CTF Training

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VERA Training
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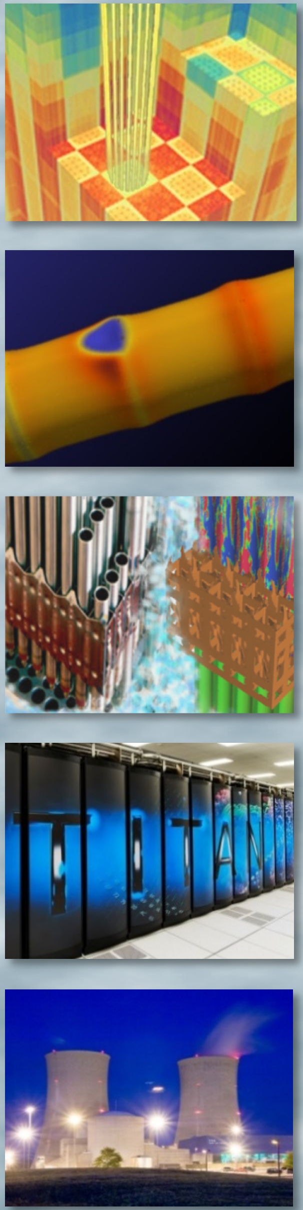

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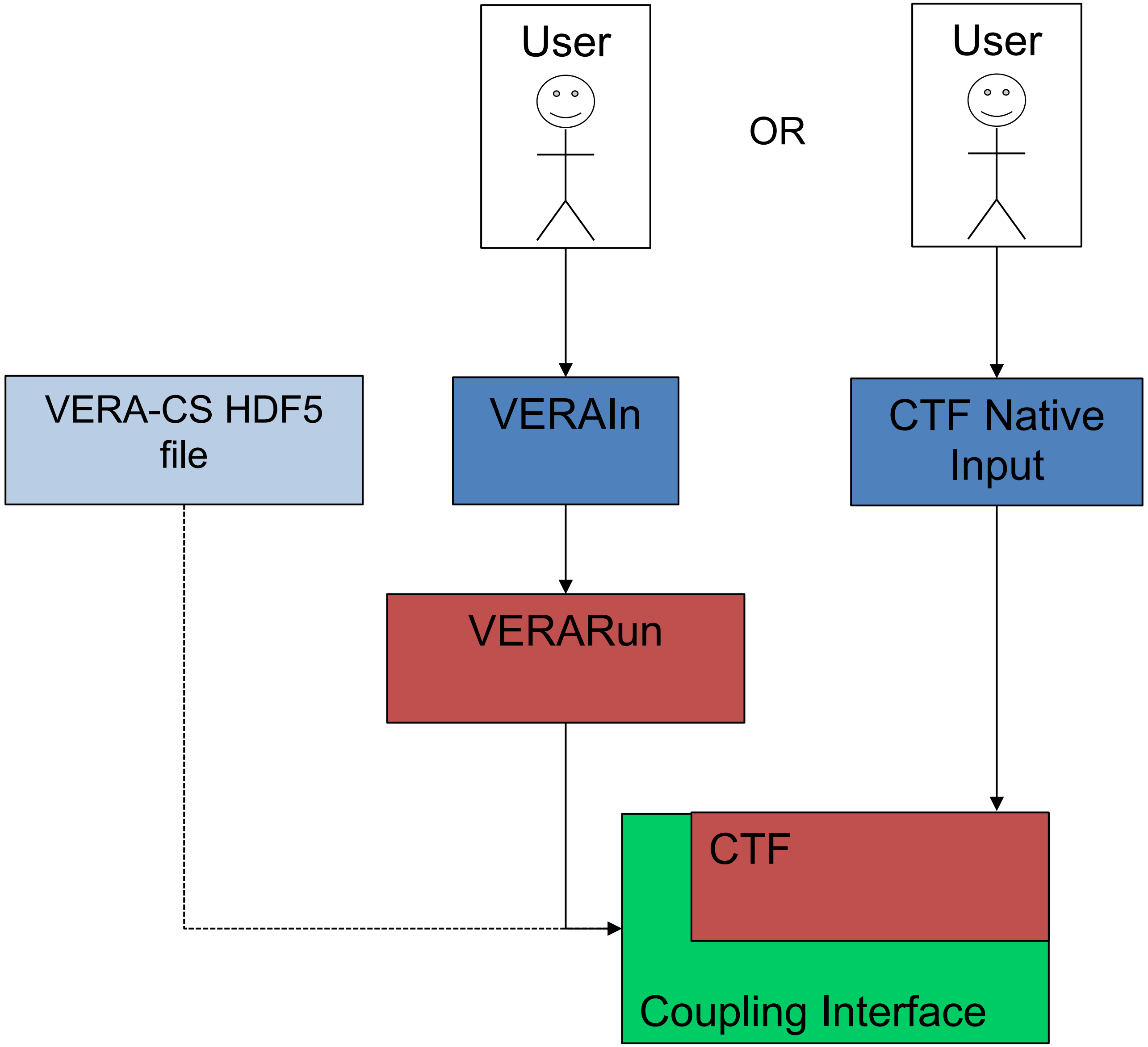
Session overview

1. CTF workflows
2. BWR sensitivity study
3. MSLB simulation
4. Results analysis

CTF workflows

- CTF can be run as a standalone code, which can be useful if T/H is the only physics of interest in a given problem
- The user can run standalone subchannel T/H in one of two ways:
  1. Start from VERAIn input file and use VERARun to drive a standalone thermal hydraulic solution
  2. Generate a CTF native input deck by hand
- This session will focus on the first use case

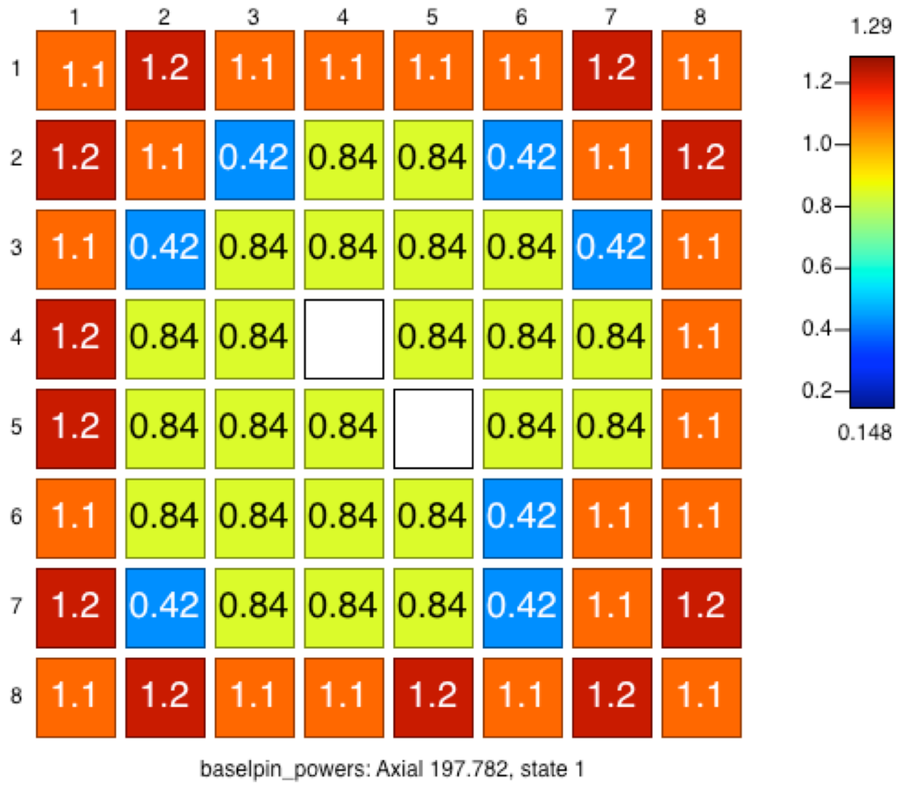


Single BWR assembly

- Single 8x8 BWR assembly with 49 axial levels
- Manufactured power distribution
- Nominal operating conditions

Goals:

1. Test the sensitivity of the outlet void distribution to the void drift model
2. Test the sensitivity of the outlet void distribution to the interfacial drag



	1	2	3	4	5	6	7	8
1	1.1	1.2	1.1	1.1	1.1	1.1	1.2	1.1
2	1.2	1.1	0.42	0.84	0.84	0.42	1.1	1.2
3	1.1	0.42	0.84	0.84	0.84	0.84	0.42	1.1
4	1.2	0.84	0.84		0.84	0.84	0.84	1.1
5	1.2	0.84	0.84	0.84		0.84	0.84	1.1
6	1.1	0.84	0.84	0.84	0.84	0.42	1.1	1.1
7	1.2	0.42	0.84	0.84	0.84	0.42	1.1	1.2
8	1.1	1.2	1.1	1.1	1.2	1.1	1.2	1.1

