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

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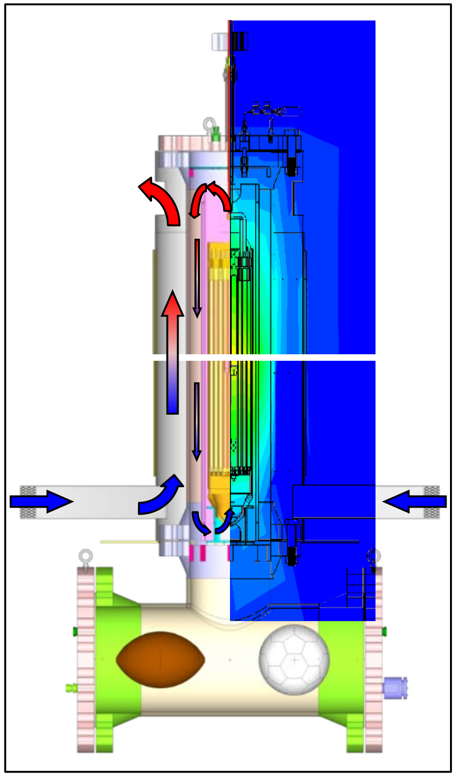

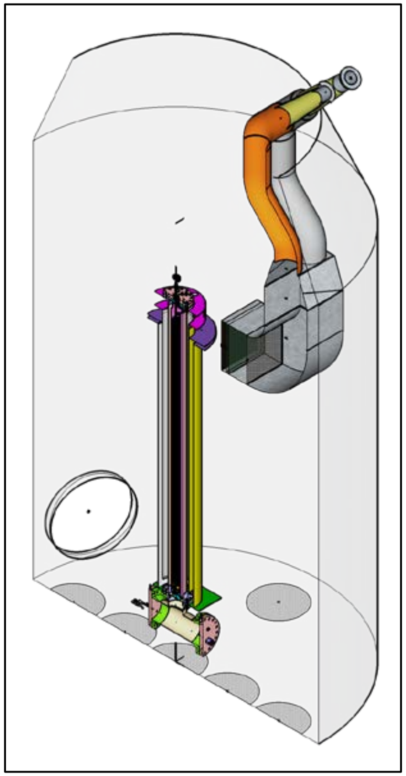

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U.S. DEPARTMENT OF ENERGY

NNSA
National Nuclear Security Administration

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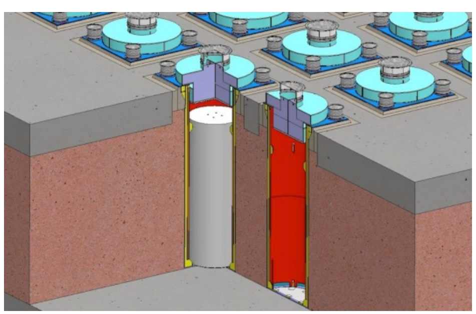
Overview

