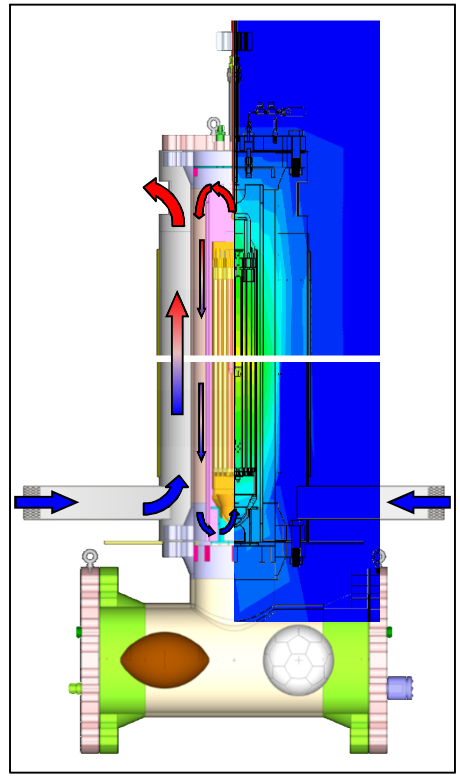
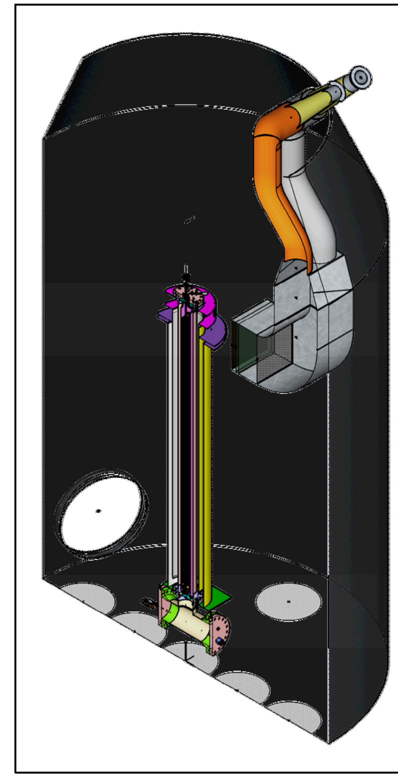
SAND2017-11325C

# Summary of a Dry Cask Simulator with Applications to CFD Model Validation





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E.R. Lindgren

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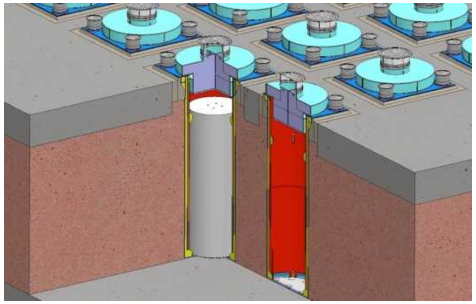
# Overview

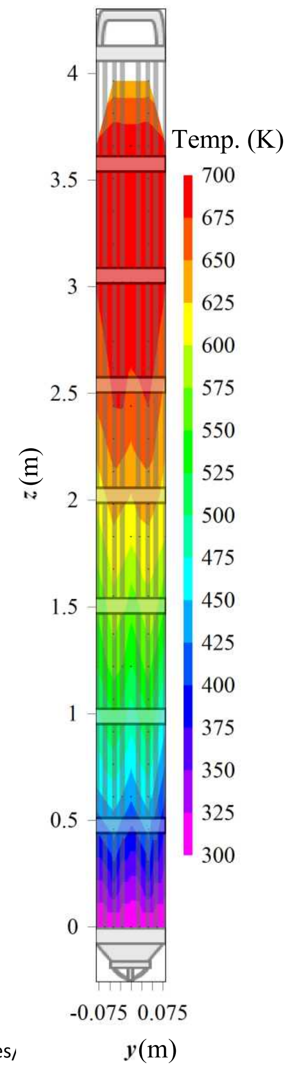
Aboveground Storage

Source: www.nrc.gov/reading-rm/doc-collections/fact-sheets/storage-spent-fuel-fs.html



Belowground Storage

Source: ww.holtecinternational.com/productsandservices/wasteandfuelmanagement/hi-storm/




- Purpose: Validate assumptions in CFD calculations for spent fuel cask thermal design analyses
  - Used to determine steady-state cladding temperatures in dry casks
  - Needed to evaluate cladding integrity throughout storage cycle
- Measure temperature profiles for a wide range of decay power and helium cask pressures
  - Mimic conditions for above and belowground configurations of vertical, dry cask systems with canisters using Dry Cask Simulator (DCS)
  - Simplified geometry with well-controlled boundary conditions
  - Provide measure of mass flow rates and temperatures throughout system
- Use existing prototypic BWR Incoloy-clad test assembly

