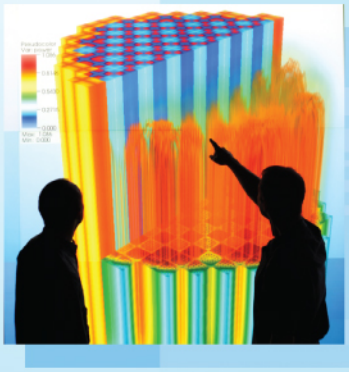
Power uprates
and plant life extension

CASL-U-2014-0009-000

Consortium for Advanced Simulation of LWRs



Engineering design
and analysis

Milestone L1:CASL.P7.04

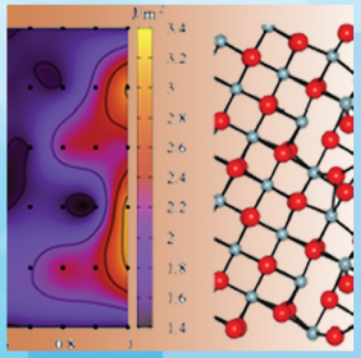
RSICC Release Testing Results Summary

Andrew Godfrey

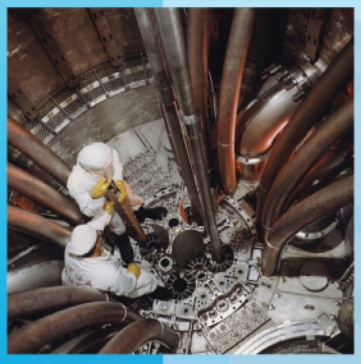
Oak Ridge National Laboratory

September 30, 2013

Science-enabling
high performance
computing



Fundamental science



Plant operational data

U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Date: 9/30/2013

To: Matt Sieger

c: Jess Gehin

From: Andrew Godfrey

Subject: RSICC Release Testing Results

Matt,

I have completed a thorough technical review of the VERA capabilities which are being released to RSICC. This memo provides documentation of the readiness of VERA for external release for several specific capabilities. In summary, I have found that all the components meet our expectations of capability and performance at this time. The capabilities tested are described in this memo, and any limitations are noted.

Attached is a detailed description of the test cases, computation requirements, and relevant results used for determining the readiness of the tested components. Included are eigenvalue and pin power comparisons to CE KENO-VI for over sixty cases used to assess VERA for its neutronics capability.

The following release tarball was created by Ross Bartlett for testing:
/projects/vera/tarballs/vera-3.2-Source.20130927.tar.gz

The contents of this release was built by Mark Baird in two locations for testing:
natasha.ornl.gov: /projects/vera/Andrew_2013927
titan.ccs.ornl.gov: /tmp/proj/nfi007/mbaird/Andrew_20130927

The following capabilities have been tested (for Westinghouse PWR 17x17-type assemblies);

1. Zero power neutronics calculations (no T/H feedback)
   a. 2D and 3D, up to quarter core, calculations with Insilico.
   b. 2D single pin cell and single lattice calculations with MPACT.
2. Stand-alone thermal-hydraulics calculations for single fuel rods and single assemblies using COBRA-TF.
3. Full power neutronics+T/H coupled calculations for a single assembly using Insilico and COBRA-TF.

These capabilities correspond to the Core Physics Benchmark Progression Problems 1-6 (Reference 1). All the tested cases used the common VERA input structure (VERAIN). Only the SP_N neutronics method was tested (not the S_N).

Please review the assessment in the attached checklist and feel free to let me know if you have any questions.

Regards,

Andrew T. Godfrey

References:

1. A.T. Godfrey, "VERA Core Physics Benchmark Progression Problem Specifications", Revision 2, CASL-U-2012-0131-002, CASL, March 29, 2013.

RSICC Release Testing Results – Completed 9/30/2013

1. Core Physics Problems

A series of neutronics-only problems were executed with Insilico using the SP_5 approximation and 252 energy group cross sections, and MPACT using the 60 group ORNL sub-group library.

