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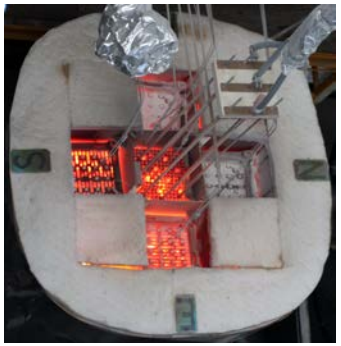

Dry Cask Simulator for a Boiling Water Reactor Fuel Assembly

Sam Durbin, Eric Lindgren, and Ken Sorenson

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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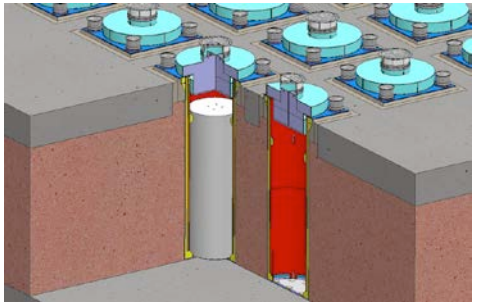
Overview

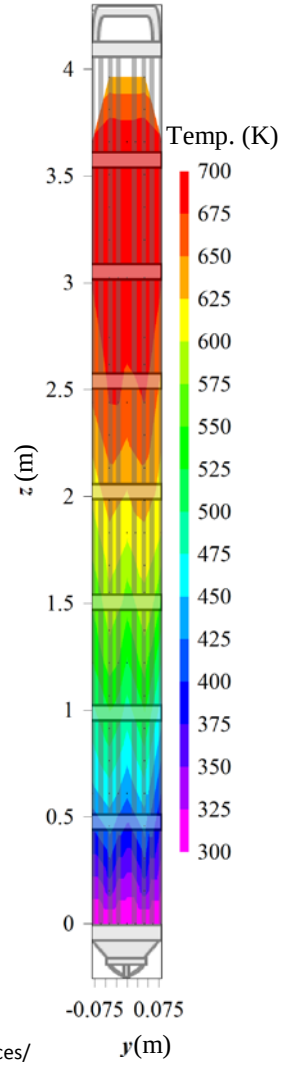
Aboveground Storage

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



Underground Storage

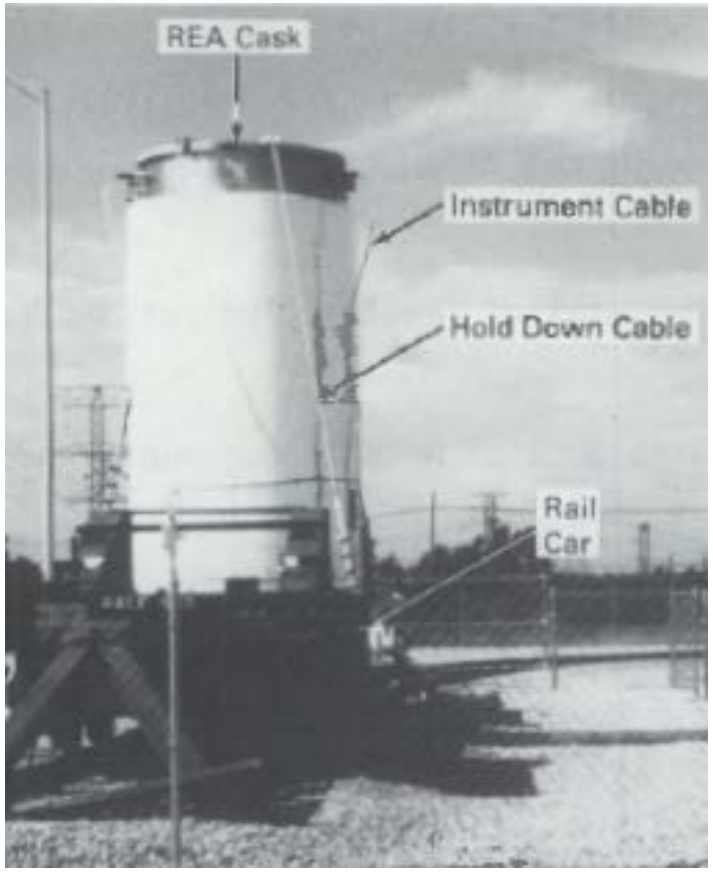
Source: www.holtecinternational.com/productsandservices/wasteandfuelmanagement/hi-storm/