# Past Validation Efforts

Sandia National Laboratories

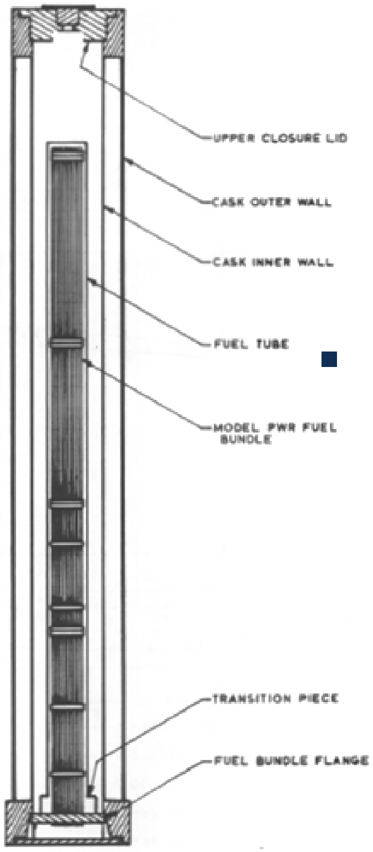
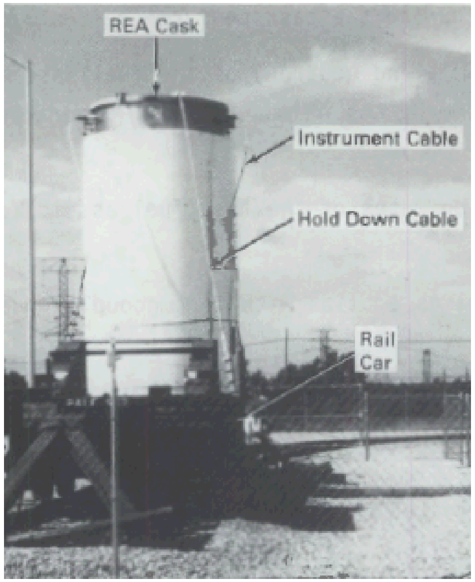



FIGURE 4-1. SAHTT Assembly

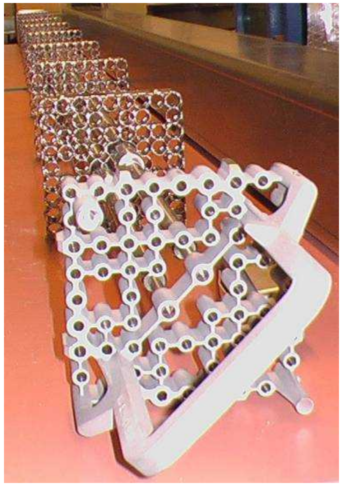
- Full scale, multi-assembly
  - Castor-V/21 [1986: EPRI NP-4887, PNL-5917]
    - Unconsolidated, unpressurized, unventilated
  - REA 2023 [1986: PNL-5777 Vol. 1]
    - Unconsolidated, unpressurized, unventilated
  - VSC-17 [1992: EPRI TR-100305, PNL-7839]
    - Consolidated, unpressurized, early ventilated design

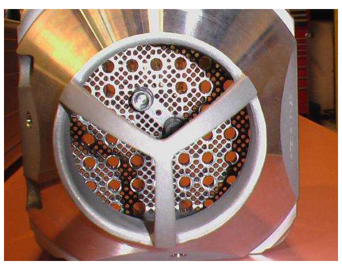



- Small scale, single assembly
  - FTT (irradiated, vertical) [1986 PNL-5571]
  - SAHTT (electric, vertical & horizontal) [1986 PNL-5571]
  - Mitsubishi (electric, vertical & horizontal) [1986 IAEA-SM-286/139P]
  - For all three studies:
    - Unconsolidated
    - BC: Controlled outer wall temperature (unventilated)
    - Unpressurized
- <u>None</u> appropriate for elevated helium pressures or modern ventilated configurations

# Prototypic Assembly Hardware

**Upper tie plate**

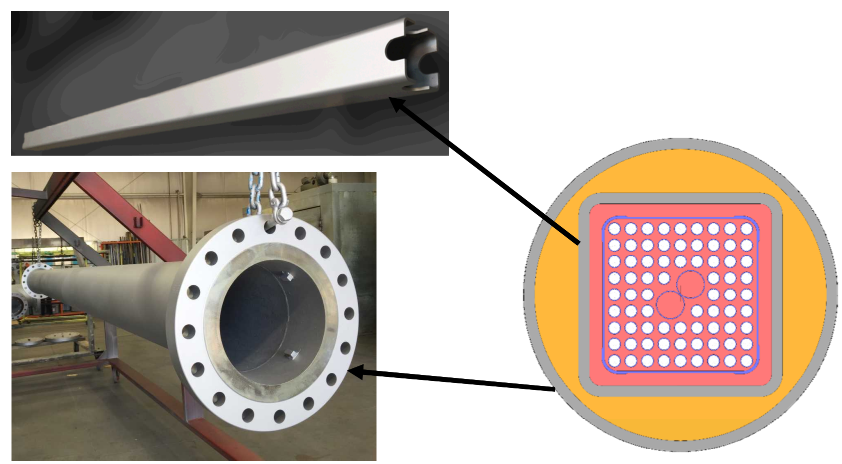




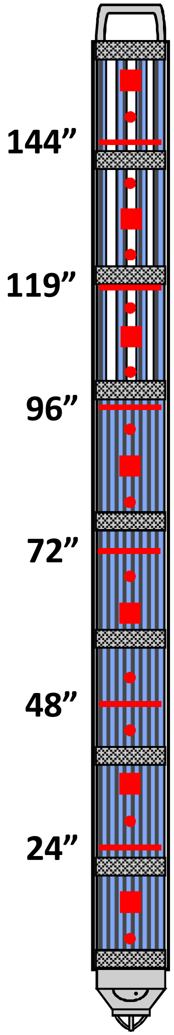
**Nose piece and debris catcher**

**BWR channel, water tubes and spacers**

- Most common 9×9 BWR in US
- Prototypic 9×9 BWR hardware
  - Full length, prototypic 9×9 BWR components
  - Electric heater rods with Incoloy cladding
  - 74 fuel rods
    - 8 of these are partial length
    - Partial length rods 2/3 the length of assembly
  - 2 water rods
  - 7 spacers



