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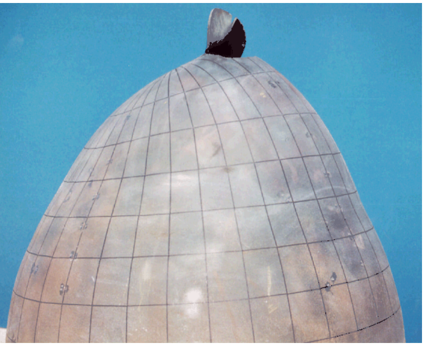

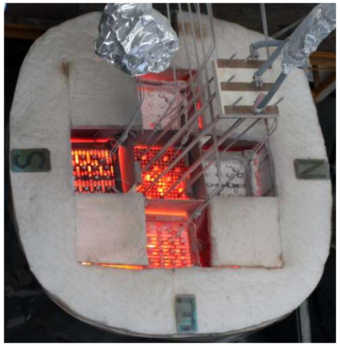

# Dry Cask Simulator for a Boiling Water Reactor Fuel Assembly

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Presented at the Used Fuel Disposition Working Group Meeting
Las Vegas, Nevada
June 11th, 2015

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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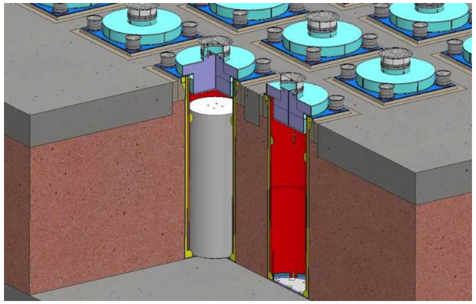
# Overview

Sandia National Laboratories

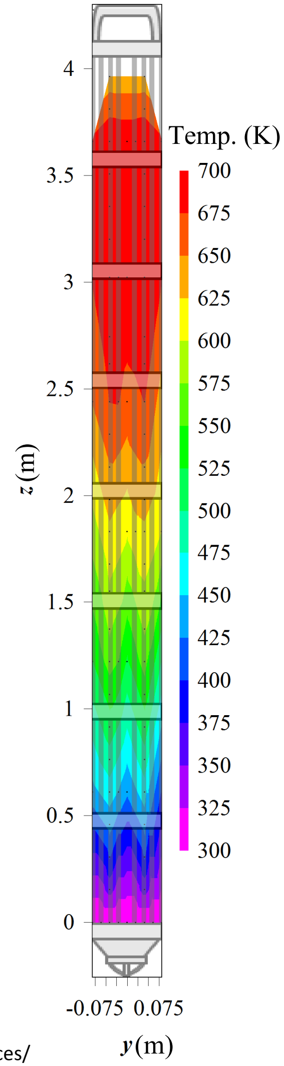
Aboveground Storage

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



Underground Storage

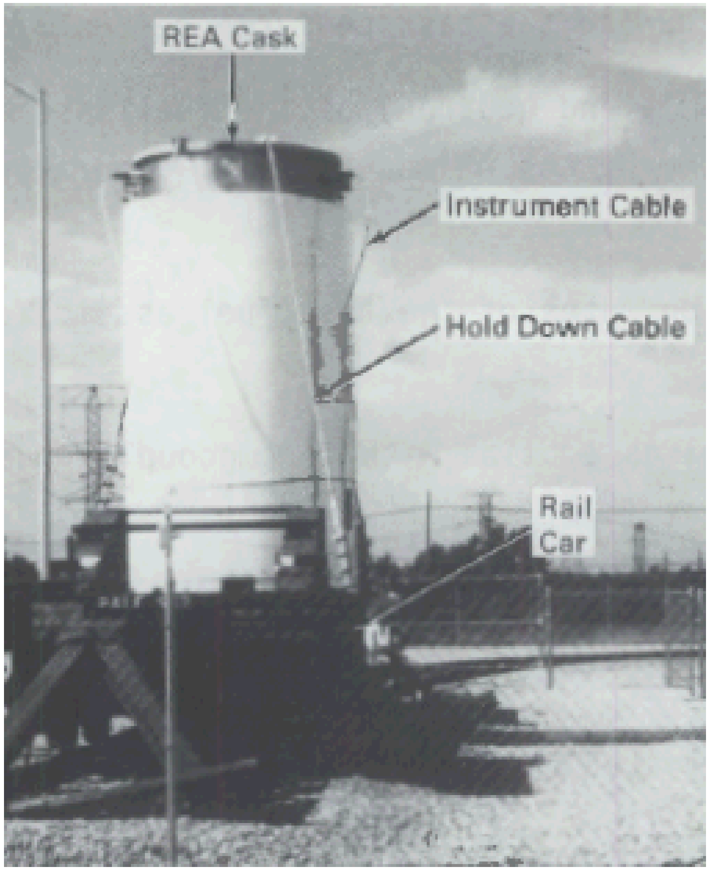
Source: www.holtecinternational.com/productsandservices/wasteandfuelmanagement/hi-storm/




