Crud Status Update and Crud Challenge Problem FY17 Milestones

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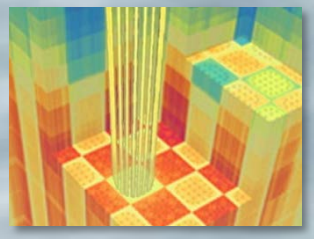

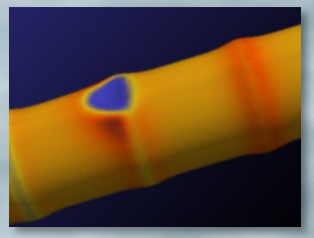

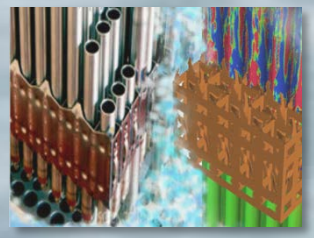

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Crud Challenge Problem Status

- Level 1 CILC milestone
- Cladding Oxidation Model for CILC
- Mass Balance for Corrosion Product Coolant Concentrations
- Crud Restart File
- Seabrook Modeling – Cycles 1-5
  - Cycle 5 experienced both CIPS and CILC

Crud Challenge Problem Status - 2016

L1 CILC milestone – 9/30/2016

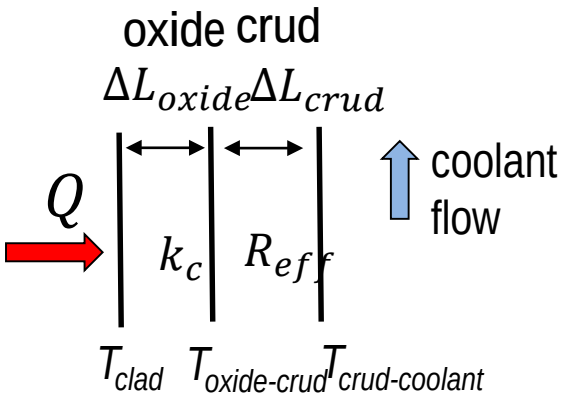
- Results of the CIPS analysis will be used as boundary conditions to model individual assemblies that are predicted to have thick crud deposits and may be susceptible to CILC
- STAR-CCM+/MAMBA-3D coupling
- Effects of sub-cooled boiling will be modeled in CFD to obtain more appropriate/consistent clad temperatures
- Annalisa Manera, Victor Petrov, Dan Walter (UMich) and Brian Kendrick (LANL), were the principal investigators
- Seabrook VERA-CS models (MPACT/CTF/MAMBA-1D) established by Westinghouse (Kucukboyaci) and used as power distribution input to STAR-CCM+

Status CILC L1.CASL.P13.04 Milestone

- Corrosion model by UT/LANL implemented in MAMBA-3D
  - Action Completed
- Implementation of new MAMBA-3D in CCM+ coupling
  - MAMBA-3D source code received at UM on June 30, 2016
  - Ongoing work: clean-up of MIMIC (Michigan Interface for Multi-state In-memory Coupling) and implementation of MAMBA-3D (with corrosion code) into MIMIC.
    - STAR-CCM+/MAMBA3D-corrosion coupling will be ready for use by end of July 2016.
  - Two pathways for CILC L1 milestone:
    - Use CICADA coupling if all features are available in time (i.e. by August 1, 2016)
    - Backup parallel route: use MIMIC
- STAR-CCM+ Seabrook model
  - Updated from previous L2 2013 Milestone model to properly account for V5H rotated grids
  - VERA-CS model established including CIPS effects for power distribution input