# Thermocouple Layout




**Internal Thermocouples**

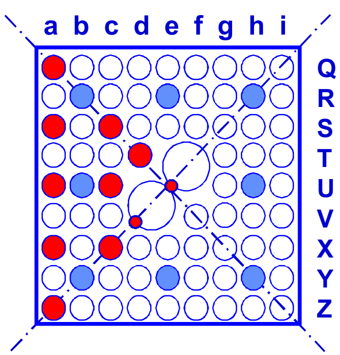
**Radial Array**
**24” spacing**
**11 TC’s each level**
**66 TC’s total (details below)**

**Axial array A1**
**6” spacing**
**20 TC’s**

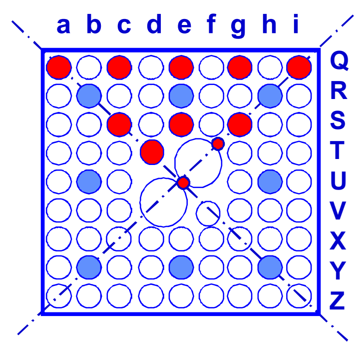
**Axial array A2**
**12” spacing – 7 TC’s**
**Water rods inlet and exit – 4 TC’s**
**Total of 97 TC’s**

- 97 total TC’s internal to assembly
- 10 TC’s mounted to channel box
  - 7 External wall
    - 24 in. spacing starting at 24 in. level
  - 3 Internal wall
    - 96, 119, and 144 in. levels

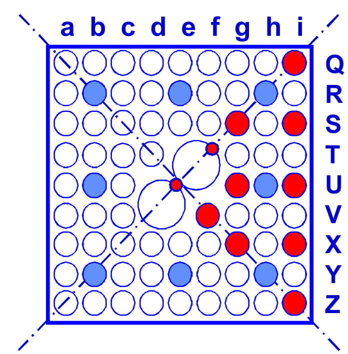
24” & 96” levels



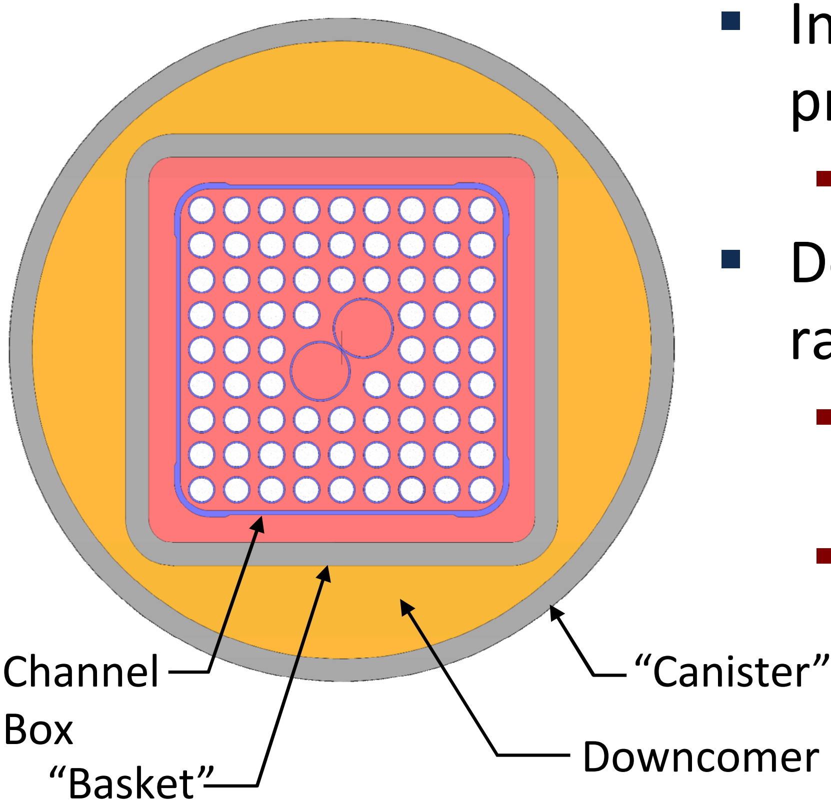

48” & 119” levels




72” & 144” levels



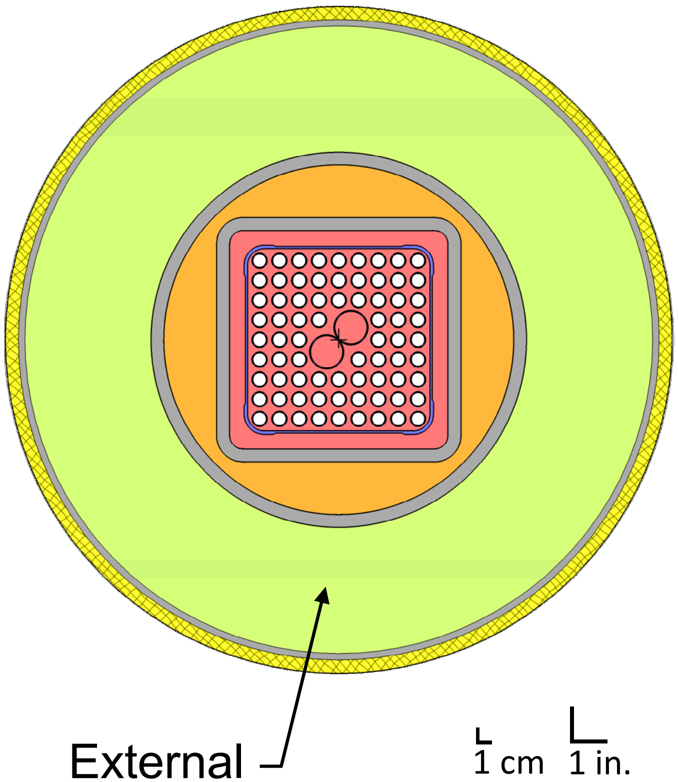
# Internal Dimensional Analyses




- Internal flow and convection near prototypic
  - Prototypic geometry for fuel and basket
- Downcomer scaling insensitive to wide range of decay heats
  - External cooling flows matched using elevated decay heat
  - Downcomer dimensionless groups