- Purpose: Validate assumptions and calculations 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 below ground storage configurations of vertical, dry cask systems with canisters
  - Simplified geometry with well-controlled boundary conditions
  - Provide indirect measure of mass flow rates and convection heat transfer coefficients
- Use existing prototypic BWR Incoloy-clad test assembly

# Past Validation Efforts

## Unconsolidated Fuel




- Full scale, multi-assembly
  - Castor-V/21 cast iron/graphite with polyethylene rod shielding
    - 1986: EPRI NP-4887, PNL-5917
    - 21 PWRs
    - 95 Thermocouples (TC's) total
      - 60 TC's on 10 lances deployed in 8 guide tubes and 2 basket void spaces
      - 35 TC's on outer surface of cask
    - Unventilated
    - Sub-atmospheric (air and He) and vacuum
  - REA 2023 prototype steel-lead-steel cask with glycol water shield
    - 1986: PNL-5777 Vol. 1
    - 52 BWRs
    - 70 TC's total
      - 38 TC's at 8 axial levels in the basket and 7 assemblies
      - 32 TC's on outer cask surface
    - Unventilated
    - Sub-atmospheric (air & He) and vacuum

# Past Validation Efforts (cont.)

## Unconsolidated Fuel

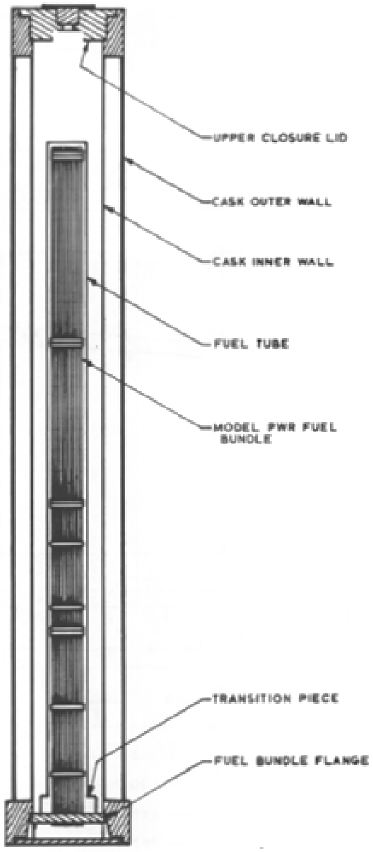
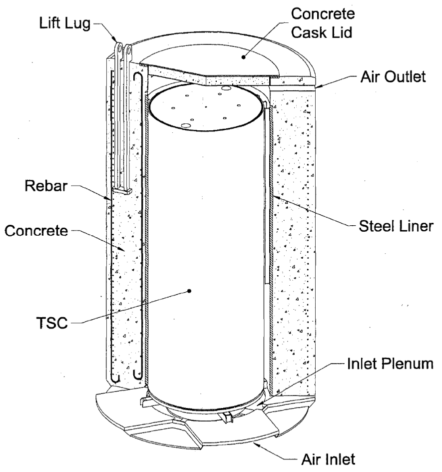
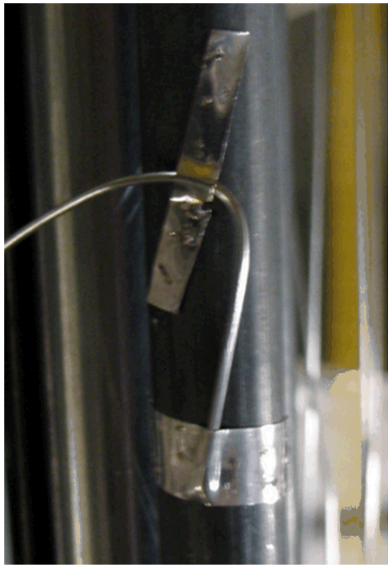