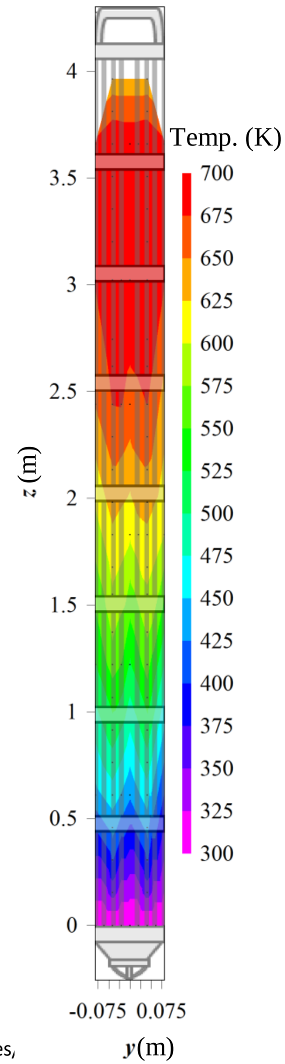
Aboveground Storage

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

- 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

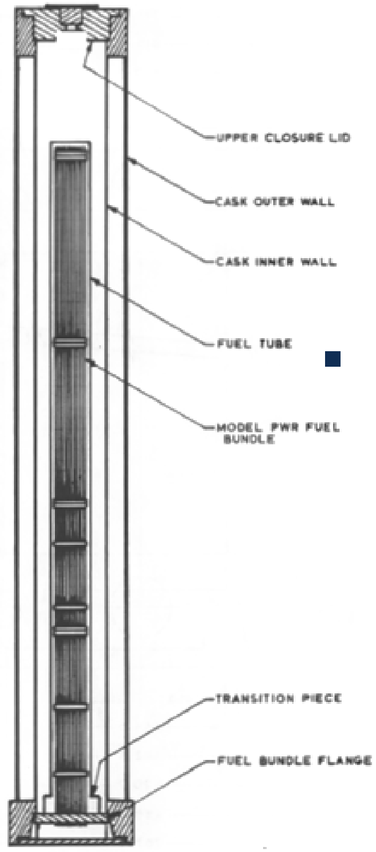
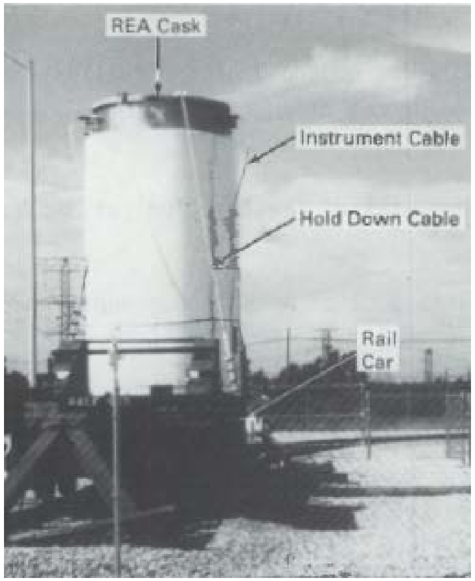
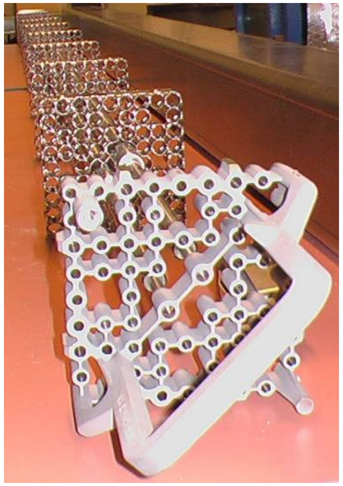


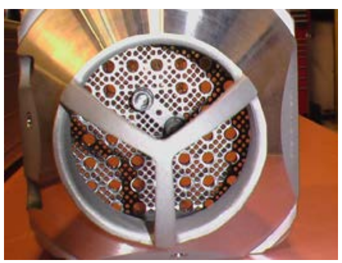
FIGURE 4-1. SAHTT Assembly



Prototypic Assembly Hardware

Upper tie plate

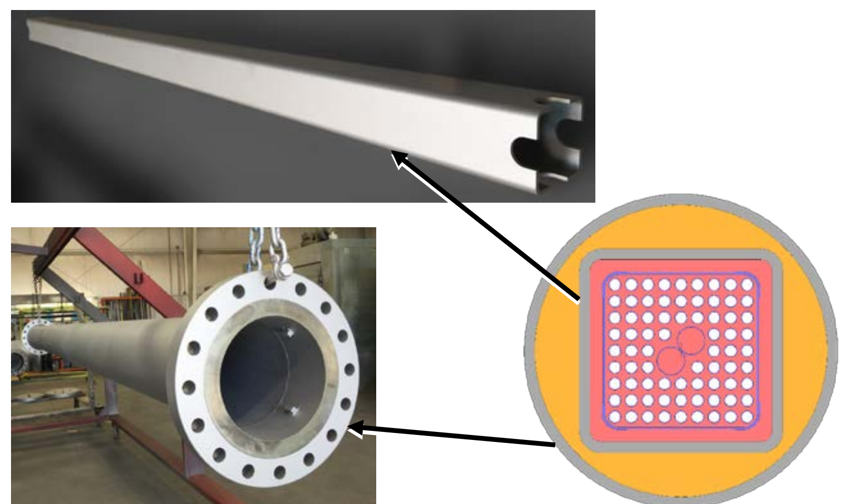




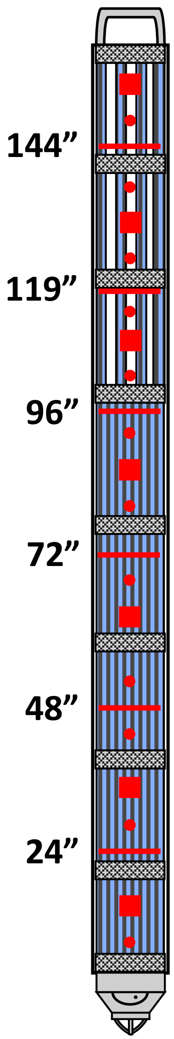
Nose piece and debris catcher

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

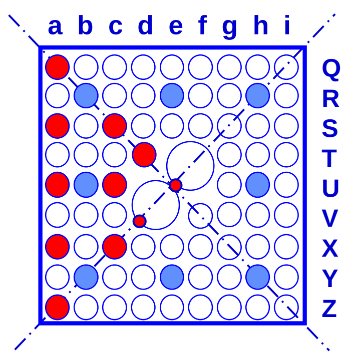
Radial Array
24” spacing
11 TC’s each level
66 TC’s total (details below)

