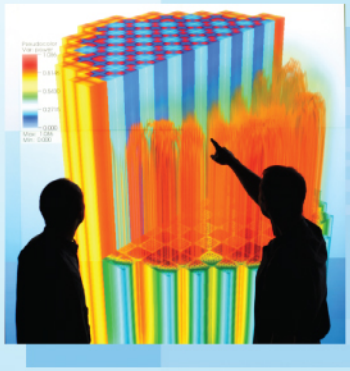
CASL-U-2014-0067-000

Power uprates
and plant life extension

Consortium for Advanced Simulation of LWRs



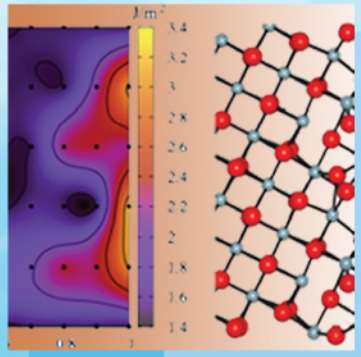
Engineering design
and analysis

MAMBA (MPO Advanced Model for Boron Analysis) Development for CASL: Update and Applications

B. Kendrick and C. Stanek, LANL
Mike Short, MIT

Science-enabling
high performance
computing

February 27, 2014



Fundamental science

Plant operational data

U.S. DEPARTMENT OF ENERGY | Nuclear Energy

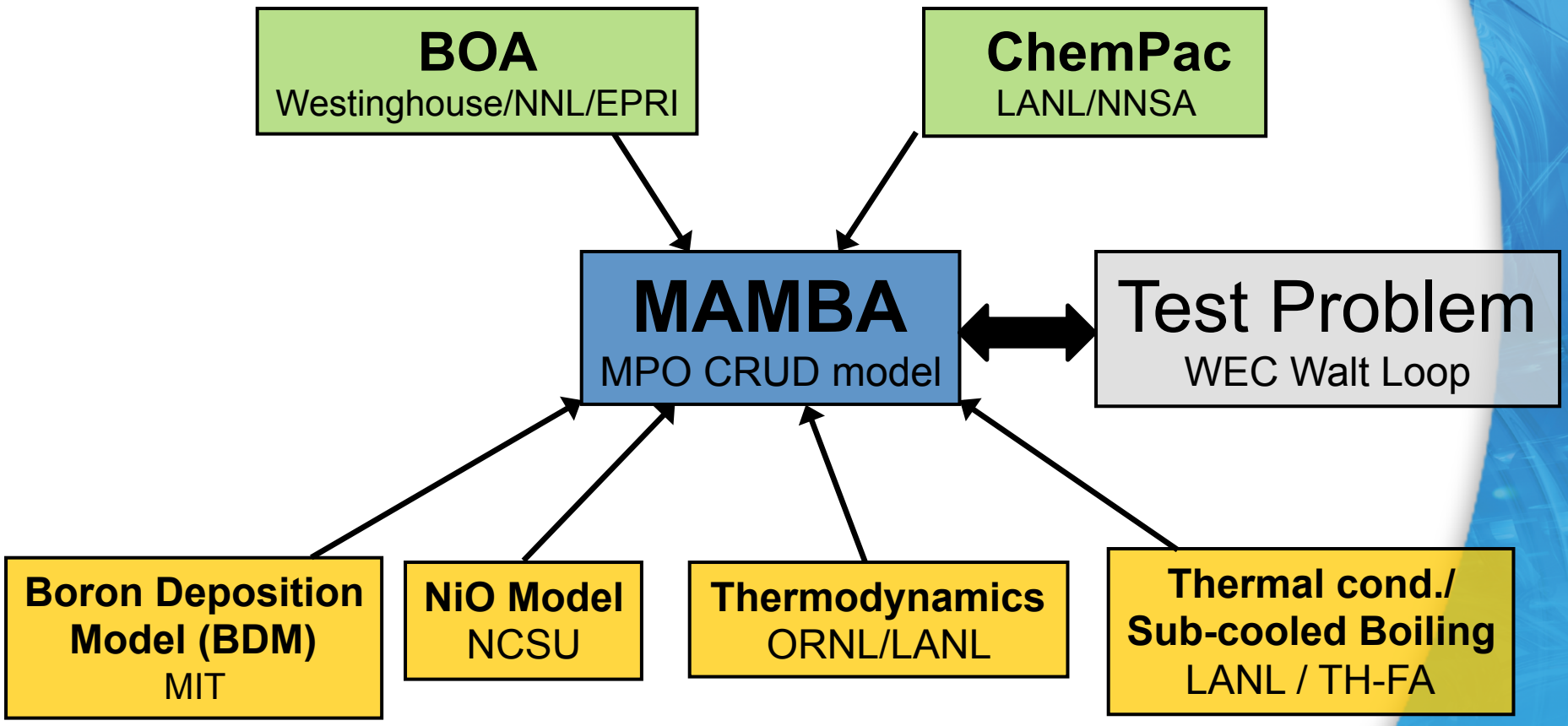
MAMBA (MPO Advanced Model for Boron Analysis) Development for CASL: update and applications

EPRI – PTAC Meeting
San Antonio, TX
February 27, 2014

Brian Kendrick – Los Alamos National Laboratory
Chris Stanek – Los Alamos National Laboratory
Mike Short – Massachusetts Institute of Technology

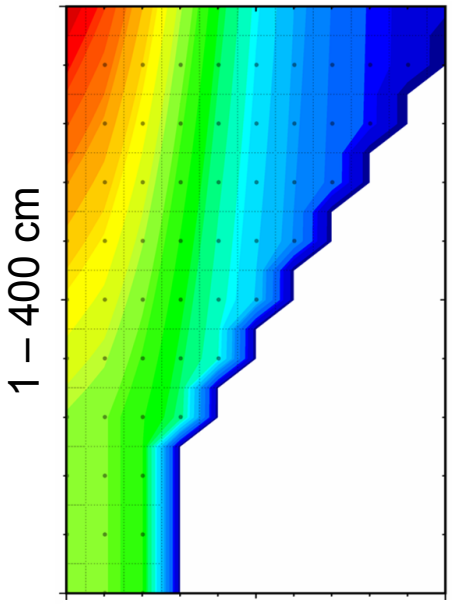
CASL-U-2014-0067-000

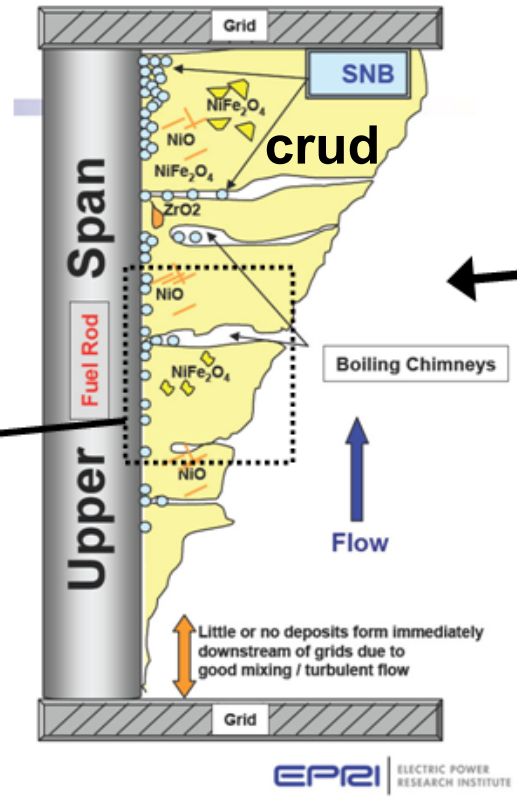
MPO - Material Framework for Crud Test Problem