| Parameter | Aboveground DCS Low Power | Aboveground DCS High Power | Aboveground Cask |
|---|---|---|---|
| Power (kW) | 0.5 | 5.0 | 36.9 |
| $Re_{Down}$ | 170 | 190 | 250 |
| $Ra_H^*$ | 3.1E+11 | 5.9E+11 | 4.6E+11 |
| $Nu_H$ | 200 | 230 | 200 |

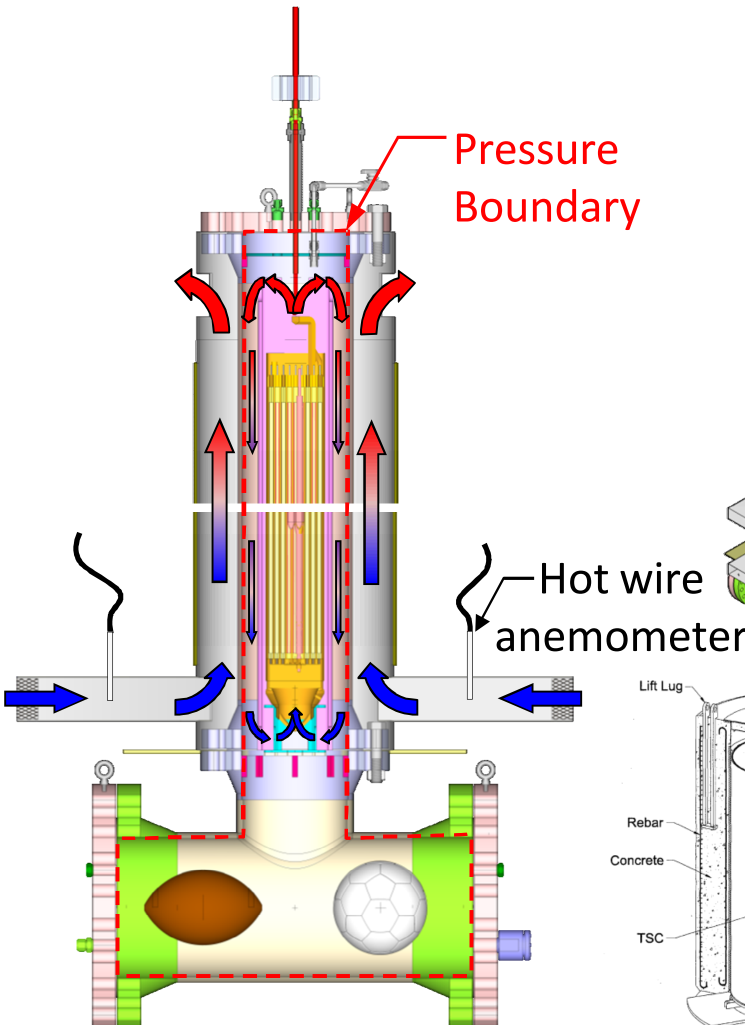
# External Dimensional Analyses

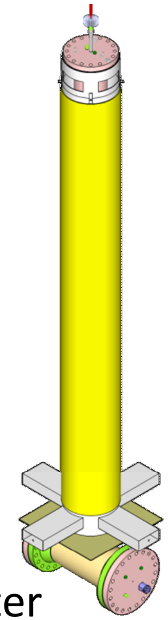


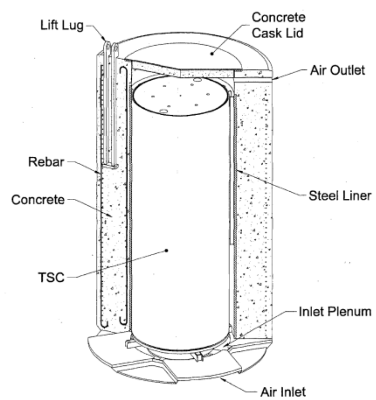

- External cooling flows evaluated against prototypic
  - External dimensionless groups

| Parameter | Aboveground | | |
|---|---|---|---|
| | DCS Low Power | DCS High Power | Cask |
| Power (kW) | 0.5 | 5.0 | 36.9 |
| $Re_{Ex}$ | 3,700 | 7,100 | 5,700 |
| $Ra_{DH}^{*}$ | 2.7E+08 | 2.7E+09 | 2.3E+08 |
| $(D_{H,\,Cooling} / H_{PV}) \times Ra_{DH}^{*}$ | 1.1E+07 | 1.1E+08 | 4.8E+06 |
| $Nu_{DH}$ | 16 | 26 | 14 |