Axial array A1
6” spacing
20 TC’s

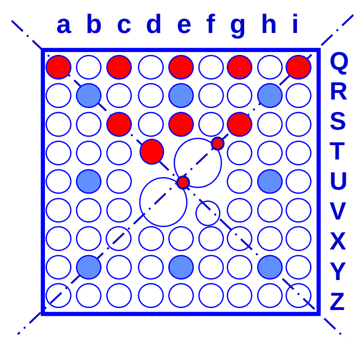
Axial array A2
12” spacing – 7 TC’s
Water rods inlet and exit – 4 TC’s
Total of 97 TC’s

- 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

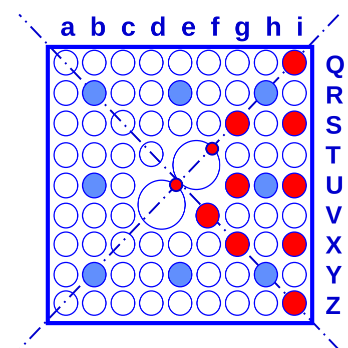
24” & 96” levels



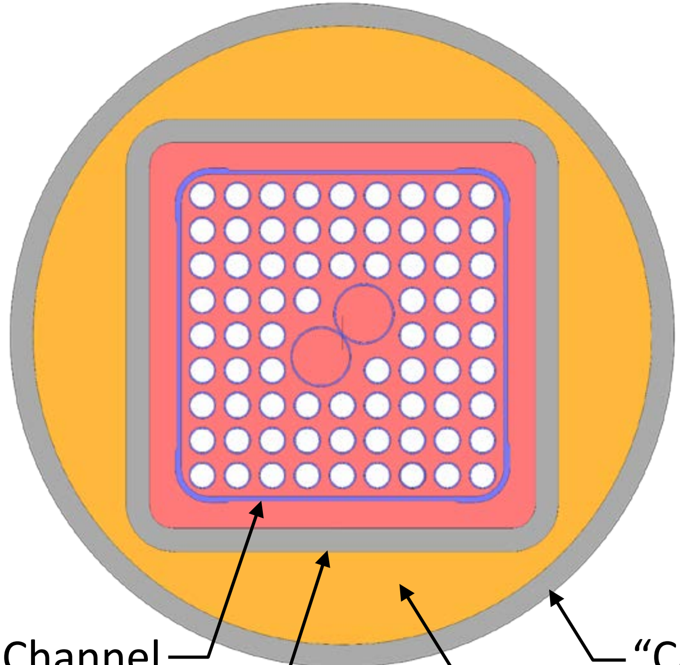
48” & 119” levels



72” & 144” levels



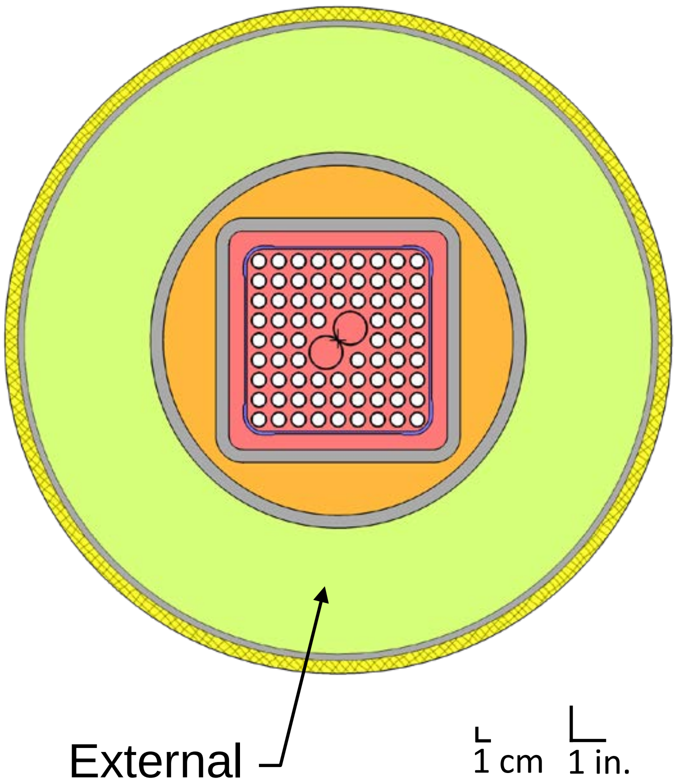
Internal Dimensional Analyses



- 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	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