FIGURE 4-1. SAHTT Assembly

- Small scale, single assembly
  - FTT (irradiated, vertical) and SAHTT (electric, vertical & horizontal)
    - 1986 PNL-5571
    - Single 15x15 PWR
    - Thermocouples (TC's)
      - FTT: 187 total, 105 TC's distributed at 7 levels in 15 guide tube thermowells, 29 on canister and lid, 53 elsewhere on test stand
      - SAHTT: 98 total, 57 TCs distributed over 7 axial levels in assembly, 20 on cask inner wall at 5 axial levels, 21 on fuel tube wall, at 7 axial levels
    - Controlled cask outer wall temperature
    - Atmospheric (air & He) and vacuum
  - Mitsubishi test assembly (electric, vertical & horizontal)
    - 1986 IAEA-SM-286/139P
    - Single 15x15 PWR
    - 92 TC's total, all distributed over 4 levels inside tube bundle
    - Controlled outer wall temperature of fuel tube (also pressure boundary)
    - Atmospheric (air & He) and vacuum

# Current Approach

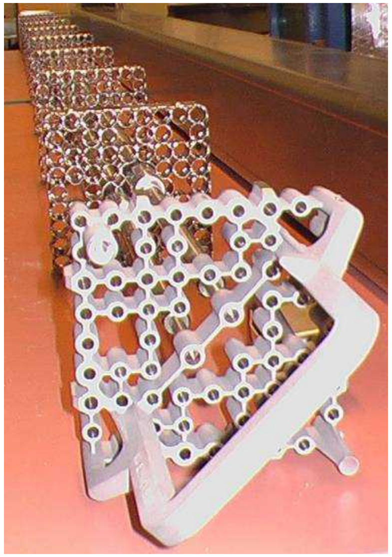


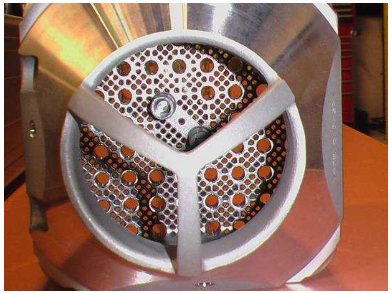



- Focus on pressurized canister systems
  - Over 20 bar internal pressure possible
    - Current commercial designs up to ~8 bar
- Ventilated designs
  - Aboveground configuration
  - Belowground configuration
    - With crosswind conditions
- TC attachment allows better peak cladding temperature measurement
  - 0.030” diameter sheath
    - Tip in direct contact with cladding

# Prototypic Hardware

Upper tie plate



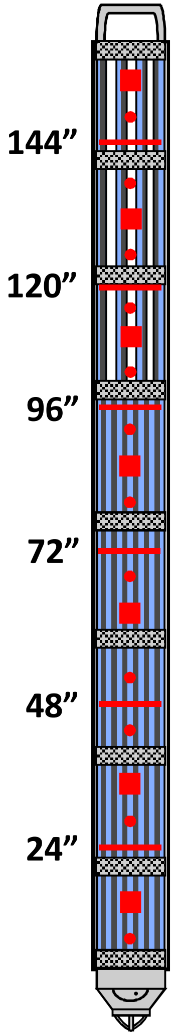


Nose piece and debris catcher

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 end 2/3 the length up assembly
  - 2 water rods
  - 7 spacers

# Thermocouple Layout




**Internal Thermocouples**

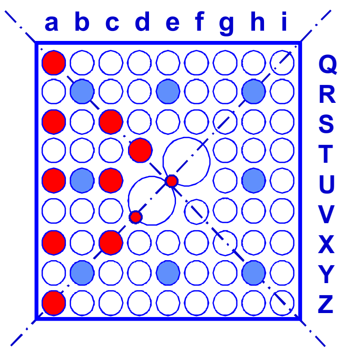
— **Radial Array**
**24” spacing**
**11 TC’s each level**
**66 TC’s total (details below)**

● **Axial array A1**
**6” spacing**
**20 TCs**

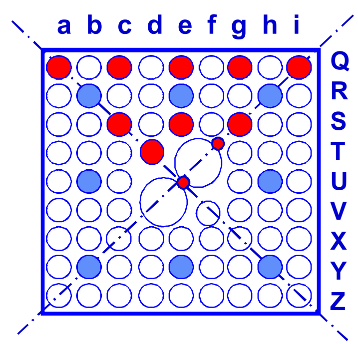
■ **Axial array A2**
**12” spacing – 7 TC’s**
**Water rods inlet and exit – 4 TC’s**
**Total of 97 TCs**

