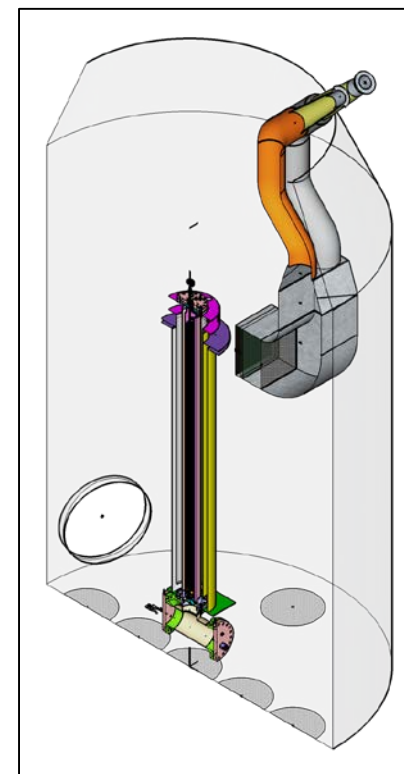
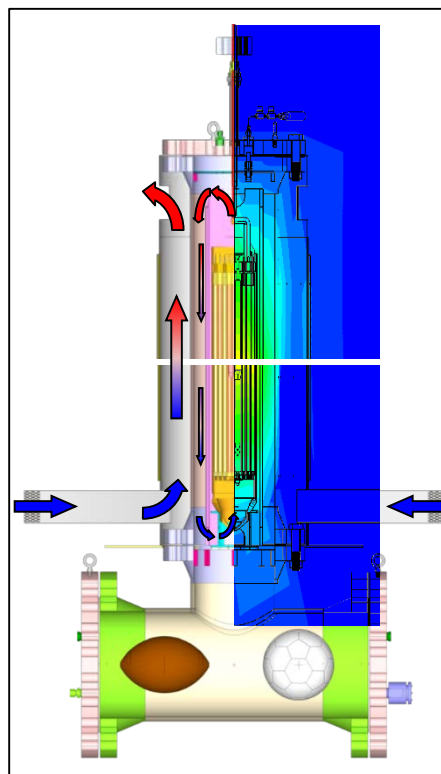


# Summary of a Dry Cask Simulator with Applications to CFD Model Validation

S.G. Durbin and  
E.R. Lindgren

*Exceptional service  
in the national interest*



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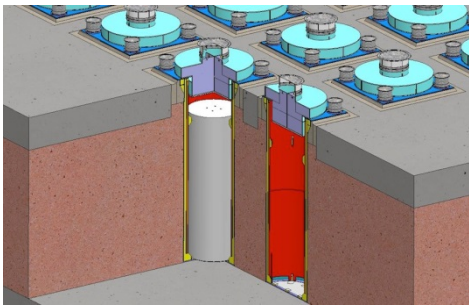
SAND2017-#### C

# Overview



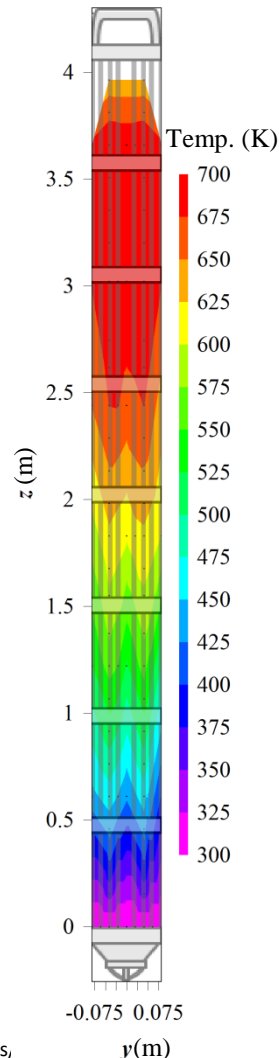
## Aboveground Storage

Source: [www.nrc.gov/reading-rm/doc-collections/fact-sheets/storage-spent-fuel-fs.html](http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/storage-spent-fuel-fs.html)



## Belowground Storage

Source: [www.holtecinternational.com/productsandservices/wasteandfuelmanagement/hi-storm/](http://www.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