<table>
<tr><th>Problem</th><th>Resources</th><th>Description</th><th>Results</th><th>Ready</th></tr>
<tr><td>a. Problem 1</td><td>1 core
2 GB/core
14 secs</td><td>Predict reactivity for single solid fuel 2D pin cells</td><td>Problems 1a-1e executed and compared to CE KENO-VI reactivity results.
Avg. eigenvalue difference = -252 pcm

MPACT was not used. Successful testing of Problem 2 provides sufficient evidence of single pin cell capability.</td><td>☑</td></tr>
<tr><td>b. Problem 2</td><td>Insilico:
16 cores
2 GB/core
46 secs
98 secs for IFBA cases

MPACT:
8 cores
?? GB/core
41 secs
310 secs for IFBA cases</td><td>Predict reactivity and pin power distributions for 2D lattices</td><td>Problems 2a-2q executed for both codes and compared to CE KENO-VI results. The pin power (fission rate only) comparisons are provided in absolute percent $(P_2\text{-}P_1)\times100$.
<table>
<tr><th>Insilico</th><th>Eigenvalue (pcm)</th><th>RMS (%)</th><th>Max (%)</th></tr>
<tr><td>Average</td><td>-131</td><td>0.26</td><td>0.64</td></tr>
<tr><td>St. Dev.</td><td>205</td><td>0.14</td><td>0.50</td></tr>
<tr><td>Max</td><td>-700</td><td>1.40</td><td>2.23</td></tr>
</table>
<table>
<tr><th>MPACT</th><th>Eigenvalue (pcm)</th><th>RMS (%)</th><th>Max (%)</th></tr>
<tr><td>Average</td><td>-119</td><td>0.16</td><td>0.56</td></tr>
<tr><td>St. Dev.</td><td>186</td><td>0.07</td><td>0.82</td></tr>
<tr><td>Max</td><td>-341</td><td>0.28</td><td>3.48</td></tr>
</table>
MPACT performs well for all cases except for 2J. A bug exists which prevents accurate results for cases with both instrumentation</td><td>☑</td></tr>
</table>

<table>
<tr><td></td><td></td><td></td><td>thimbles and discrete burnable poisons.

Insilico pin power accuracy decreases for the control lattices.

See Figure 1 for detailed eigenvalue results.</td><td></td></tr>
<tr><td>c. Problem 3</td><td>64 cores
2 GB/core
7 mins</td><td>Predict reactivity and pin power distributions for 3D assemblies – including spacer grids, Pyrex, and axial structure geometries</td><td>Problems 3a and 3b executed with Insilico and compared to CE KENO-VI.

<table><tr><th>Insilico</th><th>Eigenvalue (pcm)</th><th>RMS (%)</th><th>Max (%)</th></tr><tr><td>Average</td><td>-85</td><td>0.29</td><td>3.10</td></tr><tr><td>Max</td><td>-3</td><td>0.44</td><td>3.48</td></tr></table>
Insilico exhibits somewhat larger axial power deviations at spacer grid locations (Figure 2).</td><td>☑</td></tr>
<tr><td>d. Problem 4</td><td>144 cores
2 GB/core
11 mins</td><td>Predict reactivity, pin powers, and control rod worth for a 3D 3x3 assembly configuration – including Pyrex and hybrid control rods</td><td>Problem 4 (12 cases) was executed with Insilico only with the following results:
Average eigenvalue differences of -40 pcm (<=67 pcm)
3D pin power comparisons of 0.44% RMS and 1.8% maximum difference
3D assembly power comparisons of 0.35% RMS and 1.1% maximum difference
Differential Rod Worth differences of -3 pcm (<=23 pcm)
Integral Rod Worth error of 0.9%
See Figures 3 and 4 for detailed results.</td><td>☑</td></tr>
<tr><td>e. Problem 5</td><td>256 cores
16 GB/core
35 mins</td><td>Predict the criticality, control bank worths, boron worth, and temperature coefficient for a startup core (WBN1)</td><td>The ten critical configurations for Watts Bar Nuclear 1 (WBN1) were executed with Insilico and compared to CE KENO-VI results.</td><td>☑</td></tr>
</table>

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<table>
<tr><th>Insilico</th><th>KENO-VI Difference (pcm)</th></tr>
<tr><td>Average</td><td>54</td></tr>
<tr><td>St. Dev.</td><td>35</td></tr>
<tr><td>Max</td><td>90</td></tr>
</table>

The axial mesh size used for these calculations was increased to ~3” between spacer grids. These affected the core reactivity by less than 2 pcm. Axial power distribution convergence is reached at ~0.5”, which requires much more memory and processors to solve.

