SAND2019-5491PE

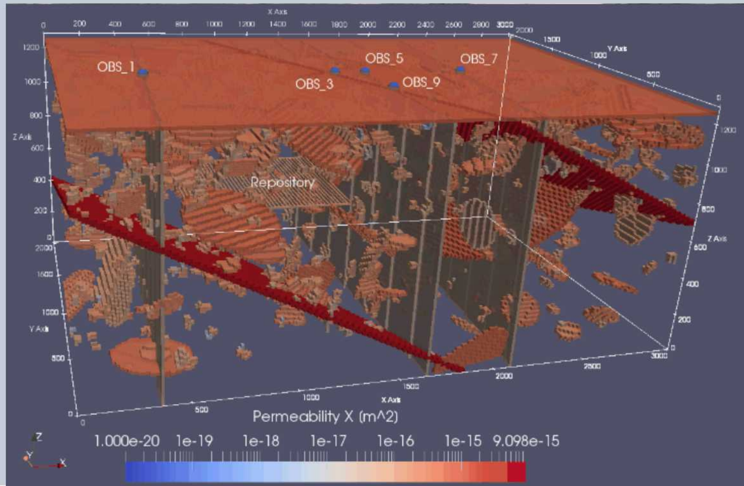
Dry Cask Simulator Model Validation Efforts

Ramon Pulido, Sam Durbin, and Eric Lindgren
Sandia National Laboratories

SFWD

SPENT FUEL &
WASTE DISPOSITION

Annual Working Group Meeting
UNLV-SEB – *Las Vegas, Nevada*
May 21-23, 2019



Modeling Contributors

United States Nuclear Regulatory Commission (NRC)

Abdelghani Zigh
Jorge Solis

Pacific Northwest National Laboratory (PNNL)

Sarah Suffield
David Richmond
Jim Fort

Centro de Investigaciones Energéticas MedioAmbientales y Tecnológicas (CIEMAT)

Luis Enrique Herranz
Francisco Feria
Jaime Penalva

Empresa Nacional del Uranio, S.A. (ENUSA)

Marta Galbán
Miriam Lloret

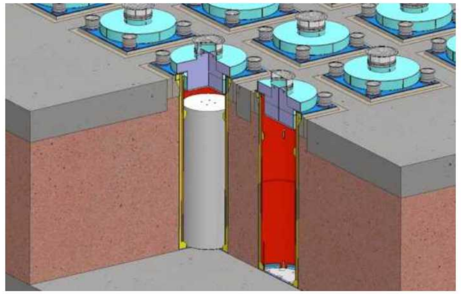
Universidad Politécnica de Madrid (UPM)

Julio Benavides
Gonzalo Jiménez

Overview

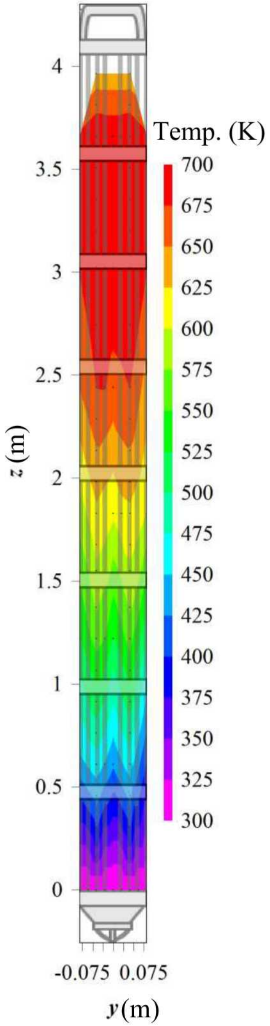
Aboveground Storage

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



Belowground Storage

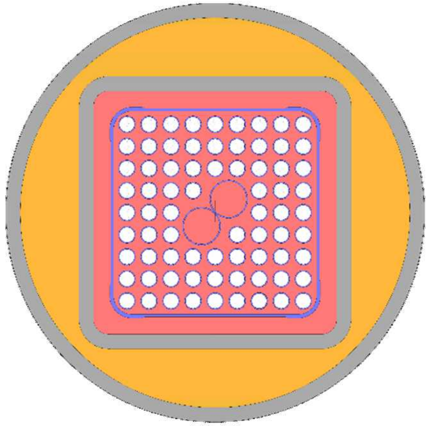
Source: www.holtecinternational.com/productsandservices/wasteandfuelmanagement/hi-storm/

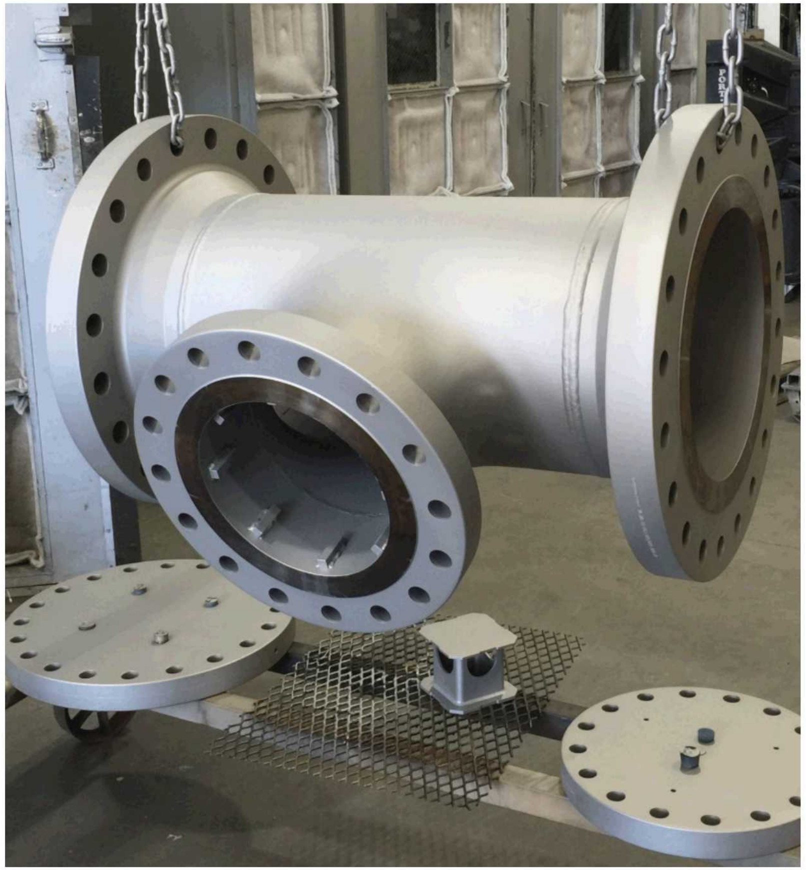


- Purpose: Validate assumptions in computational thermal-hydraulic modeling for spent fuel cask thermal design analyses
  - Used to determine steady-state cladding temperatures in dry casks
  - Needed to evaluate cladding integrity throughout storage cycle
- Measure temperature profiles for a wide range of decay power and helium cask pressures
  - Mimic conditions for ***aboveground*** and belowground configurations of vertical, dry cask systems with canisters
  - 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
  - Electrically-heated fuel simulators

