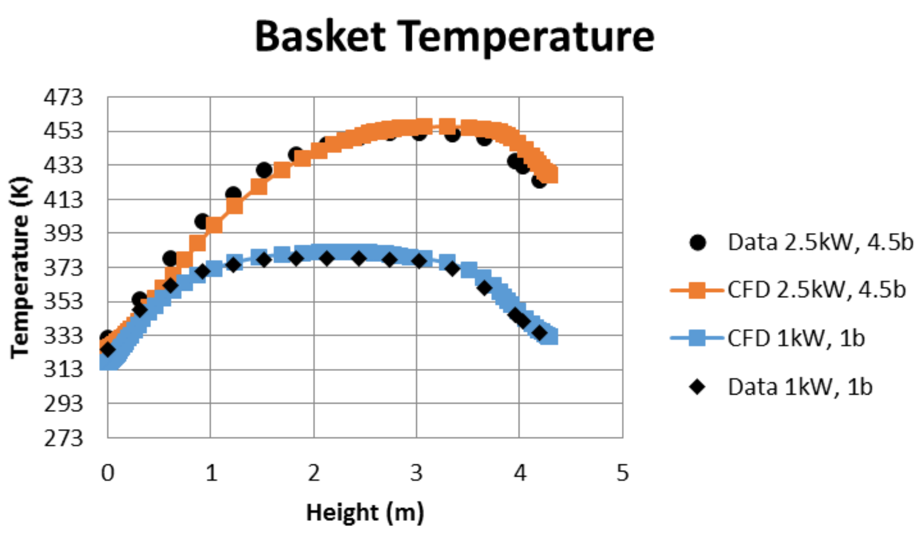
Correct PCT value, location and profile

Experimental uncertainty = 7 C

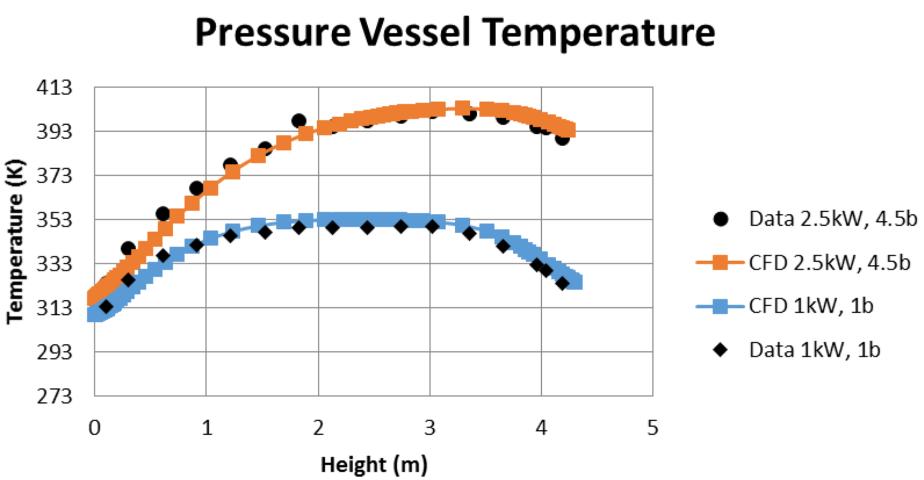
Grid refinement uncertainty close to 7 C (1% to 2 %)

Helium flows upward through the fuel rods

Aboveground Preliminary Results (continued)