- 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

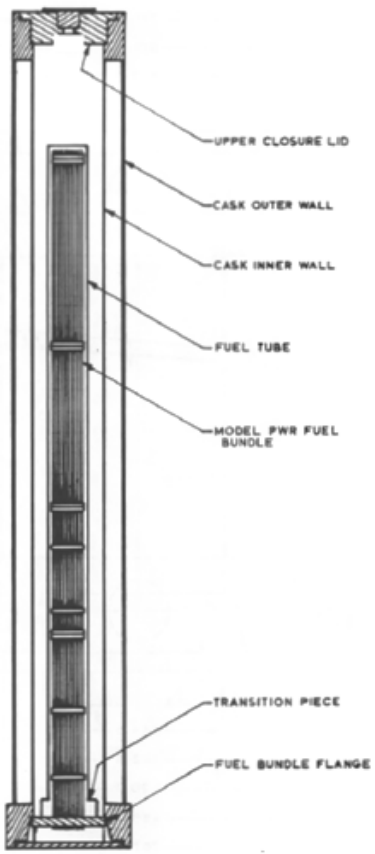
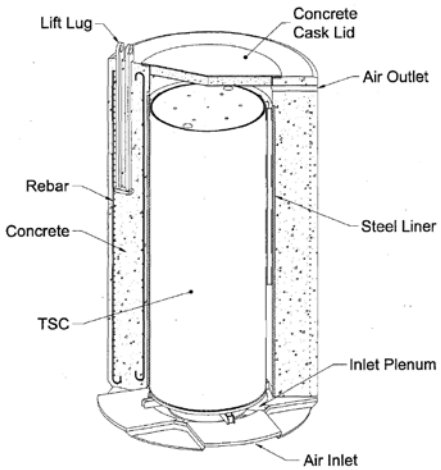


FIGURE 4-1. SAHTT Assembly

- 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

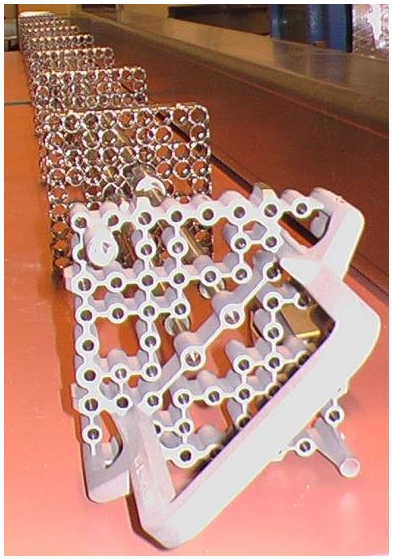
Current Approach

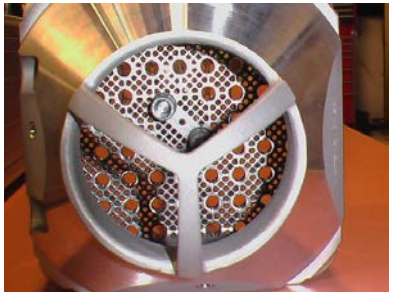


- Focus on pressurized canister systems
  - Over 20 bar internal pressure possible
    - Current commercial designs up to ~8 bar
- Ventilated designs
  - Aboveground configuration
  - Belowground configuration
    - With crosswind conditions
- TC attachment allows better peak cladding temperature measurement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