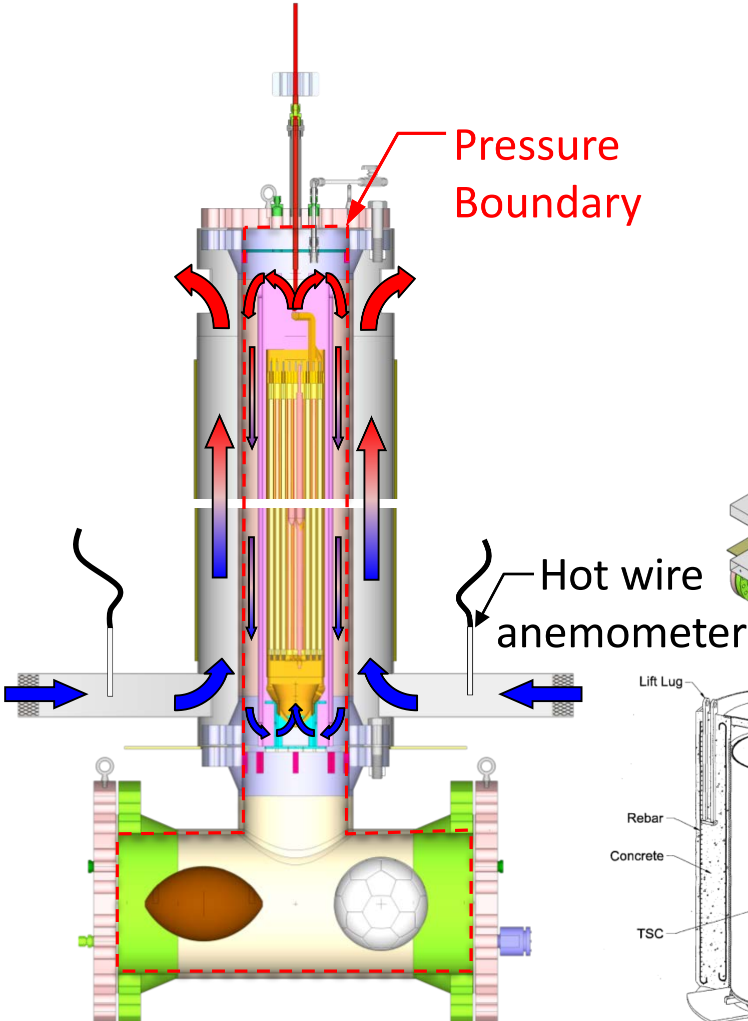
External Dimensional Analyses

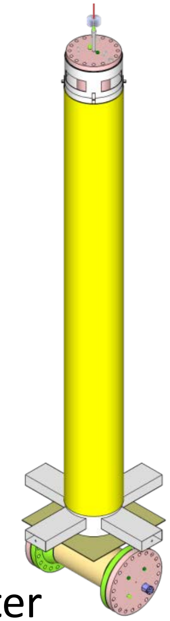


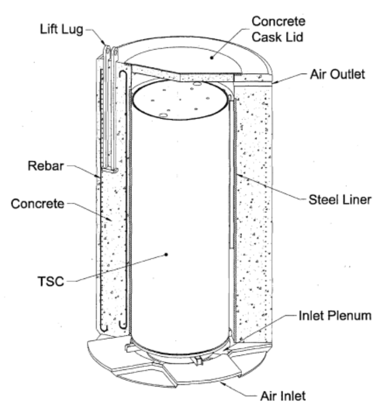
- External cooling flows evaluated against prototypic
  - External dimensionless groups