An initial oxide model has been implemented in MAMBA 3D

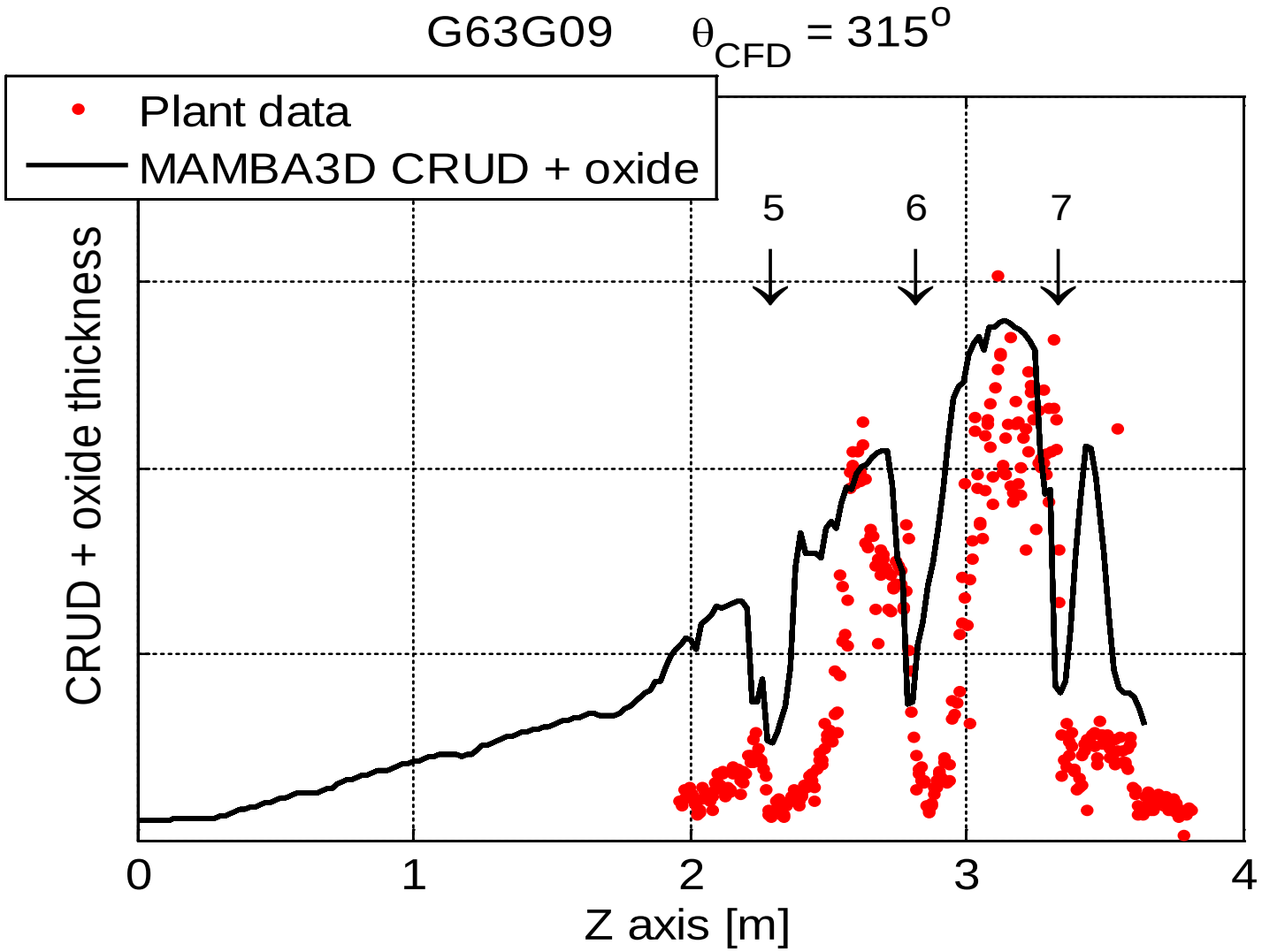
- MAMBA calls oxide model with $T_{oxide-crud}$ at each surface element
- Oxide model returns ΔL_{oxide} and k_c
- STAR-CCM+ data to MAMBA (same as before):
  - Cladding heat flux Q
  - Tcrud-coolant
- MAMBA data to STAR-CCM+:
  - Oxide layer thickness ΔL_{oxide}
  - Oxide layer thermal conductivity k_c
  - Crud layer thickness ΔL_{crud}
  - Crud layer effective thermal resistance R_{eff}
- Star-CCM+ performs its conjugate heat transfer calculation
  - including both oxide and crud layers