Power distribution was not evaluated for this test since a reference solution is not currently available.

The boron worth was not test but is expected to be accurate based on the similarity of these results with previous milestone calculations.

The Isothermal Temperature Coefficient (ITC) calculated by Insilico is known to be inaccurate. This is still being evaluated.
</td>
<td></td>
</tr>
<tr>
<td>f. Extension of Problem 5 (2D)</td>
<td>64 cores
4 GB/core
3 mins</td>
<td>Predict the pin power distribution for a 2D core (problem 5-2D)</td>
<td>Problem 5-2D was executed with Insilico with the following results:
• Eigenvalue differences of -14 pcm and -6 pcm
• 2D pin power comparisons of 0.78% RMS and 4.5% maximum difference
• 2D assembly power comparisons of 0.64% RMS and 1.1% maximum difference</td>
<td>☑</td>
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			• AIC Rod Worth error of 0.7% See Figure 5 for the power distribution results for the uncontrolled case.	

Figure 1: 2D Lattice Reactivity Results (Problem 2)

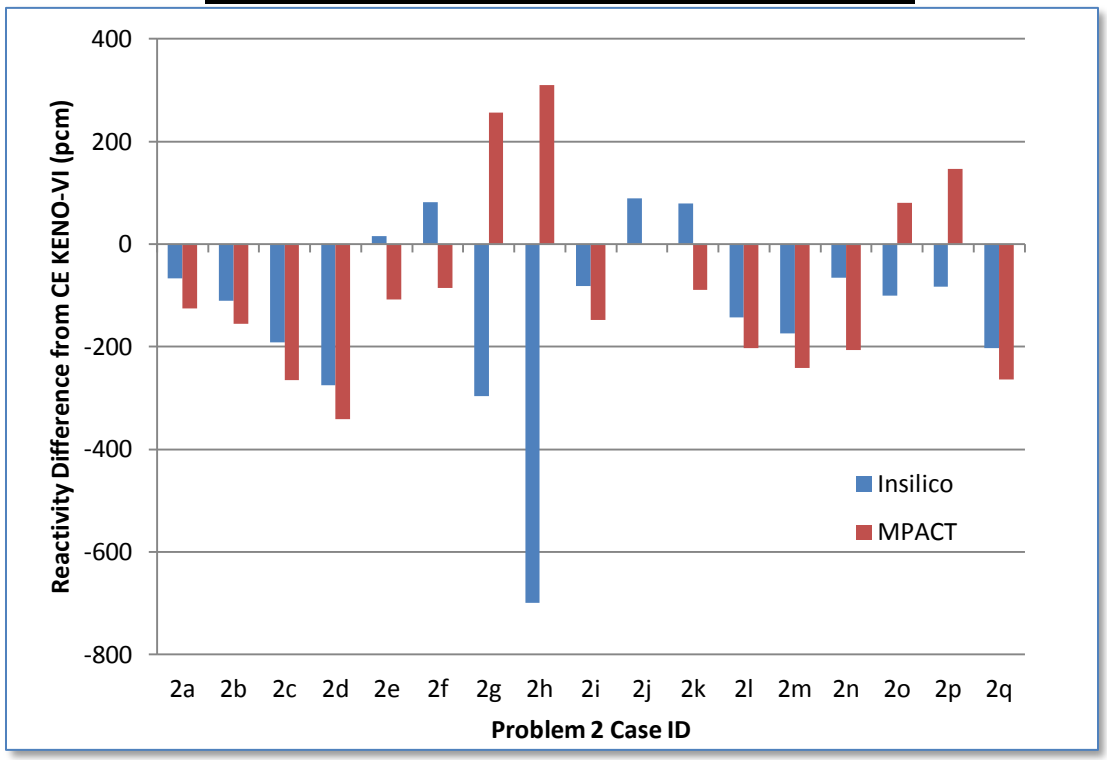


Figure 2: 3D Assembly Axial Power Distribution Results (Problem 3)