- 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, 120, and 144 in. levels

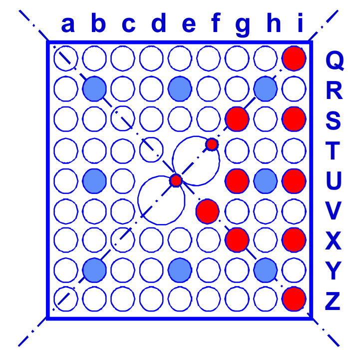
24” & 96” levels



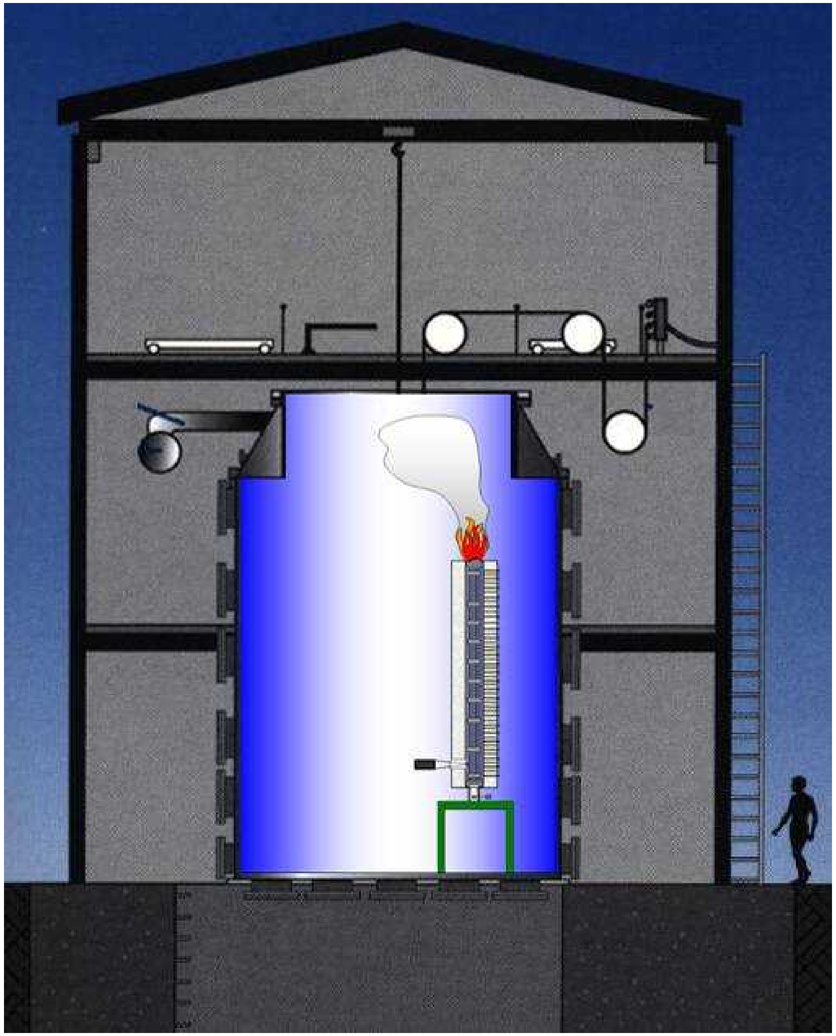

48” & 120” levels




72” & 144” levels

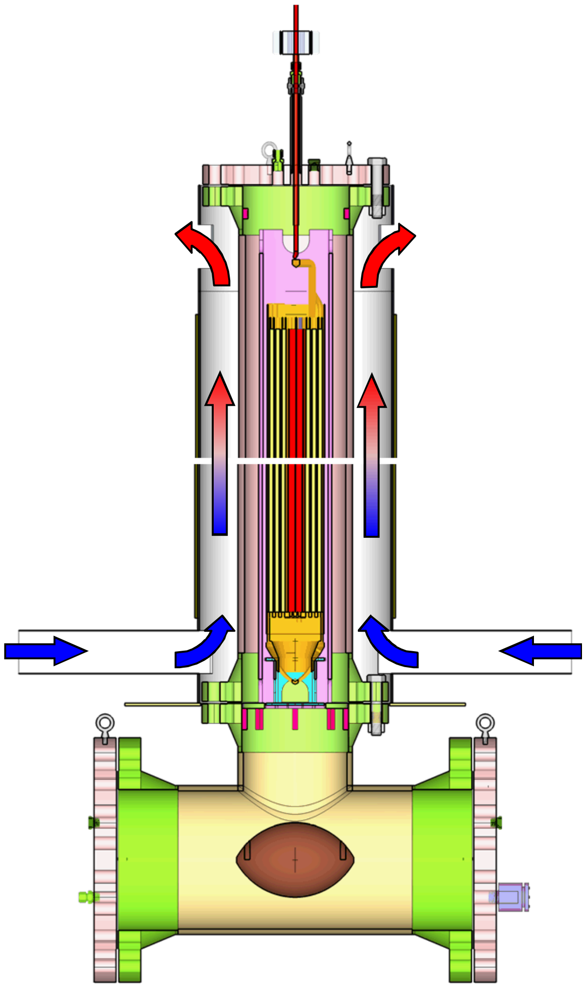


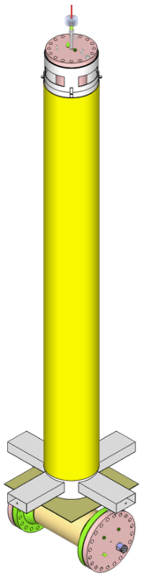
# CYBL Test Facility

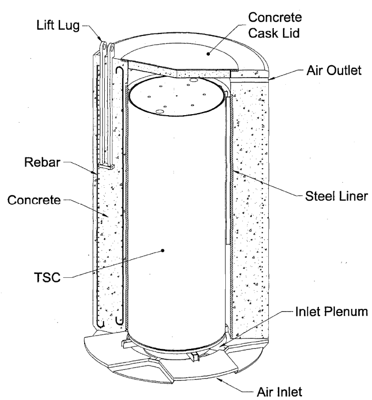


- Large stainless steel containment
  - Repurposed from earlier CYLINDRICAL BOILING Testing sponsored by DOE
  - Excellent general-use engineered barrier for isolation of high-energy tests
    - 3/8 in. stainless steel
    - 17 ft diam. by 28 ft cylindrical workspace
- Part of the Nuclear Energy Work Complex (NEWC)