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

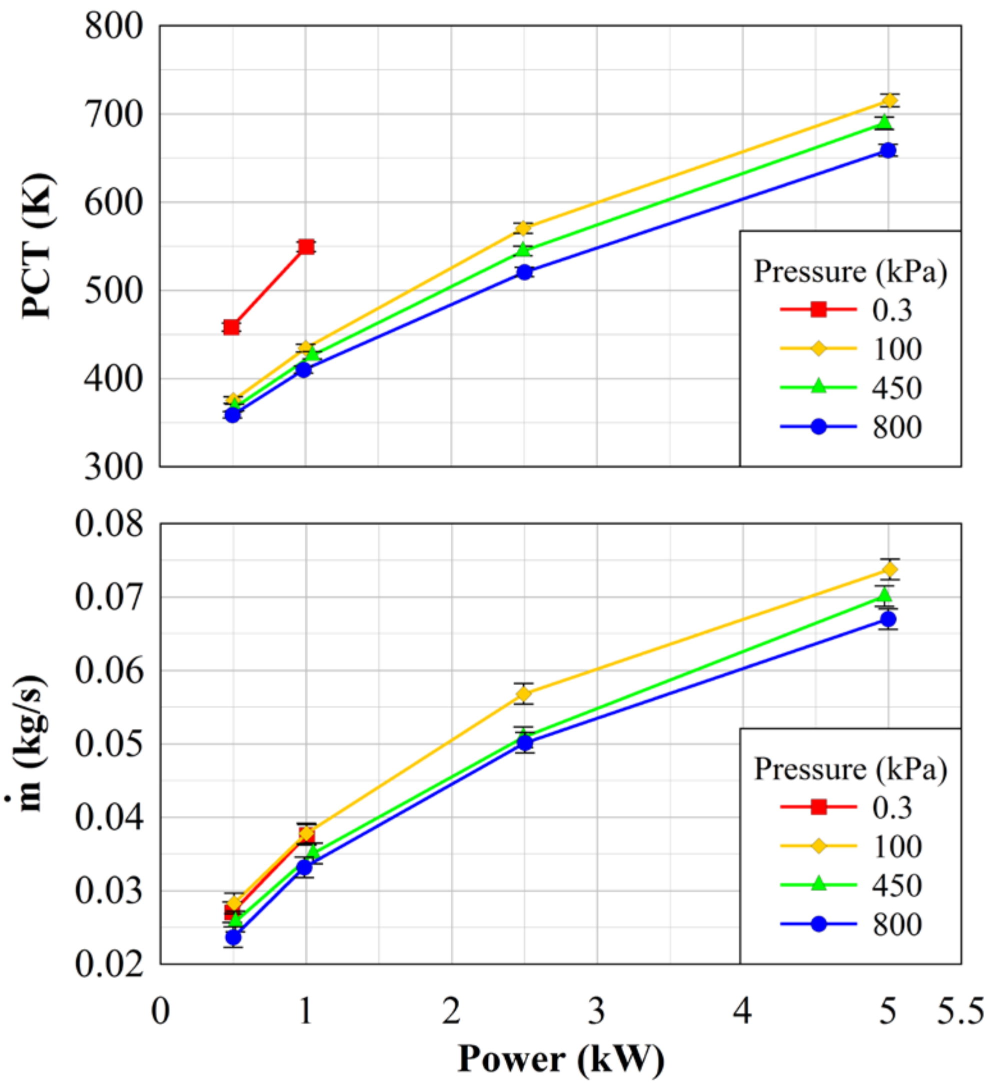




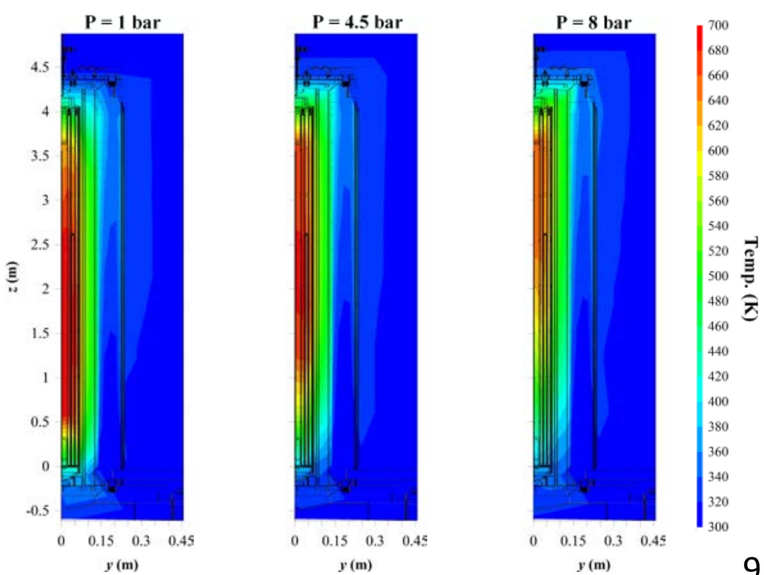


- BWR Dry Cask Simulator (DCS) system capabilities
  - Power: 0.1 – 20 kW
  - Pressure vessel
    - Vessel temperatures up to 400 °C
    - Pressures up to 2,400 kPa
    - ~200 thermocouples throughout system (internal and external)
  - Air velocity measurements at inlets
    - Calculate external mass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

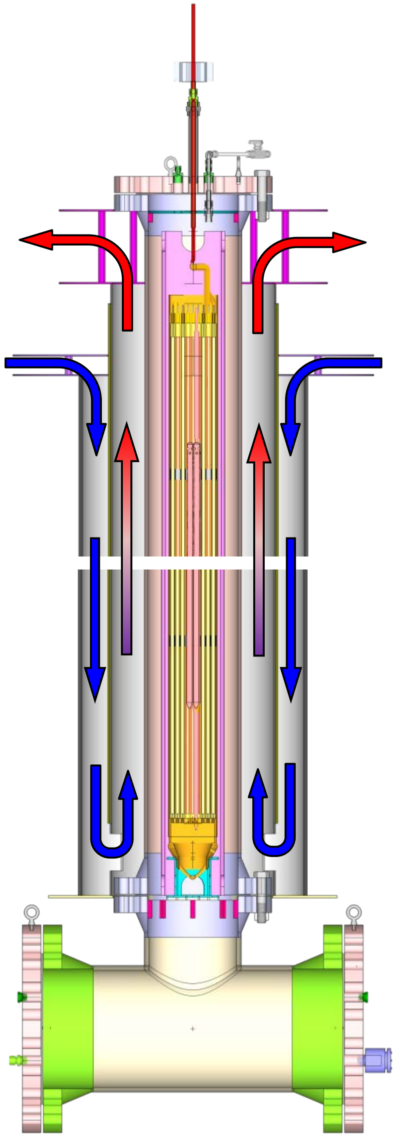
Steady State Values vs. Decay Heat
Aboveground Configuration