Prototypic Hardware

Upper tie plate



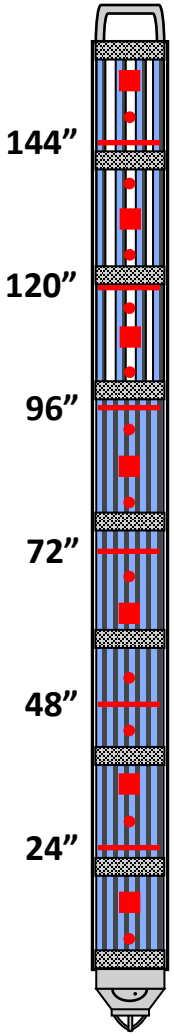


Nose piece and debris catcher

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



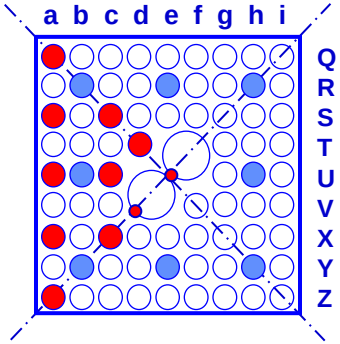
Internal Thermocouples

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

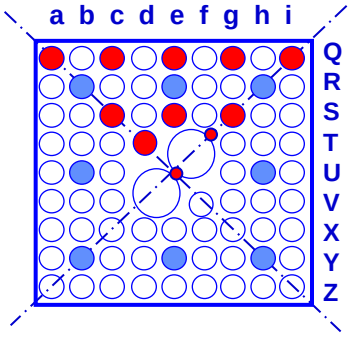
- **Axial array A1**
  6” spacing
  20 TCs
- **Axial array A2**
  12” spacing – 7 TC’s
  Water rods inlet and exit – 4 TC’s
  Total of 97 TCs