# Aboveground Configuration

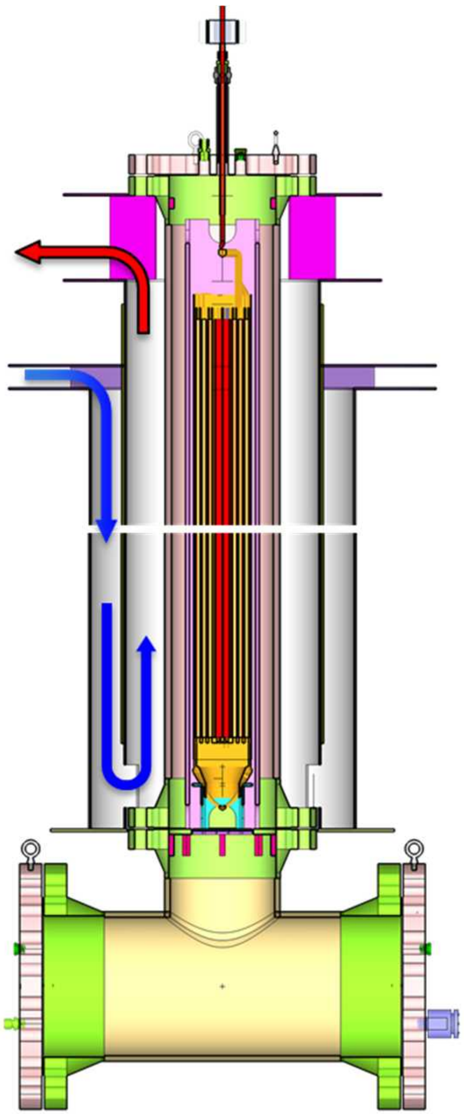


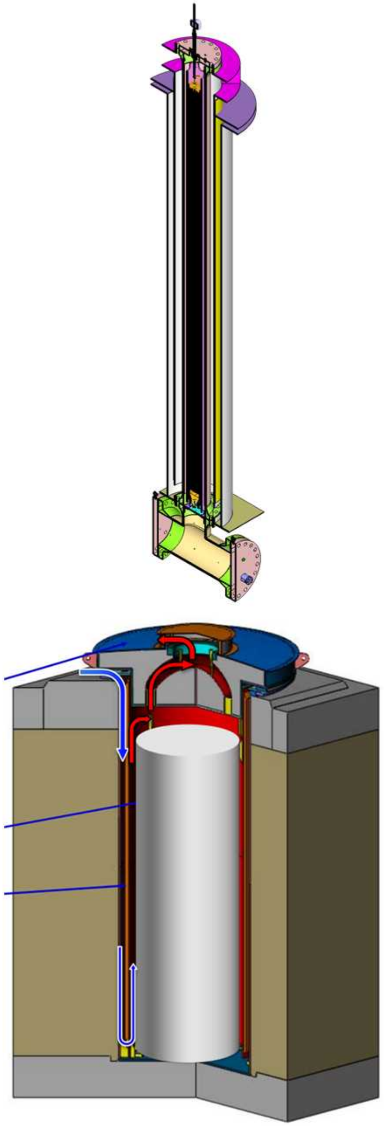





- BWR Cask Simulator (BCS) system capabilities
  - Power: 0 – 5 kW
  - Pressure vessel
    - Vessel temperatures up to 400 °C
    - Pressures up to 24 bar (anticipated)
  - ~200 thermocouples throughout system
  - Calibrated and in-situ air velocity measurements at inlets