Dry Cask Simulator (DCS) Pressure Vessel Hardware

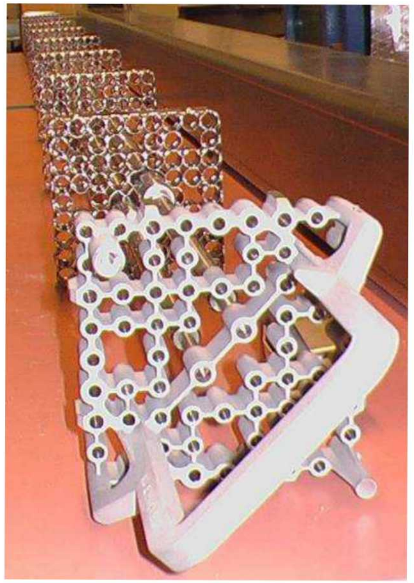
- Scaled components with instrumentation well
- Coated with ultra high temperature paint

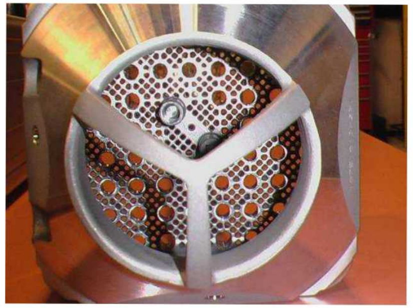




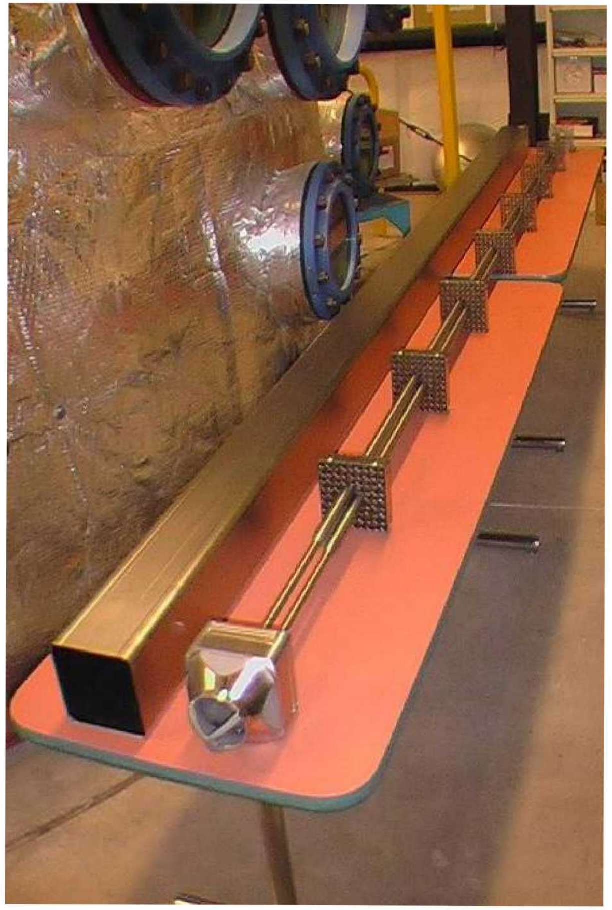
Prototypic Assembly Hardware

Upper tie plate





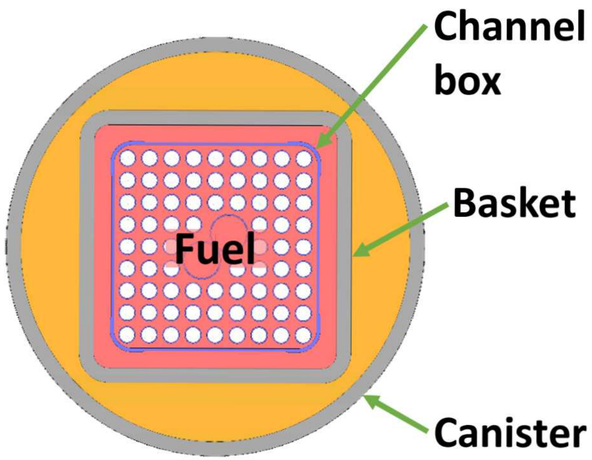
Nose piece and debris catcher



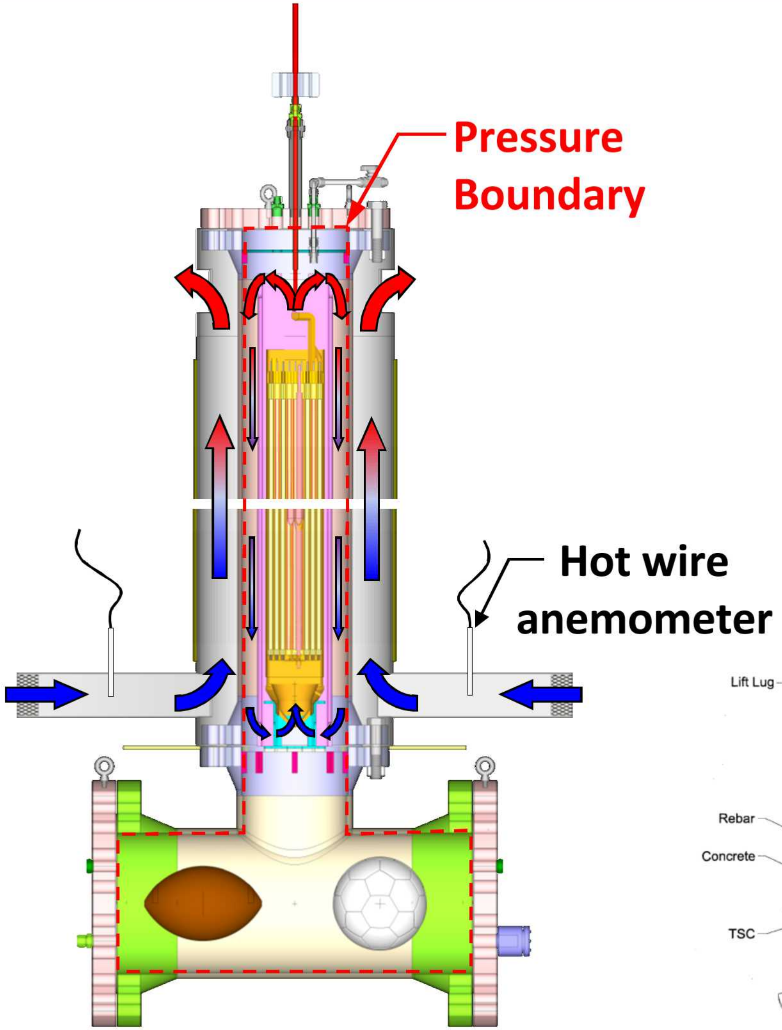
BWR channel, water tubes and spacers

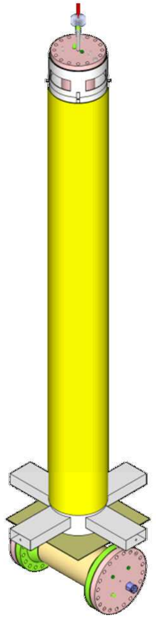
- Most common 9×9 BWR fuel in US
- Prototypic 9×9 BWR hardware
  - Full length, prototypic 9×9 BWR components
  - Electric heater rods with Incoloy cladding
  - 74 fuel rods
    - 8 of these are partial length
    - Partial length rods 2/3 the length of assembly
  - 2 water rods
  - 7 spacers

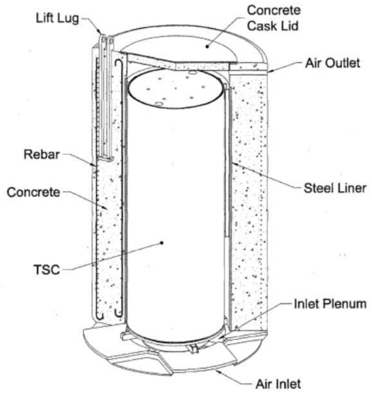
Thermocouple (TC) attached directly to cladding



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*

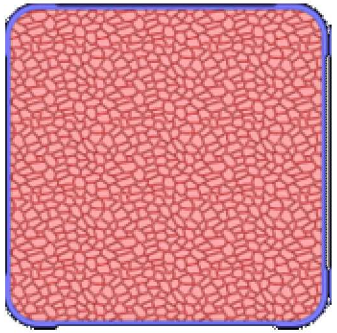
Validation Exercise Description

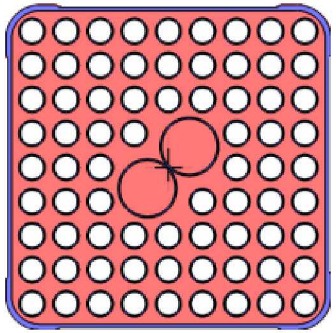
- Compare models and test results for reduced parameter set of available, steady-state data