BWR assembly radial power distribution

Single BWR assembly

- Setting exe_mode th in the RUN block means CTF will be run
- CTF will be run through a depletion, single steady-state state point, or transient depending on VERAIn deck
- CTF can run MAMBA if crud is turned on
- If a VERA HDF5 file is present and its geometry matches the model, it will be read to set the power distribution in CTF
- After reviewing the VERAIn file, submit the bwr_base job

```
[RUN]
  nprocs 1
  walltime 0.25
  exe_mode th
```

```
path: session9/bwr/base
```

```
verarun base.inp
```

Single BWR assembly

- Create a model with no void drift
- Enter the model directory
- Edit the COBRATF block to disable void drift
- Submit the job

```
path: session9/bwr/no_void_drift
```

```
[COBRATF]
  solver  0
  use_sol_stop_crit 1
  k_void_drift 0.0
```

$$(\alpha_i - \alpha_j)_{equil} = K_a(\alpha_i + \alpha_j)\frac{G_i - G_j}{G_i + G_j}$$

```
verarun no_void_drift.inp
```

Single BWR assembly

- Create a model with increased interfacial drag
- Enter the model directory

```
path: bwr/int_drag
```

- Open the vuq_mult.txt file and change the multiplier to 1.2 to make the calculated liquid/vapor drag force 20% larger

```
k_xkl = 1.2
```

- Submit the job

```
verarun int_drag.inp
```

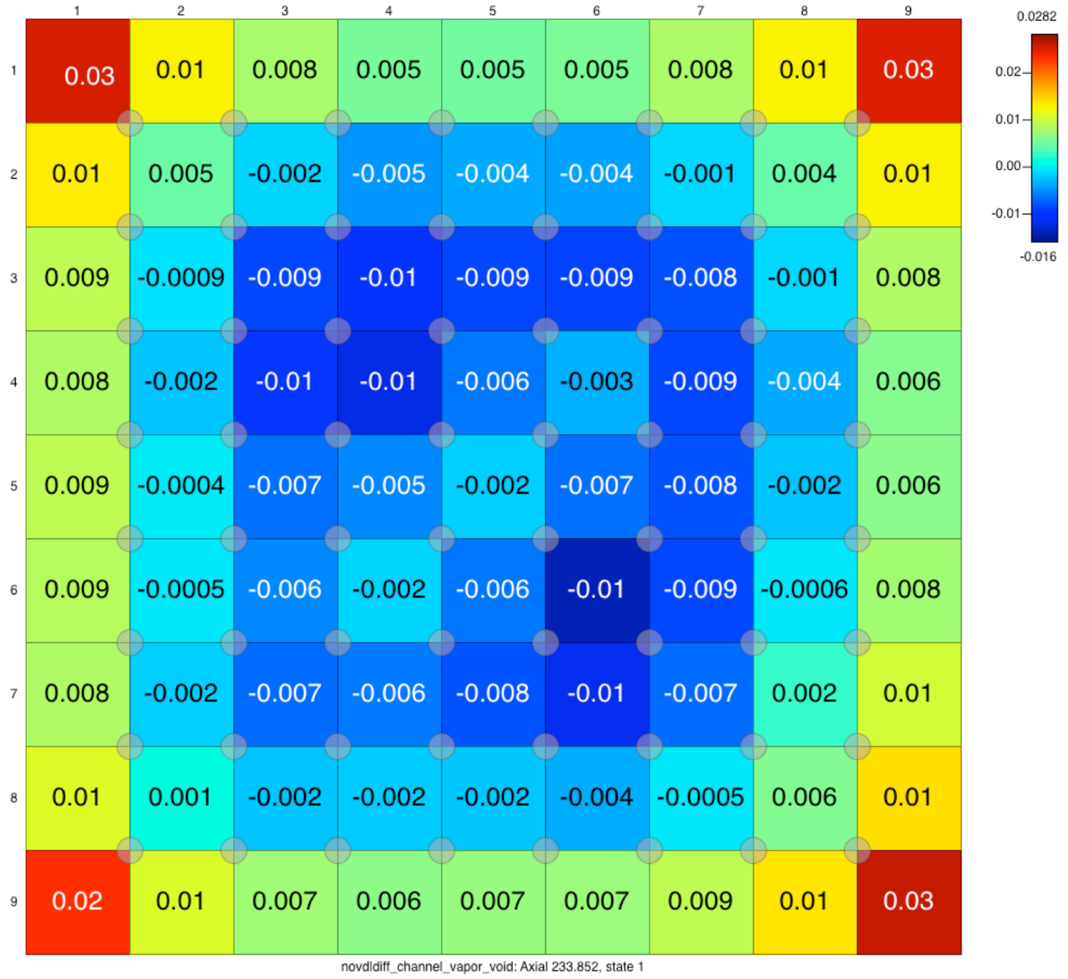
$$\tau_i = M\frac{C_d \rho_l u_{vl}^n A_i}{2\Delta x} u_{vl}$$

Single BWR assembly

- After run completes, rename `deck.ctf.h5` files to base.h5, `no_void_drift.h5`, and `int_drag.h5`, for easier identification in VERAView
- Open all HDF5 files in VERAView using the file manager
- Create a difference dataset of the channel_vapor_void datasets for
  - base and no_void_drift
  - base and int_drag
- Make three axial void plots from the three different cases in the same axial plot and compare for different channels

Single BWR assembly

- With no void drift model, void becomes higher in the corner and side channels (channels with most flow resistance and lowest mass flux) and lower in the central channels
- The void profile becomes more uniform
- Void drift is the tendency of void to migrate to the lower resistance, higher flow channels in the assembly (inner channels)



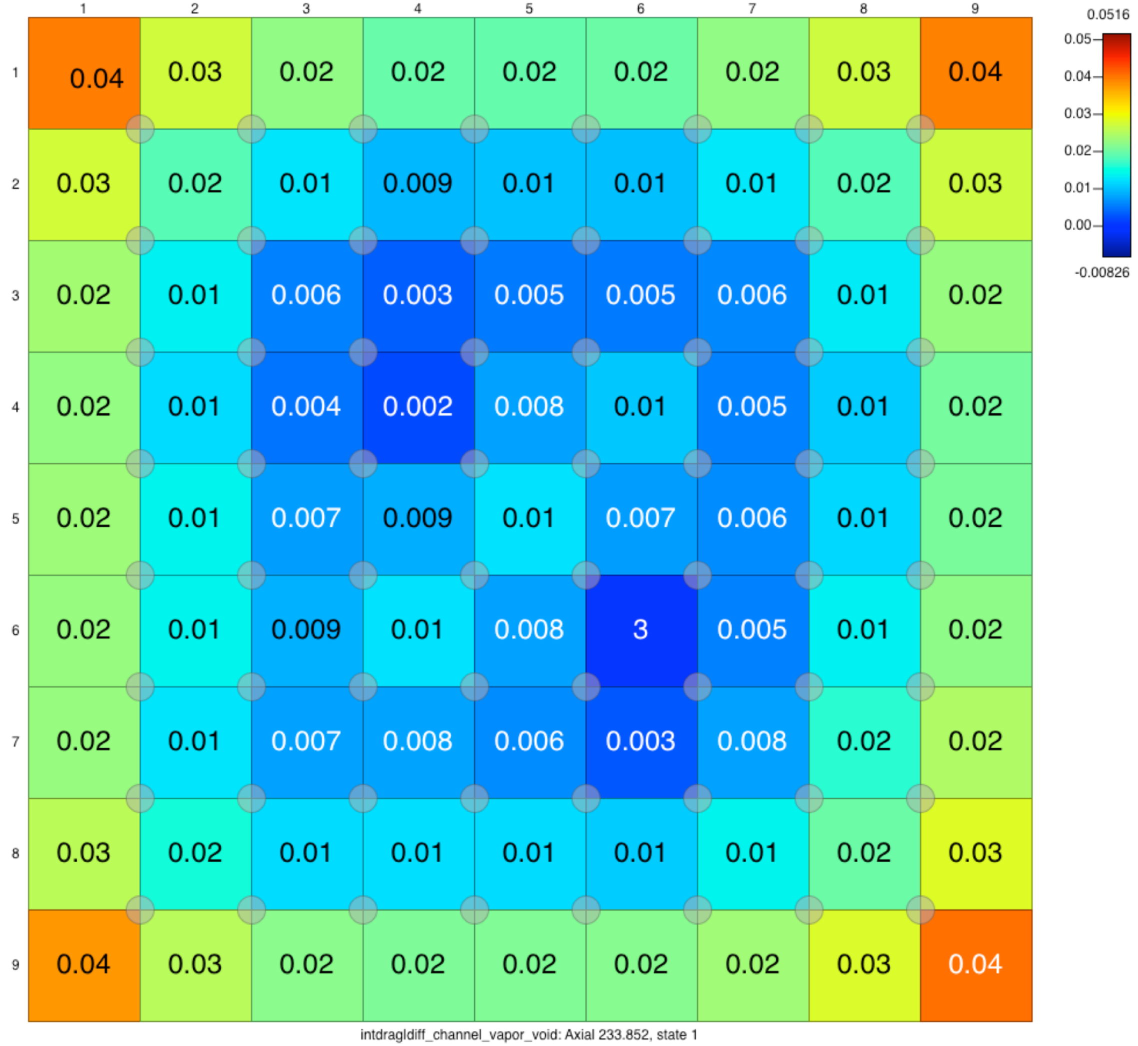
	1	2	3	4	5	6	7	8	9
1	0.03	0.01	0.008	0.005	0.005	0.005	0.008	0.01	0.03
2	0.01	0.005	-0.002	-0.005	-0.004	-0.004	-0.001	0.004	0.01
3	0.009	-0.0009	-0.009	-0.01	-0.009	-0.009	-0.008	-0.001	0.008
4	0.008	-0.002	-0.01	-0.01	-0.006	-0.003	-0.009	-0.004	0.006
5	0.009	-0.0004	-0.007	-0.005	-0.002	-0.007	-0.008	-0.002	0.006
6	0.009	-0.0005	-0.006	-0.002	-0.006	-0.01	-0.009	-0.0006	0.008
7	0.008	-0.002	-0.007	-0.006	-0.008	-0.01	-0.007	0.002	0.01
8	0.01	0.001	-0.002	-0.002	-0.002	-0.004	-0.0005	0.006	0.01
9	0.02	0.01	0.007	0.006	0.007	0.007	0.009	0.01	0.03