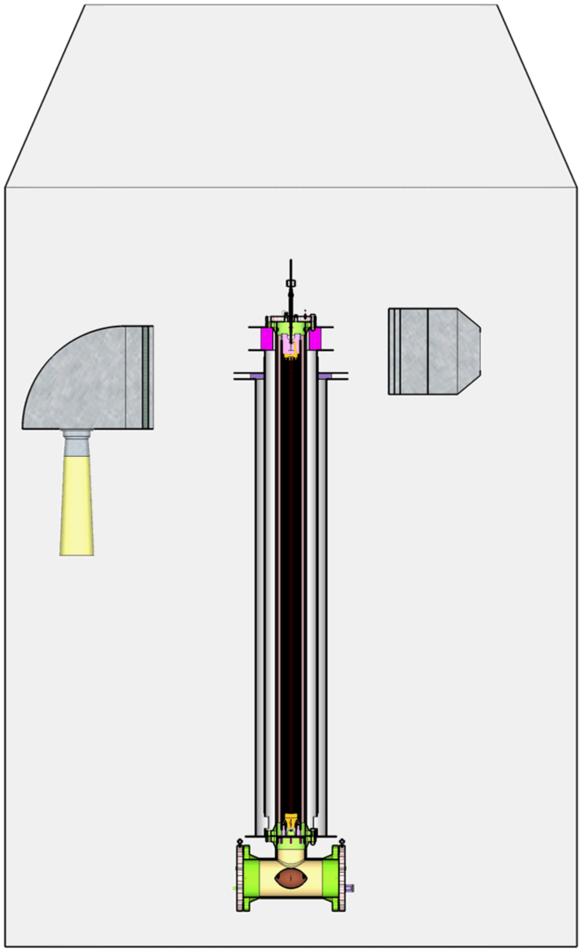
# Belowground Configuration





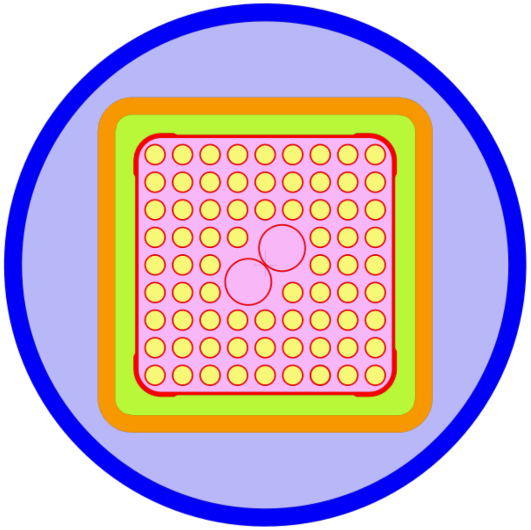
- Modification to aboveground configuration
  - Additional annular flow path
- Final design nearly complete
  - Inlet and outlet based on prototypic configuration
- Scaling analysis completed
  - Favorable comparisons
    - Modified, channel Rayleigh number ($Ra_S^*$)
    - Reynolds (Re) number