  - Aboveground configuration only
  - 4 cases – 1) 0.5 kW, 100 kPa 3) 5.0 kW, 100 kPa
    2) 0.5 kW, 800 kPa 4) 5.0 kW, 800 kPa
- 6 model submissions
  - 5 computational fluid dynamics (CFD) models, 1 subchannel model
  - Three models use porous media representation of the fuel region
  - Two models explicitly represent fuel geometry
  - One model represents the fuel as quasi-3D rods
- Temperature comparisons throughout
  - Fuel (minimum, average, and maximum) as function of height
  - Channel box, basket, canister (pressure vessel), and overpack (shell) as function of height
  - Transverse temperature profiles at PCT locations

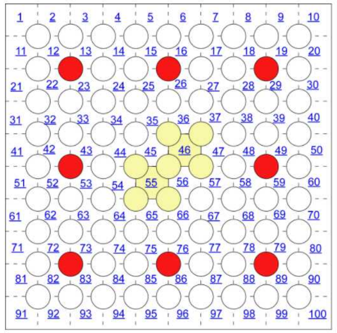
Model Descriptions

- The 6 models can be categorized by:
  - Code type
  - Fuel representation
  - Cross-sectional symmetry

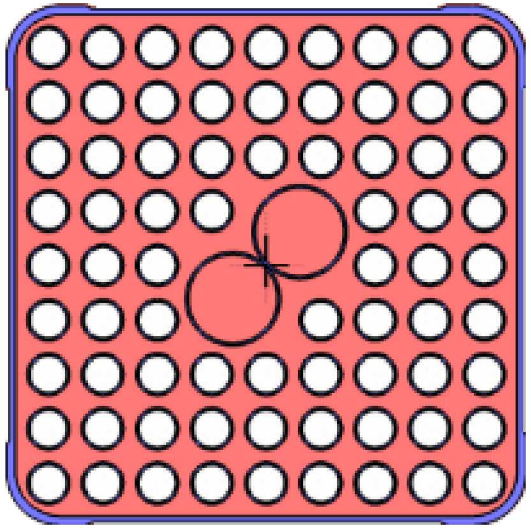
Modeling Contributor	Code Type	Fuel Representation	Cross-Sectional Symmetry
NRC	CFD	Porous Media	1/4
PNNL	CFD	Explicit	1/4
PNNL	CFD	Porous Media	1/4
PNNL	Subchannel	Quasi-3D Rods	Full
CIEMAT	CFD	Porous Media	1/8
ENUSA	CFD	Explicit	1/2