# Aboveground Configuration

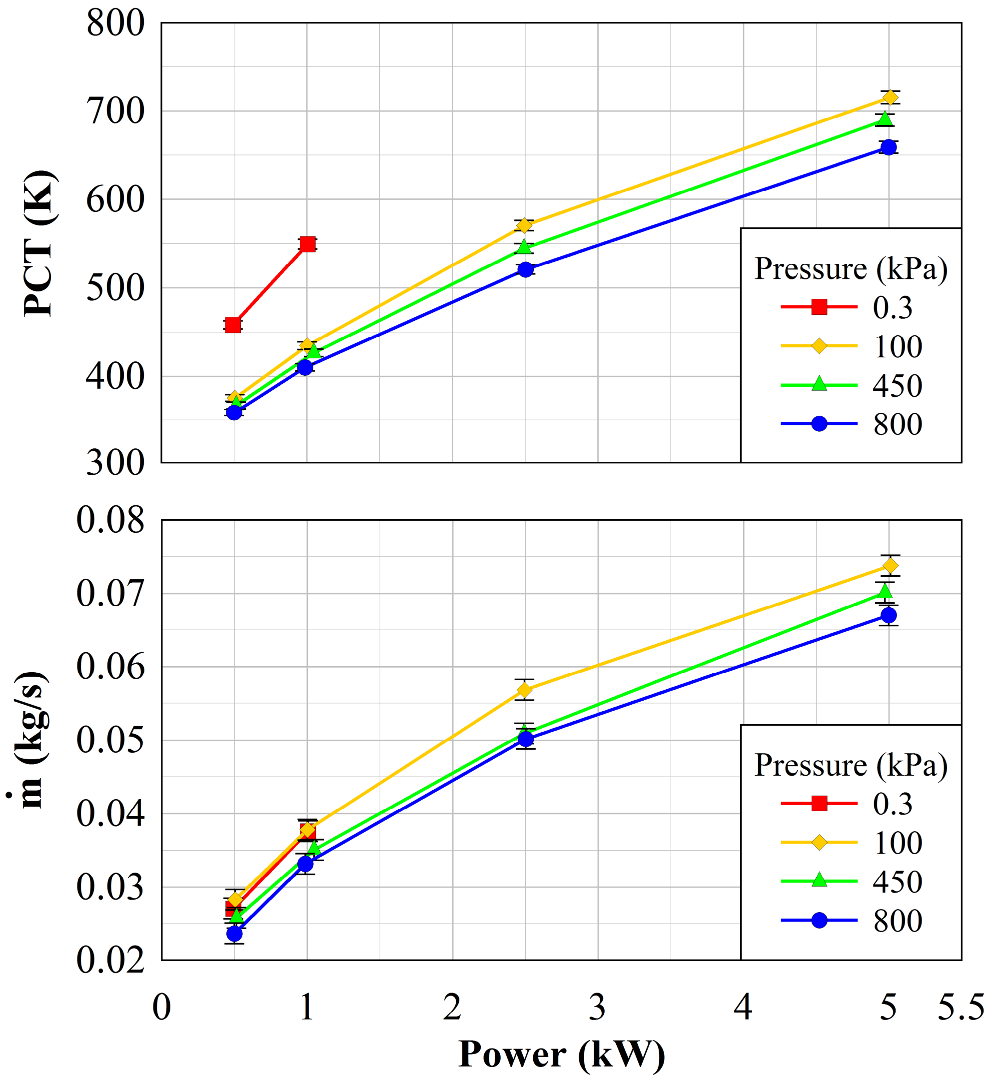


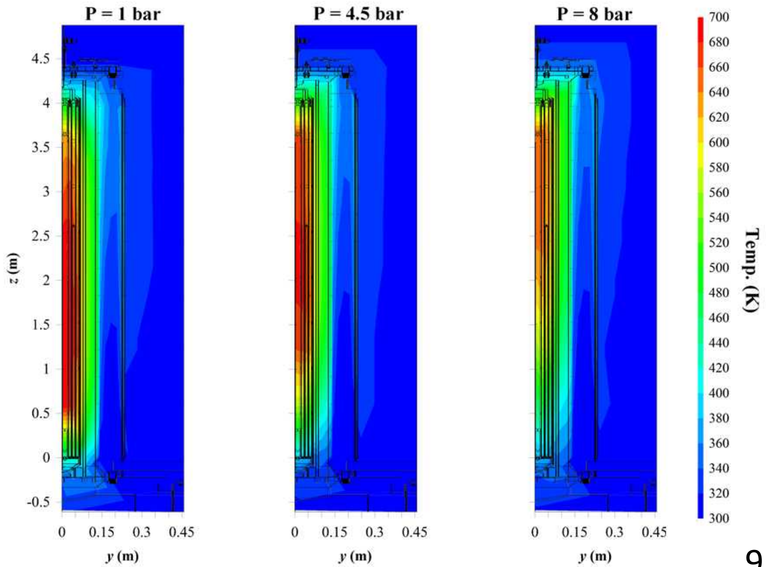



- BWR Dry Cask Simulator (DCS) system capabilities
  - Power: 0.1 – 20 kW
  - Pressure vessel
    - Vessel temperatures up to 400 °C
    - Pressures up to 2,400 kPa
    - ~200 thermocouples throughout system (internal and external)
  - Air velocity measurements at inlets
    - Calculate external mass flow rate
- *Testing Completed August 2016*
  - 14 data sets collected
    - Transient and steady state
  - Subject of proposed CFD Round Robin