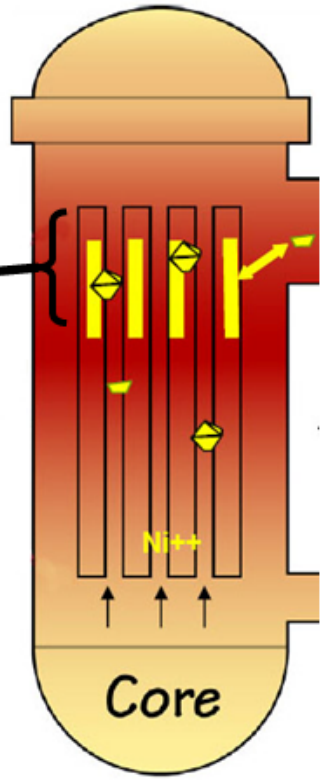


MAMBA's 3D Computational Cell

2D profile view

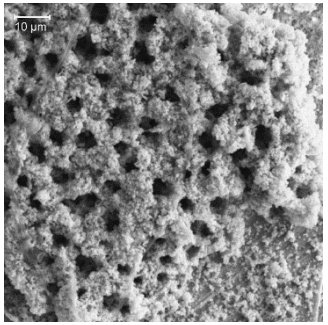


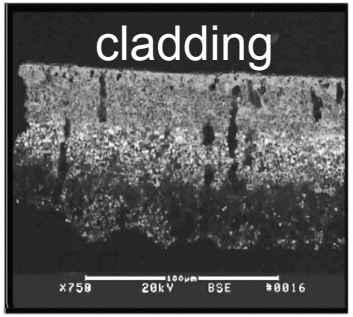




crud

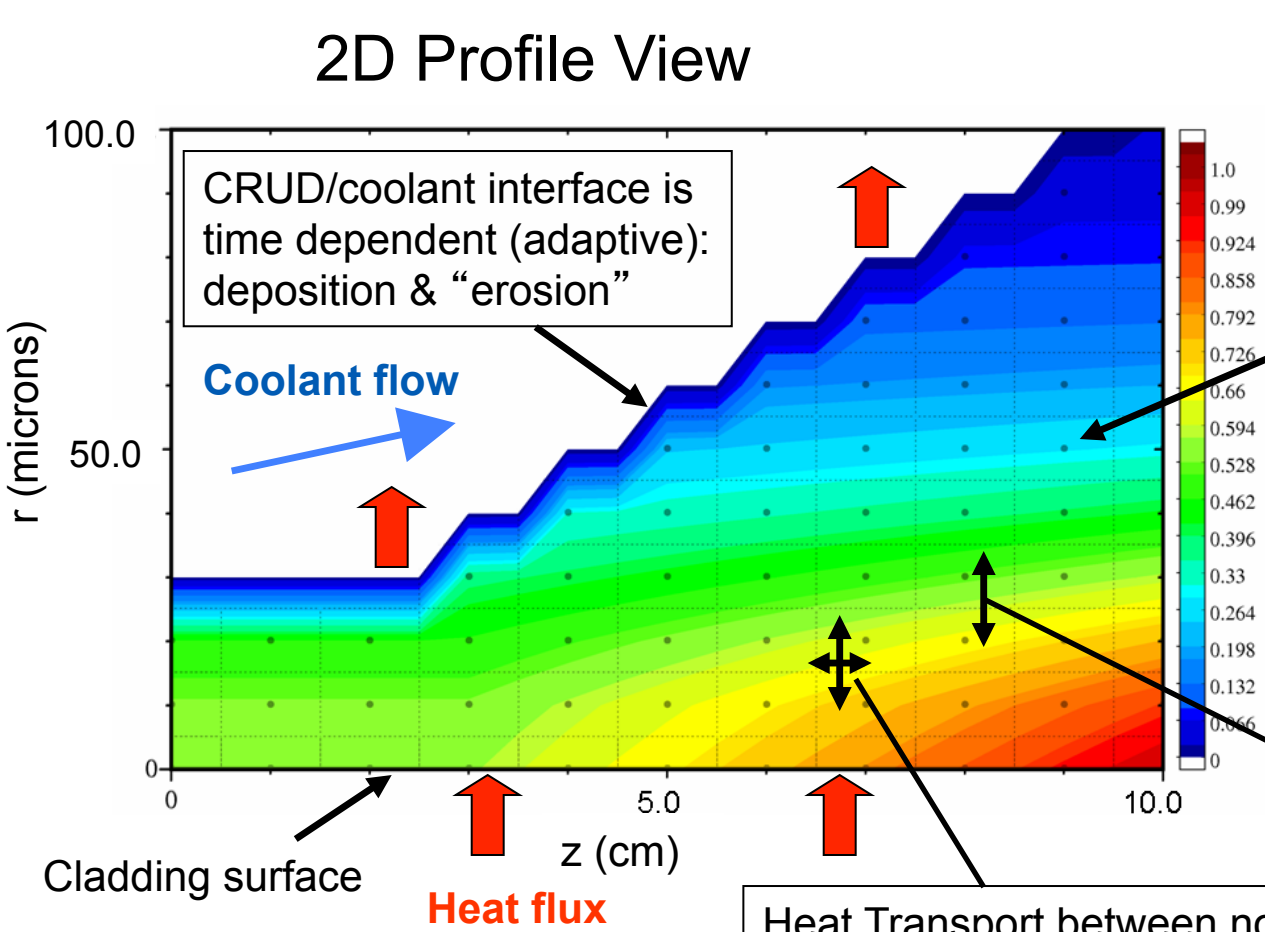
top view





side view

MAMBA example grid:



Colored contours: normalized boron concentration

Compute node and volume element

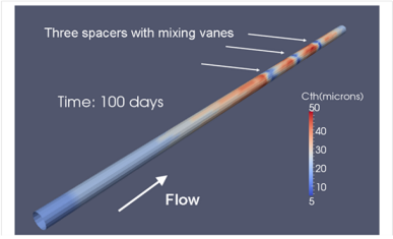
Thermodynamics and chemical kinetics computed at each node and time step

Boiling induced convective & diffusive transport between nodes and coolant

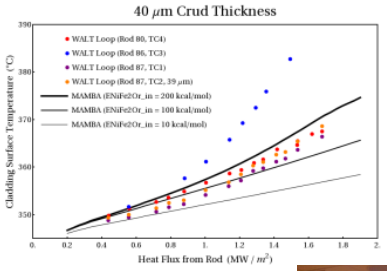
Heat Transport between nodes:
3D non-linear, iterative, numerical solution
at each time step, with local "sinks" due to boiling

MAMBA development, applications, and validation:

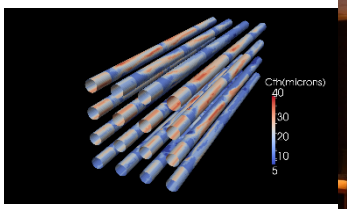
- 2D MAMBA v1.0 source code released to CASL (12/ 7/11)
- 3D MAMBA v2.0 source code released to CASL (MPO.P4.01 02/28/12)
- Coupled MAMBA / STAR-CCM+ / DeCART initial demonstration simulation for a 3D single pin cell geometry (DOE reportable CASL.P4.02 L1: 3/30/12)



- Initial Validation and Benchmark Study of 3D MAMBA v2.0 against the Walt Loop Experiment and BOA v3.0 (MPO.CRUD.P5.02 8/10/12)



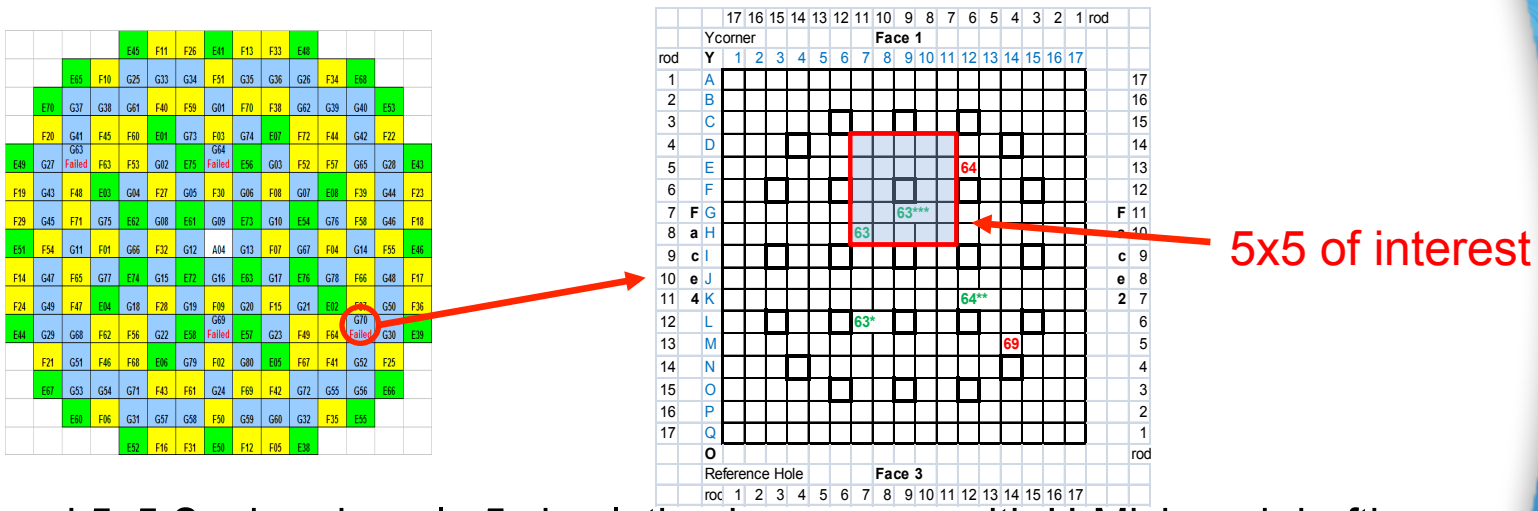
- Coupled MAMBA/STAR-CCM+/DeCART preliminary simulations for 4x4 subassembly



- Two NURETH-15 proceedings papers (May 2013) on coupled simulations for single pin and 4x4 subassembly; Full journal paper submitted (June 2013)

MAMBA development, applications, and validation:

- **MPO-crud L2.P7.06** (09/30/2014) **"CILC Studies with Comparative Analysis to Existing Plants"**, B. Kendrick (LANL), V. Petrov (U-Mich), D. Walter (U. Mich), and A. Mannera (U-Mich), coupled STAR-CCM+ / MAMBA simulation of a 5x5 subassembly with application and validation for Seabrook cycle 5.