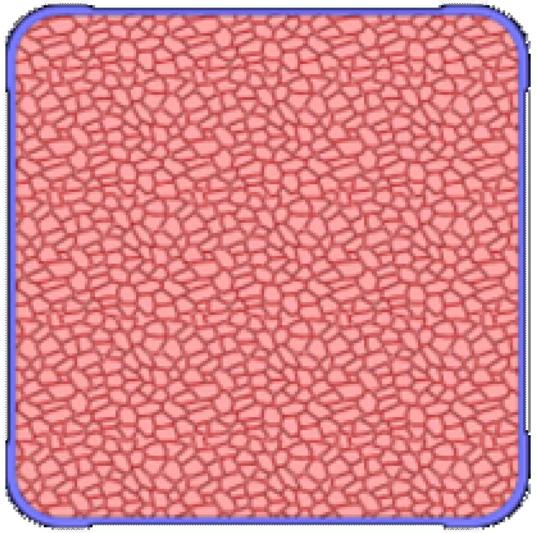




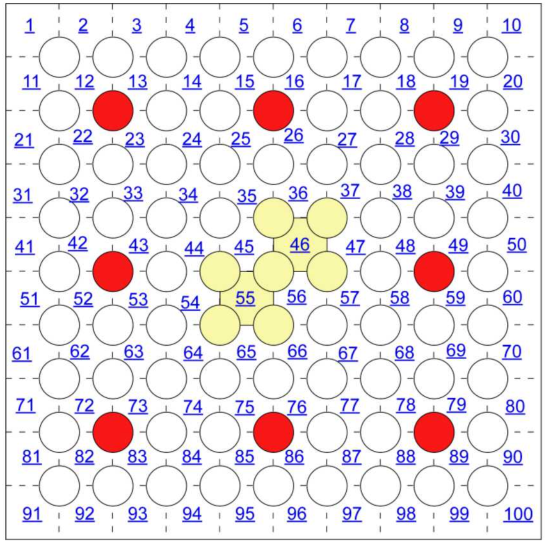
Fuel Representation



(*a*)



(*b*)



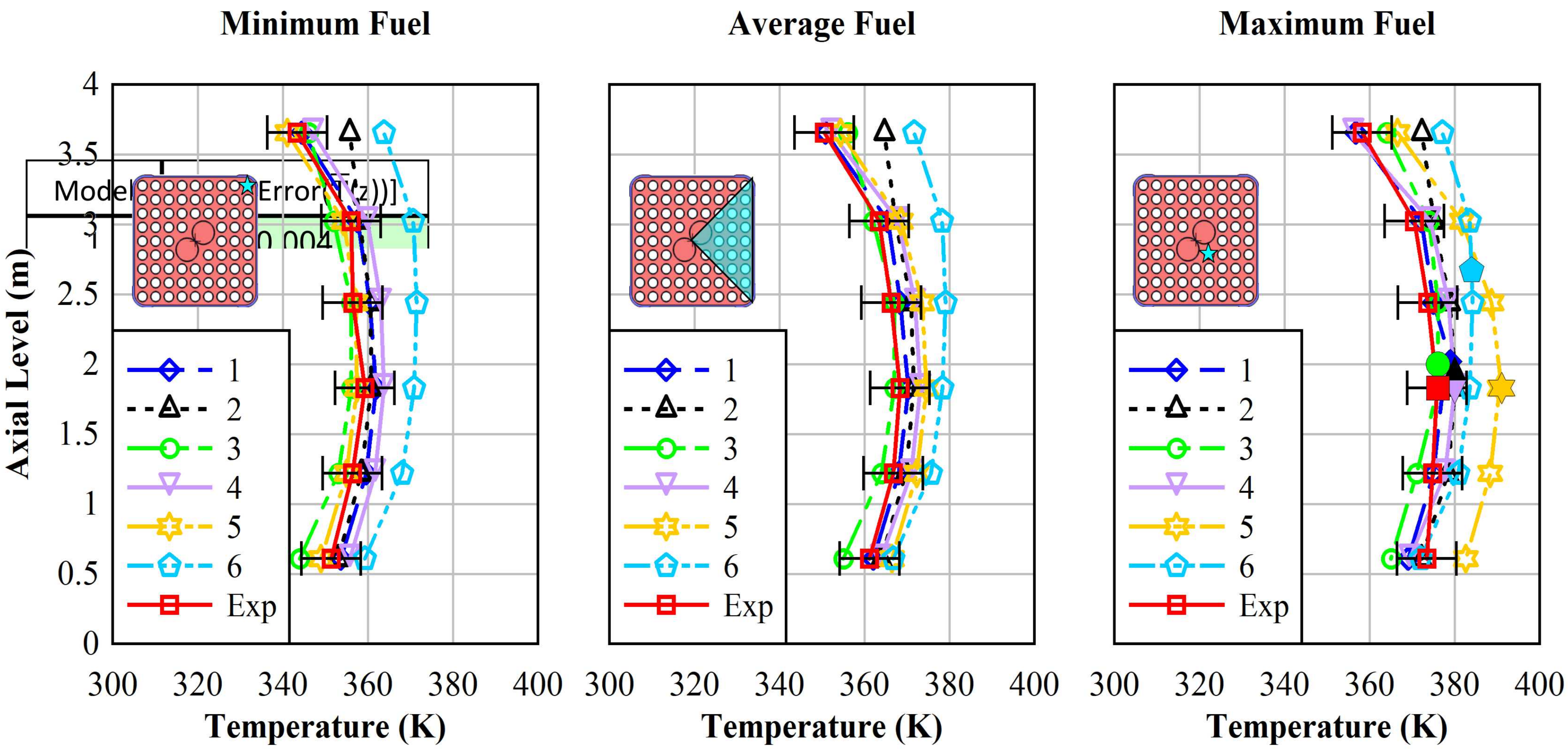
(*c*)

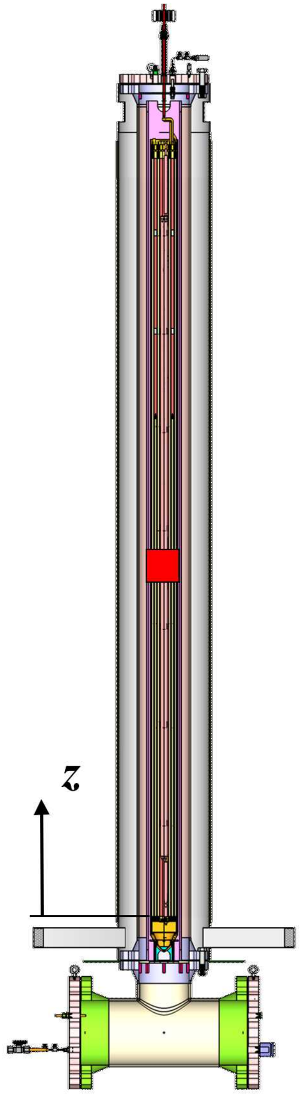
(*a*): Explicit fuel representation – fuel rods and spacers represented in detail