- 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

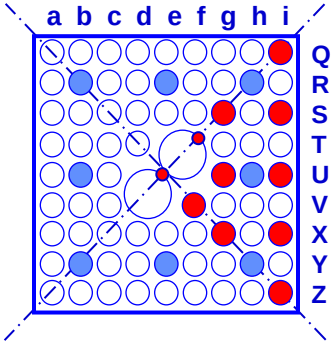
24” & 96” levels



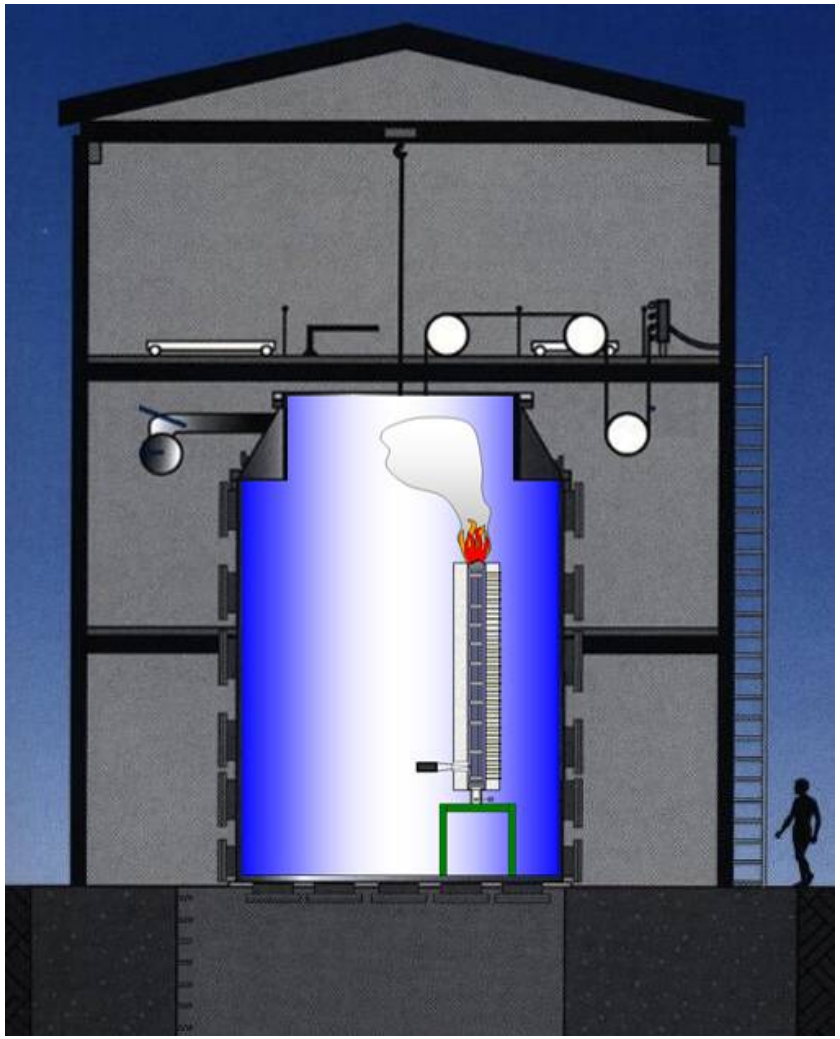
48” & 120” levels



72” & 144” levels

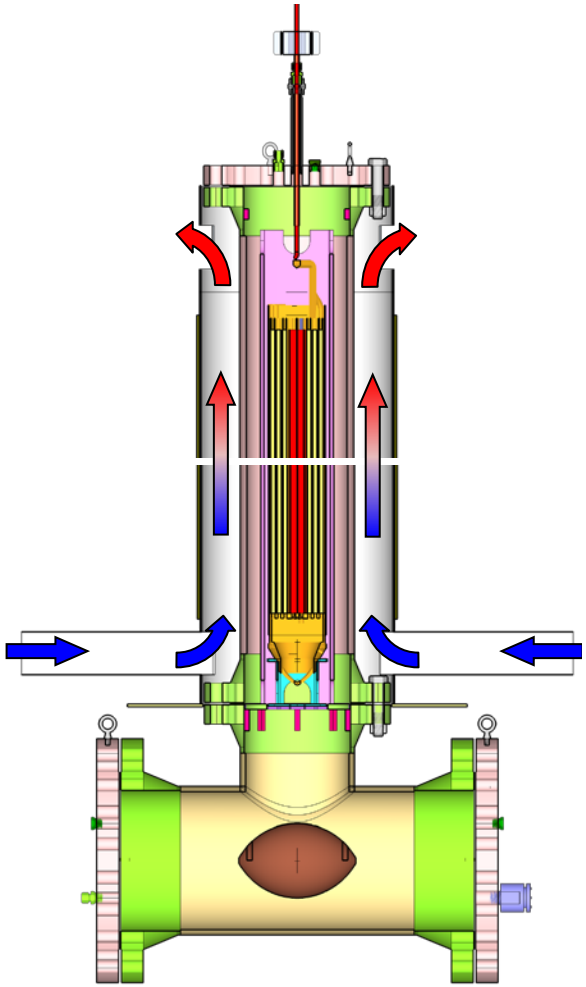


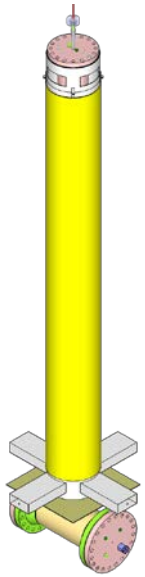
CYBL Test Facility

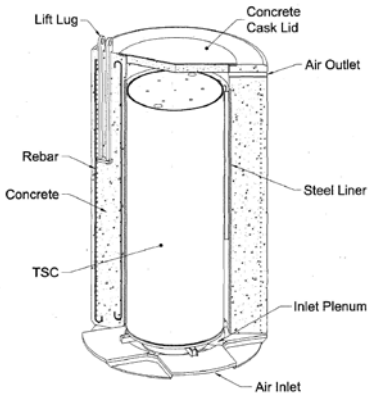


- Large stainless steel containment
  - Repurposed from earlier CYLINDRICAL BOILING Testing sponsored by DOE
  - Excellent general-use engineered barrier for isolation of high-energy tests
    - 3/8 in. stainless steel
    - 17 ft diam. by 28 ft cylindrical workspace
- Part of the Nuclear Energy Work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