novdldiff_channel_vapor_void: Axial 233.852, state 1

No void drift model minus baseline at 234 cm axial

Single BWR assembly

- With increased interfacial drag, the slip between phases (velocity difference between vapor and liquid) is lessened
- The slower vapor phase leads to increased vapor void
- Vapor void is increased everywhere

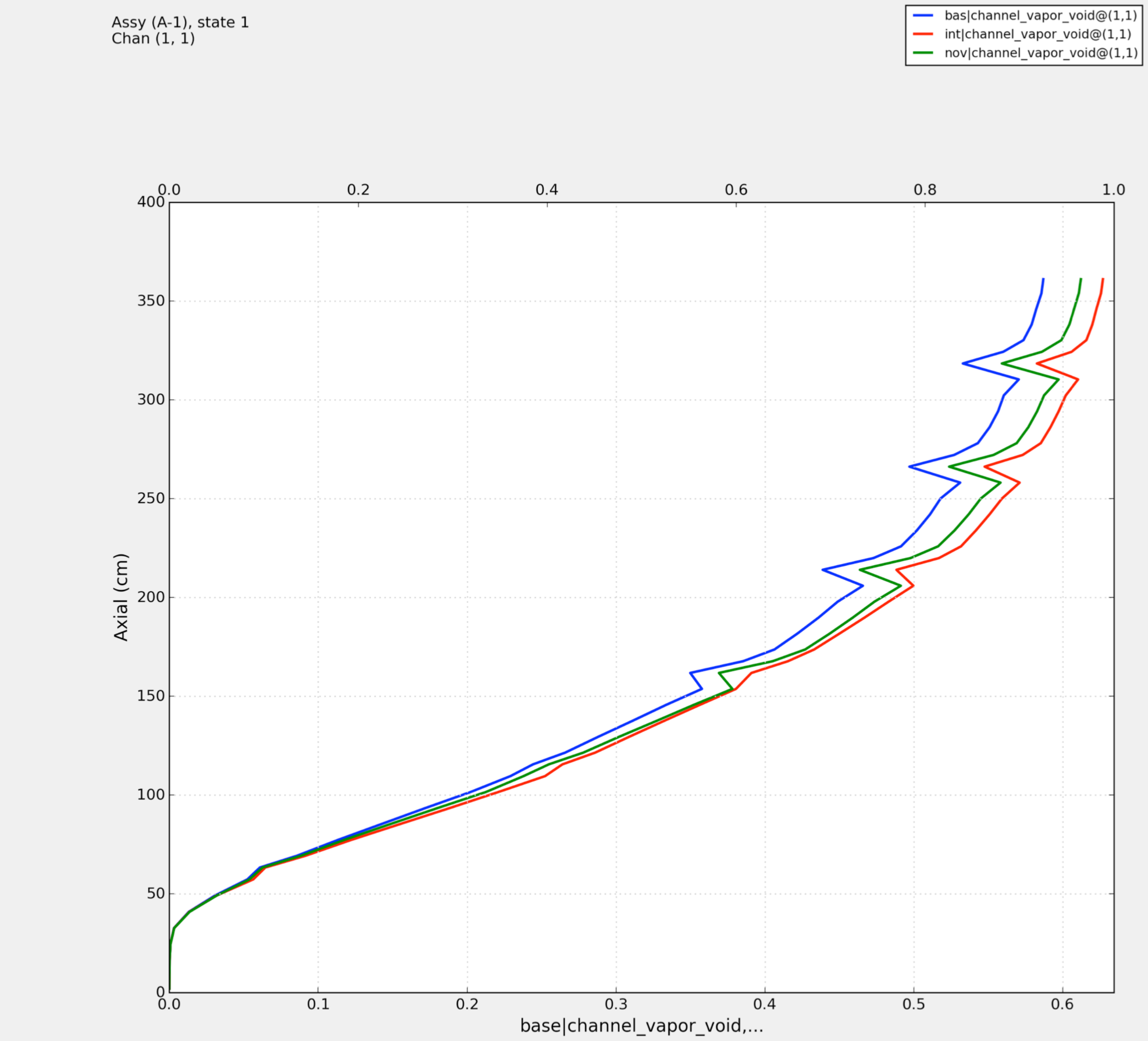


	1	2	3	4	5	6	7	8	9
1	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.04
2	0.03	0.02	0.01	0.009	0.01	0.01	0.01	0.02	0.03
3	0.02	0.01	0.006	0.003	0.005	0.005	0.006	0.01	0.02
4	0.02	0.01	0.004	0.002	0.008	0.01	0.005	0.01	0.02
5	0.02	0.01	0.007	0.009	0.01	0.007	0.006	0.01	0.02
6	0.02	0.01	0.009	0.01	0.008	3	0.005	0.01	0.02
7	0.02	0.01	0.007	0.008	0.006	0.003	0.008	0.02	0.02
8	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.03
9	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.04

Increased interfacial drag minus baseline at 234 cm

Single BWR assembly

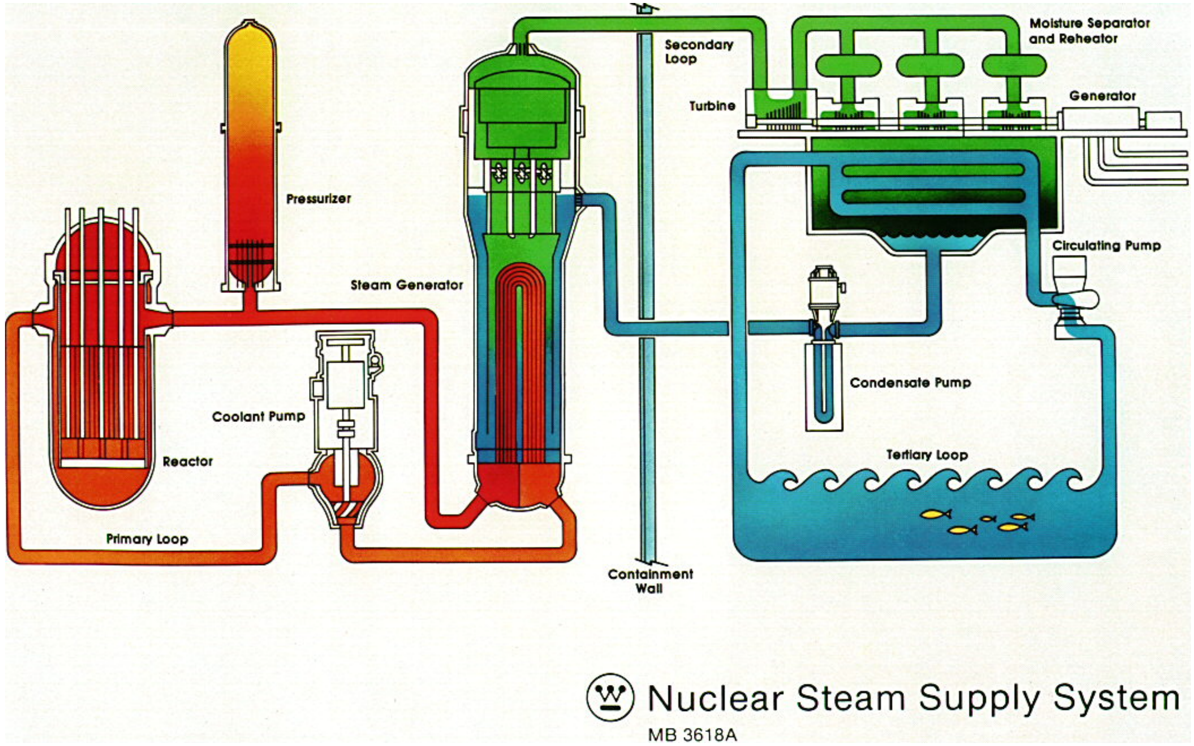
- The interfacial drag increase has the largest impact on void distribution in all channels
- The void drift model has a more significant impact in boundary channels than inner channels
- The “dips” in the void profile are from the change in the phase slip ratio due to the presence of the spacer grids