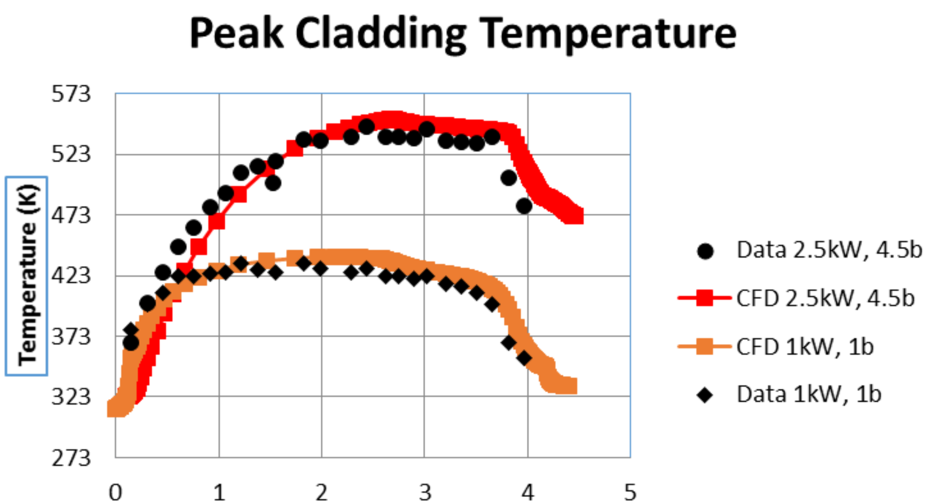


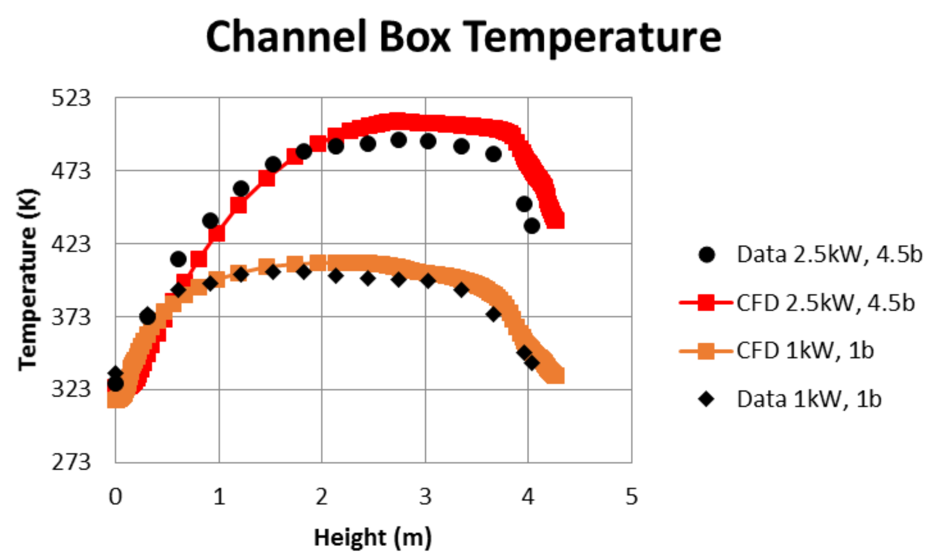
Helium flow upward between the Channel box and the Basket.



Helium flow downward between the Basket and Pressure vessel

Belowground Preliminary Results





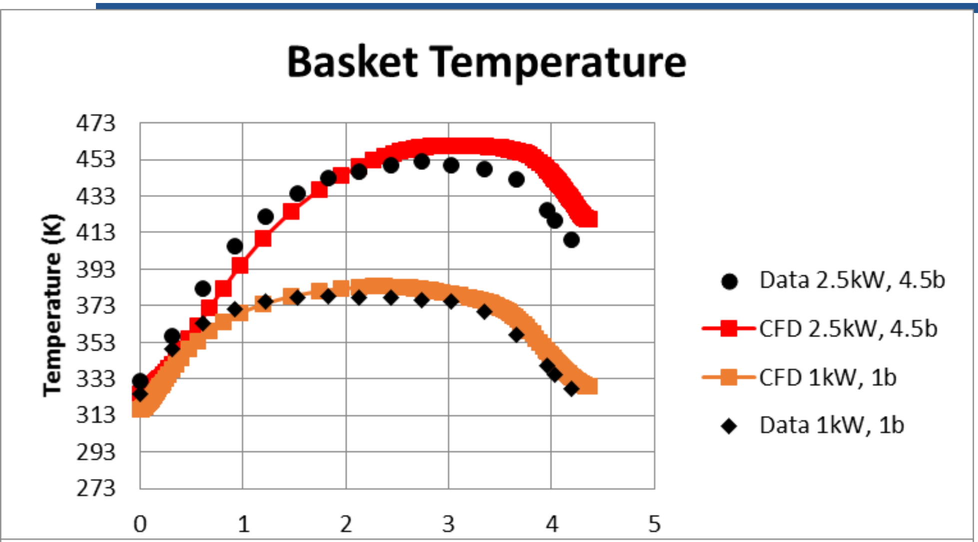
Correct PCT value, location and profile

Experimental uncertainty = 7 C

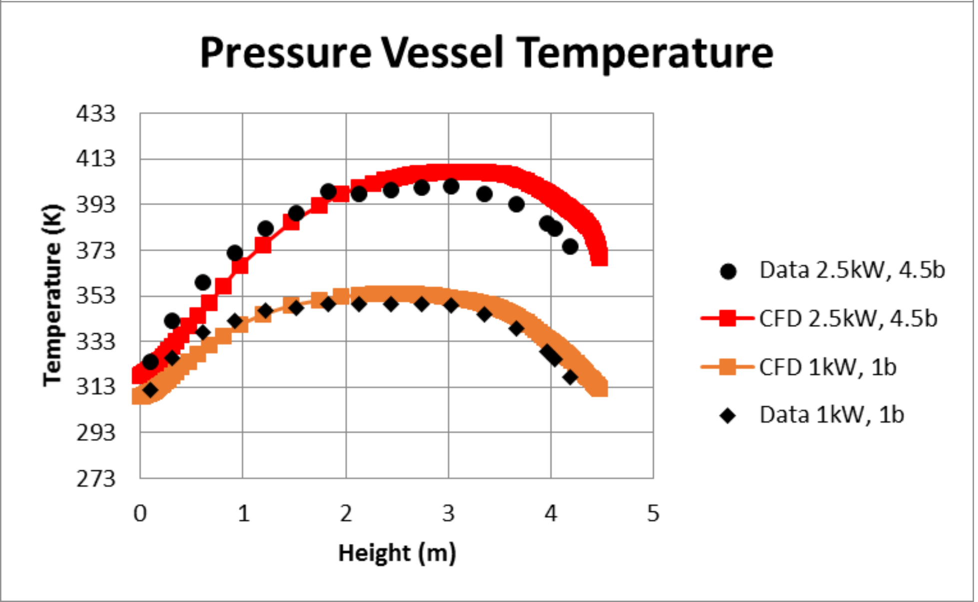
Grid refinement uncertainty close to 7 C (1% to 2 %)