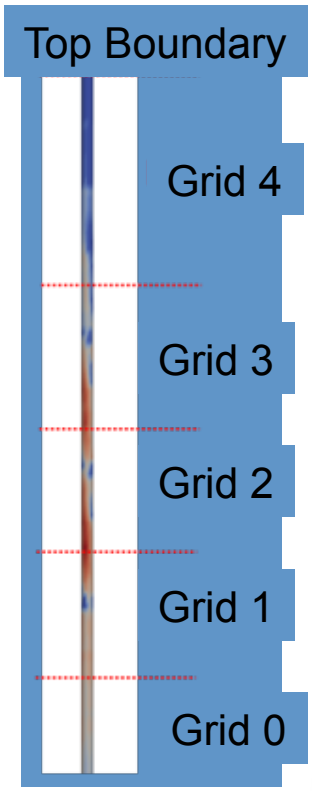
- Improved 5x5 Seabrook cycle 5 simulation in progress with U-Mich and drafting manuscript for publication.
- MAMBA development in progress: implement new thermodynamic models, include additional species (Ni, NiO, $LiBO_2$, Ni_2FeBO_5), dissolution, ^{10}B depletion, improved erosion, microstructure, thermal conductivity / boiling models.
- MPO – Crud group meeting and MAMBA status update at EPRI - PTAC Meeting, San Antonio, TX, February 25-27.

MAMBA development, applications, and validation:

- MAMBA "1D" subgrid module and interface with Hydra (and Cobra) in progress

- Phase 2 planning / pre-proposal support: coupled MAMBA-Hydra for simulating LOCA scenarios, BWR version of MAMBA, and PWR CILC/CIPS applications. Met with PWROG in regards to LOCA (Dec. 3, Jan. 7 and Jan. 22)

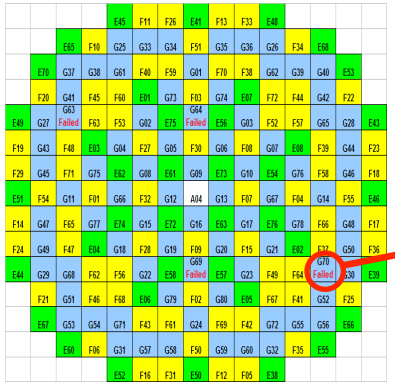
- Implement variable axial grid (completed) and paralle progress for both single pin and multiple pins.

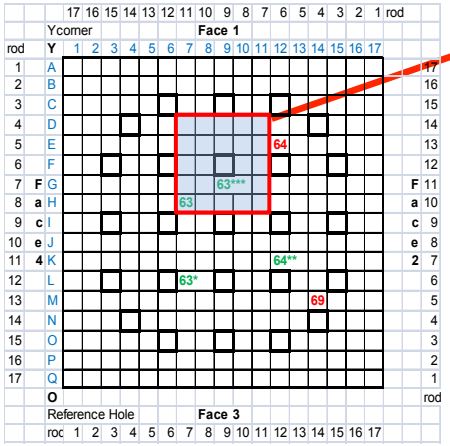


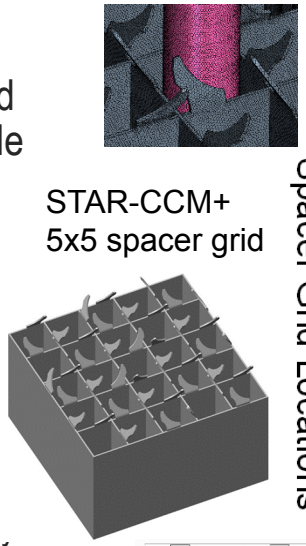
Simulation of Seabrook 1 Cycle 5 CRUD formation using coupled STAR-CCM+ and MAMBA3D

CASL's high-fidelity CRUD simulation capability using STAR-CCM+ and MAMBA3D has been used to simulation the formation of CRUD in Cycle 5 at the Seabrook 1 PWR

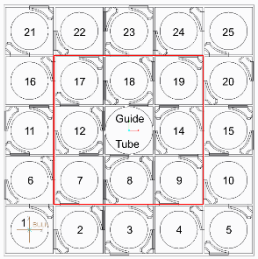
- 5-rod by 5-rod array for which qualitative and quantitative data is available was selected for analysis
- First high-fidelity, two-way coupled CFD/CRUD simulation of an industrial relevant plant cycle
- Input power provided by industry simulations
- Showed that <u>both</u> axial and azimuthal thermal hydraulic effects dramatically affect CRUD deposition patterns
- Showed that azimuthal power variations have very little impact on CRUD deposition patterns
- Axial and azimuthal CRUD deposition patterns were consistent with plant data



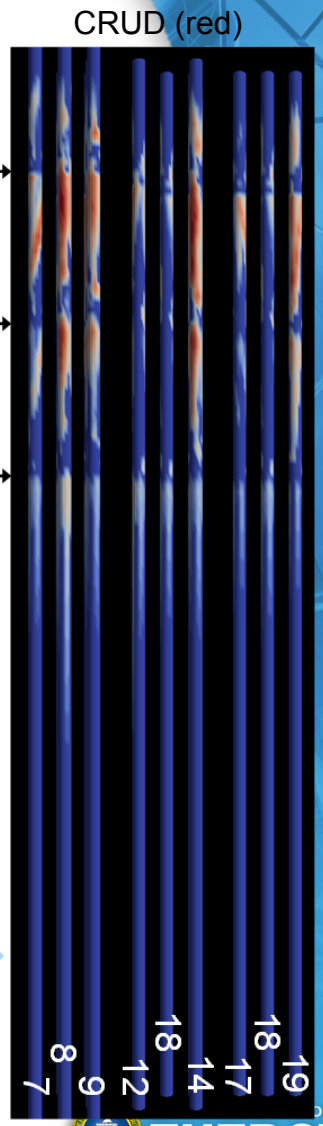




STAR-CCM+
5x5 spacer grid



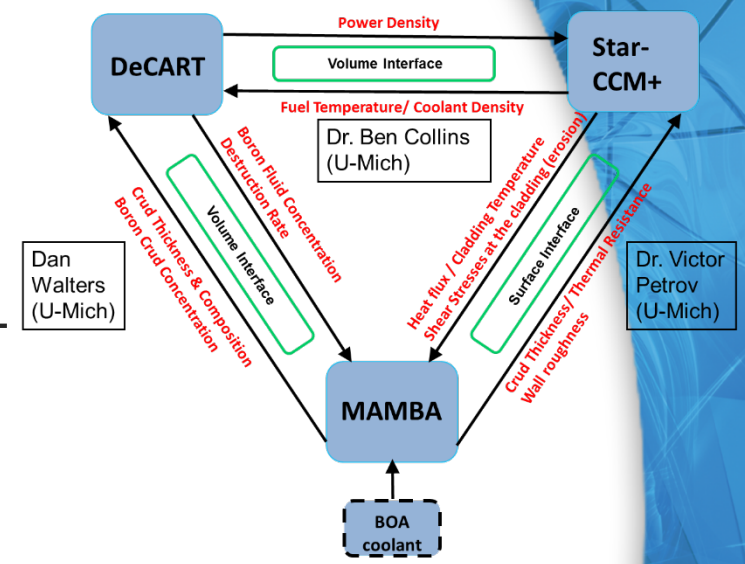
view



L2 MPO-crud (completed 09/30/2013): Coupled CFD / MAMBA

Primary Goals:

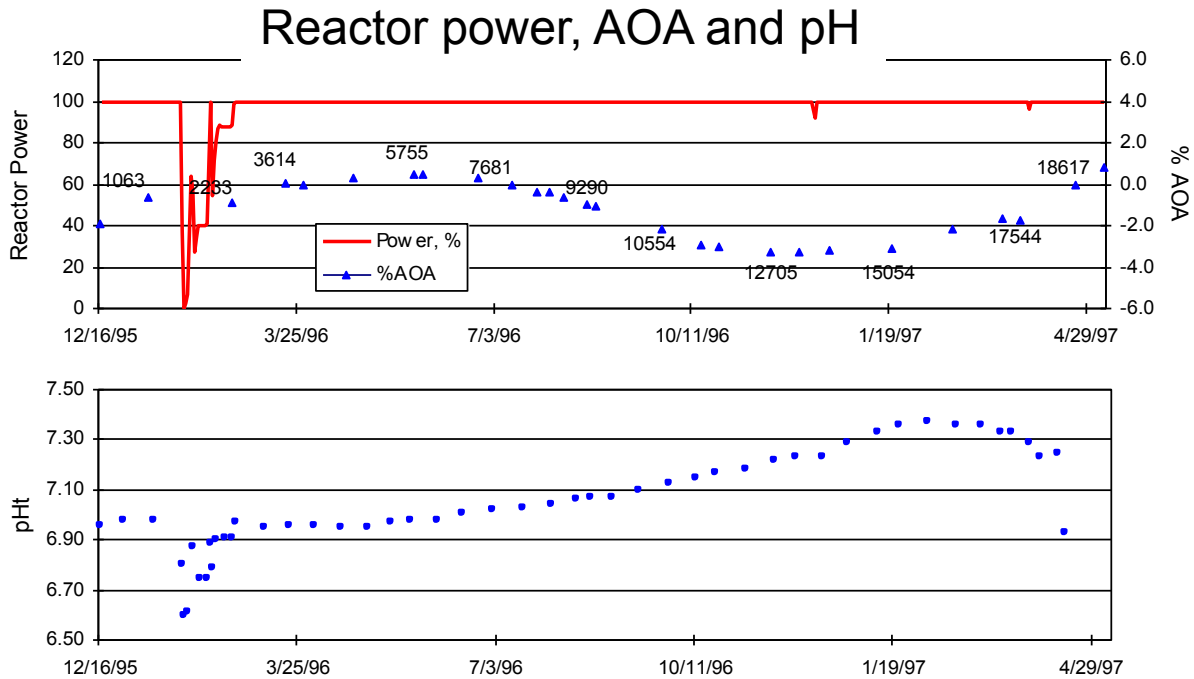
- Simulate conditions of Seabrook Cycle 5.
- Implement and assess tighter coupling between CFD & MAMBA using STAR-CCM+
- Validate crud deposition against Seabrook data for a selected 5x5 subassembly