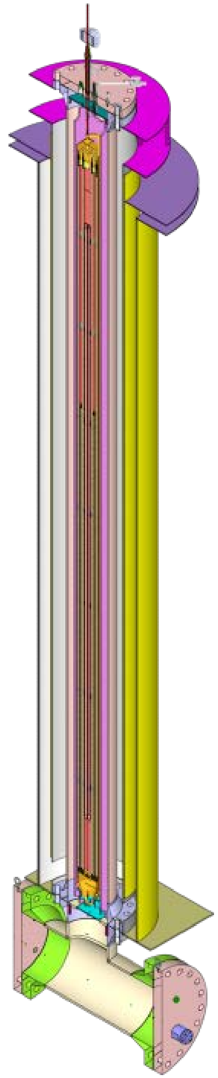


- PCT and air flow ↑ as simulated decay heat ↑
  - Significant increase in PCT for P = 0.3 kPa
    - Due to air in “canister” instead of helium

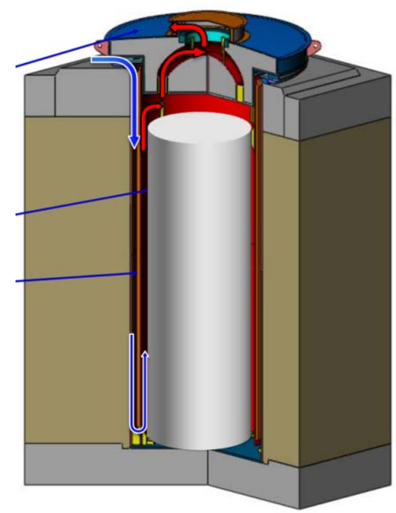


Belowground Configuration



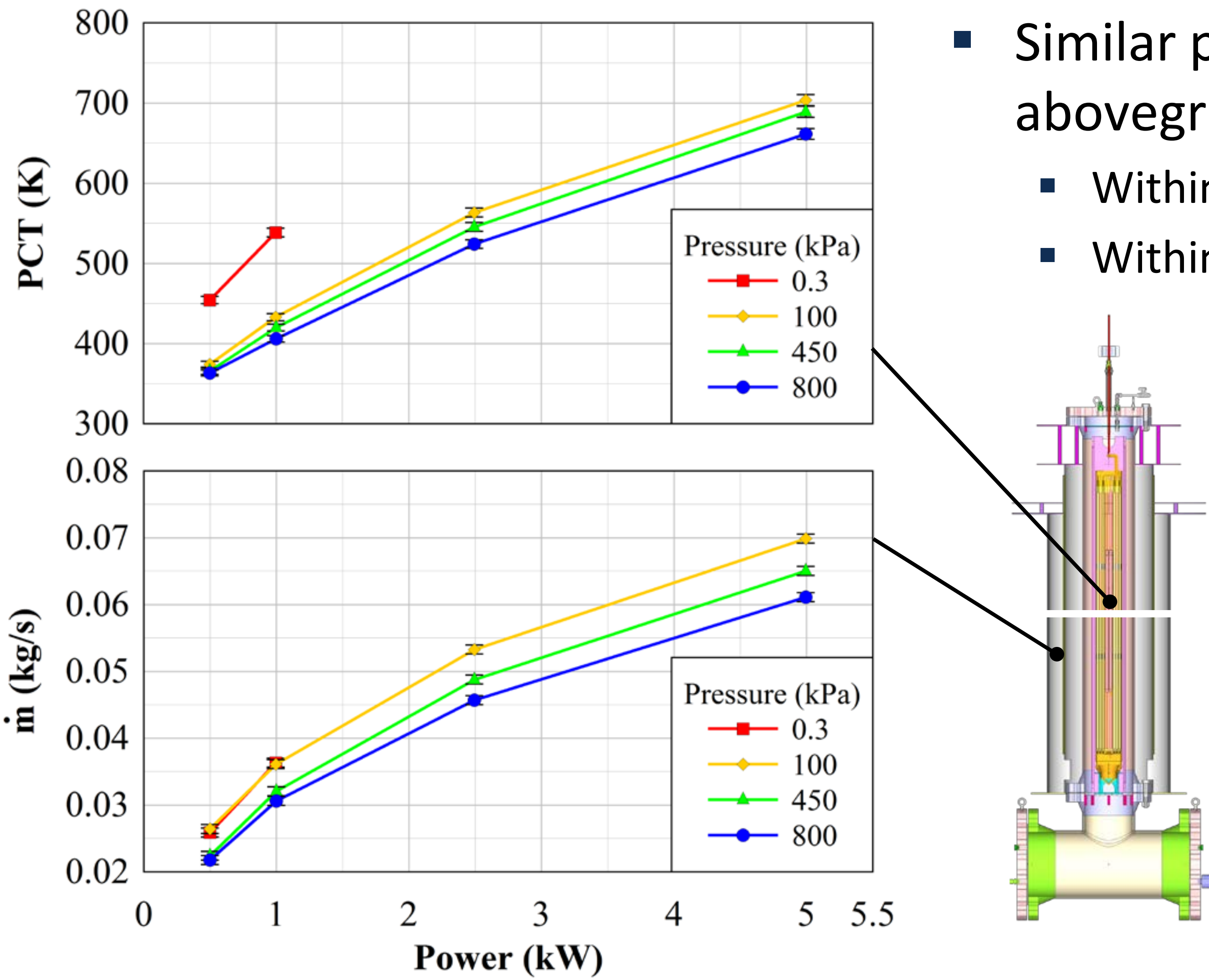


- Modification to aboveground ventilation configuration
  - Additional annular flow path
- *Testing Completed April 2017*
  - 14 data sets recorded
    - Transient and steady state