Helium flows upward through the fuel rods

Belowground Preliminary Results (continued)

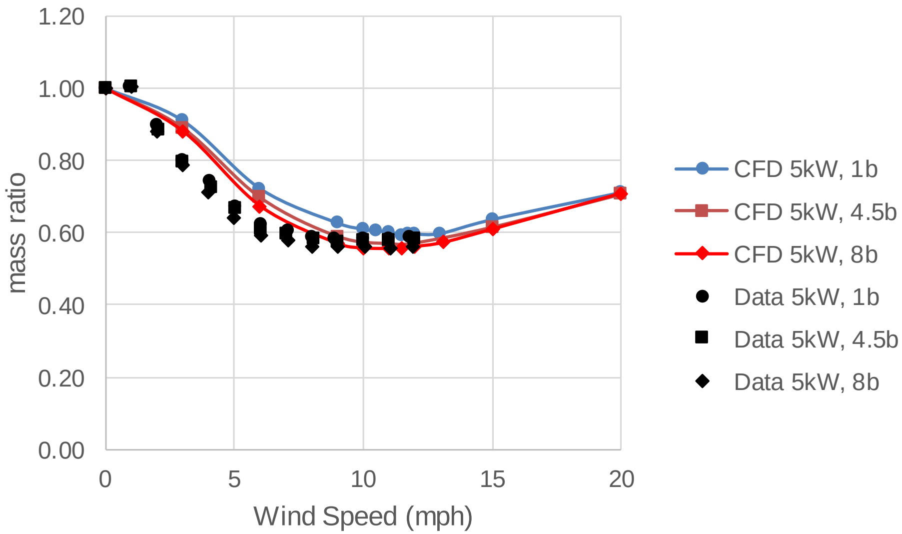


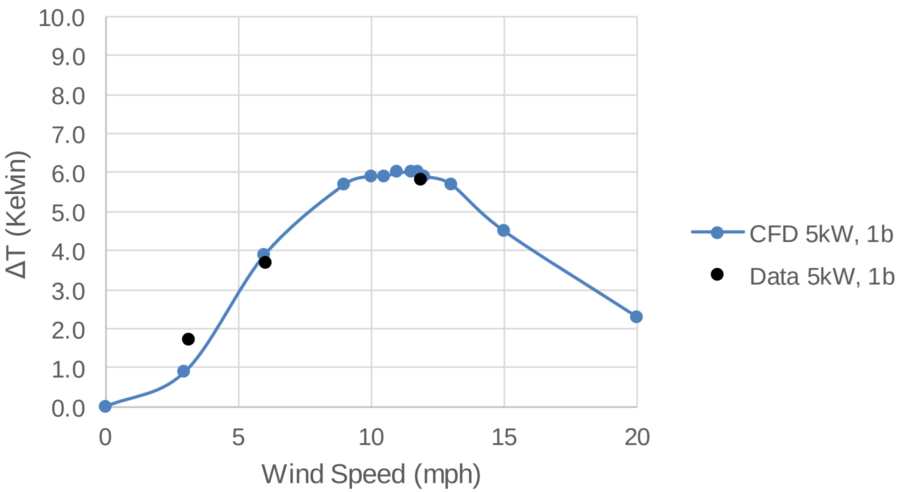
Helium flow upward between the Channel box and the Basket.



Helium flow downward between the Basket and Pressure vessel

Cross Wind Preliminary Results





- Minimum mass flow rate at a specific wind speed
- Temperature increases as the wind speed increases
- CFD shows same trend as experiment

Summary

- Dry cask simulator (DCS) testing complete for aboveground, underground and cross wind configuration.

- NUREG/CR about the experimental work will be published by the beginning of next year.

- Preliminary Comparisons with CFD simulations show favorable agreement:

  - PCT and air flow rate within experimental uncertainty for nearly all cases.

  - Additional steady state comparisons for basket, canister, and overpack also show good agreement.

  - The existing modeling and CFD guidelines that were followed led to a favorable validation.

- Report of the validation will be published by next summer.

- Lessons learned from this validation will be added to CFD best practice guidelines (NUREG-2152).