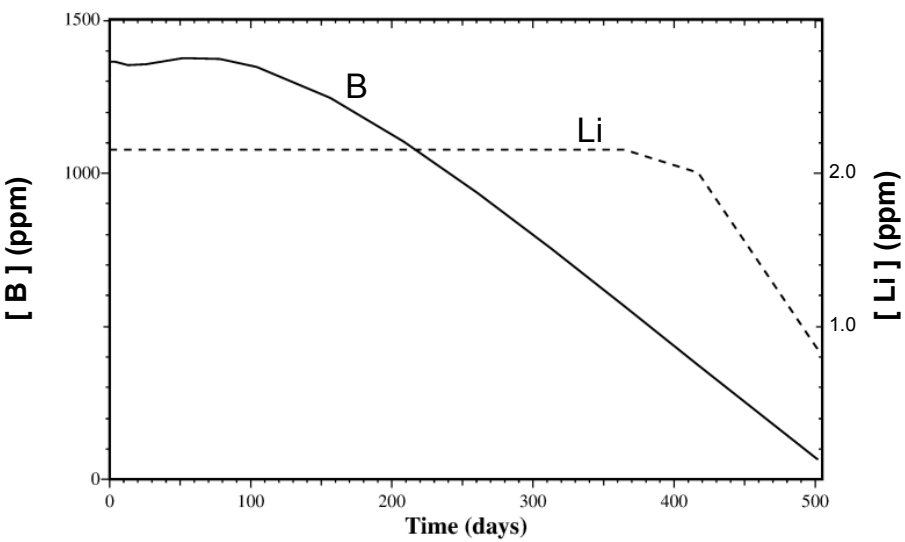


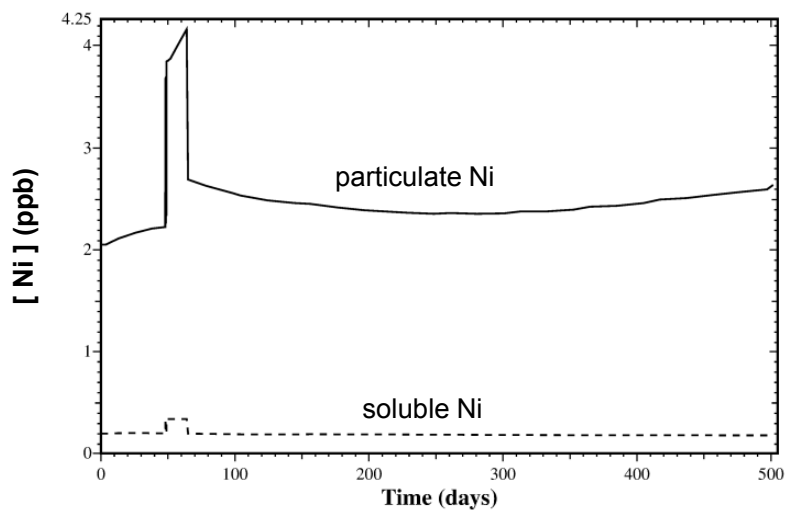
Required Inputs for Seabrook (vs. time):

- Pin powers from ANC (WEC)
- Boron let down curve & other coolant chemistry
- Geometry & mixing vane orientation ← suitable (non-proprietary) geometry provided
- Seabrook oxide measurement data provided

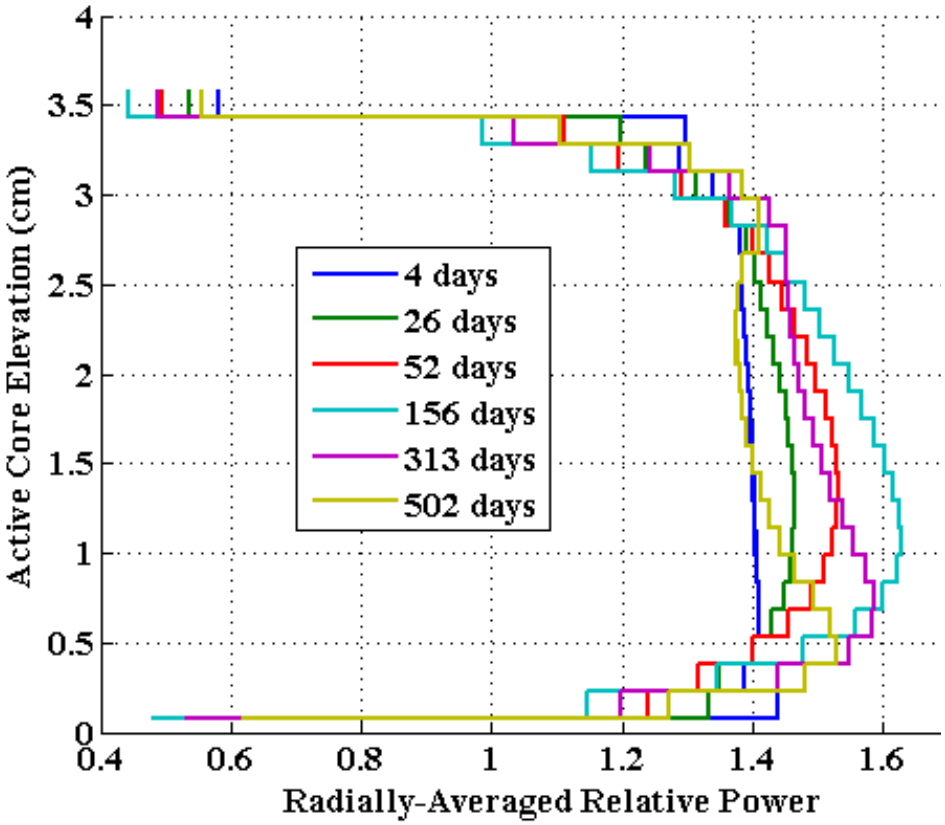
Seabrook cycle 5 operating conditions

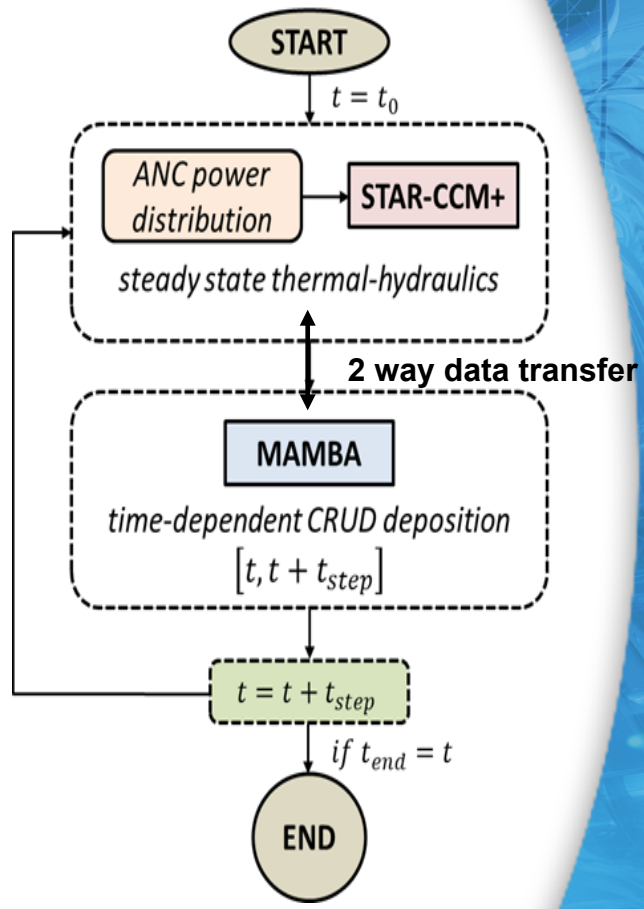






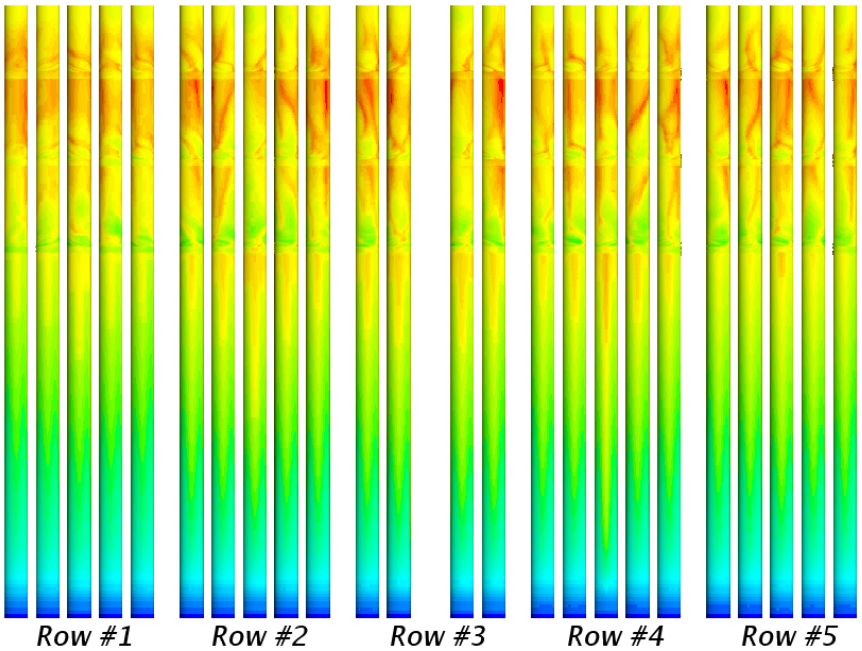
Seabrook cycle 5 ANC axial power profile and coupled time stepping approach