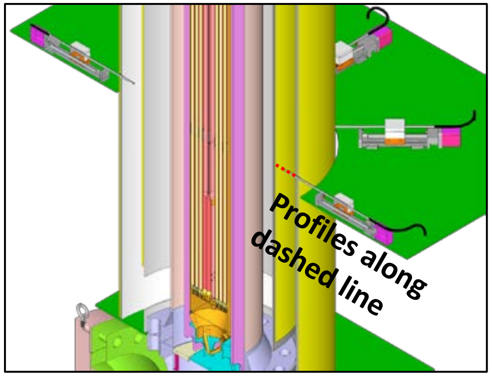


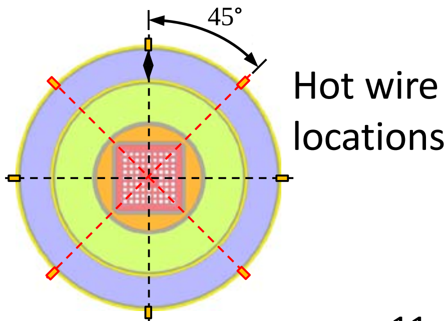
Steady State Values vs. Decay Heat

Belowground Configuration

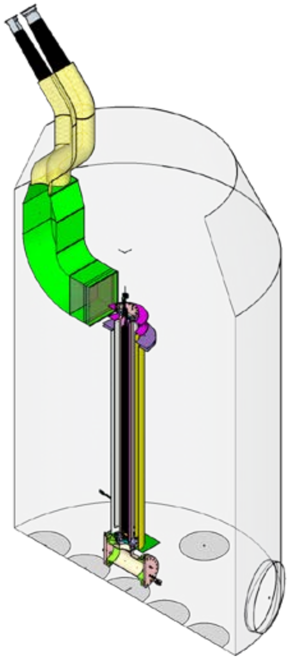


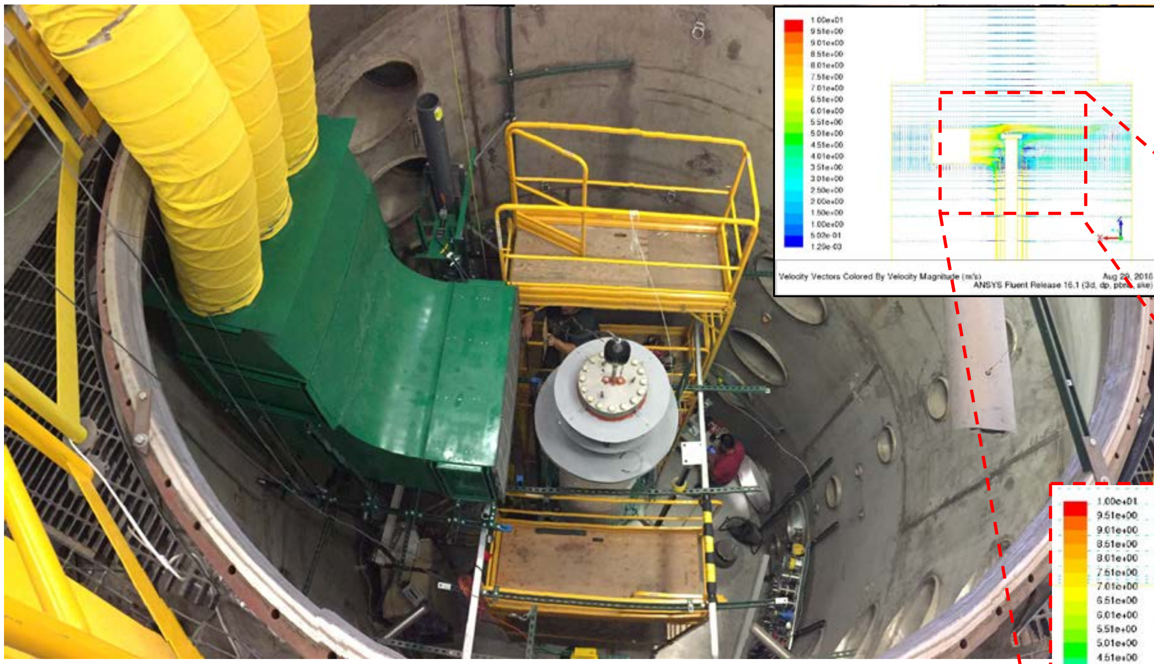
- Similar performance to aboveground configuration
  - Within 2% for PCT
  - Within 5% for ṁ