# Crosswind Conditions



- Crosswind conditions imposed on belowground configuration
  - Speeds of 0 to 15 mph
- Air forced across inlet and outlet ducts
  - Push/Pull system currently considered for use in CYBL
    - Vessel size limitations / Minimization of vorticity
    - Ducting not shown
- CFD modeling indicates reduction in cooling air flow rate at sustained crosswinds of 5 mph
  - NUREG -2174

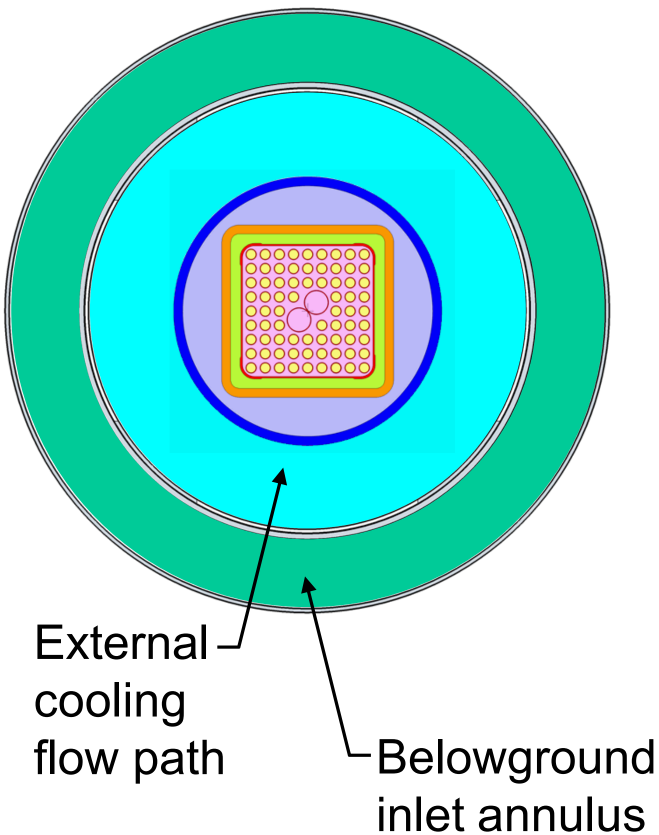
# Internal Dimensional Analyses



- Internal flow and convection prototypic
  - Near prototypic geometry for fuel and basket
- Downcomer and external cooling flows matched using elevated decay heat (5 kW)
  - Downcomer dimensionless groups

| | BCS High Power | NAC TSC-87 | Holtec 100U |
|---|---|---|---|
| $Re_{Down}$ | 290 | 220 | 220 |
| $Ra_H^*$ | 4.7E+11 | 4.7E+11 | 5.6E+11 |
| $Nu_H$ | 220 | 210 | 220 |

# External Dimensional Analyses




- External cooling flows matched using elevated decay heat (5 kW)
  - External dimensionless groups

| | BCS High Power | NAC TSC-87 | Holtec 100U |
|---|---|---|---|
| **External Cooling** | | | |
| $Re_{Ex}$ | 11200 | 7300 | 7700 |
| $Ra_{DH}^{*}$ | 4.7E+09 | 3.0E+09 | 2.0E+09 |
| $(D_{H,\ Cooling} / H_{PV}) \times Ra_{DH}^{*}$ | 1.9E+08 | 1.2E+08 | 6.9E+07 |
| $Nu_{DH}$ | 29 | 26 | 23 |
| **Aboveground Inlet Duct** | | | |
| $Re_{Above,\ Inlet}$ | 10700 | 11200 | -- |
| **Belowground Inlet Annulus** | | | |
| $Re_{Below,\ Inlet}$ | 8300 | -- | 8600 |

# BCS Status

- Project is on schedule and budget
  - 2 of 24 months elapsed
  - Initial safety analysis conducted May
- Pressure vessel FEA analysis complete
  - Final pressure rating will be based on a hydrotest at 1.3x of MAWP
- Overpack and inlet channel dimensions were optimized to match $Ra_S^*$ and Re
- Refinements of design ongoing with NRC staff
  - Current configurations are likely final
  - Remaining tasks include layout of instrumentation
- Draft test plan anticipated before end of FY15