(*b*): Porous media representation – fuel is homogenized into a simplified volume with corresponding k_{eff} and loss coefficients

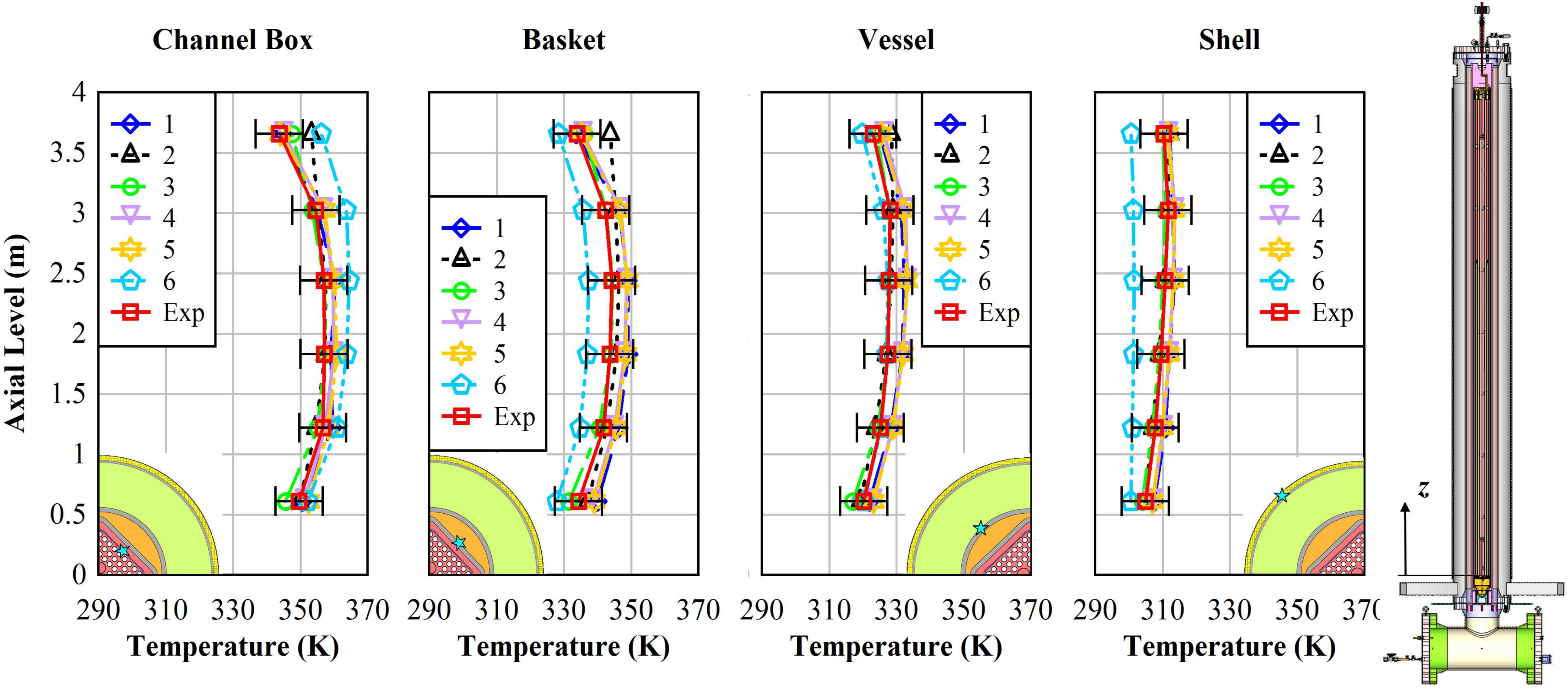
(*c*): Subchannel representation – fuel is divided into a number of flow paths or channels

Fuel Comparisons (0.5 kW, 100 kPa)