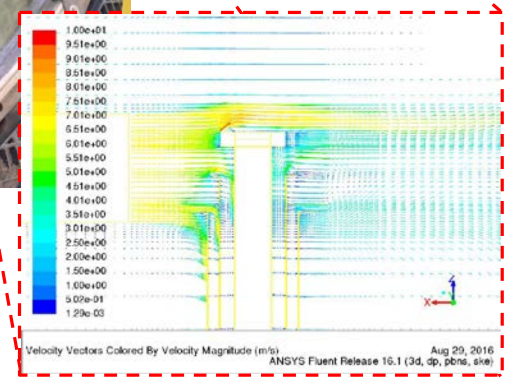




Cross Wind Testing



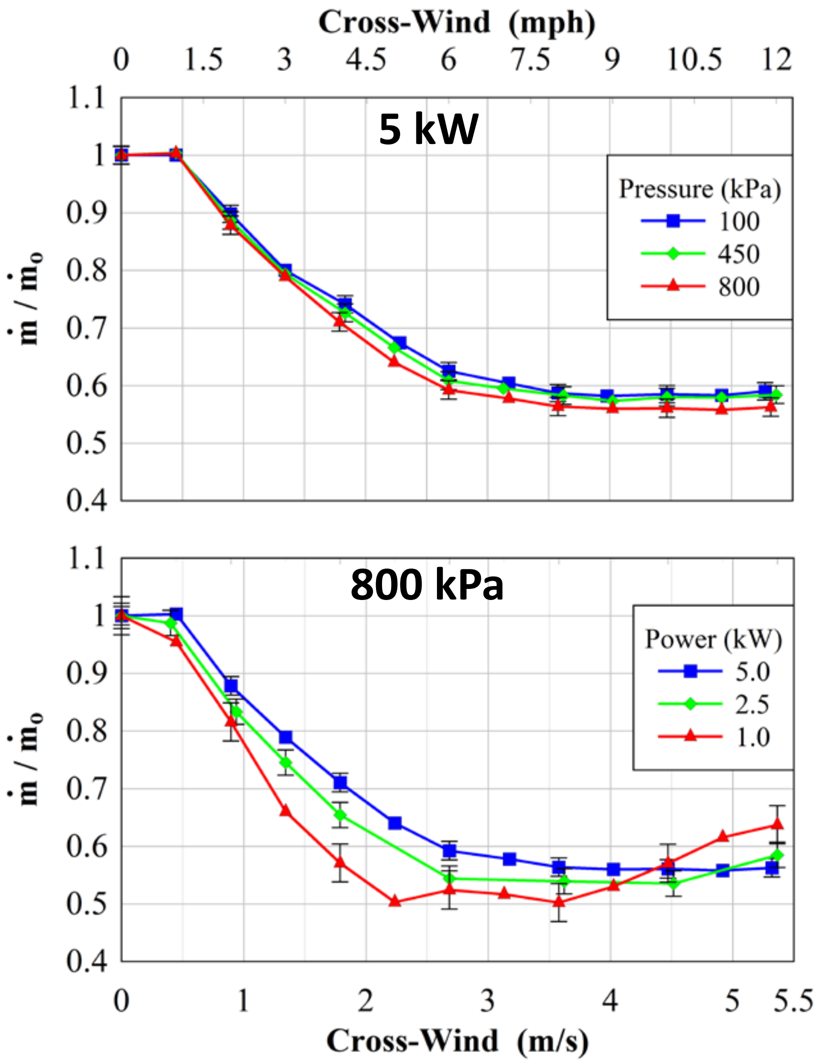




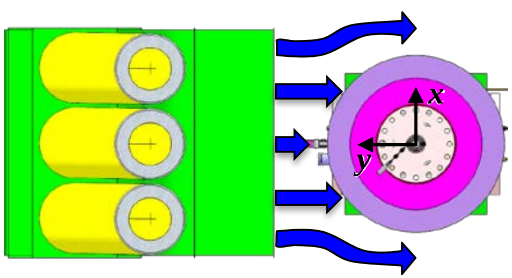
CFD simulations by A. Zigh (USNRC)

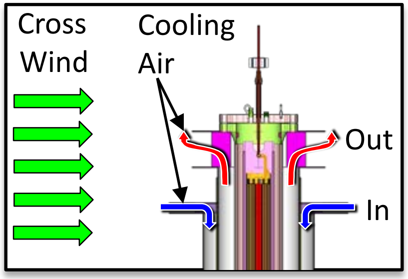
- Wind machine installed inside test enclosure
  - Three air-driven blowers
  - Specially fabricated duct with flow straightening
  - Cross winds of up to 5.4 m/s (12 mph)

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