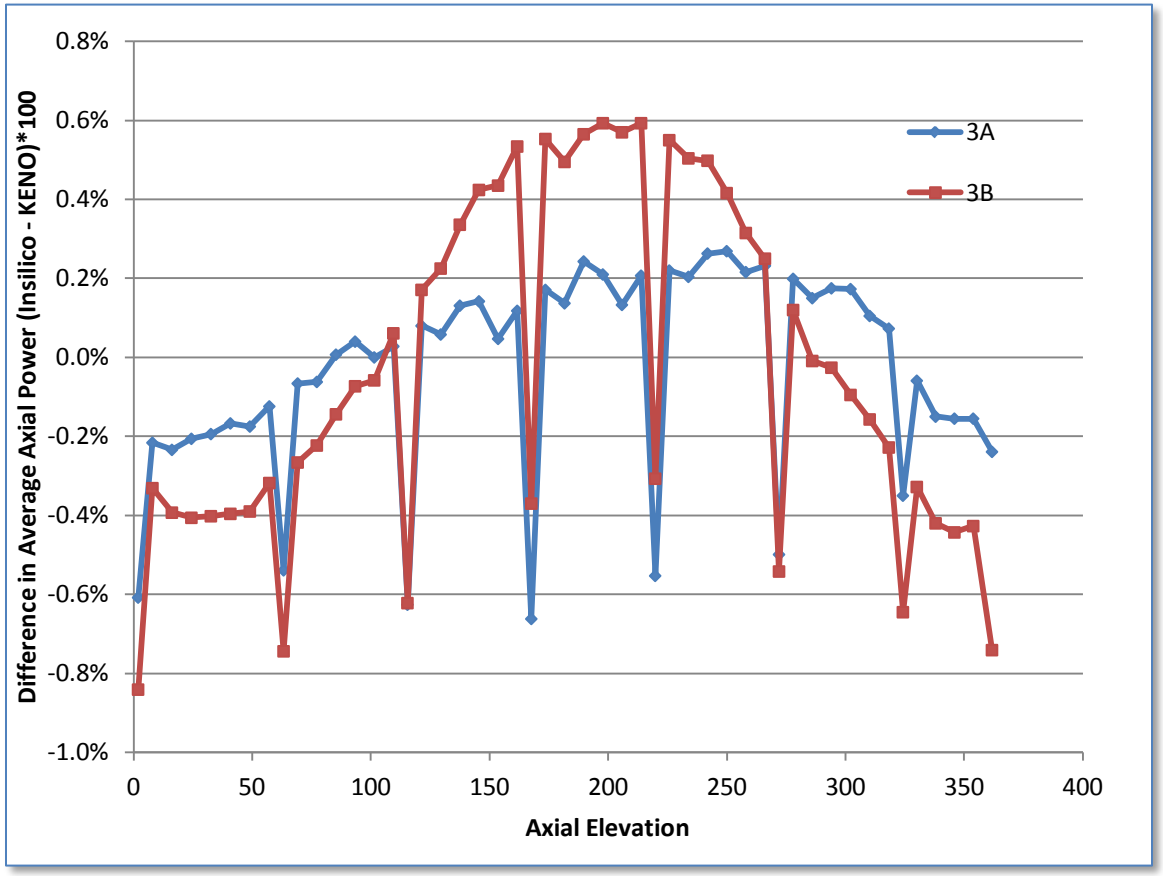


Figure 3: 3D Multi-Assembly with Control Rod Axial Power Distribution Results (Problem 4)