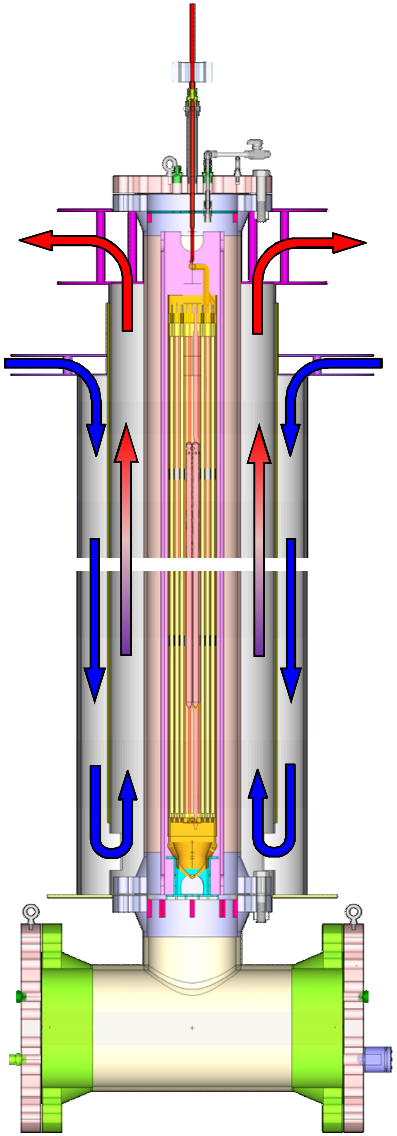
# Steady State Values vs. Decay Heat
## Aboveground Configuration



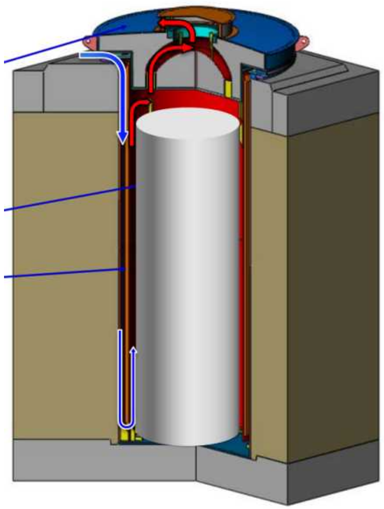

- PCT and air flow ↑ as simulated decay heat ↑
  - Significant increase in PCT for P = 0.3 kPa
    - Due to air in "canister" instead of helium