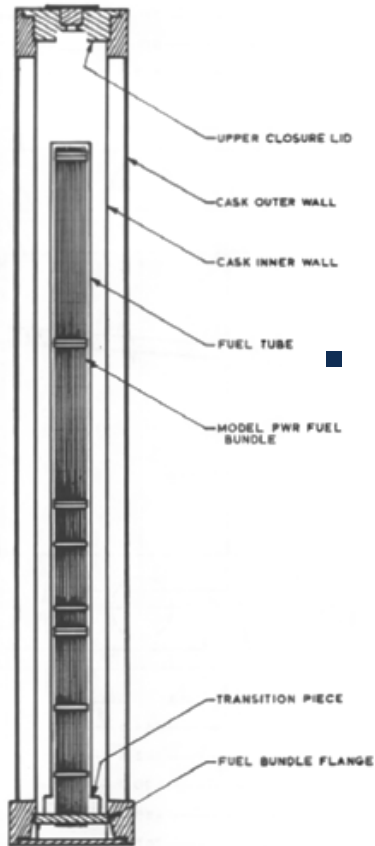


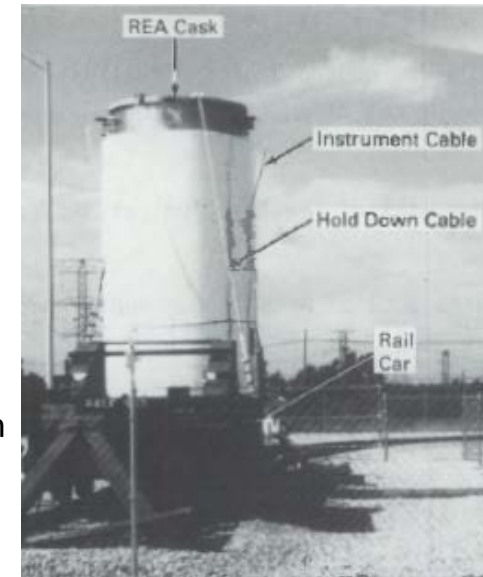
FIGURE 4-1. SAHTT Assembly

- 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

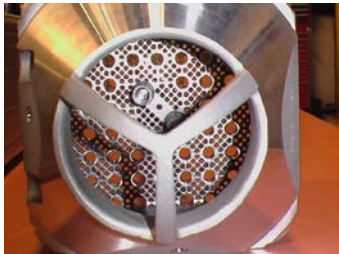
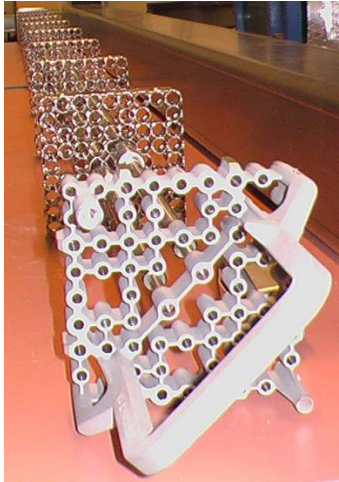
- FTT (irradiated, vertical) [1986 PNL-5571]
- SAHTT (electric, vertical & horizontal) [1986 PNL-5571]
- Mitsubishi (electric, vertical & horizontal) [1986 IAEA-SM-286/139P]
- For all three studies:
  - Unconsolidated
  - BC: Controlled outer wall temperature (unventilated)
  - Unpressurized

- None appropriate for elevated helium pressures or modern ventilated configurations