Corner channel axial void profiles for three cases

MSLB problem description

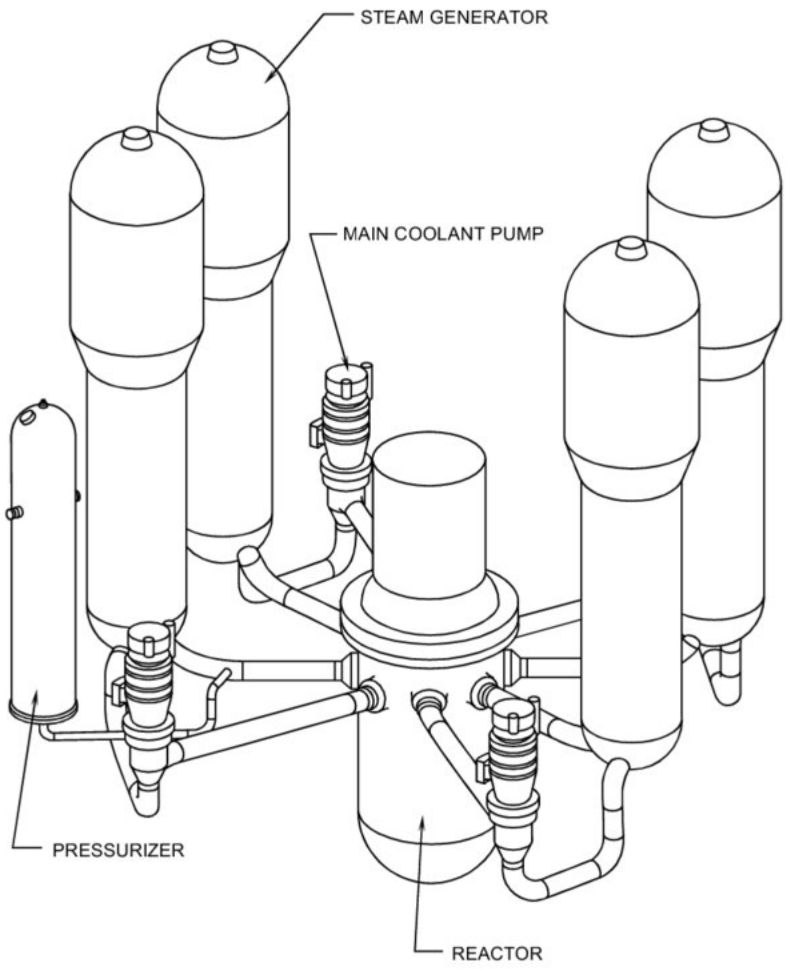
- Main steamline break (MSLB) transient:
  - Steam generator pipe (secondary side) breaks leading to increased cooling in one loop
  - Localized overcooling in the reactor core region leads to a reactivity insertion
  - The safety analysis assumes the most reactive rod cluster control assembly is fully withdrawn
  - The main concern is that fuel failures are minimized (minimum departure from nucleate boiling ratio (MDNBR) greater than 1)



Primary and secondary coolant flow loop in a PWR

MSLB problem description

- A 4-loop plant is used for the analysis
- Two scenarios are possible: high flow (pumps operating) and natural circulation (pumps not operational)
- The MDNBR typically occurs minutes after transient initiation, so it is suitable to model as a steady state simulation during the most limiting point of the transient
- This analysis was originally performed by Westinghouse Electric Company[1] as part of the CASL program



1. V. Kucukboyaci, et al., “VERA-CS Modeling and Simulation of PWR Main Steam Line Break Core Response to DNB,” ICONE24-60865, 2016

MSLB activity

- High-flow case will be modeled
- Two models will be generated from the base input
  - Use W-3 CHF correlation
  - Use Groeneveld CHF lookup tables
- Due to limited resources, the class will be split into two groups for the sensitivity study

Problems to be completed this training session

Group	Test
A	Base case
B	Switch CHF model to Groeneveld

Goals:

1. Determine minimum DNBR for the high-flow MSLB problem
2. Test the minimum DNBR sensitivity to the critical heat flux model

```
Path:
A: session9/mslb/w3
B: session9/mslb/groeneveld
```

MSLB Activity

- Both groups: modify model to the conditions of the high flow case

Parameter	Value
Core power [%]	22.9
Core flow [%]	100
Nominal core inlet temperature [F]	426.3
Outlet pressure [psi]	489

```
[STATE]
  title 'WBN1C1 EOC SLB'
  power    22.9
  flow     100.0
  tinlet   426.3 F
  pressure 489.0 ! psia
```

Turn on DNB edits in CTF

```
[COBRATF]
  proc_per_assem 1
  edit_dnb 1
```

MSLB Activity

Group A

Change the CHF model to use the W-3 correlation

```
[COBRATF]
  chf     1
```

Submit job

```
verarun mslb.inp
```

Group B

Change the CHF model to use the Groeneveld lookup tables

```
[COBRATF]
  chf     3
```