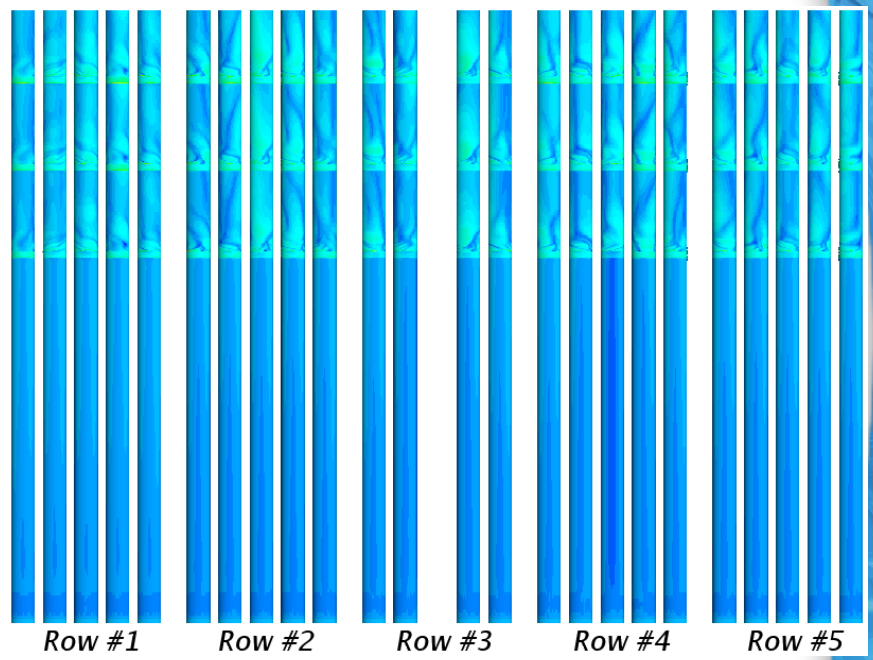


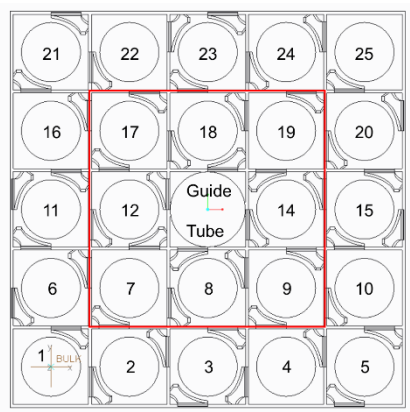
STAR-CCM+ computed surface cladding temperature and turblent kinetic energy