# Prototypic Assembly Hardware

Upper tie plate

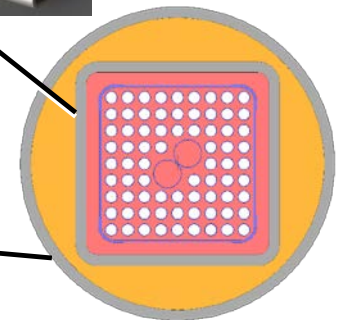


Nose piece and  
debris catcher

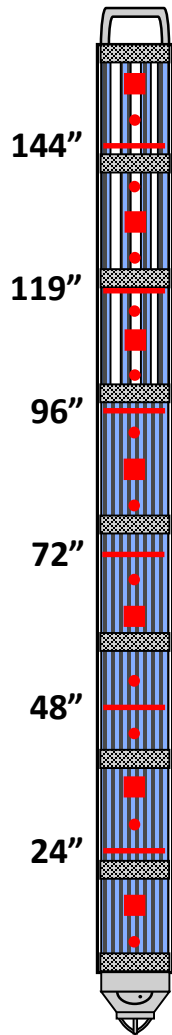


BWR channel, water tubes  
and spacers

- 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



# 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

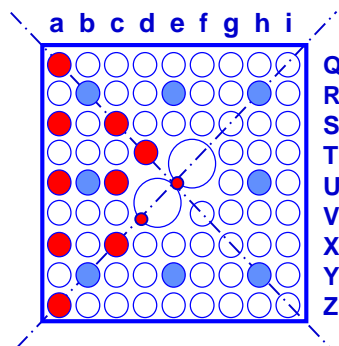
12" spacing – 7 TC's

Water rods inlet and exit – 4 TC's

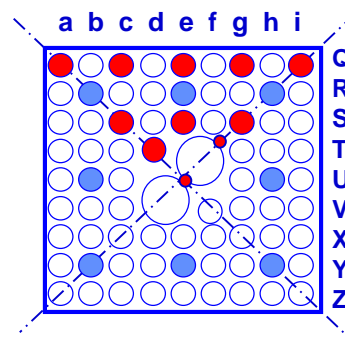
Total of 97 TC's

- 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

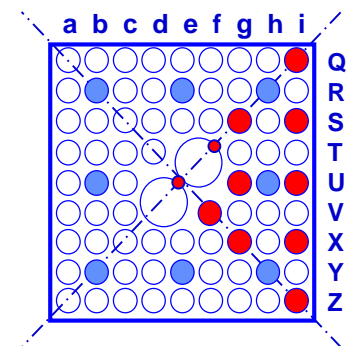
24" & 96" levels



48" & 119" levels

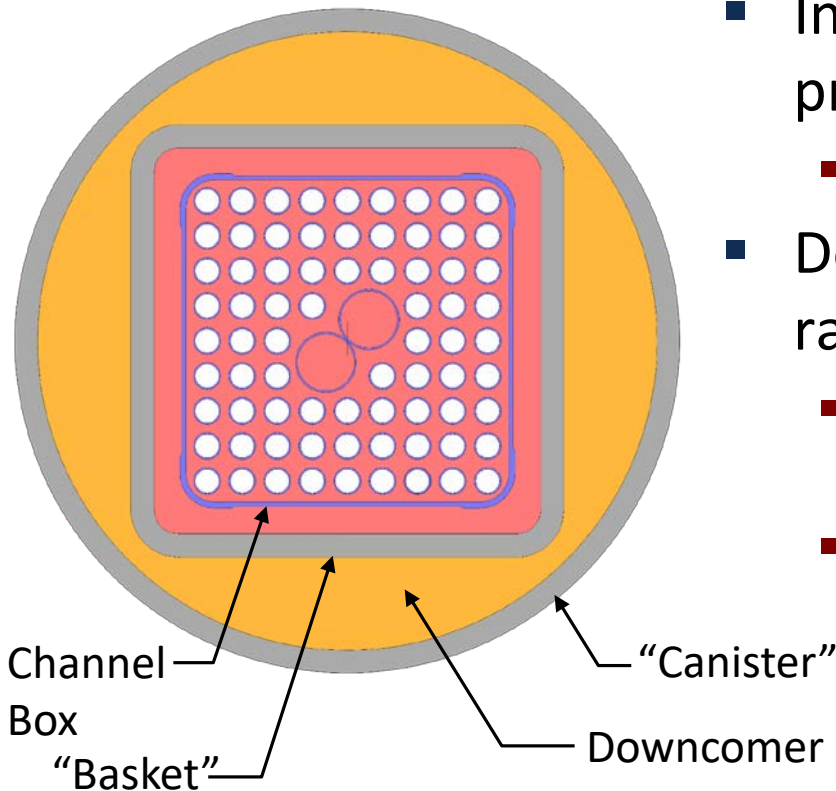


72" & 144" levels





# Internal Dimensional Analyses



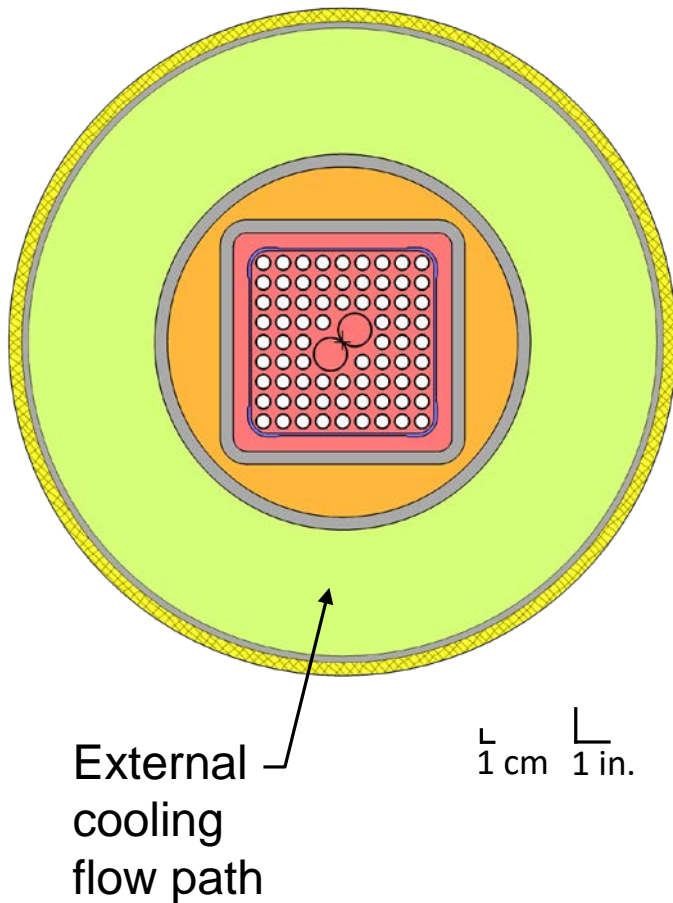
- Internal flow and convection near prototypic
  - Prototypic geometry for fuel and basket
- Downcomer scaling insensitive to wide range of decay heats
  - External cooling flows matched using elevated decay heat
  - Downcomer dimensionless groups

Parameter	Aboveground		
	DCS Low Power	DCS High Power	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