Submit job

```
verarun mslb.inp
```

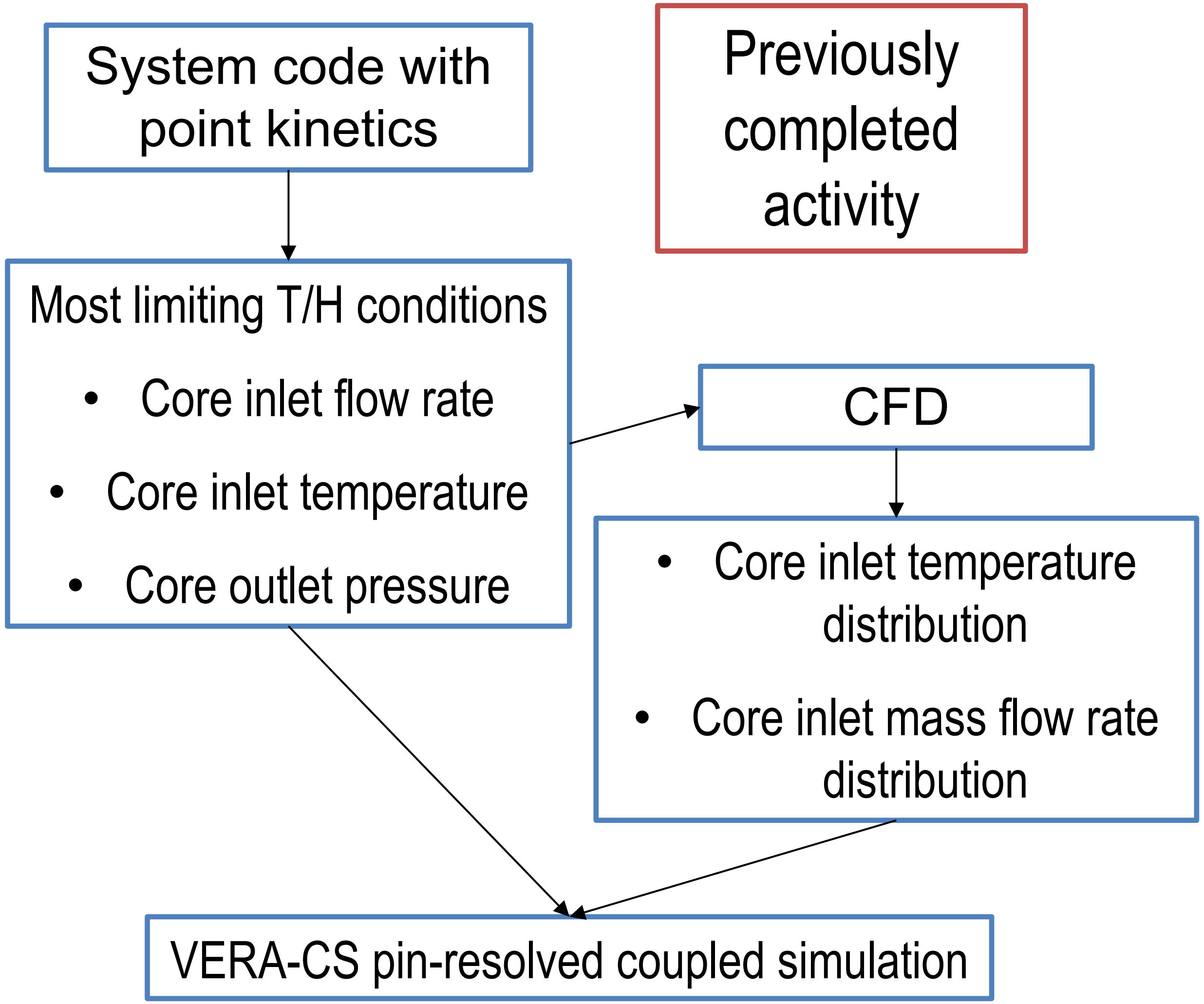
MSLB Activity

- The inlet flow and temperature distribution can be specified in the STATE block
- Inlet temperatures are added to the nominal inlet temperature
- Inlet flow multipliers are multiplied by the nominal inlet mass flow rate

```
tinlet_dist
                          6.6   6.4   5.9  6.5  7.5  8.3  9.0
              3.7   2.8   3.1   2.6   3.4  4.2  4.1  6.3  8.6 10.1 10.9
       -1.8  -0.3  -0.4  -2.1  -0.6  -0.2 -0.1  1.1  5.3  7.3  9.3 11.5 12.4
       -5.4  -4.9  -5.4  -5.3  -8.0  -5.6 -3.4  0.2  2.3  7.1  9.3 11.5 12.4
 -9.0  -9.3 -10.6 -10.5 -12.0 -11.3 -10.2 -7.2 -1.1  3.2  5.9 10.0 11.1 12.3 12.6
-13.1 -13.8 -15.5 -15.9 -15.3 -11.5 -10.9 -7.8 -1.2  3.2  7.4  9.6 11.1 11.9 12.7
-16.8 -17.6 -18.2 -17.7 -13.9 -10.1  -6.4 -2.3 -0.3  4.5  6.4  9.5 10.7 12.0 12.9
-22.0 -21.9 -19.8 -17.3 -14.7  -8.3  -1.4 -1.4 -0.9  5.0  8.4 10.2 11.2 12.3 12.9
-26.3 -25.2 -21.5 -18.4 -12.2  -5.6  -0.1 -0.1  3.5  7.6  8.8 11.1 12.3 12.9 13.2
-27.5 -25.9 -22.3 -15.0 -10.2  -3.1   1.7  5.3  8.6  9.2 10.8 11.5 12.7 13.2 13.3
-27.2 -26.8 -20.3 -15.3  -6.5  -2.1   3.0  7.8  9.2 11.2 11.4 12.4 12.6 13.1 13.2
      -24.0 -19.6 -12.3  -5.3  -0.5   4.4  7.7  9.7 10.7 11.5 12.0 12.4 12.9
      -18.5 -16.5  -9.4  -4.9  -0.1   4.0  6.8  9.0 10.0 10.6 11.2 11.8 12.4
            -10.2  -6.5  -4.1  -0.7   1.9  4.2  7.4  8.8  9.0  9.6  9.9
                         -3.2  -1.2   0.7  2.7  5.3  7.1  7.2
```

MSLB problem description

- Model setup:
  - A system analysis code was used to generate core boundary conditions throughout the transient (inlet flow, inlet temperature, and outlet pressure) and determine the most limiting thermal hydraulic point
  - STAR-CCM+ was used to model the vessel downcomer and lower plenum regions to determine inlet flow and temperature distribution
  - A coupled neutronics and thermal-hydraulics simulation was performed with VERA for both cases
  - The power distribution from one of those cases will be used as input to this simulation



System code with point kinetics

Previously completed activity

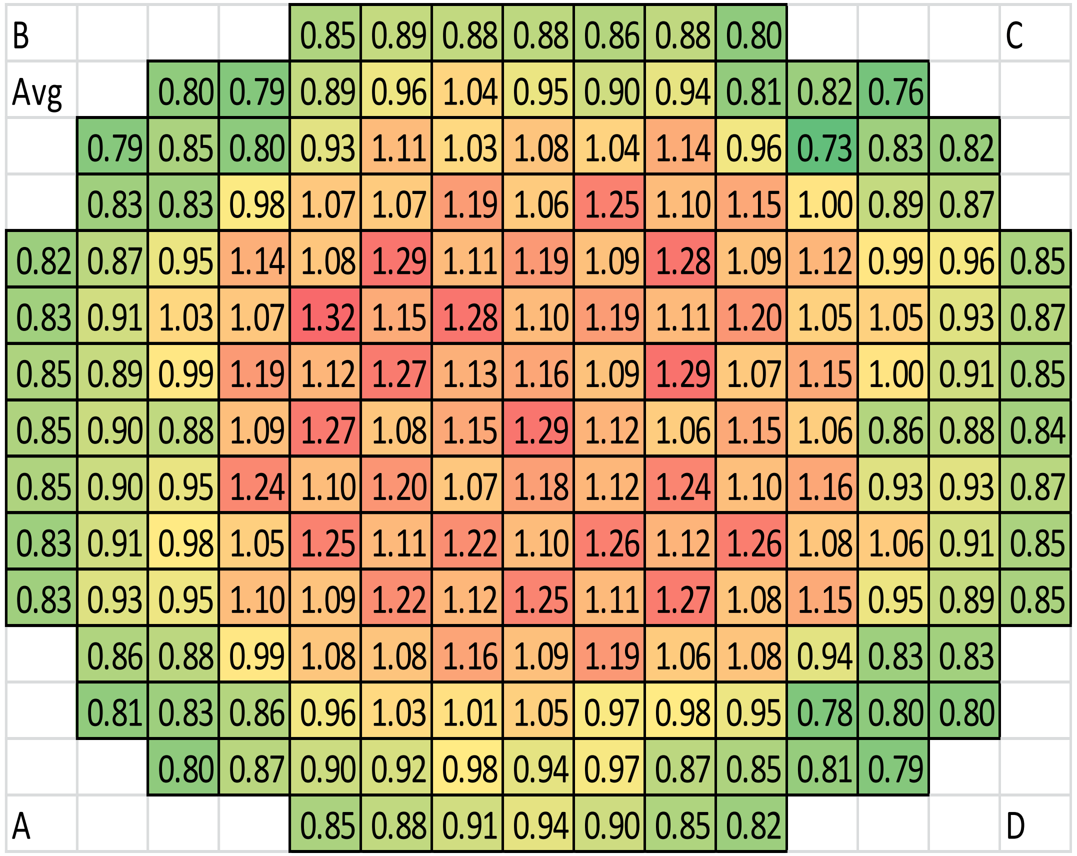
Most limiting T/H conditions
- Core inlet flow rate
- Core inlet temperature
- Core outlet pressure