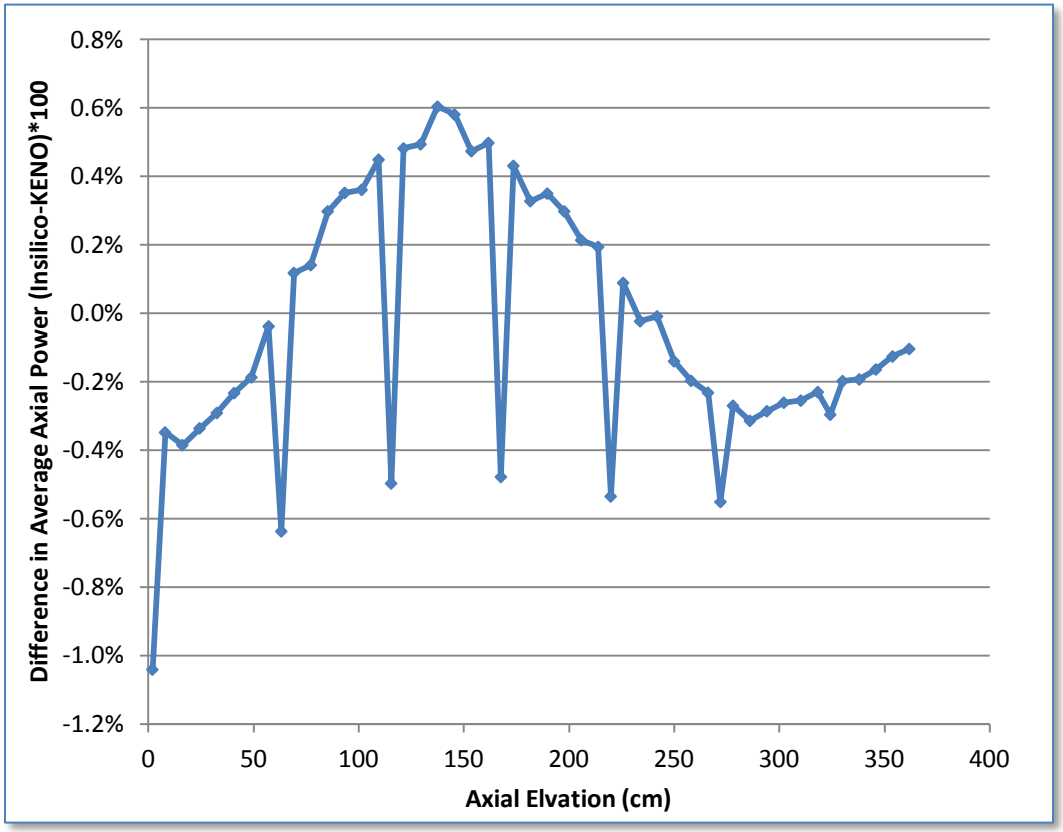


Figure 4: 3D Multi-Assembly Control Rod Worth Results (Problem 4)