Cladding Temperature at 502 days



Turbulent kinetic energy at 502 days





5

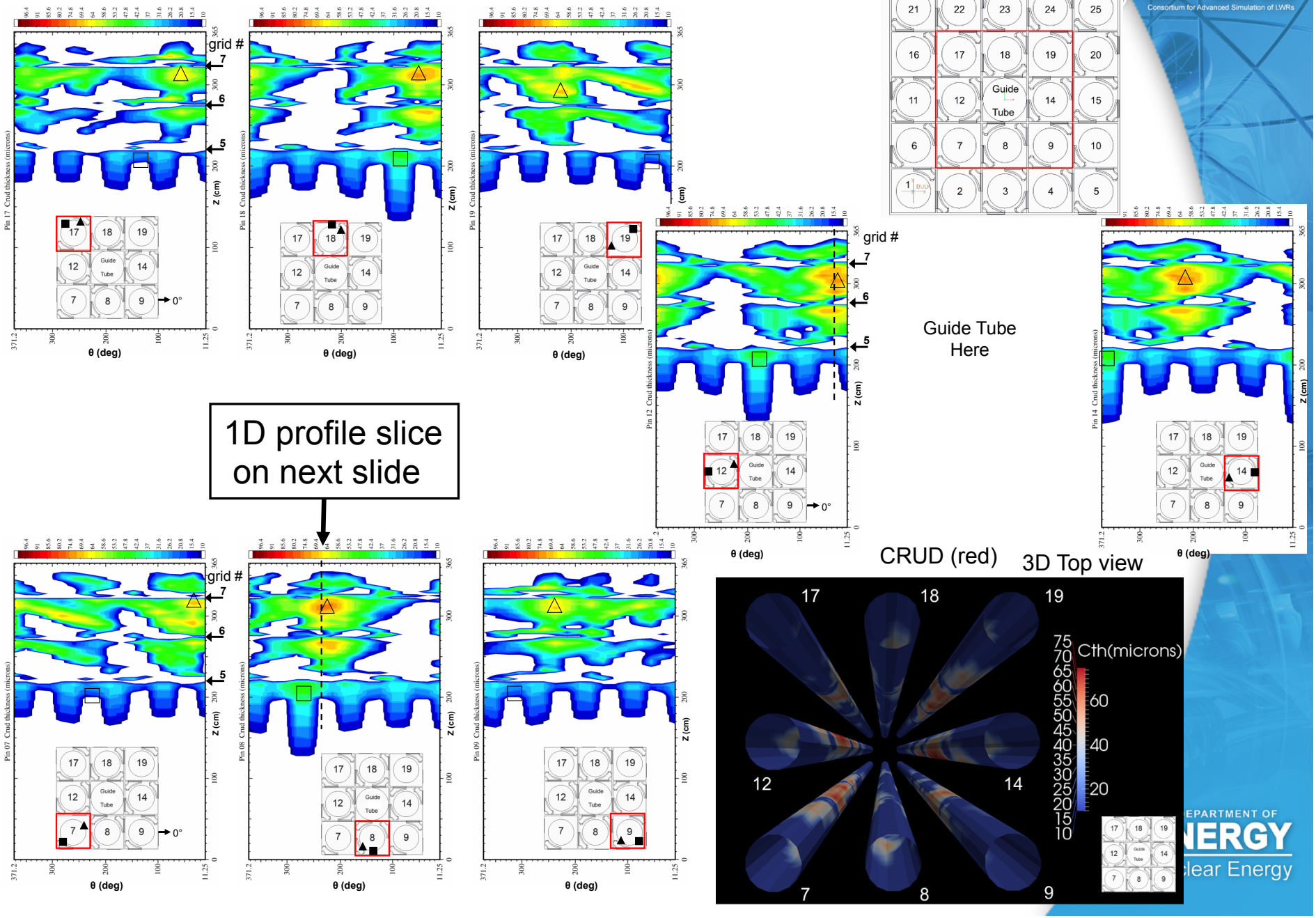
4

3

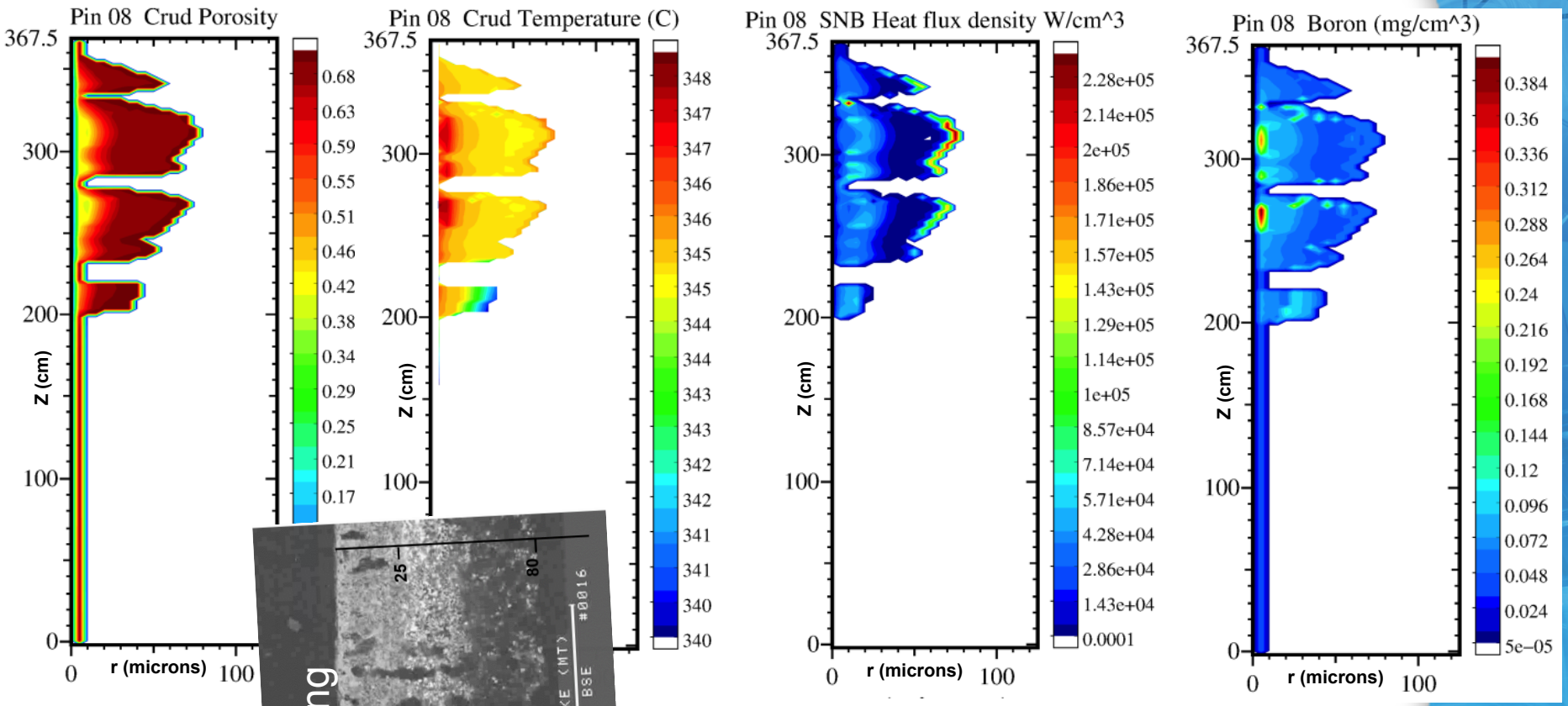
2

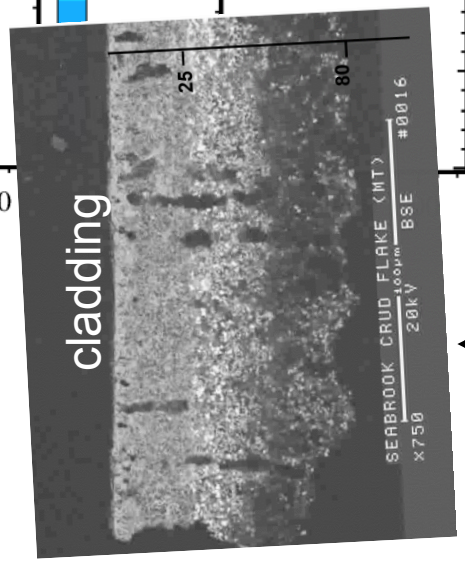
1 row

MAMBA computed crud thickness at 502 days



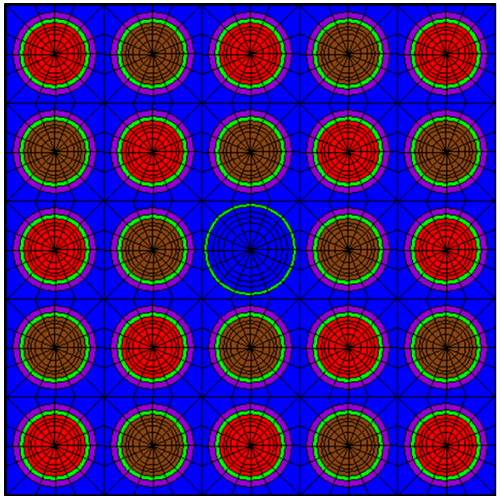
Profile view of crud layer for pin 8 at 502 days

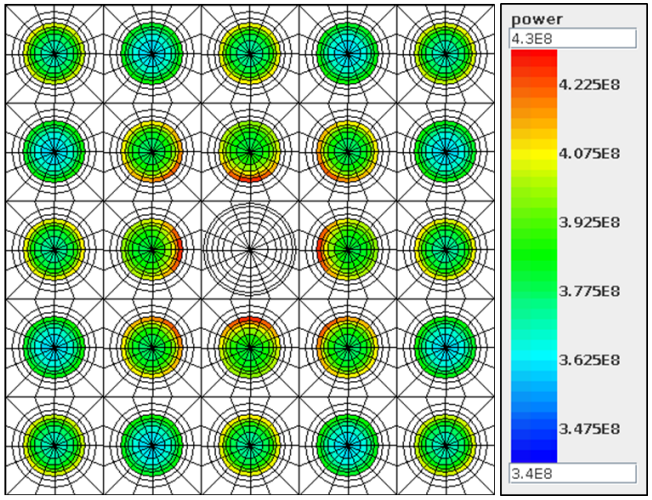




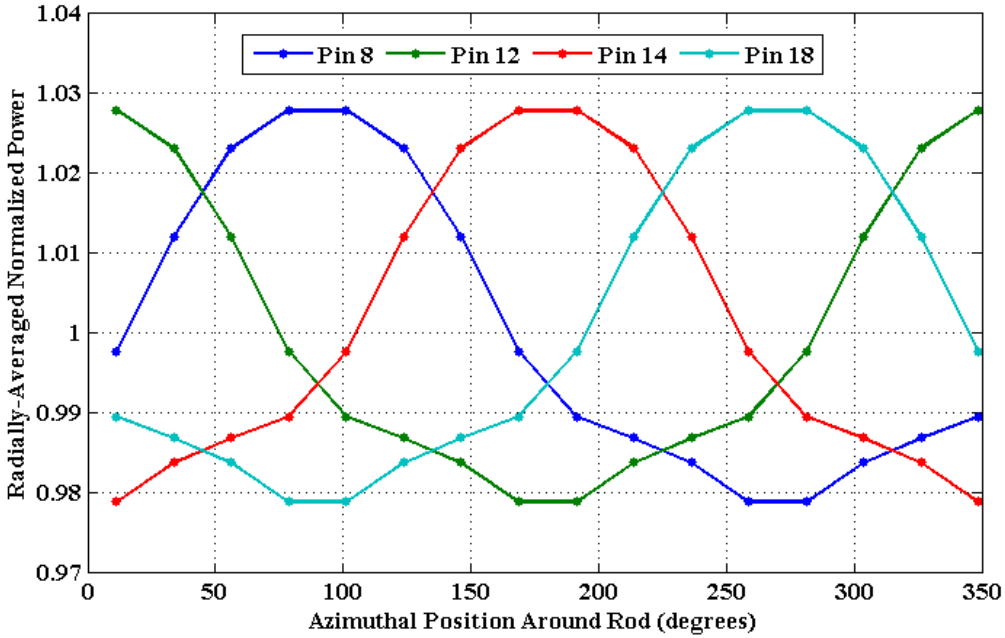
Actual Seabrook crud flake (80 microns thick)

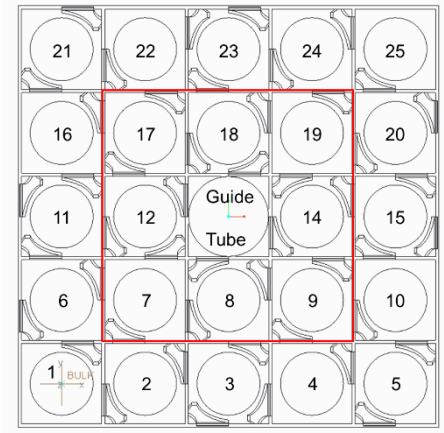
DeCart computed azimuthal power variations