CFD

- Core inlet temperature distribution
- Core inlet mass flow rate distribution

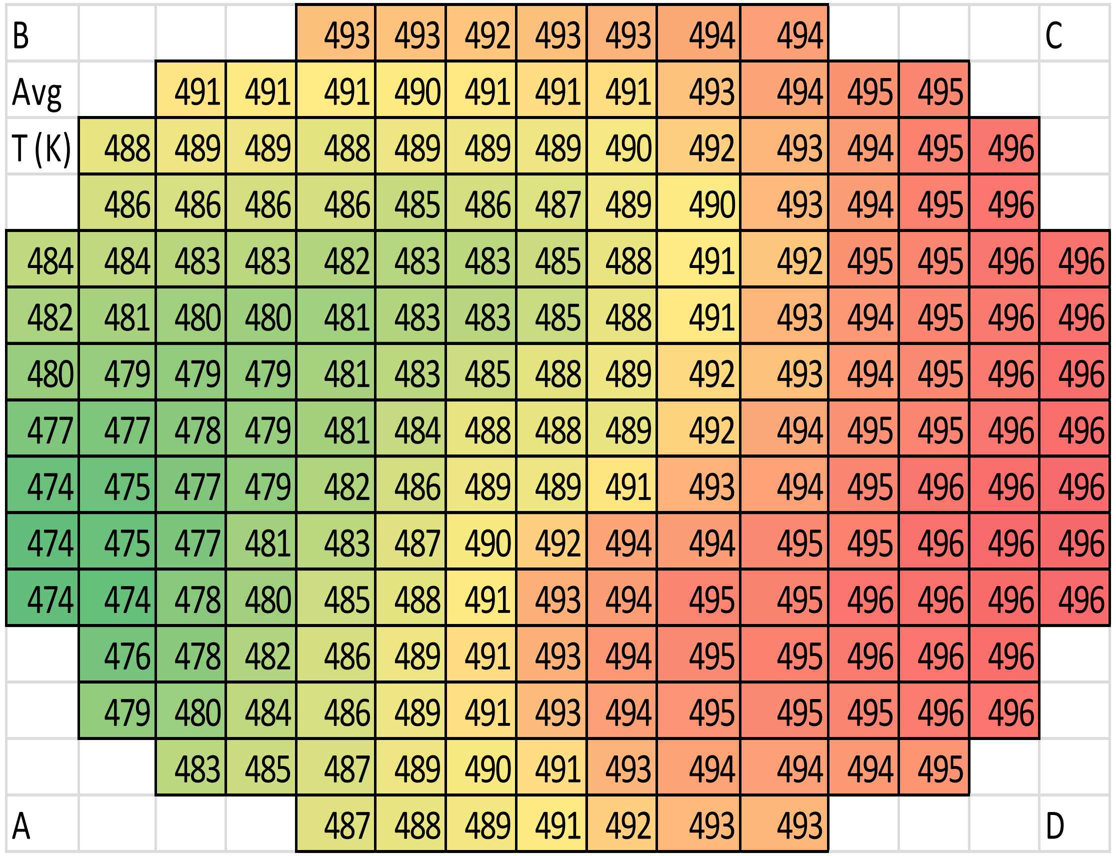
VERA-CS pin-resolved coupled simulation

MSLB Activity



B				0.85	0.89	0.88	0.88	0.86	0.88	0.80				C
Avg		0.80	0.79	0.89	0.96	1.04	0.95	0.90	0.94	0.81	0.82	0.76		
	0.79	0.85	0.80	0.93	1.11	1.03	1.08	1.04	1.14	0.96	0.73	0.83	0.82	
	0.83	0.83	0.98	1.07	1.07	1.19	1.06	1.25	1.10	1.15	1.00	0.89	0.87	
0.82	0.87	0.95	1.14	1.08	1.29	1.11	1.19	1.09	1.28	1.09	1.12	0.99	0.96	0.85
0.83	0.91	1.03	1.07	1.32	1.15	1.28	1.10	1.19	1.11	1.20	1.05	1.05	0.93	0.87
0.85	0.89	0.99	1.19	1.12	1.27	1.13	1.16	1.09	1.29	1.07	1.15	1.00	0.91	0.85
0.85	0.90	0.88	1.09	1.27	1.08	1.15	1.29	1.12	1.06	1.15	1.06	0.86	0.88	0.84
0.85	0.90	0.95	1.24	1.10	1.20	1.07	1.18	1.12	1.24	1.10	1.16	0.93	0.93	0.87
0.83	0.91	0.98	1.05	1.25	1.11	1.22	1.10	1.26	1.12	1.26	1.08	1.06	0.91	0.85
0.83	0.93	0.95	1.10	1.09	1.22	1.12	1.25	1.11	1.27	1.08	1.15	0.95	0.89	0.85
	0.86	0.88	0.99	1.08	1.08	1.16	1.09	1.19	1.06	1.08	0.94	0.83	0.83	
	0.81	0.83	0.86	0.96	1.03	1.01	1.05	0.97	0.98	0.95	0.78	0.80	0.80	
		0.80	0.87	0.90	0.92	0.98	0.94	0.97	0.87	0.85	0.81	0.79		
A				0.85	0.88	0.91	0.94	0.90	0.85	0.82				D

Inlet mass flow rate multiplier map



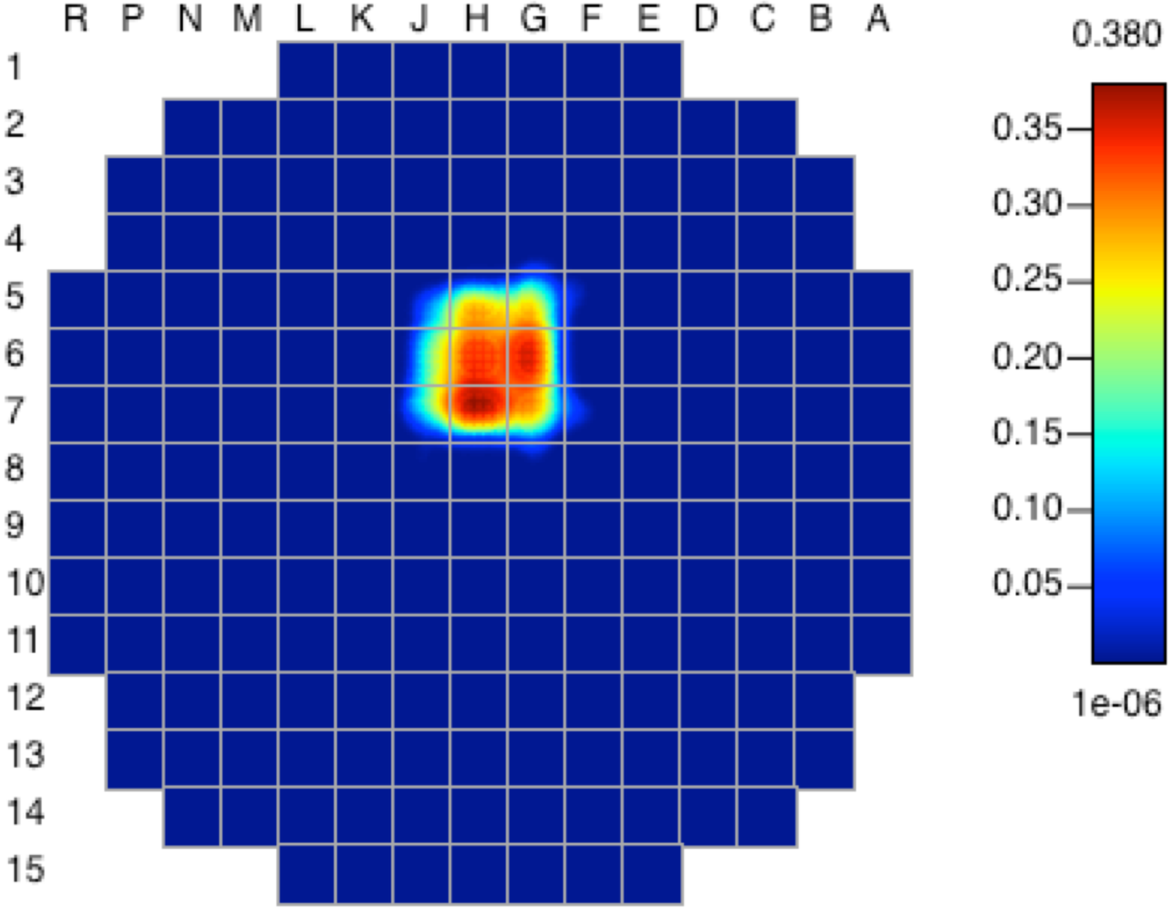
B				493	493	492	493	493	494	494				C
Avg		491	491	491	490	491	491	491	493	494	495	495		
T (K)	488	489	489	488	489	489	489	490	492	493	494	495	496	
	486	486	486	486	485	486	487	489	490	493	494	495	496	
484	484	483	483	482	483	483	485	488	491	492	495	495	496	496
482	481	480	480	481	483	483	485	488	491	493	494	495	496	496
480	479	479	479	481	483	485	488	489	492	493	494	495	496	496
477	477	478	479	481	484	488	488	489	492	494	495	495	496	496
474	475	477	479	482	486	489	489	491	493	494	495	496	496	496
474	475	477	481	483	487	490	492	494	494	495	495	496	496	496
474	474	478	480	485	488	491	493	494	495	495	496	496	496	496
	476	478	482	486	489	491	493	494	495	495	496	496	496	
	479	480	484	486	489	491	493	494	495	495	495	496	496	
		483	485	487	489	490	491	493	494	494	494	495		
A				487	488	489	491	492	493	493				D