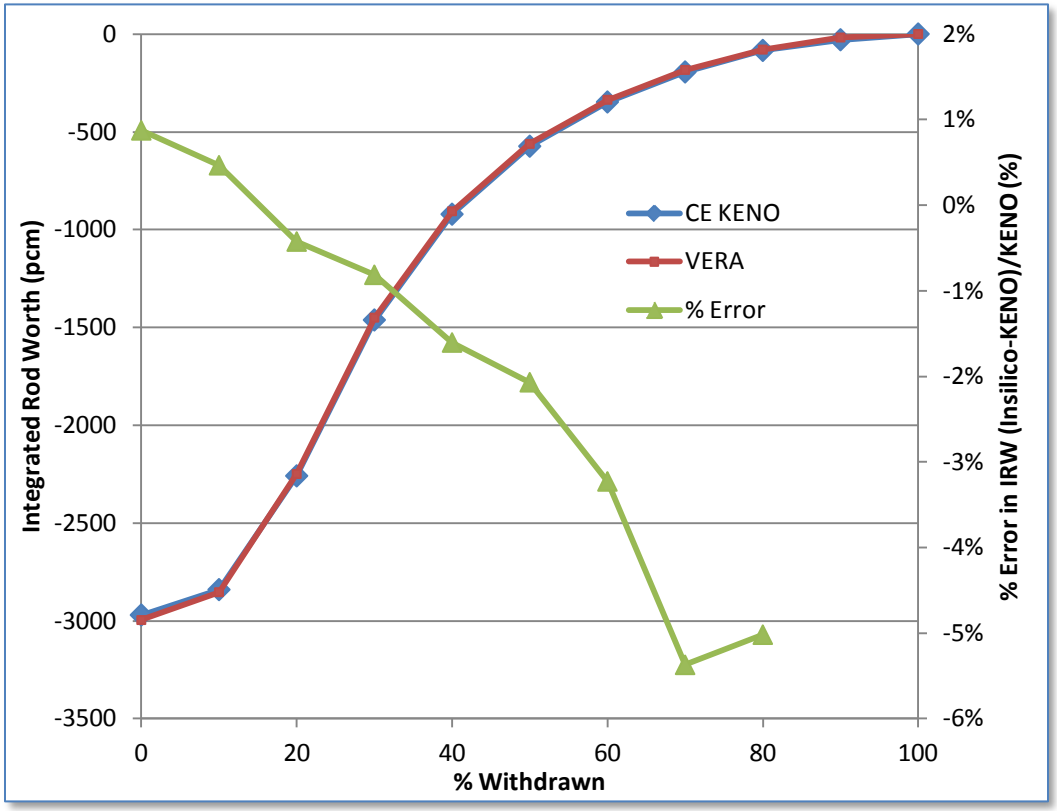
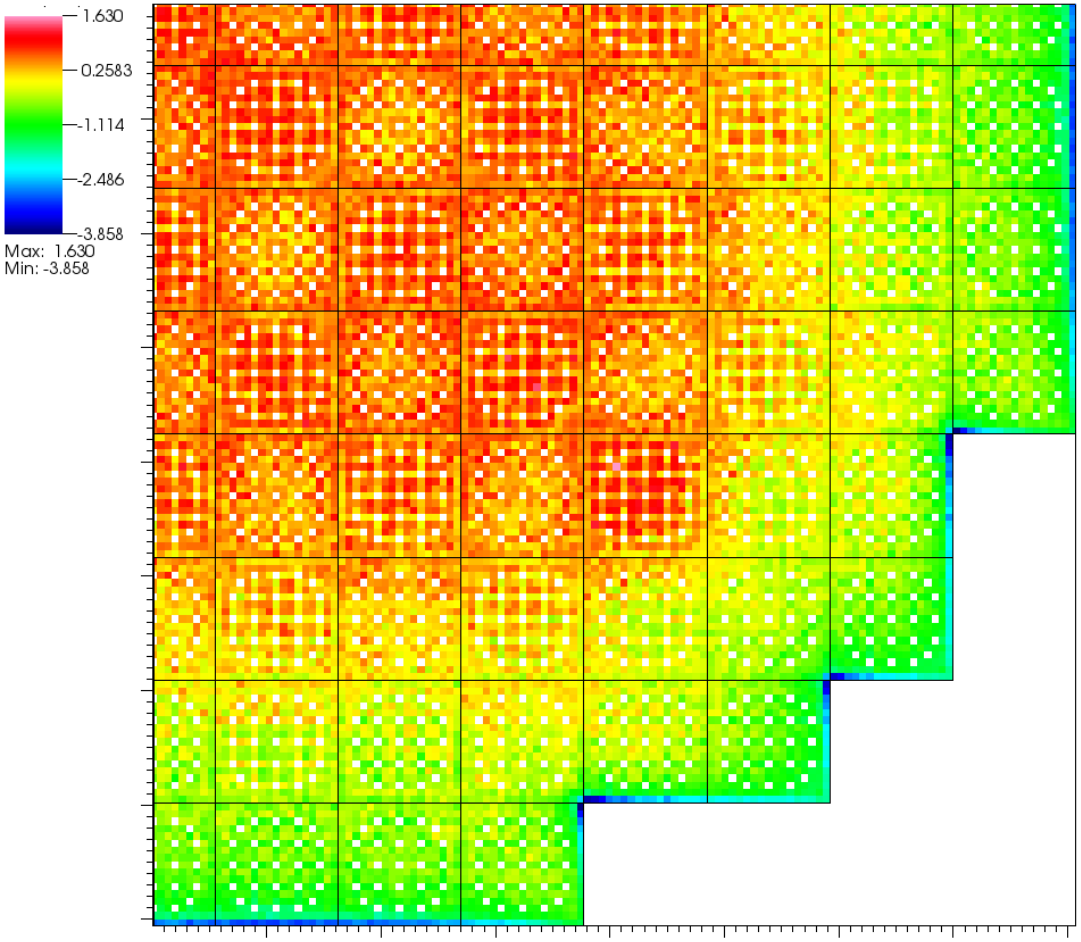


Figure 5: 2D Quarter Core Pin Powers Results (Insilico-KENO)×100



2. Single COBRA-TF Calculations

A series of thermal-hydraulics-only problems were executed with COBRA-TF using the VERA common input. No reference solutions exist, but the results were reviewed and appeared reasonable for the given reactor conditions. The power distribution used for these calculations was provided by default by the COBRA-TF pre-preprocessor.