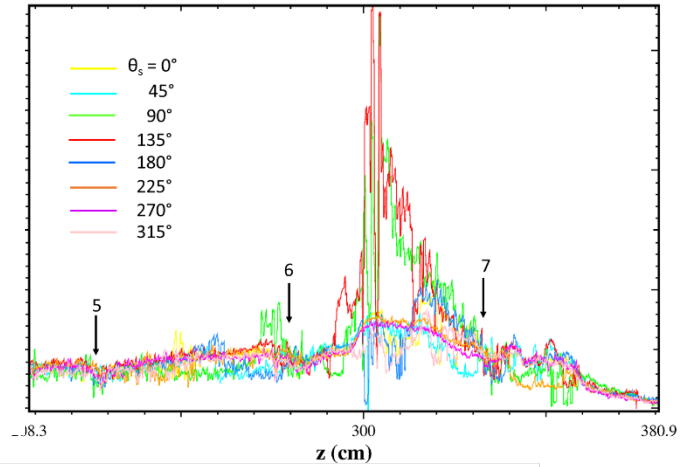
5 % variations did not affect crud



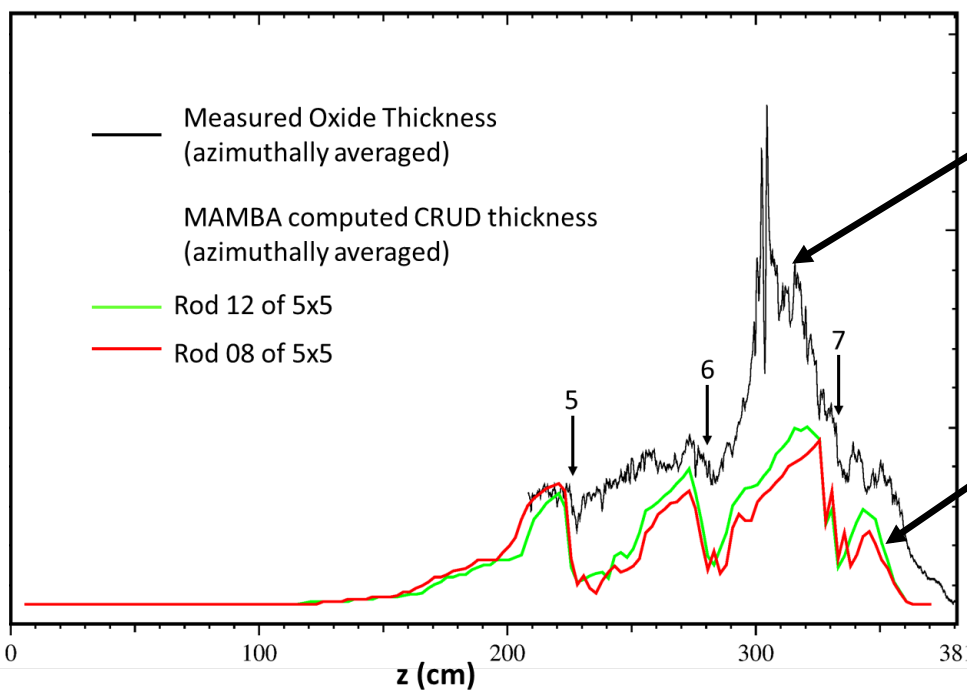


Comparisons with Seabrook cycle 5 oxide data

Measured Oxide Thickness for FA G70 Rod G09



Average Oxide/CRUD Thickness for FA G70 Rod G09

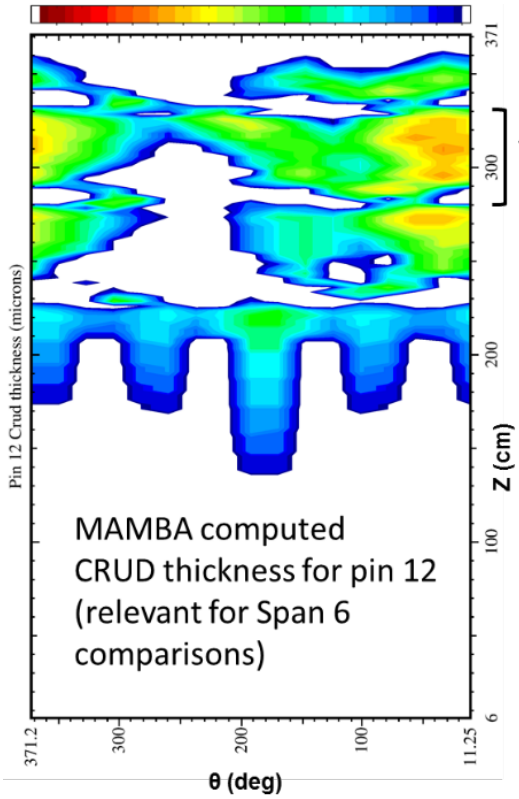


Average of azimuthal data plotted in black

MAMBA computed crud thickness plotted in color

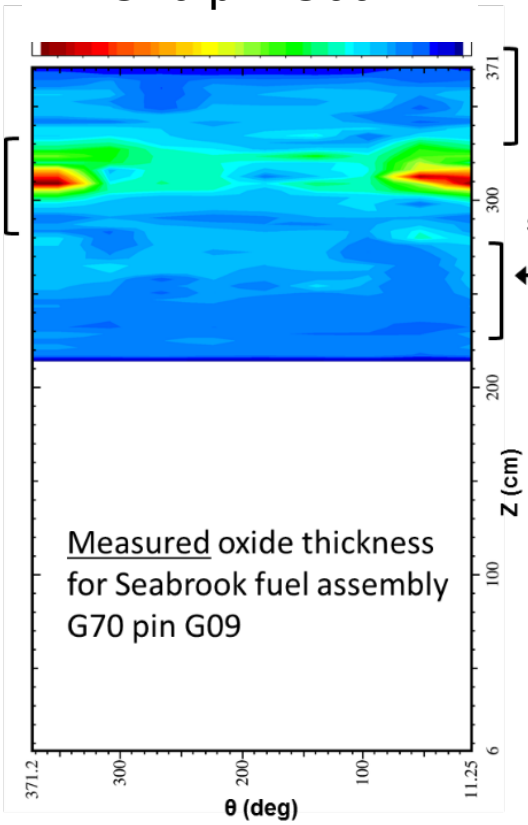
Comparisons with Seabrook cycle 5 oxide data

MAMBA computed crud thickness (pin 12)



Span 6

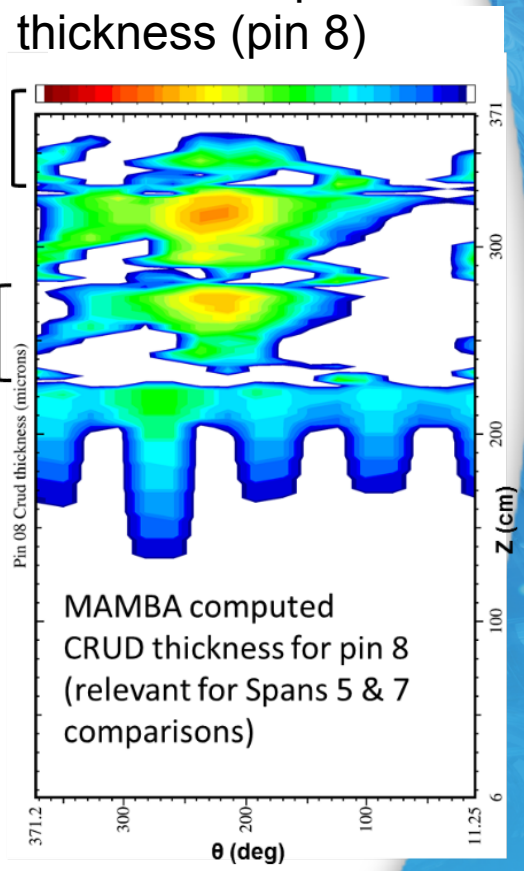
Measured oxide data FA G70 pin G09



Span 7

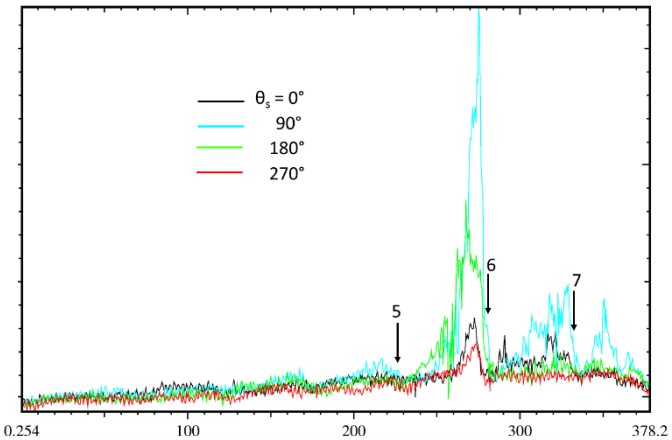
Span 5

MAMBA computed crud thickness (pin 8)