Inlet temperature multiplier map

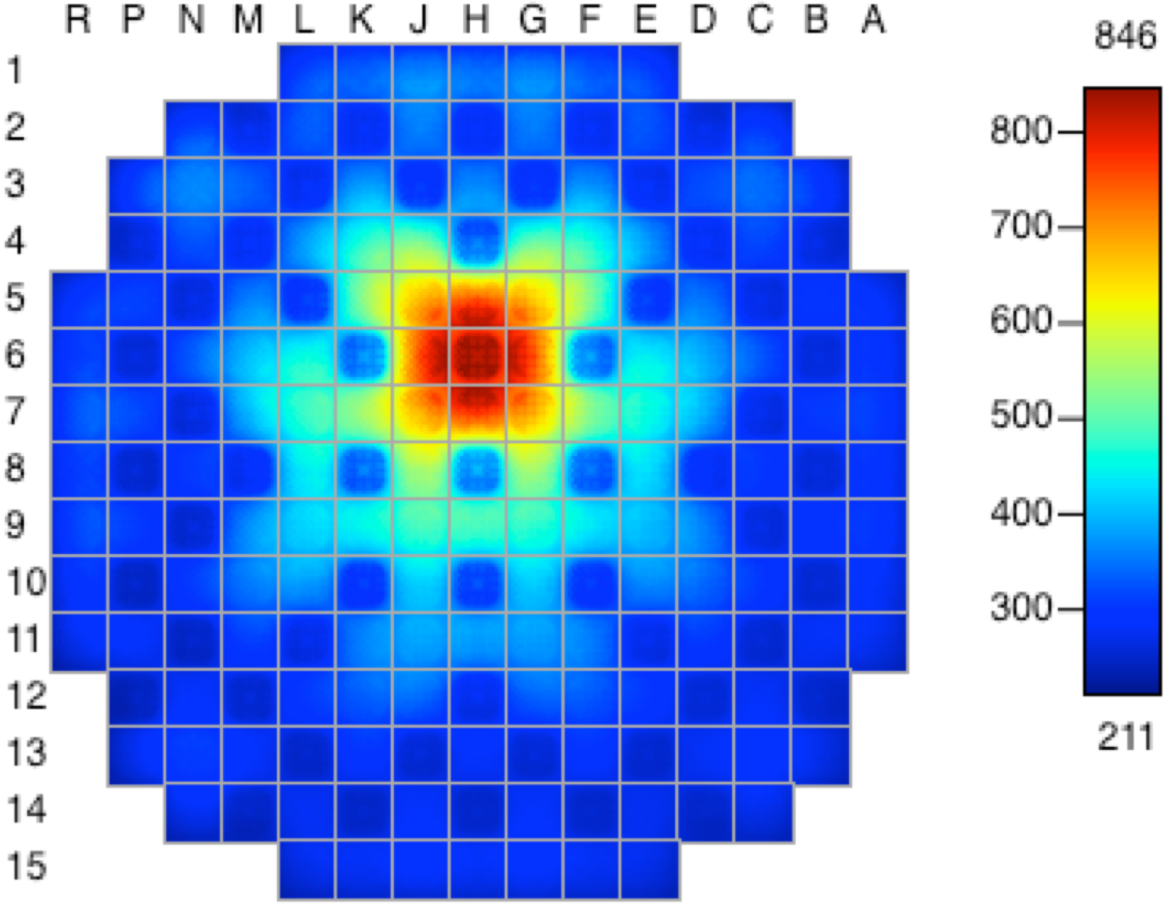
Analyze Results

- Find the minimum DNBR
- Compare values of two CHF models

Analyze results

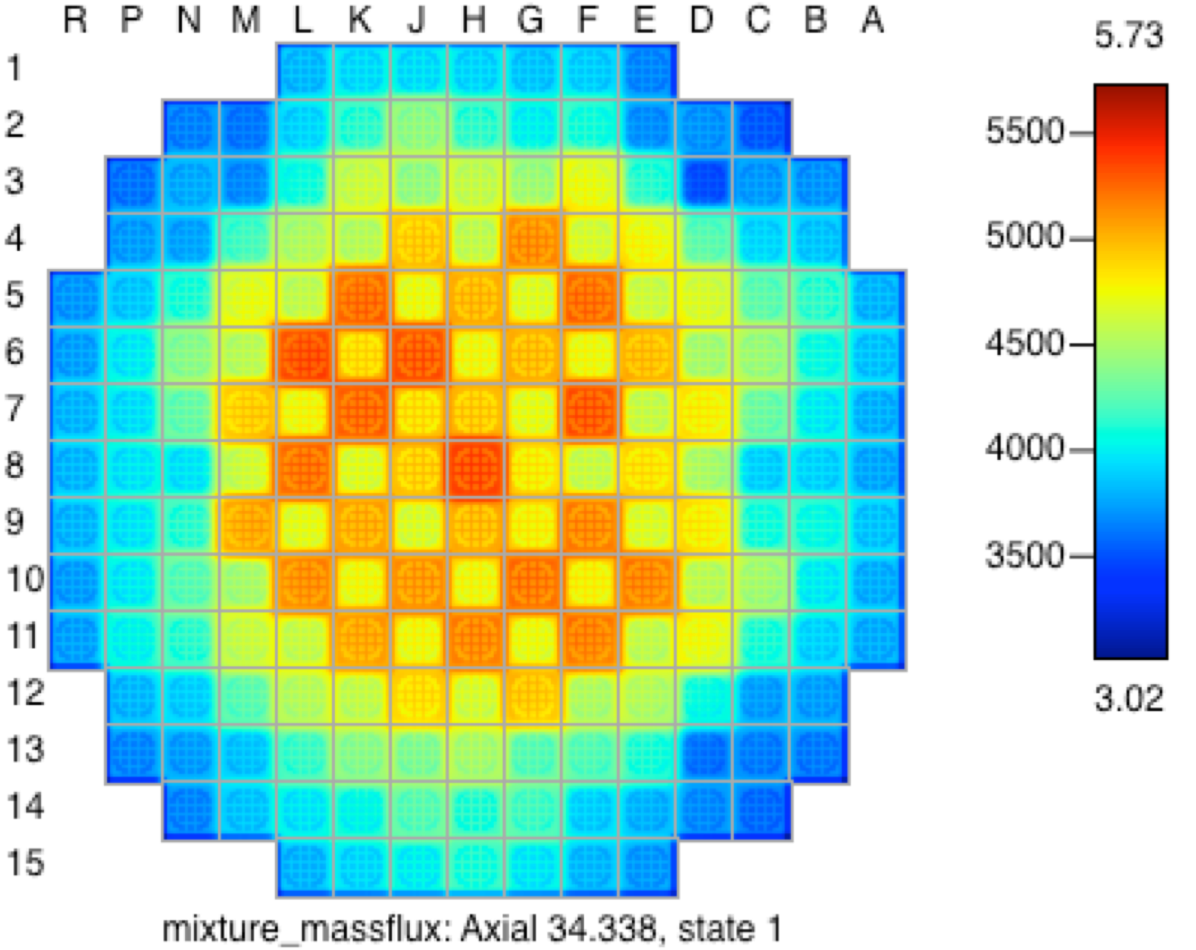


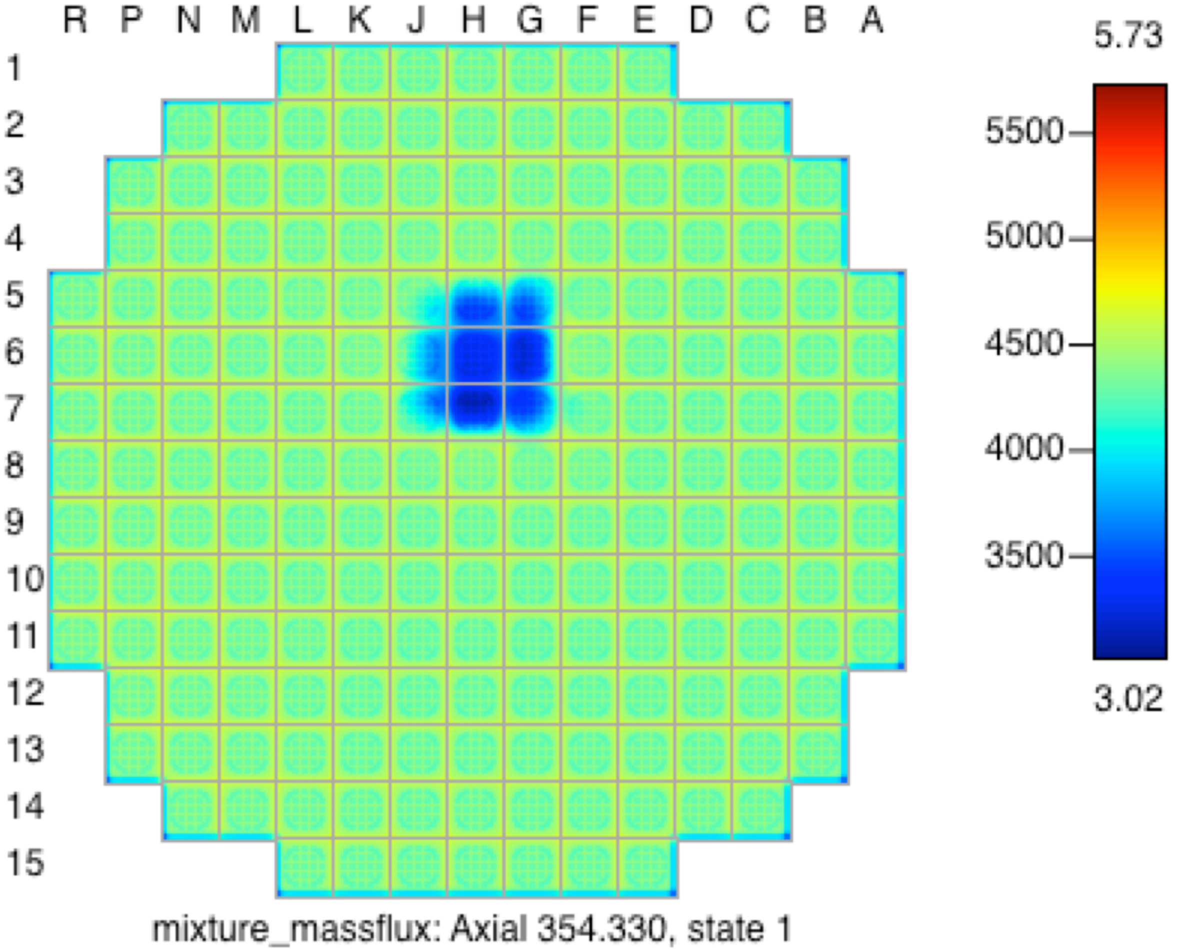
vapor_void: Axial 361.950, state 1