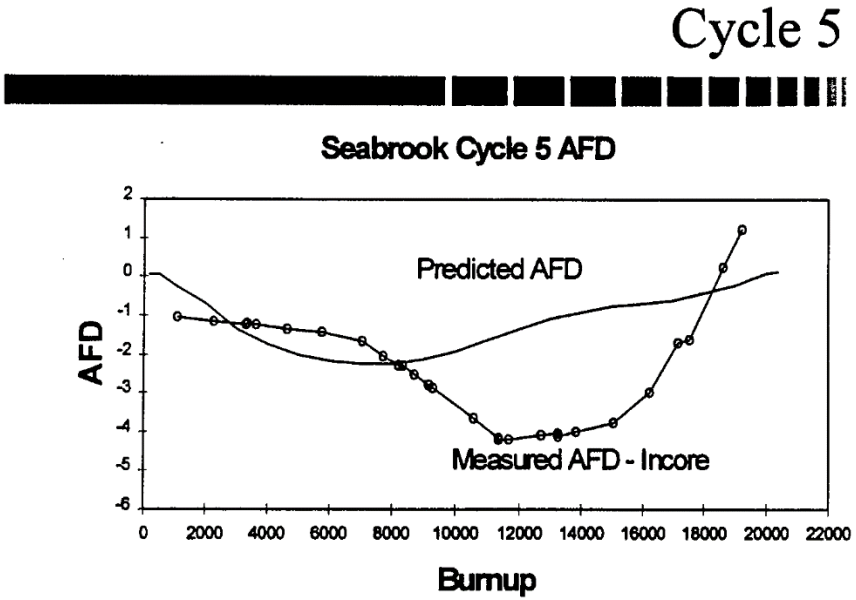
Uniform Oxidation Model Implementation

- Implemented the EPRI/KWU/CE model in MAMBA-3D
  - Calculates oxide formation for PWR fuel rods.
  - Includes a post-transition enhancement factor for fast neutron flux
  - Currently uses a constant neutron flux: 9.00E+14 neutrons/cm^2-s
    - Working to couple with BISON (Aug/Sept FMC milestone)
  - Does not (yet) consider cladding metal consumption
- Eventually moving to higher fidelity EPRI/SLI model
  - Includes pre-transition modification factors for LiOH coolant concentration and intermetallic particle re-solution
  - Includes post-transition modification factors for LiOH coolant concentration, intermetallic particle resolution, tin content in cladding, heat flux, hydrogen redistribution, and fast neutron flux

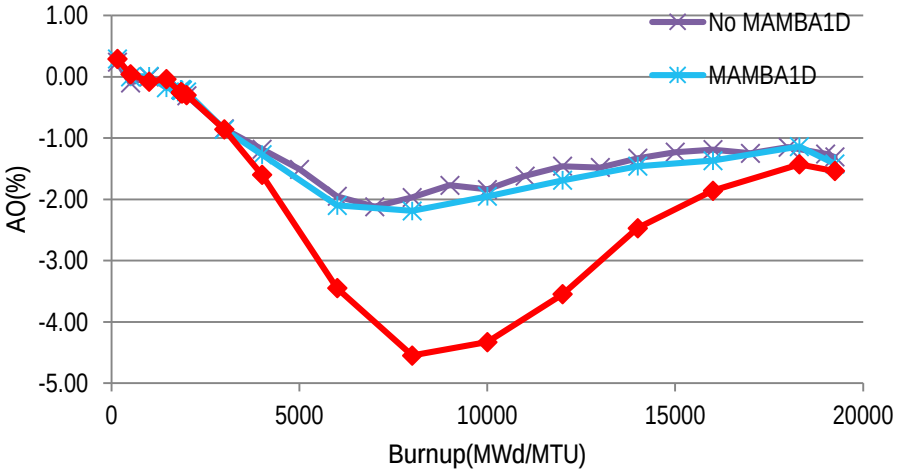
CILC L1 Milestone Results



Seabrook VERA-CS Model Results



Measured Data



VERA-CS/MAMBA-1D Prediction

Corrosion Product Mass Balance

- Efforts have begun to add an overall corrosion product mass balance model to determine coolant corrosion product concentrations consistent with MAMBA deposition rates
- Components
  - Ongoing corrosion and release to coolant
  - Crud release from out of core surfaces
  - Crud deposition on fuel
  - Crud deposition on out of core surfaces
  - Release of crud from previous fuel deposits
  - Cleanup from Chemical Volume and Control System
- Will be completed and implemented in FY2017