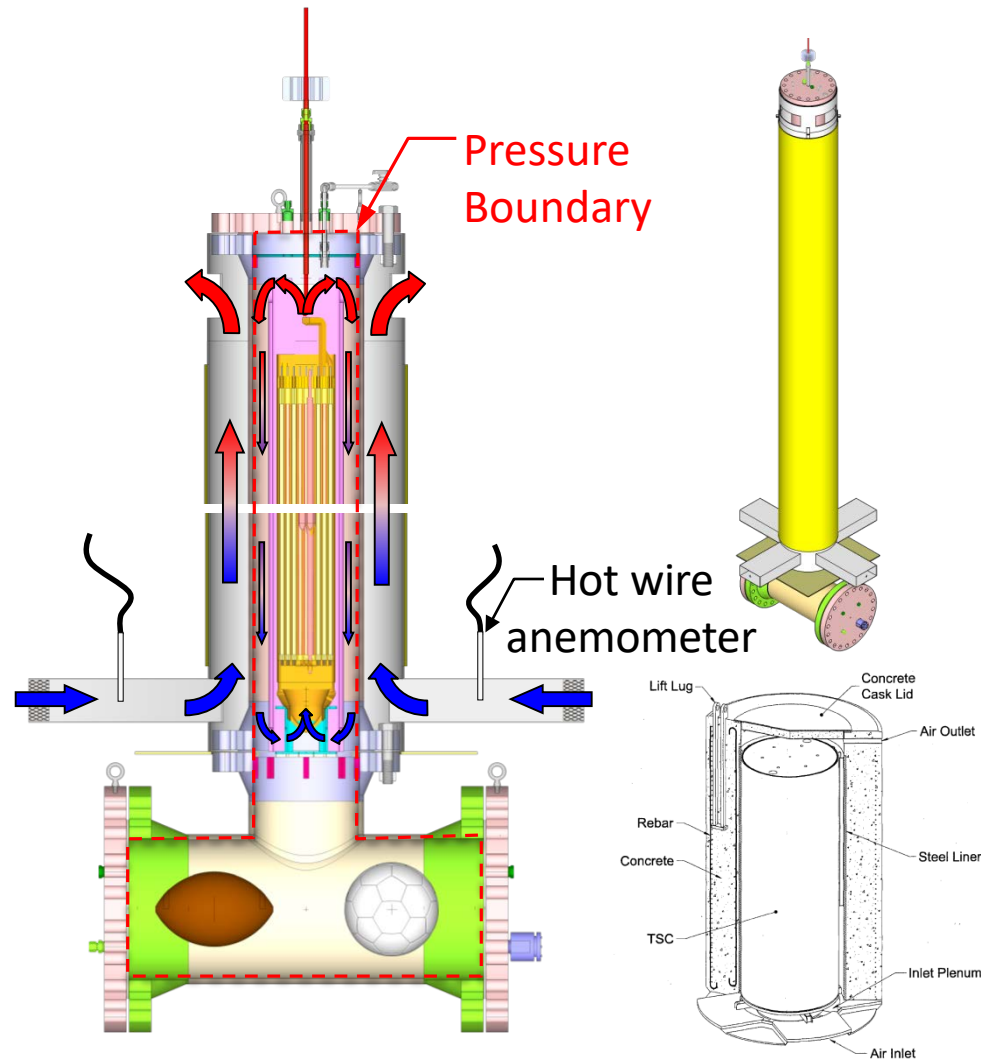
# External Dimensional Analyses

- 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

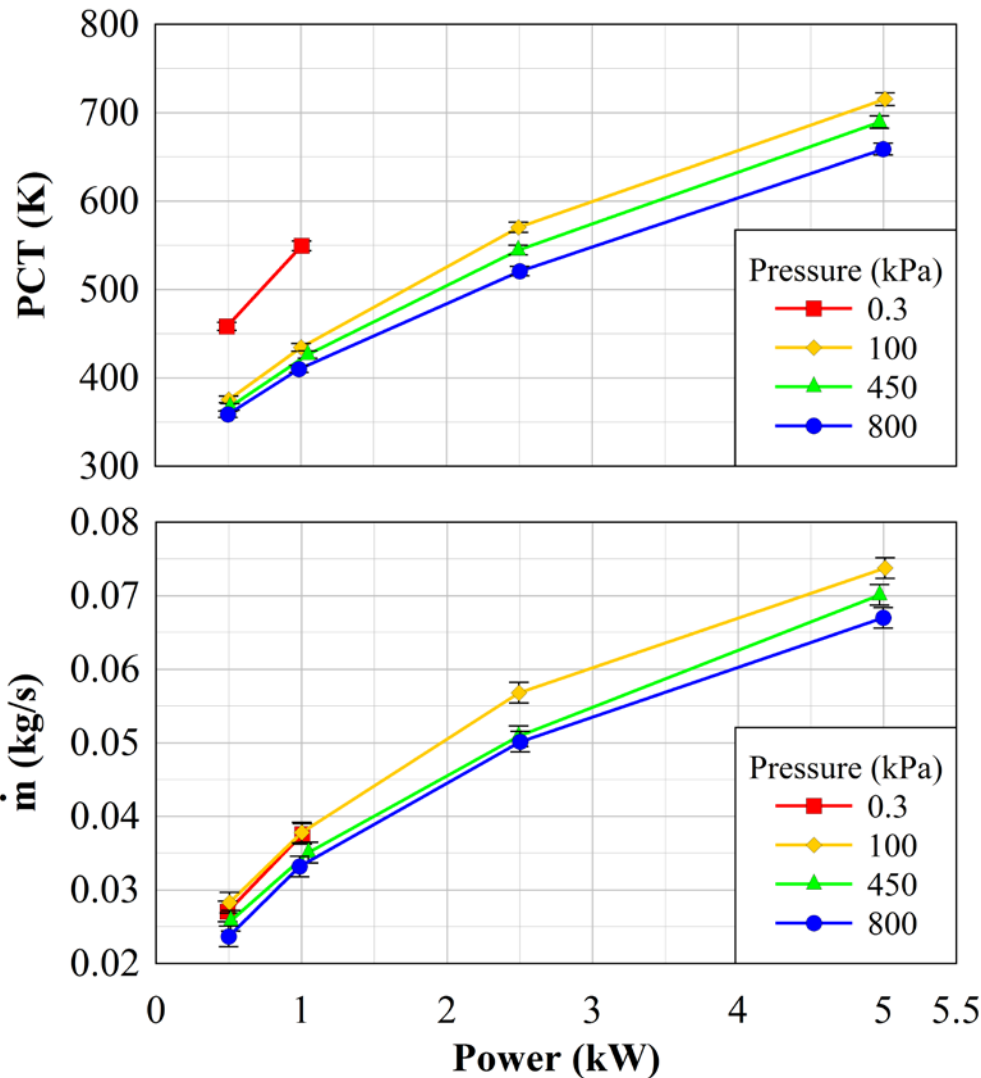


- BWR Dry Cask Simulator (DCS) system capabilities
  - Power: 0.1 – 20 kW
  - Pressure vessel
    - Vessel temperatures up to 400 °C
    - Pressures up to 2,400 kPa