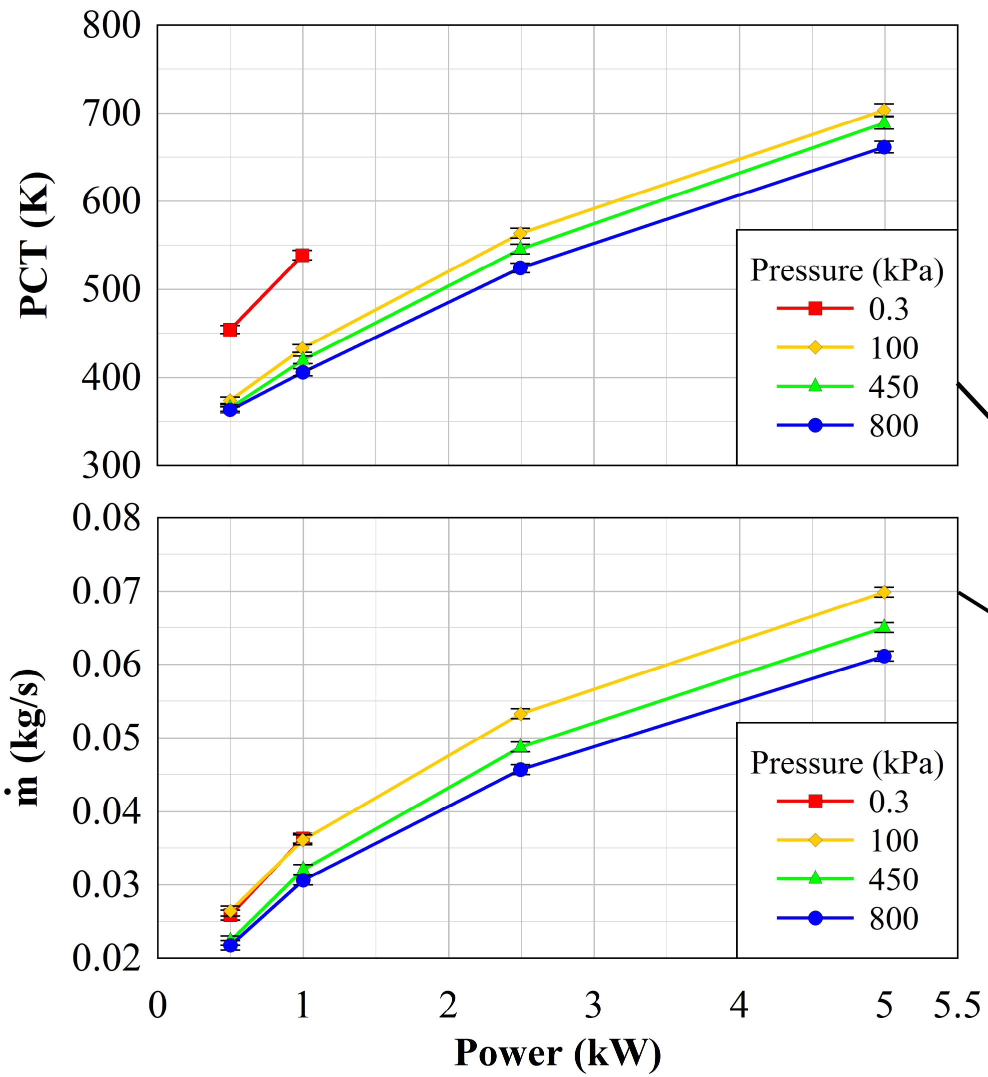
# Belowground Configuration



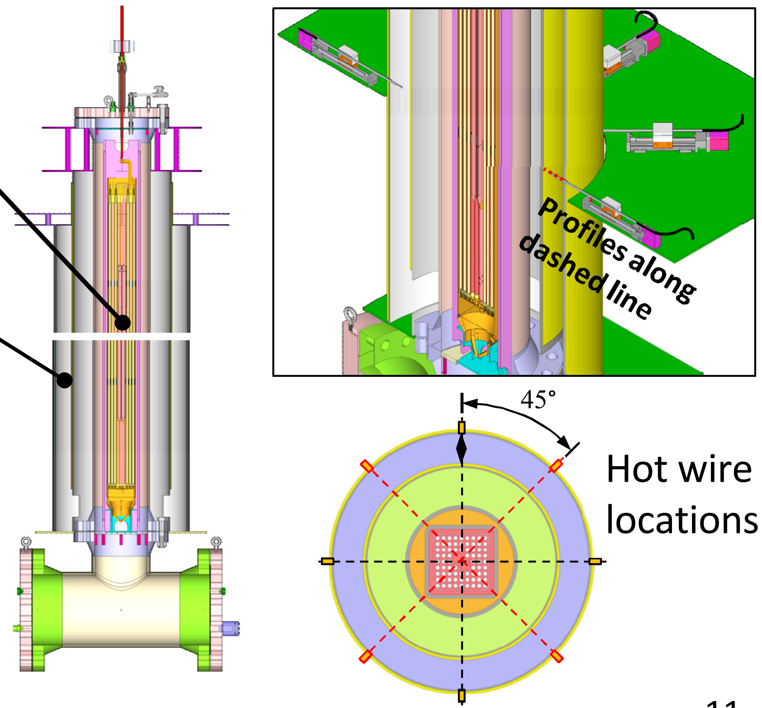
- Modification to aboveground ventilation configuration
  - Additional annular flow path
- *Testing Completed April 2017*
  - 14 data sets recorded
    - Transient and steady state



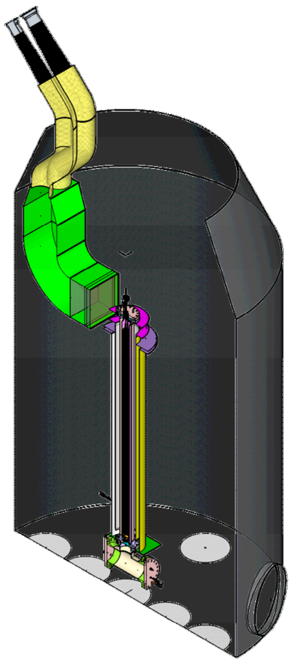
# Steady State Values vs. Decay Heat
## Belowground Configuration