Crud Restart File

- For multiple cycle modeling of CIPS a crud restart file is needed
- Fuel with crud is reloaded into next cycle and must be shuffled to proper location
  - Burned fuel deposits provide a source of additional corrosion products to the coolant – crud is released to the coolant when the burned fuel crud is not longer undergoing sub-cooled boiling
- A fraction of the crud is also removed during the refueling outage as part of the shutdown chemistry evolution
- Crud restart file, ability to shuffle, and ability to remove a fraction of the crud has not yet been implemented

MAMBA-3D and -1D run time comparison

- Two power peakings are considered, where boron precipitation occurs in the 150% power case
- 500-days cycle simulation
- For MAMBA3D => 16 azimuthal sectors, 5μm radial increments
- All calculations are performed on **one core** (Intel Xeon X5650 @ 2.67 GHz)
- 320+ planes are required in MAMBA-3D to resolve TKE used in erosion
- **MAMBA-3D is approximately 2-3 orders of magnitude slower than MAMBA-1D**

Power peaking (%)	Number of planes	CPU time (min)	Increase factor from MAMBA-1D	CPU time / planes (min)
130	60	92	43	1.53
	80	153	71	1.91
	160	619	287	3.87
	320	1589	738	4.97
150	60	324	151	5.41
	80	647	300	8.09
	160	1912	888	11.95
	320	4771	2215	14.91

Crud Challenge Problem Status

- Cladding Corrosion Model added to MAMBA-3D for CILC predictions
- Corrosion Product Mass Balance approach has been outlined; work to establish models just getting underway
- Crud restart file has been deferred to FY2017
- VERA-CS/MAMBA-1D model established for Seabrook Cycles 1-5
- L1 DOE reportable CILC milestone modeling Seabrook is complete

FY2017 Crud Plans

- Complete and Implement Corrosion Product Mass Balance for Crud Modeling
- Implement MAMBA-3D for CIPS analysis rather than MAMBA-1D
- Repeat Watts Bar 1 CILC analysis with MAMBA-3D
- Add another CIPS plants for validation – Callaway
- Add another CILC plant for validation – Palo Verde 2

Corrosion Product Mass Balance Model

- Initial Work Underway but not complete in FY2016
- Coolant Corrosion Product input currently taken from plant BOA models
  - Boiling areas and rates may not be consistent between BOA and MAMBA-3D because of explicit rod by rod modeling
- Implementation road map to be completed in October
- First delivery of model/sub-routine late 2016/early 2017
  - L2:FMC.P10.01 Initial primary piping corrosion product source term mass balance
  - L3:FMC.CRUD.P10.02 Initial primary piping corrosion product source term mass balance Status – Completed?
    - Completion presentation appears to be about cladding corrosion and hydriding
  - L3:FMC.CRUD.P13.02 Develop Crud Bonnacordite formation theory- Status - Complete
  - L3:FMC.CRUD.P13.04 Steam Generator source term for CRUD/CILC modeling Status: In Progress - OK

Crud Restart File for MAMBA

- Not completed in 2016
- Needed for accurate crud modeling and to complete CIPS validation
- To be implemented for MAMBA-3D

FY17 Crud Milestones - POR14/15

- AMA
  - L3:VMA.AMA.P13.01, Updated Watts Bar Cycle 7 CIPS analysis (Collins) #1577
  - L3:AMA.CP.P14.01, 12/30/2016, Independently Review and Assess CASL CRUD capabilities (Epperson) #1896
  - L3:AMA.CP.P14.04, 3/15/2017, Catawba 2 Cycle 22 CIPS Calculations with VERA (Lange) #1899
  - ACT:AMA.CPI.P15.02, 9/30/2017, CRUD Challenge Problem Integration (Secker) #1878
  - L3:AMA.CP.P15.01, 6/30/2017, Development of New VERA model for CIPS application (Secker) #1902
  - L3:AMA.CP.P15.07, 8/31/2017, Perform Comparisons of BOA and MAMBA results for Commercial Reactor with CIPS (Epperson) #1908
  - L3:AMA.CP.P15.06, 9/29/2017, Initial with STAR-CCM+CILC/MAMBA-3D (Secker) #1907
  - ACT:AMA.CP.P15.10, 9/30/2017, Support PHI Milestone for CIPS Application Using VERA and MAMBA-3D (Secker) #1911