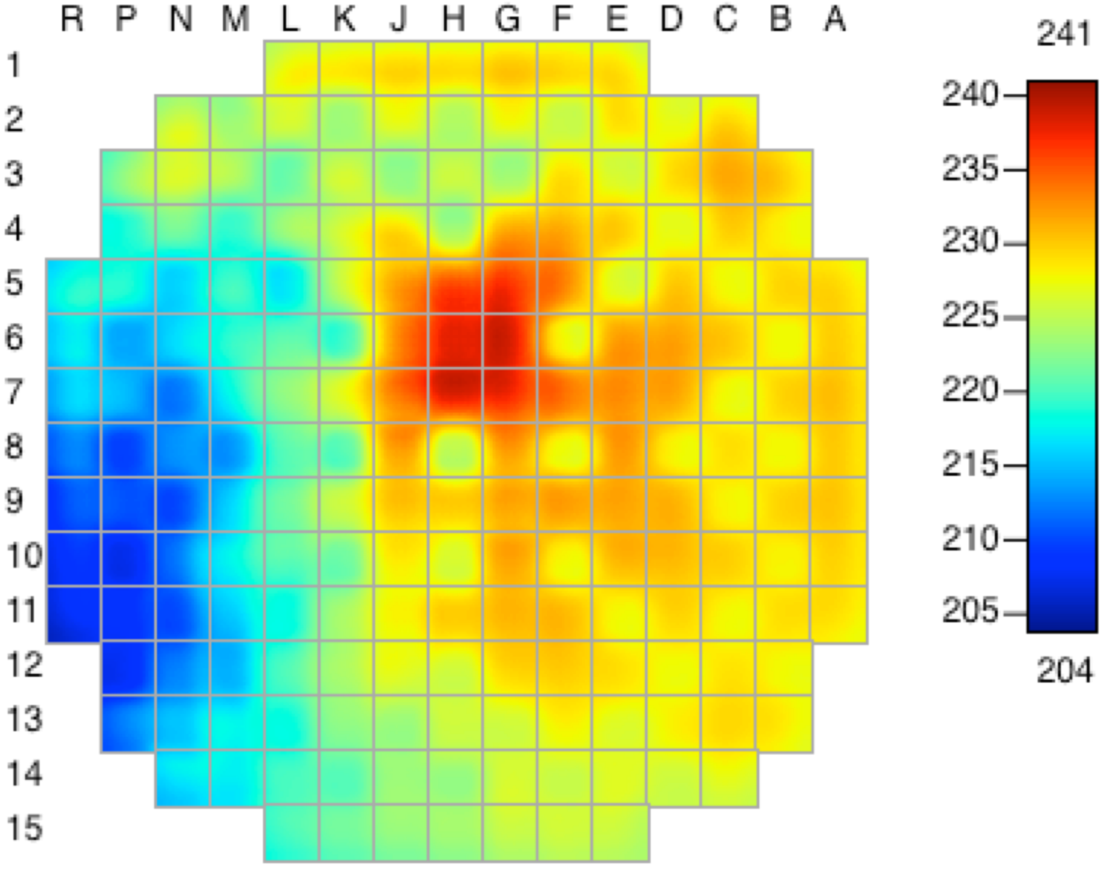
pin_fueltemps: Axial 34.338, state 1

Analyze results

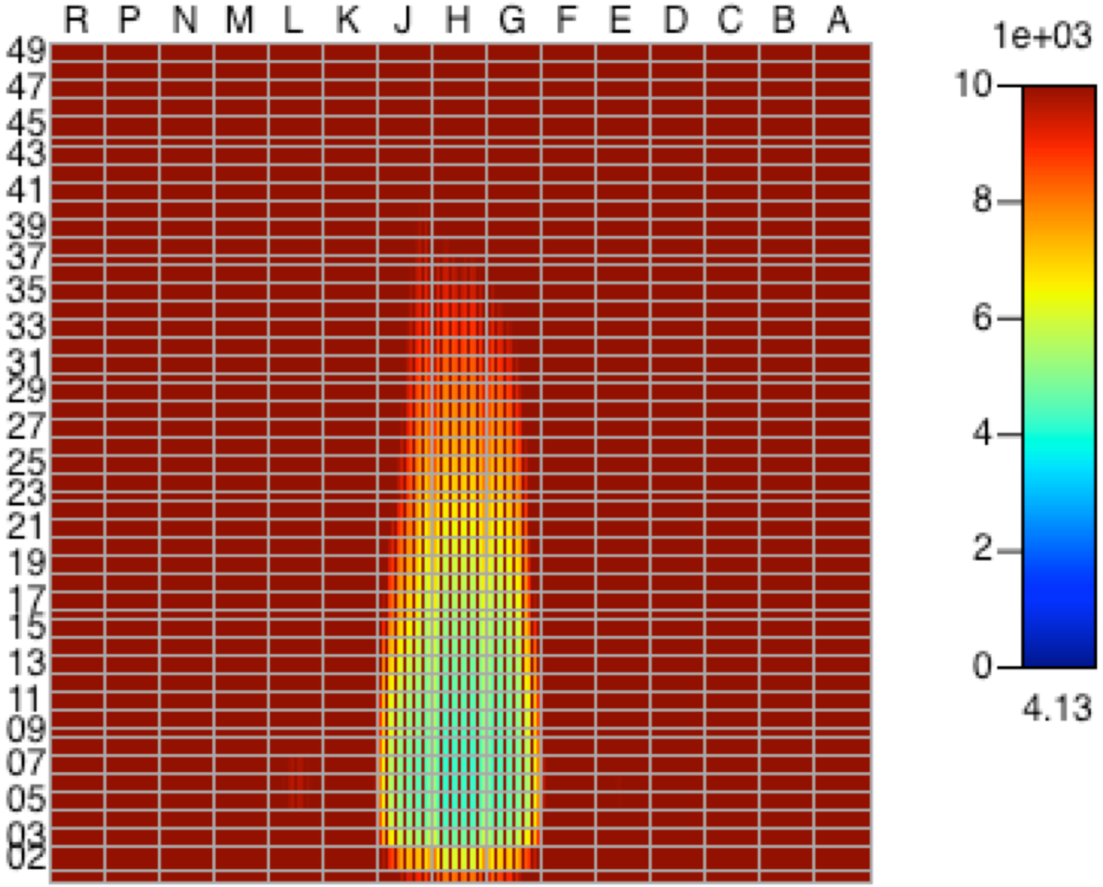




Analyze results



channel_liquid_temps: Axial 219.837, state 1



pin_dnbr: Assy Row 6, Pin Col 9, state 1

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