Problem	Resources	Description	Results	Ready
a. Single Rod	1 core ? GB/core 3 secs	Predict coolant density, fuel temperature, and pressure drops for flow up a typical PWR fuel rod at typical conditions.=	Execution successful. Outlet temperature and density, peak fuel temperature, and pressure drops appear reasonable. Results also evaluated by Bob Salko (PHI, ORNL) and accepted.	☑
b. 3x3 Rods	1 core ? GB/core 4 secs	Predict coolant density, fuel temperature, and pressure drops for flow up a typical PWR fuel rod cluster at typical conditions. This is eight fuel rods surrounding a central control rod guide tube, and including six intermediate spacer grids (as per WB1)	Execution successful. Outlet temperature and density, peak fuel temperature, and pressure drops appear reasonable. Results also evaluated by Bob Salko (PHI, ORNL) and accepted.	☑
c. Single Fuel Assembly	1 cores ? GB/core 105 secs	Same as above. Input used geometrically identical to Core Physics progression problems 3 and 6.	Same as above.	☑

Note that the single problem must be run with symmetry set to full or COBRA-TF will crash.

3. Coupled Insilico-COBRA-TF Calculation

A hot-full-power single assembly coupled calculation was performed representing Core Physics Problem 6 on Titan using the exact geometric input from Problem 3 and the same Insilco configuration and settings. This job ran successfully on 289 cores with 4 GB of memory per core and completed in approximately 2 hours. The coupling traversed 11 outer iterations and converged on a reasonable eigenvalue and power distribution; though no reference solution is available for comparison, so the accuracy of this capability cannot be determined. The COBRA-TF output files were also reviewed for reasonableness and quantities such as the outlet coolant conditions, peak fuel temperature, and axial pressure drops all were sensible. Figure 6 displays the 3D pin power distribution results from the uncoupled problem (Problem 3) on the left and the coupled result (Problem 6) on the right. Note that an axial shift in power

distribution is not necessarily expected due to the high soluble boron concentration used for this calculation (1300 ppm). Also, there is a current limitation in the COBRA-TF coupling that prevents the use of quarter symmetry.

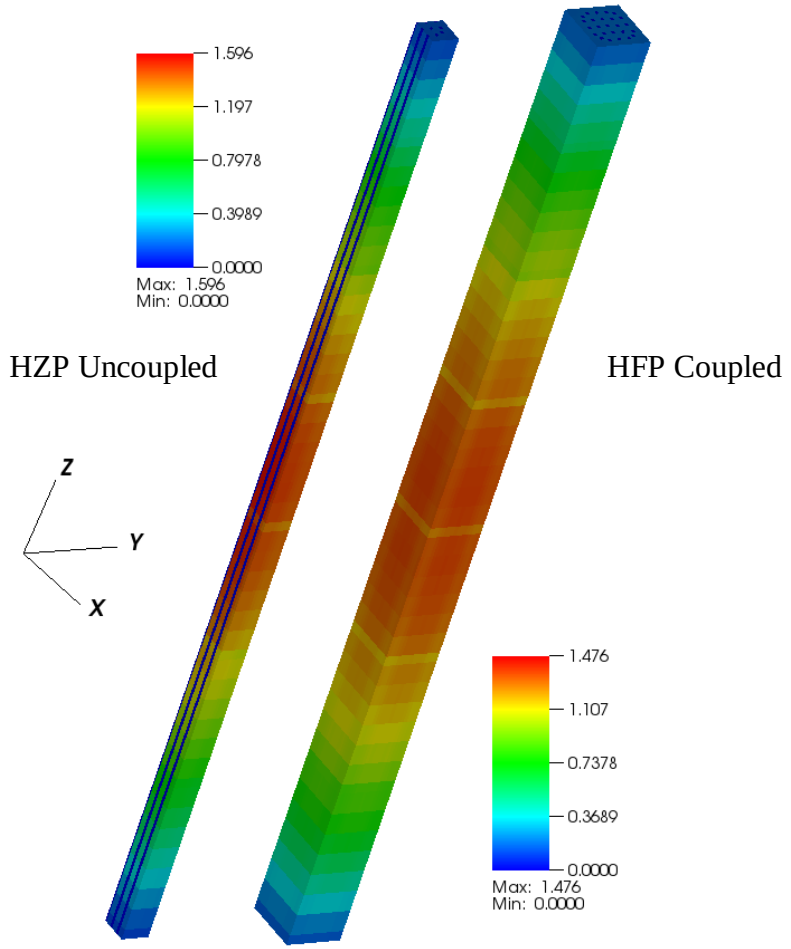



Figure 6: 3D Assembly Pin Powers For Problems 3 and 6