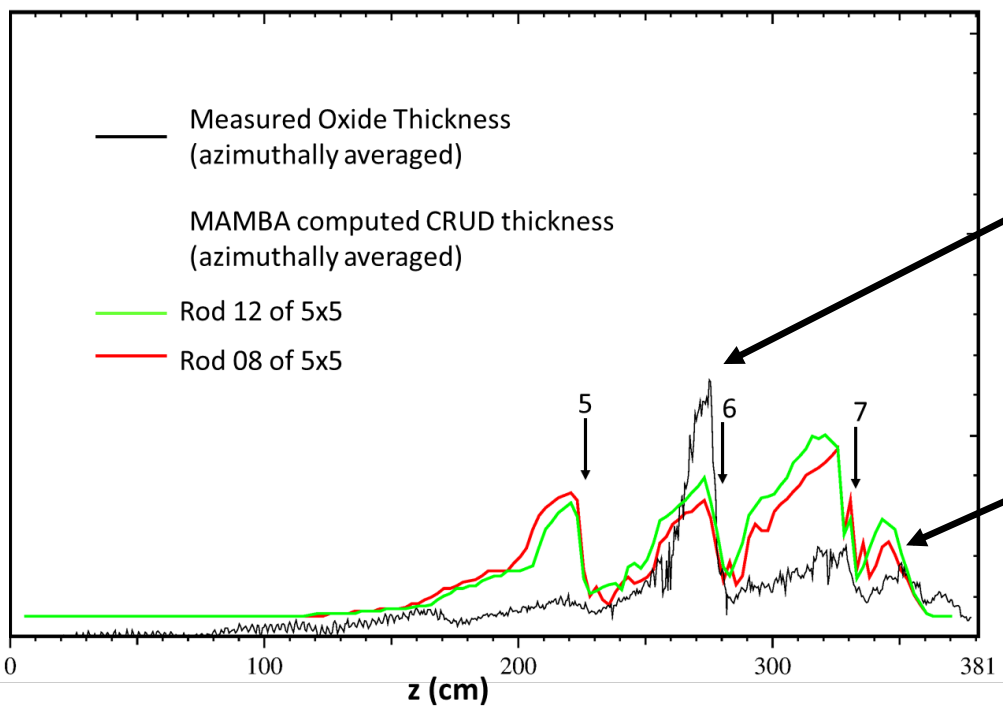


Comparisons with Seabrook cycle 5 oxide data

Measured Oxide Thickness for FA G63 Rod L07



Average Oxide/CRUD Thickness for FA G63 Rod L07

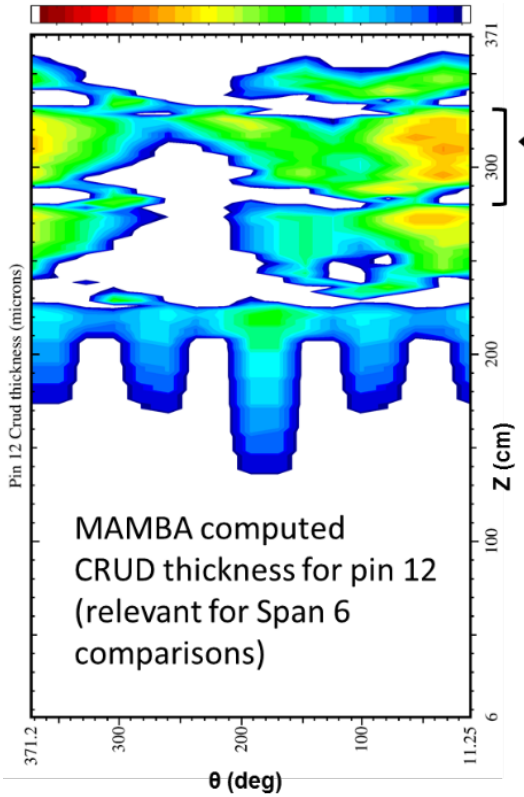


Average of azimuthal data plotted in black

MAMBA computed crud thickness plotted in color

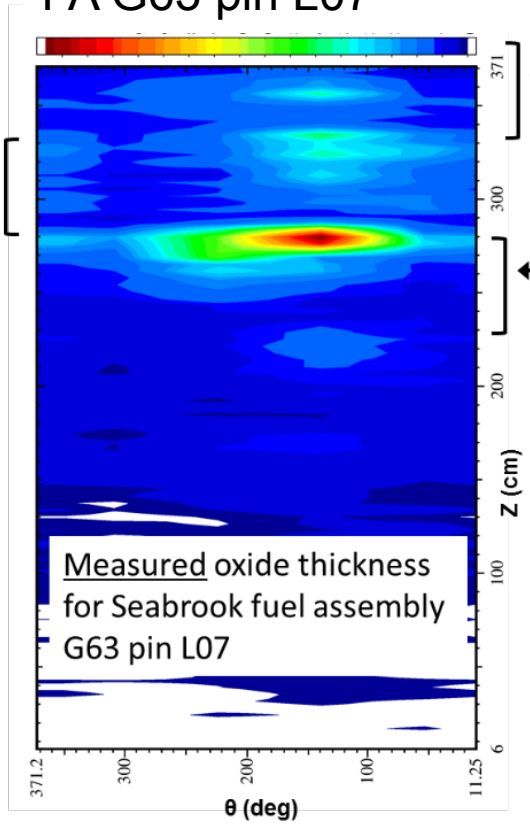
Comparisons with Seabrook cycle 5 oxide data

MAMBA computed crud thickness (pin 12)



Span 6

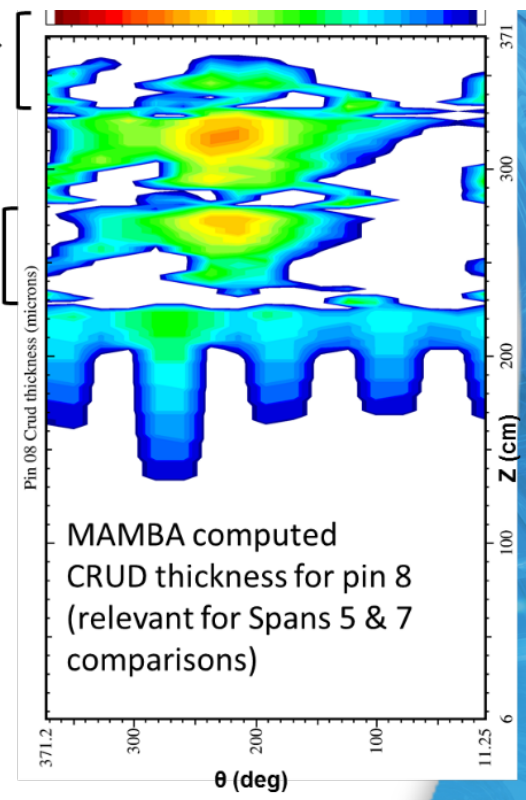
Measured oxide data FA G63 pin L07



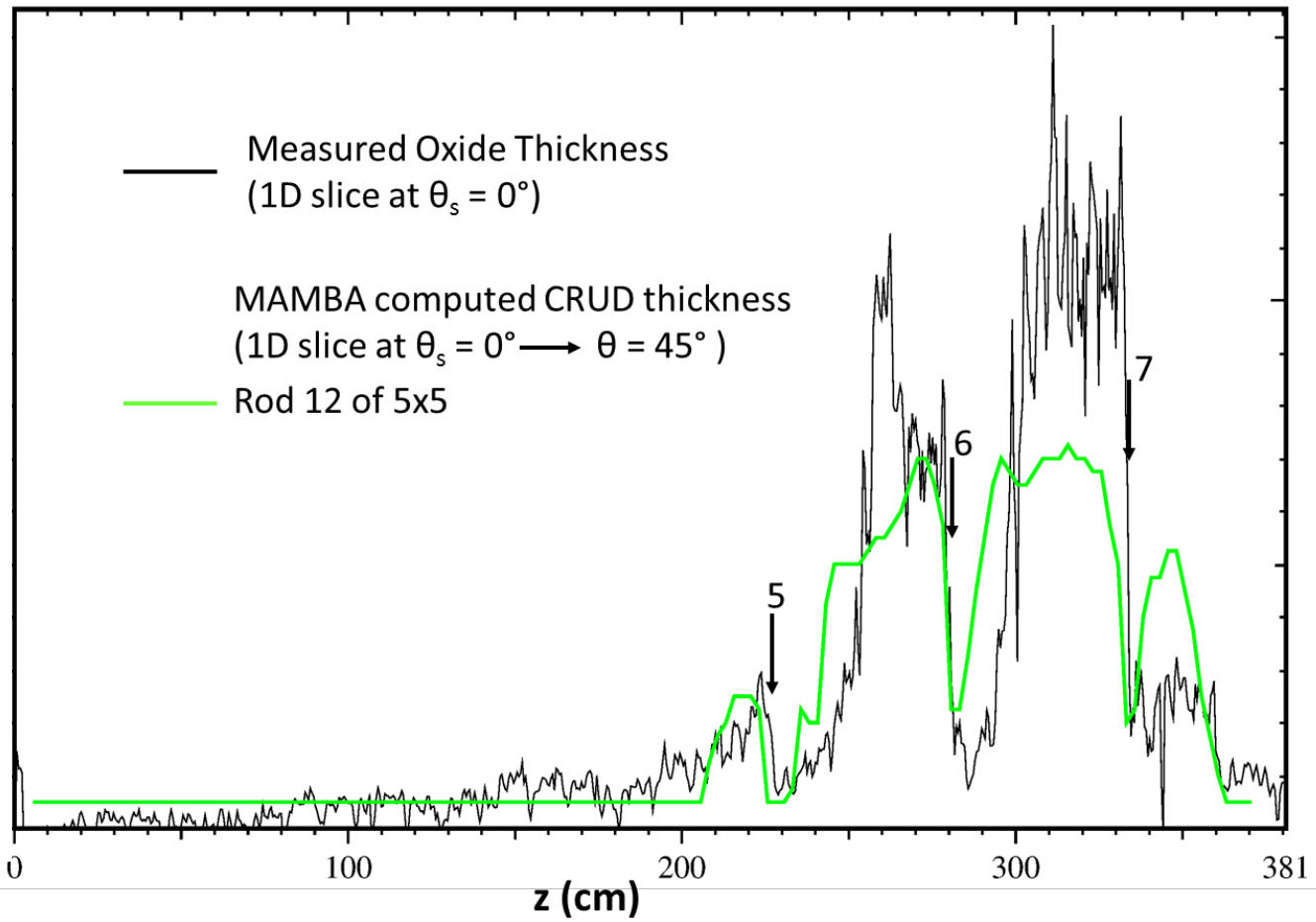
Span 7

Span 5

MAMBA computed crud thickness (pin 8)



Comparisons with Seabrook cycle 5 oxide data



Summary / Ongoing Work

- First coupled MAMBA / STAR-CCM+ simulation of Seabrook cycle 5 predicted crud surface distributions that are consistent with measured oxide data

- Improved MAMBA / STAR-CCM+ simulation of Seabrook cycle 5 in progress

- MAMBA "1D" subgrid module development and interface with Hydra in progress (MPO-crud L2, Jeff Secker):
  (a) An initial demonstration Hydra / MAMBA simulation (3x3) early summer
  (b) An initial Hydra / MAMBA simulation of Seabrook cycle 5 (5x5)

- Implement new (non-proprietary) thermodynamic models, improved boric acid chemistry, erosion, microstructure, thermal conductivity / boiling models

- Phase 2 planning / renewal proposal support for coupled MAMBA/Hydra and MAMBA/Cobra applications including LOCA, BWR, CIPS and CILC