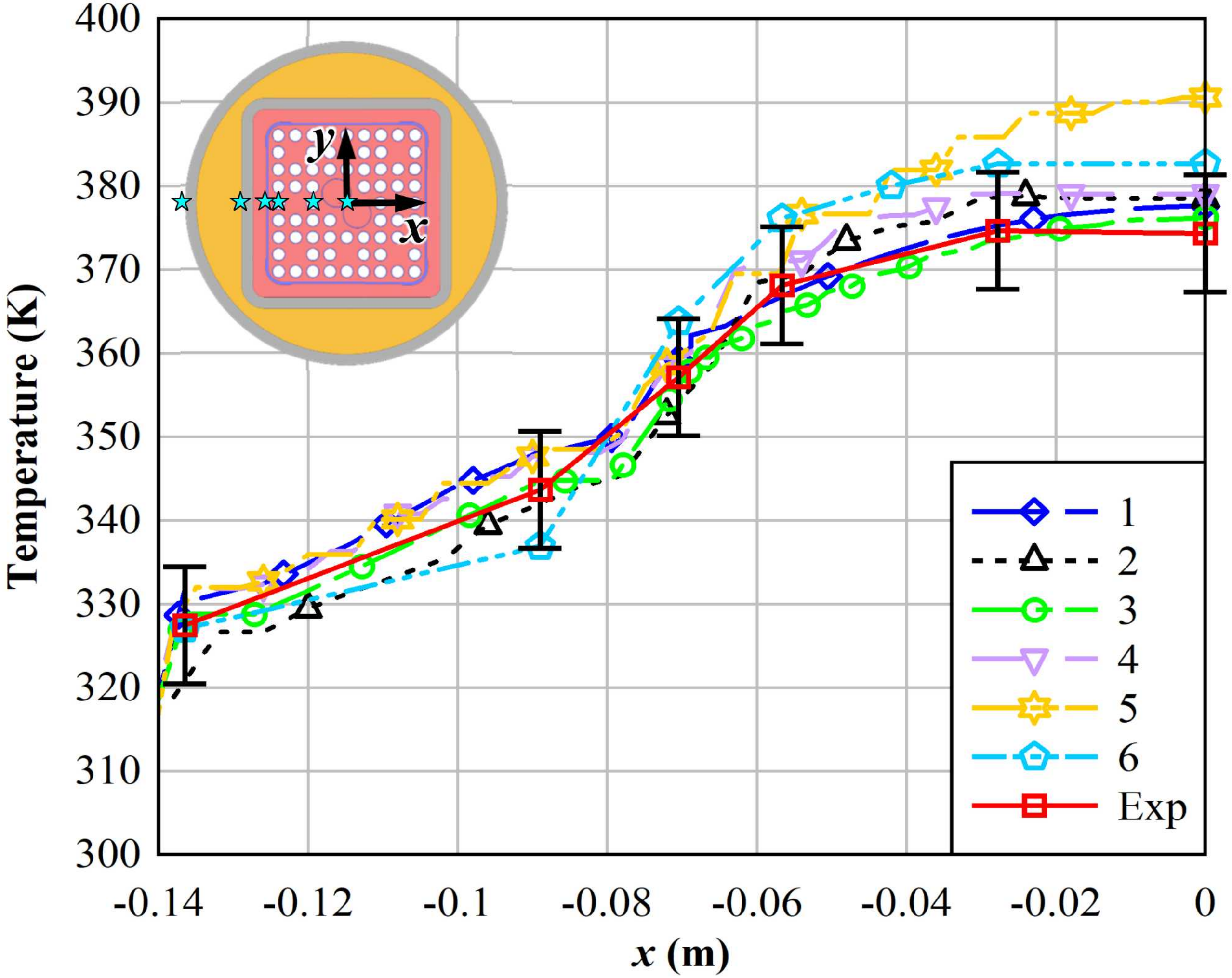


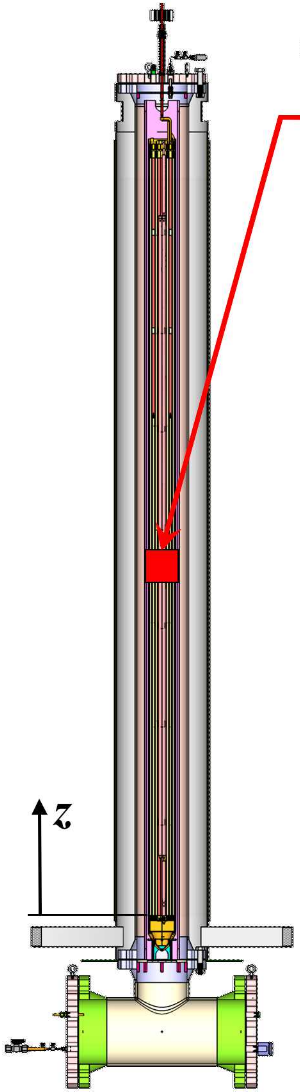


Apparatus Components (0.5 kW, 100 kPa)



Transverse Temperature (0.5 kW, 100 kPa)

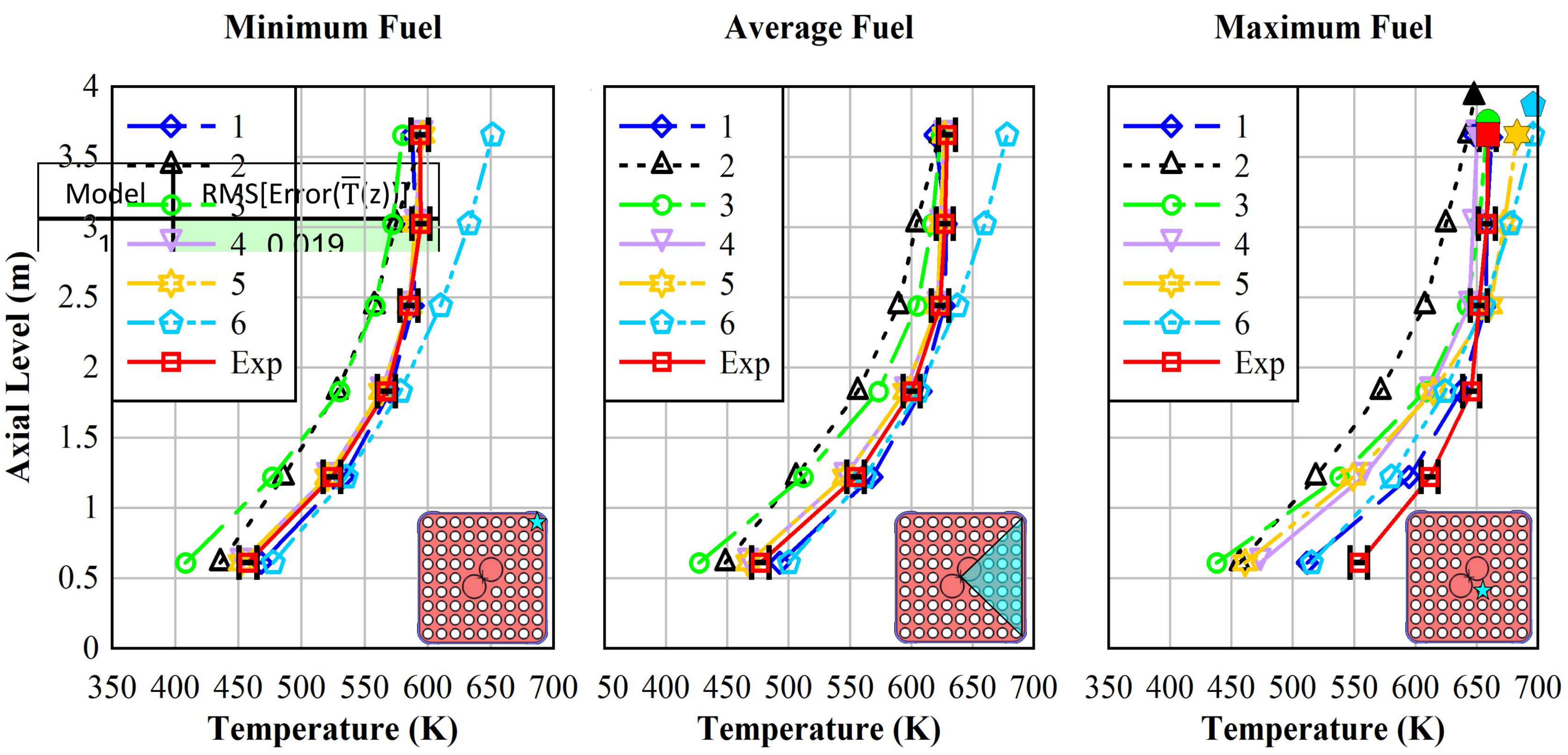


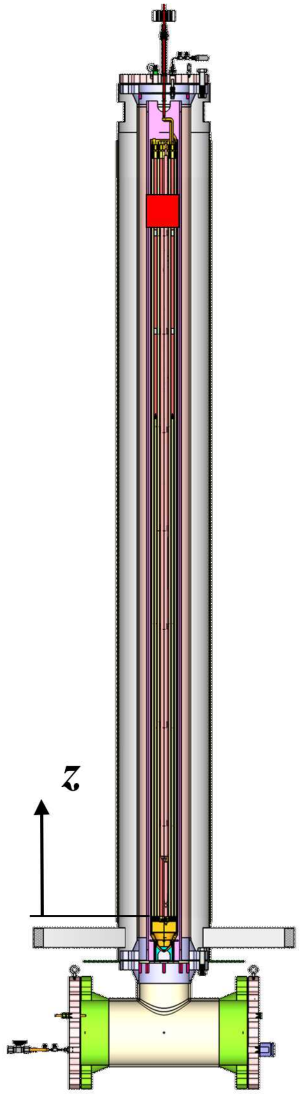


- Transverse profile at *z* = 1.83 m
  - Location of experimental PCT
  - Maximum experimental uncertainty shown