    - ~200 thermocouples throughout system (internal and external)
  - Air velocity measurements at inlets
    - Calculate external mass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

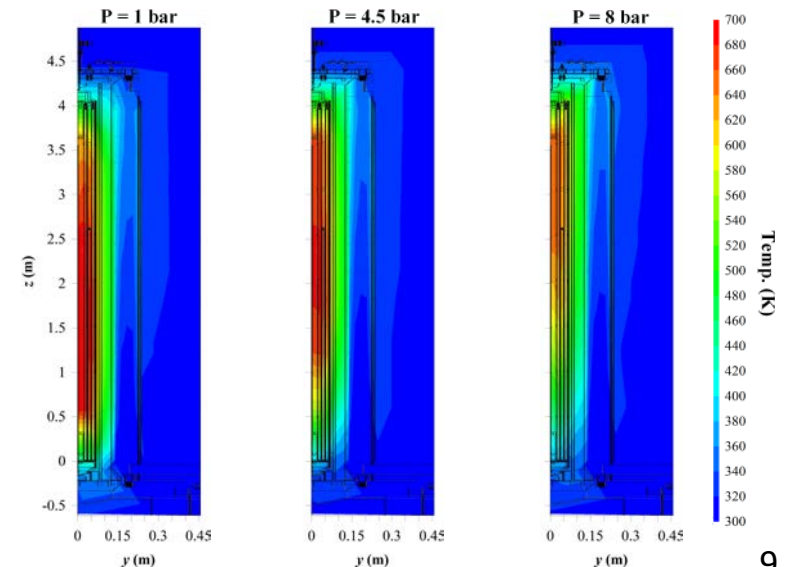


# Steady State Values vs. Decay Heat

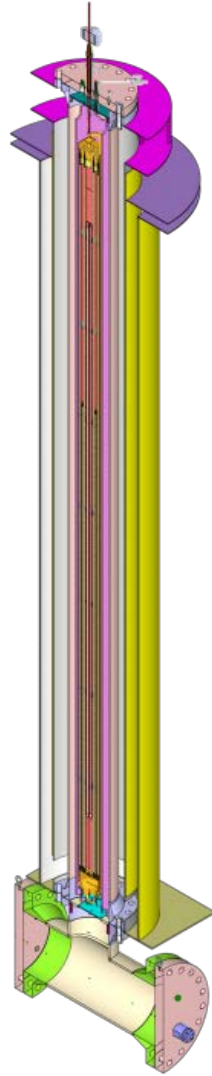
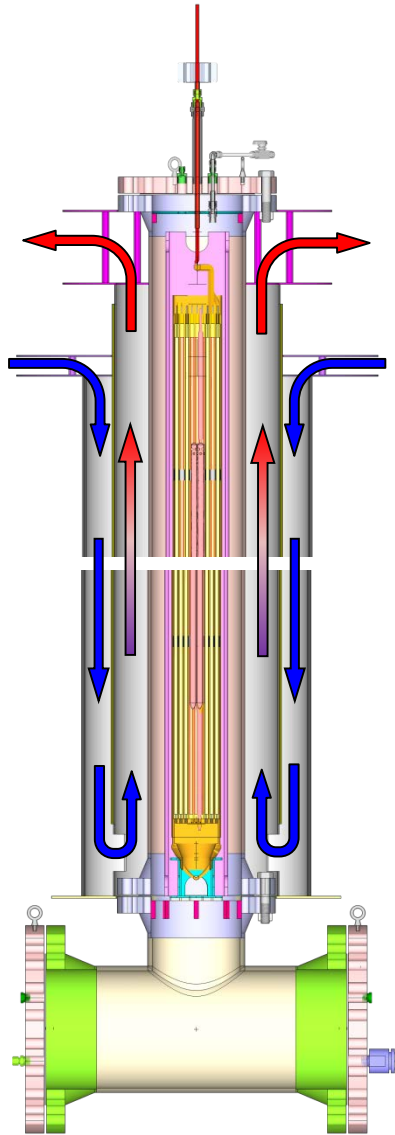
## Aboveground Configuration