Aboveground Configuration

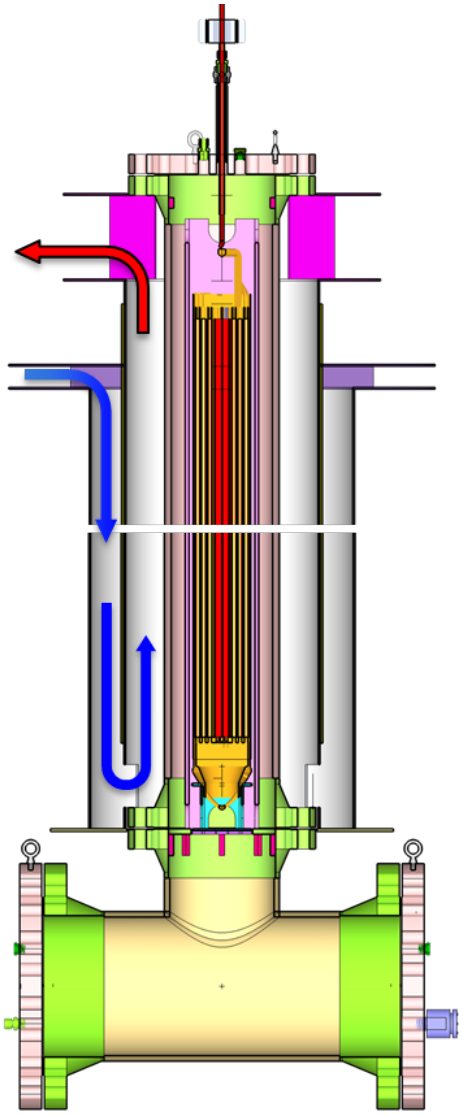


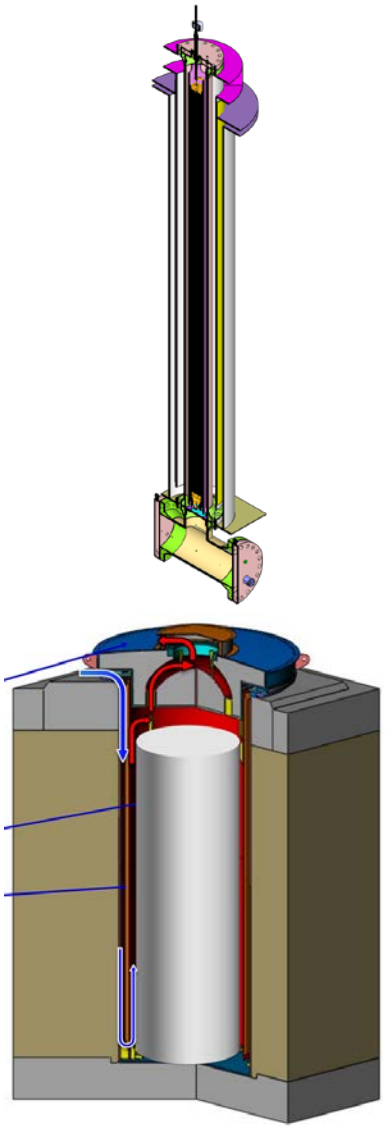




- BWR Cask Simulator (BCS) system capabilities
  - Power: 0 – 5 kW
  - Pressure vessel
    - Vessel temperatures up to 400 °C
    - Pressures up to 24 bar (anticipated)
  - ~200 thermocouples throughout system
  - Calibrated and in-situ air velocity measurements at inlets