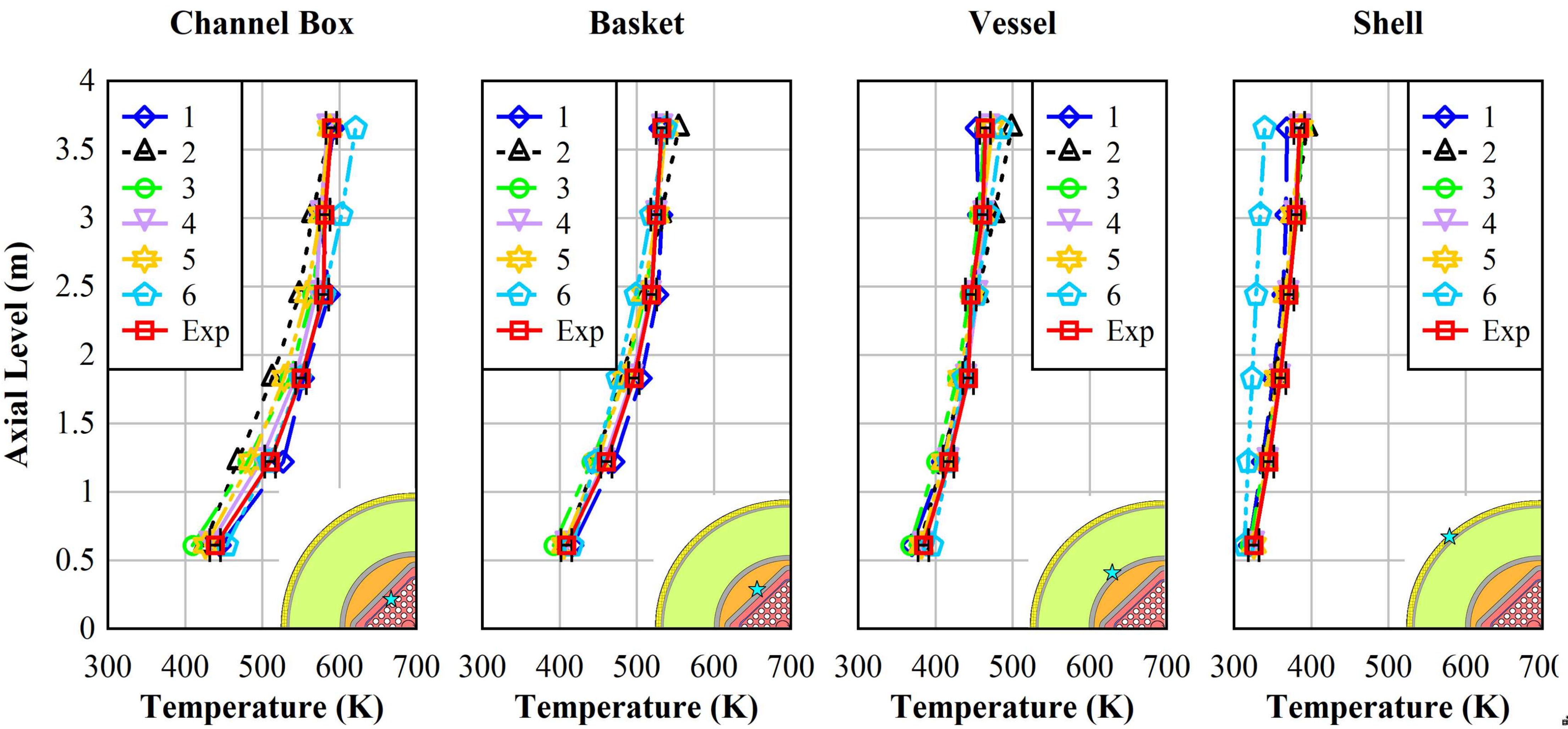
Model	RMS[Error(T(x))]
1	0.010
2	0.007
3	0.005
4	0.011
5	0.025
6	0.019

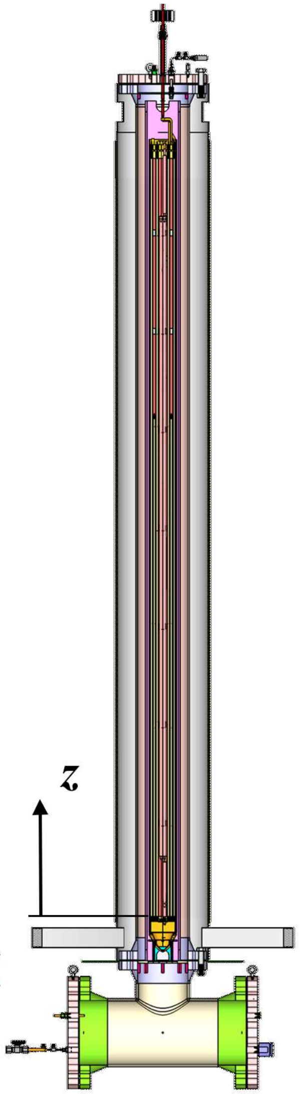
Fuel Comparisons (5 kW, 800 kPa)