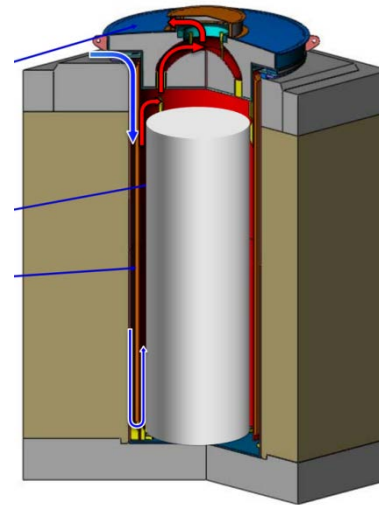
- PCT and air flow  $\uparrow$  as simulated decay heat  $\uparrow$ 
  - Significant increase in PCT for  $P = 0.3$  kPa
    - Due to air in “canister” instead of helium



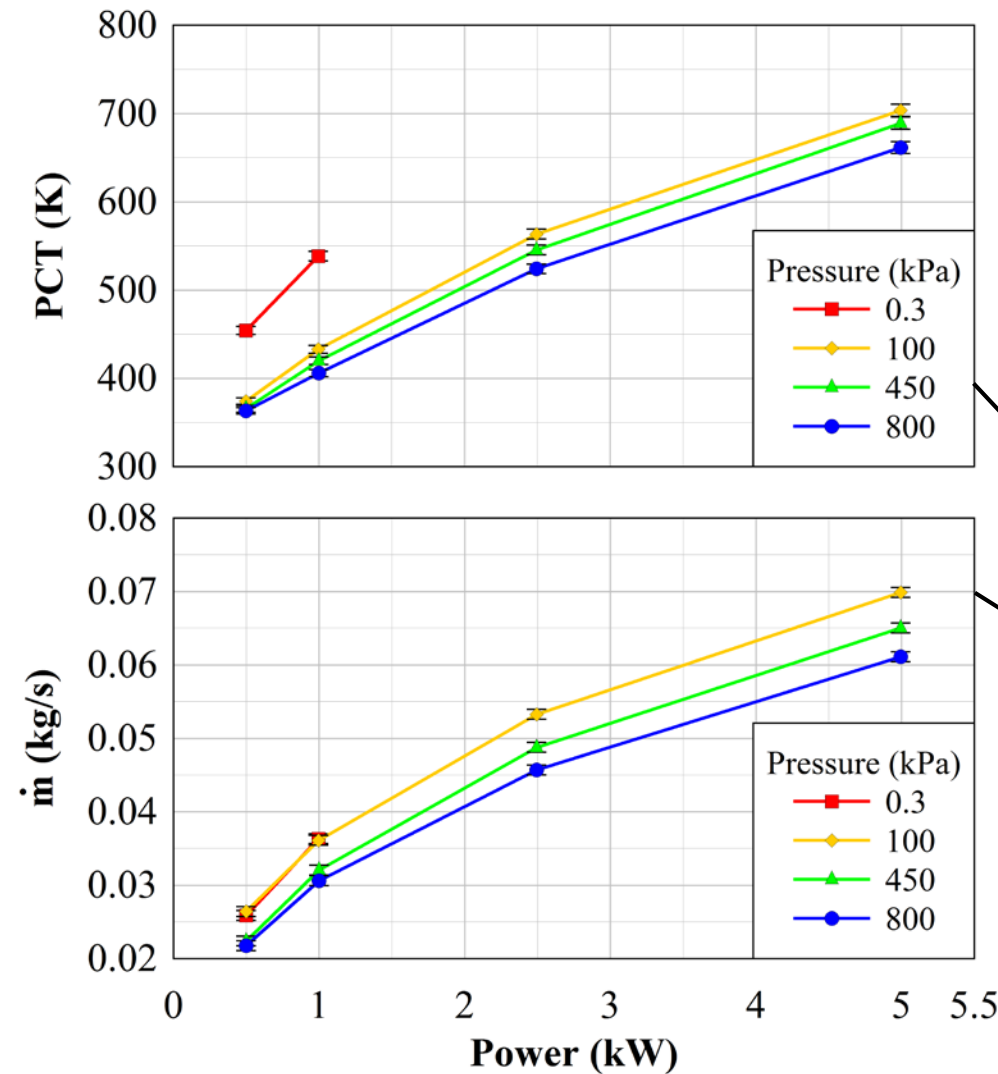
# Belowground Configuration



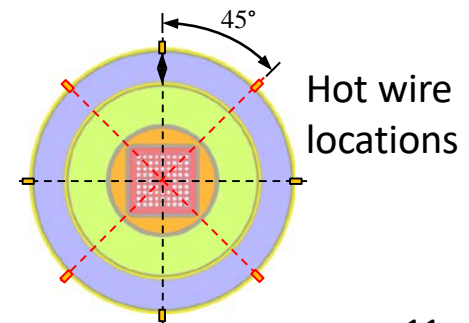
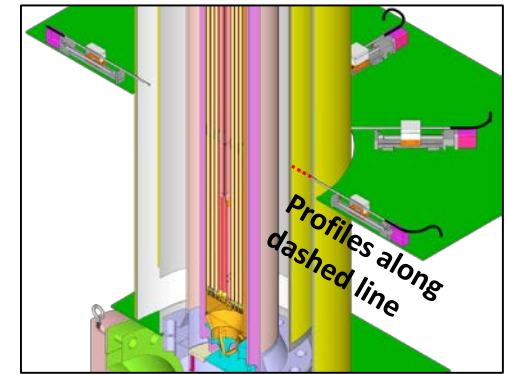
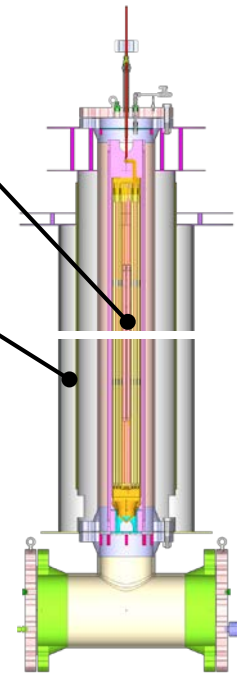