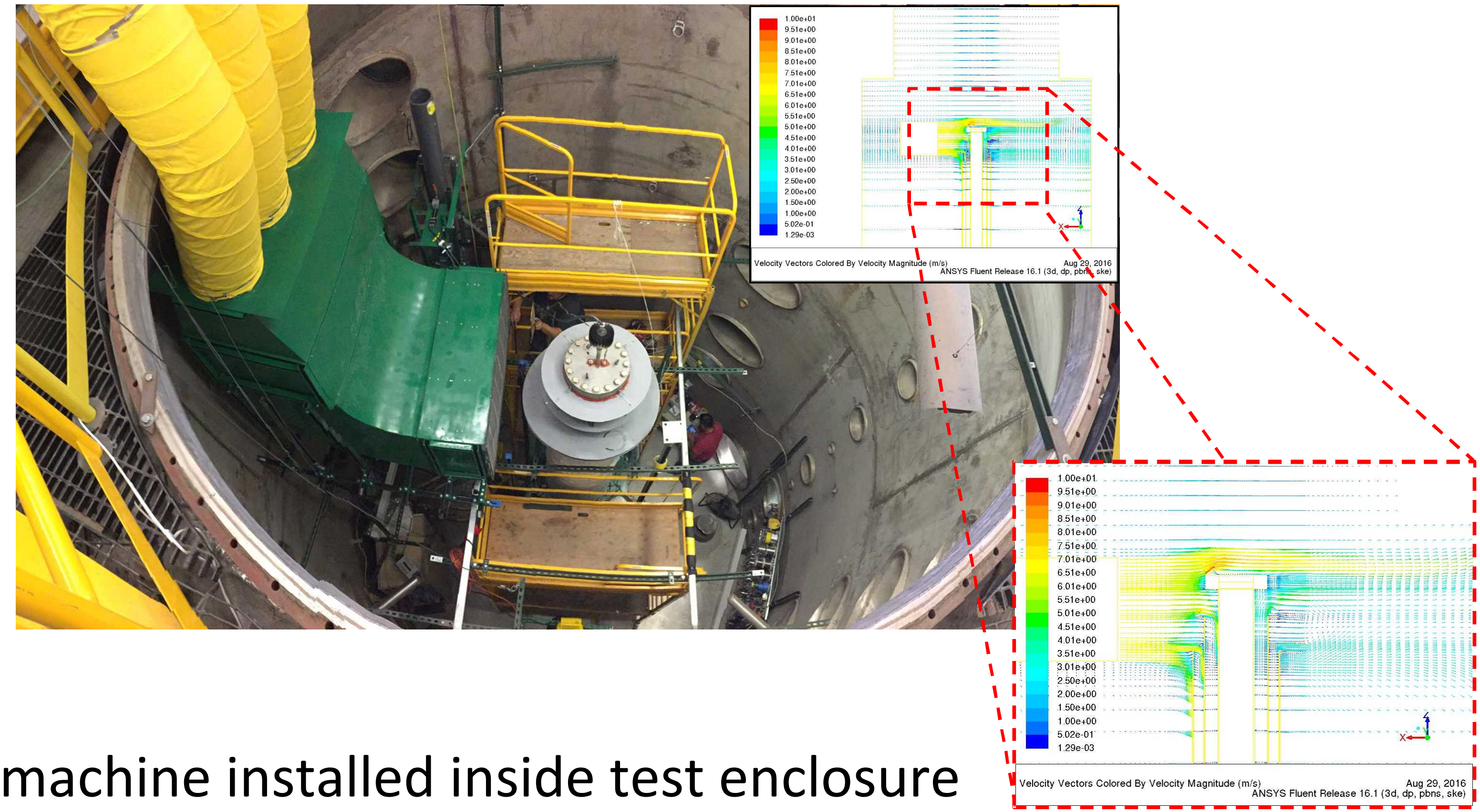



- Similar performance to aboveground configuration
  - Within 2% for PCT
  - Within 5% for ṁ



# Cross Wind Testing

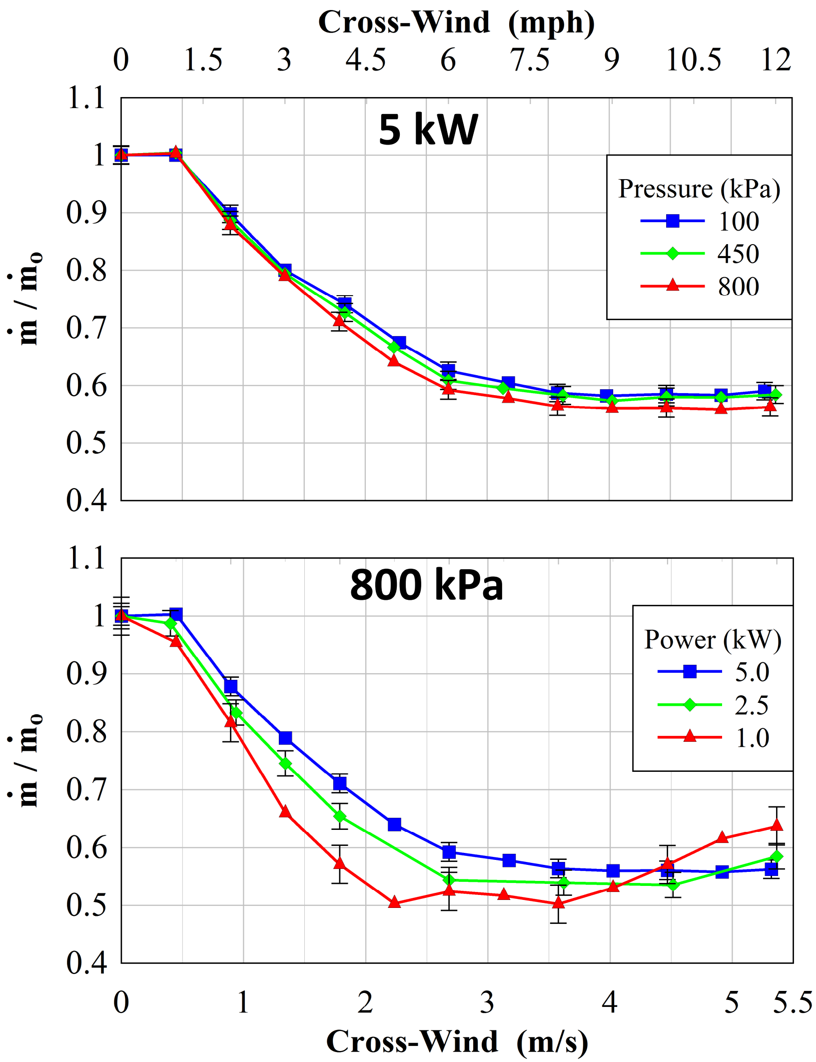




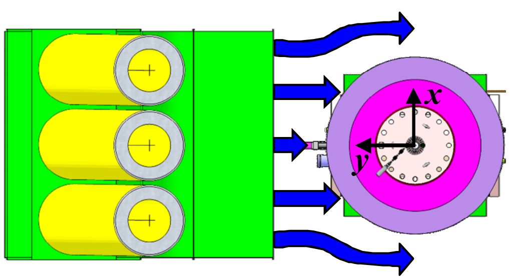

**CFD simulations by A. Zigh (USNRC)**

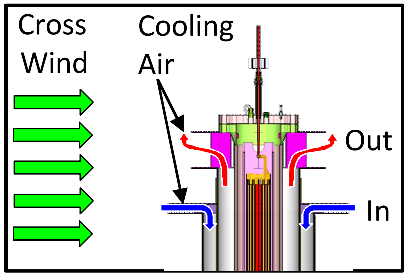
- Wind machine installed inside test enclosure
  - Three air-driven blowers
  - Specially fabricated duct with flow straightening
  - Cross winds of up to 5.4 m/s (12 mph)

# Reduction of External Air Flow Rate




- Moderate, sustained cross winds have significant impact on external air mass flow rate
  - Reductions of up to 50%
  - Thermal impact limited for DCS
  - Potentially more significant effect for prototypic systems





# Summary

- Dry cask simulator (DCS) testing complete for all configurations
  - Over 40 unique data sets collected
    - 14 each for two primary configurations
      - Aboveground and belowground
    - 13 additional data sets for cross-wind testing
    - Main results will be reported in a NUREG/CR
- Comparisons with CFD simulations show favorable agreement
  - Within experimental uncertainty for nearly all cases
  - Additional steady state comparisons for basket, “canister”, and “overpack” also show good agreement