FY17 Crud Milestones - POR14/15

- PHI
  - L3:PHI.CMD.P13.02, 10/7/2016, Support for CILC L1 milestone using STAR-CCM+ (Slattery) #1305
  - L3:PHI.CMD.P14.01, 12/15/2016, Integrate MAMBA 3D within VERA (Collins) #1739
  - L3:PHI.VCS.P14.02, 1/30/2017, Create and initial global CRUD source term capability in CTF (Wysocki) #1742
  - L3:PHI.CTF.P15.01, 4/30/2017, CFD-informed CTF for CRUD, (Salko) #1743
  - L2:PHI.P15.01, 6/30/2017, Demonstrate initial VERA-CIPS Capability (Collins) #1808
  - L1:CASL.P15.04, 9/15/2017, Create VERA-CIPS: VERA-CS+MAMBA-3D (Clarno) #1967

FY17 Crud Milestones - POR14/15

- THM
  - L3:THM.CFD.P15.03, 3/31/2017, Status STAR-CCM+/MAMBA Coupling, (Manera) #1695
  - L3:THM.CFD.P15.04, 6/30/2016, Generate CFD Data for CIPS/CILC Hi2Lo, (Pointer) #1696
  - L1:CASL.P15.04, 9/15/2017, Create VERA-CIPS: VERA-CS+MAMBA-3D (Clarno) #1967
  - L3:THM.CFD.P15.06, 9/30/2017, CRUD/CILC Deliver (Manera) #1698

FY17 Crud Milestones - POR14/15

- FMC
  - L4:FMC.CRUD.P14.xx, 12/31/2016, Establish Framework for integration of CRUD deposition model and develop implementation plan (Mathews) #1977
  - L3:FMC.CRUD/P14.xx, 3/15/2017, Development of MAMBA test suite and PHI integration of MAMBA-3D code (Galloway) #1978
  - L2:FMC.P14.01, 3/30/2017, Sytem-Level corrosion source term model development (Galloway), #1958
  - L2:FMC.P15.01, 6/30/2017, Watts Bar CIPS comparisons and benchmarking between BOA and MAMBA (1D/3D), (Mathews) #1648
  - L3:FMC.CRUD.P15.01, 7/30/2017, Loop exptl data supporting corrosion source term (Short) #1674
  - L3:FMC.CRUD.P15.03, 8/30/2017, Kinetic behavior of spinels as it relates to steel corrosion and as a source of CRUD (Uberaga) #1654
  - L3:FMC.CRUD.P15.02, 8/30/2017, Oxide particulate formation – crud source term (Brenner) #1675
  - L2:FMC.P15.xx, 8/31/2017, Development of CRUD deposition code for CIPS/CILC analysis and integration within VERA (Mathews) #1979
  - L2:FMC.P15.09, 9/30/2017, MAMBA development and support workscope for 2017 (Kendrick) #1647

FY17 Crud Milestones - POR14/15

- FMC
  - L3:FMC.CRUD.P15.04, 9/30/2017, Coordination of EPRI-NNL-CASL source term (Hussey) #1676
  - L3:FMC.CRUD.P15.05, 9/30/2017, FMC leadership – CRUD source term (Wirth) #1677
  - L4:FMC.MGMT.P15.03, 9/30/2017, Management in support of CRUD source term (FMC leadership), (Andersson) #1736

FY17 Crud Milestones - POR14/15

- VVI
  - L3:VVI.H2L.P15.03, 3/30/2017, MAMBA (Chemistry) Hi2Lo Calculations, demonstration, and validation (O'brien) #1836
  - L3:VVI.VUQ.P15.03, 9/30/2017, MAMBA V&V, (O'brien) #1845

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