- Modification to aboveground ventilation configuration
  - Additional annular flow path
- *Testing Completed April 2017*
  - 14 data sets recorded
    - Transient and steady state



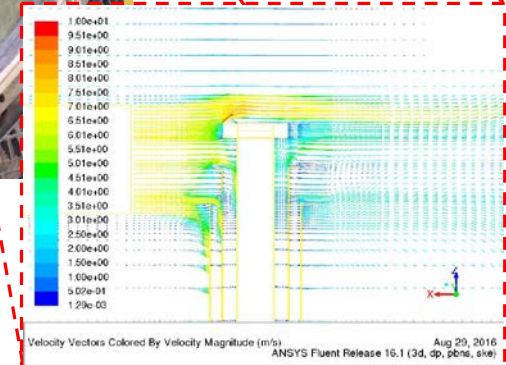
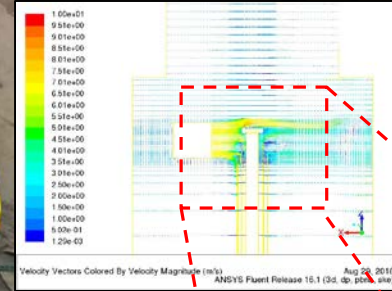
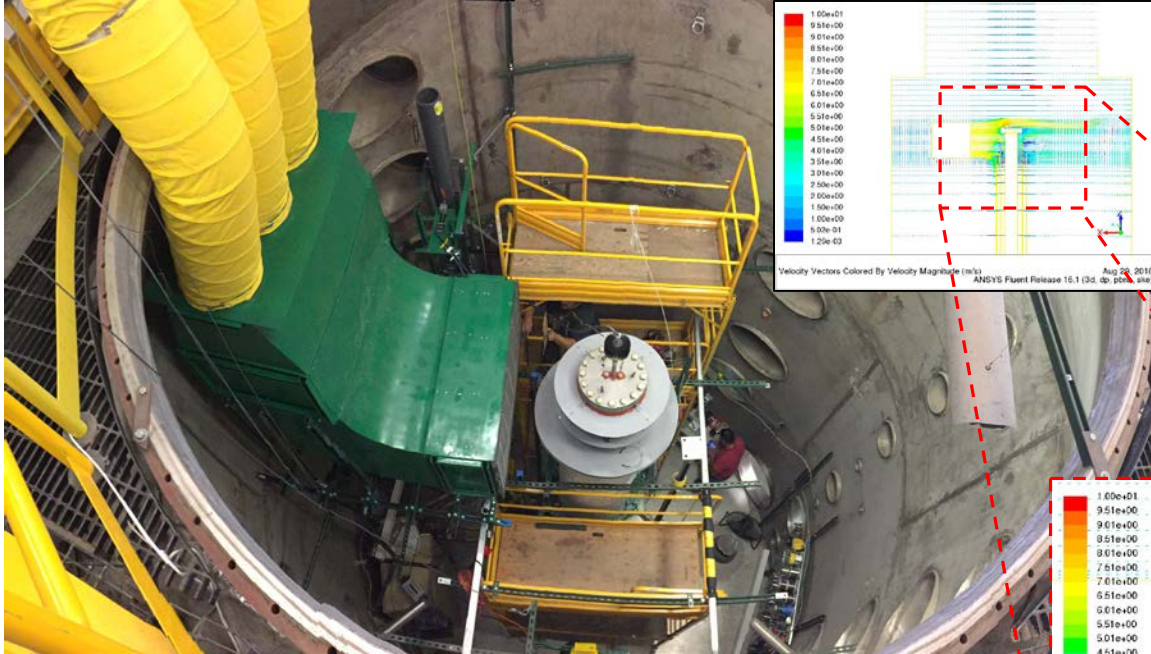
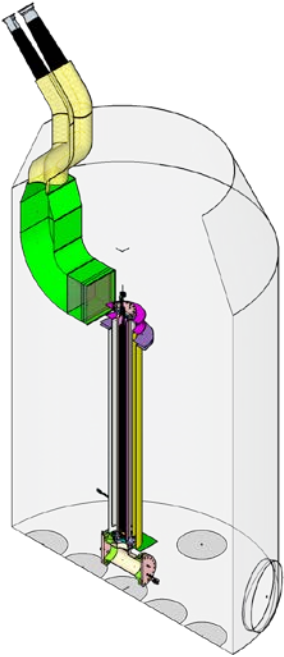
# Steady State Values vs. Decay Heat Belowground Configuration