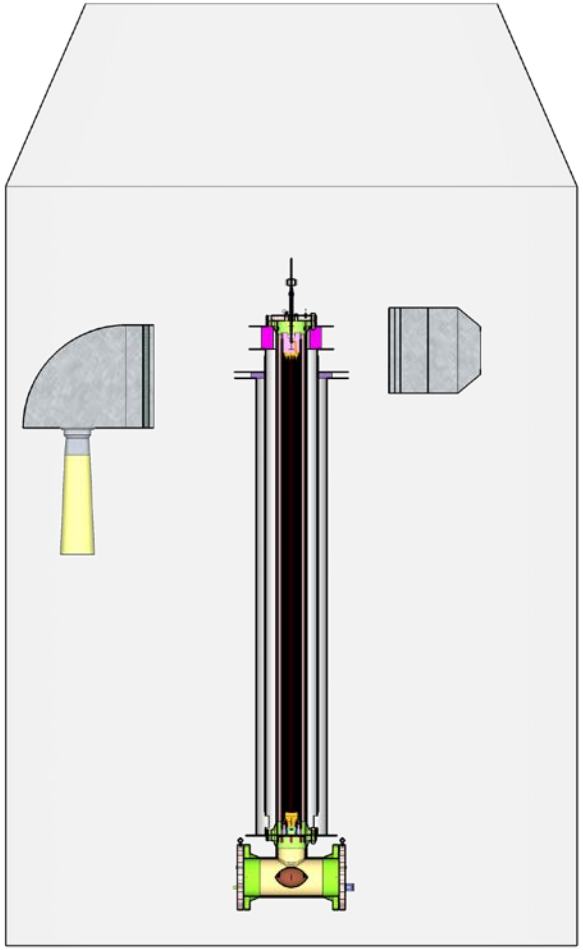
Belowground Configuration





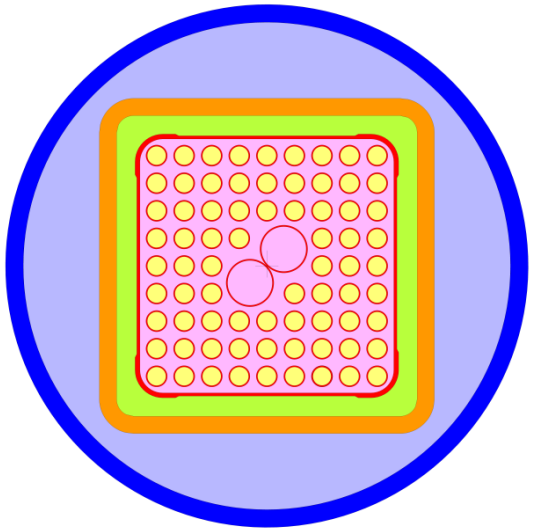
- Modification to aboveground configuration
  - Additional annular flow path
- Final design nearly complete
  - Inlet and outlet based on prototypic configuration
- Scaling analysis completed
  - Favorable comparisons
    - Modified, channel Rayleigh number (Ra_S^*)
    - Reynolds (Re) number

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

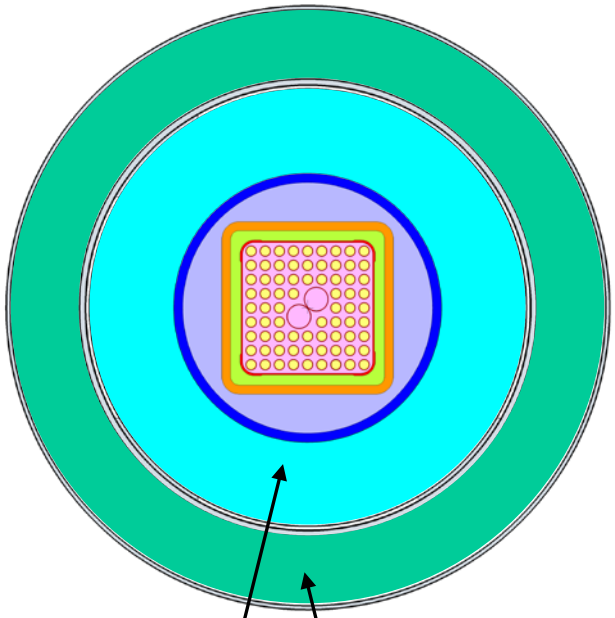
Internal Dimensional Analyses



- 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