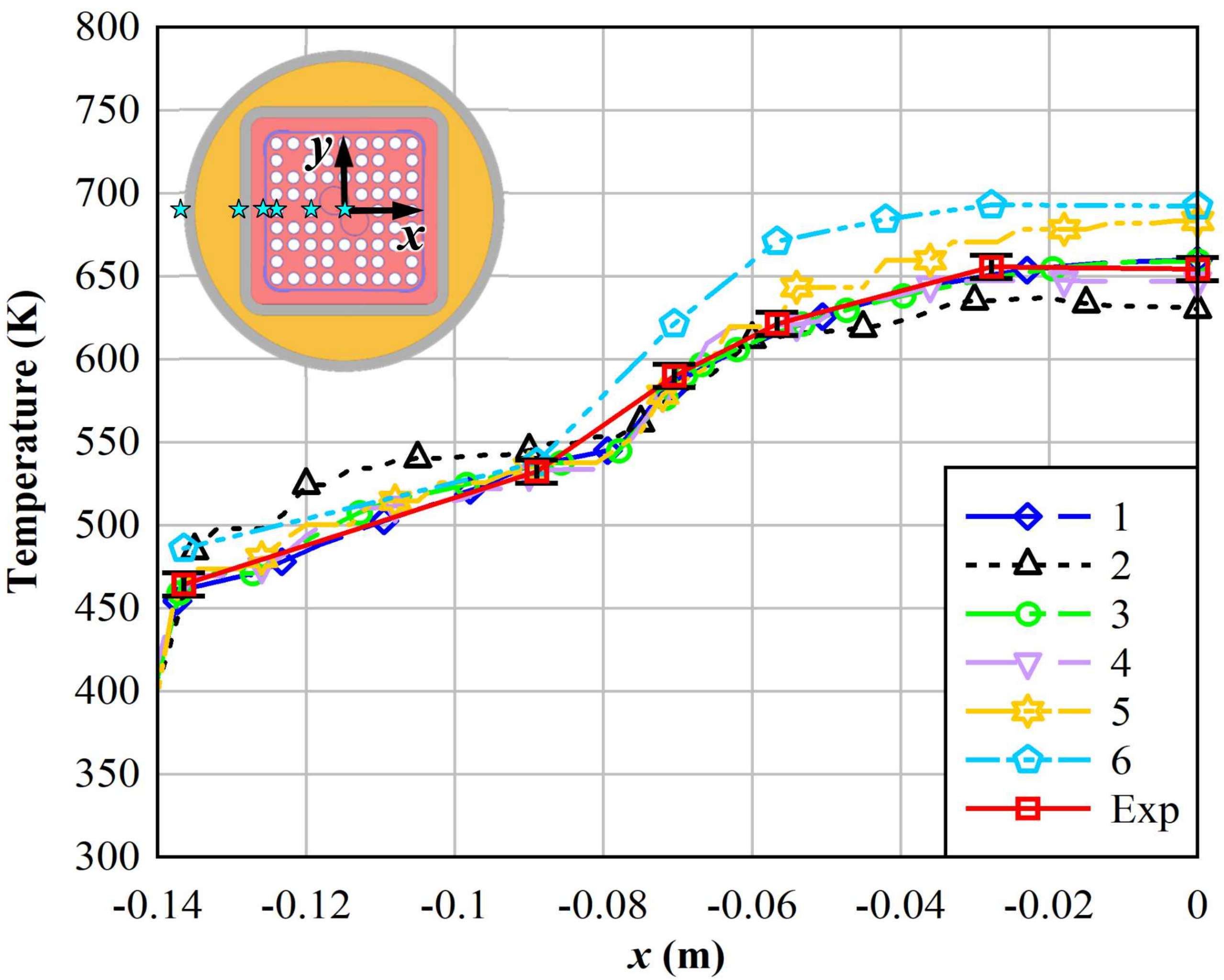


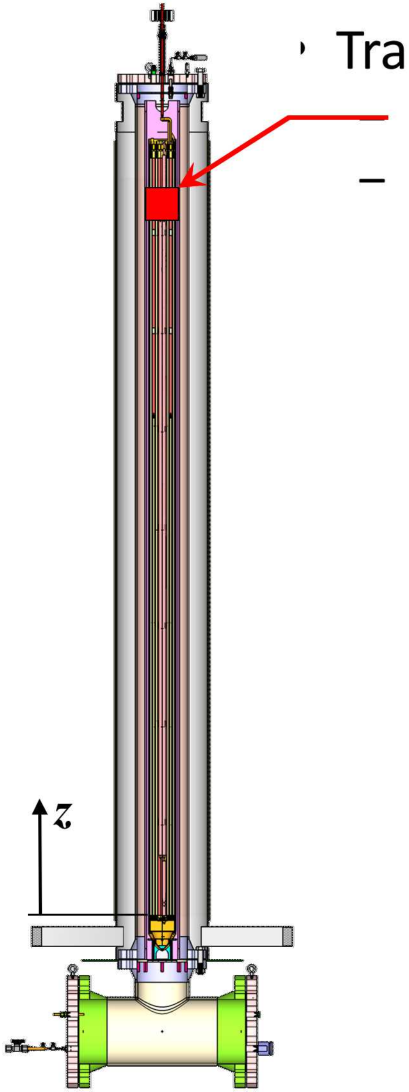
Apparatus Components (5 kW, 800 kPa)





Transverse Temperature (5 kW, 800 kPa)





- Transverse profile at *z* = 3.66 m
  - Location of experimental PCT
  - Maximum experimental uncertainty shown

Model	RMS[Error(T(x))]
1	0.008
2	0.030
3	0.009
4	0.009
5	0.027
6	0.055

Summary

- Validation exercise conducted for 4 cases of the dry cask simulator (DCS)
  - Simulated decay heat: 0.5 and 5.0 kW
  - Internal helium pressure: 100 and 800 kPa
  - Configured to simulate vertical, aboveground storage systems
  - Temperatures and air mass flow rates compared
    - Peak cladding temperature and location included
    - Axial and transverse temperature profiles also studied throughout fuel and apparatus
- 6 model submissions
  - Variety of modeling codes and techniques represented
    - Codes: FLUENT, STAR-CCM+, and COBRA-SFS
    - Fuel representations: Explicit, porous media, and subchannel

RMS Error Across All Models

RMS Error \ Model	1	2	3	4	5	6
PCT	0.021	0.018	0.006	0.015	0.046	0.032
$\overline{T}(z)$	0.020	0.035	0.034	0.016	0.017	0.044
$T(x)$	0.017	0.022	0.012	0.014	0.030	0.032
$\dot{m}$	0.013	0.123	0.018	0.058	0.067	0.489
Combined	0.018	0.066	0.020	0.032	0.044	0.246

Questions?

SFWD

Spent Fuel & Waste Disposition

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May 21-23, 2019

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