- Similar performance to aboveground configuration
  - Within 2% for PCT
  - Within 5% for  $\dot{m}$



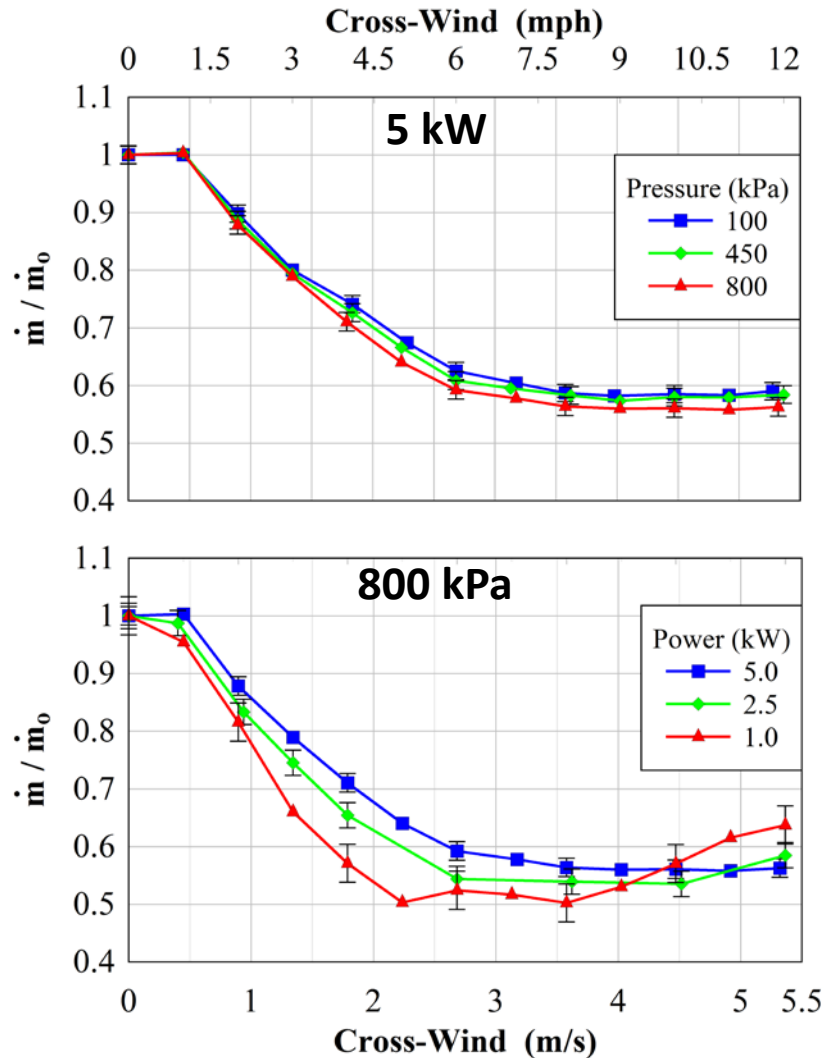
# Cross Wind Testing



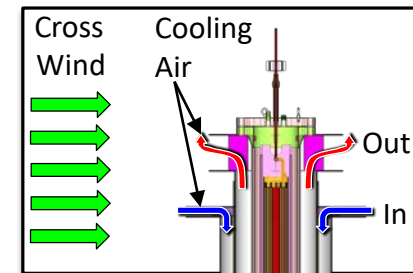
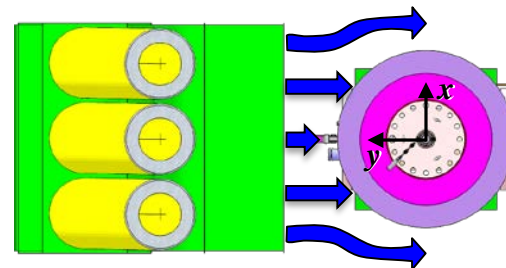
- Wind machine installed inside test enclosure
  - Three air-driven blowers
  - Specially fabricated duct with flow straightening
  - Cross winds of up to 5.4 m/s (12 mph)

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

# 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