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Title: THM-GTRF: New Spider meshes, New Hydra-TH runs

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THM-GTRF: New Spider meshes, New Hydra-TH runs

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CASL Virtual Round Table Meeting, June 11-14, 2012

THM-GTRF: New Spider meshes, New Hydra-TH runs

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Abstract: Progress is reported on computational capabilities for the grid-to-rod-fretting (GTRF) problem of pressurized water reactors. Numeca's Hexpress/Hybrid mesh generator is demonstrated as an excellent alternative to generating computational meshes for complex flow geometries, such as in GTRF. Mesh assessment is carried out using standard industrial computational fluid dynamics practices. Hydra-TH, a simulation code developed at LANL for reactor thermal-hydraulics, is demonstrated on hybrid meshes, containing different element types. A series of new Hydra-TH calculations has been carried out collecting turbulence statistics. Preliminary results on the newly generated meshes are discussed; full analysis will be documented in the L3 milestone, THM.CFD.P5.05, Sept. 2012.

Overview

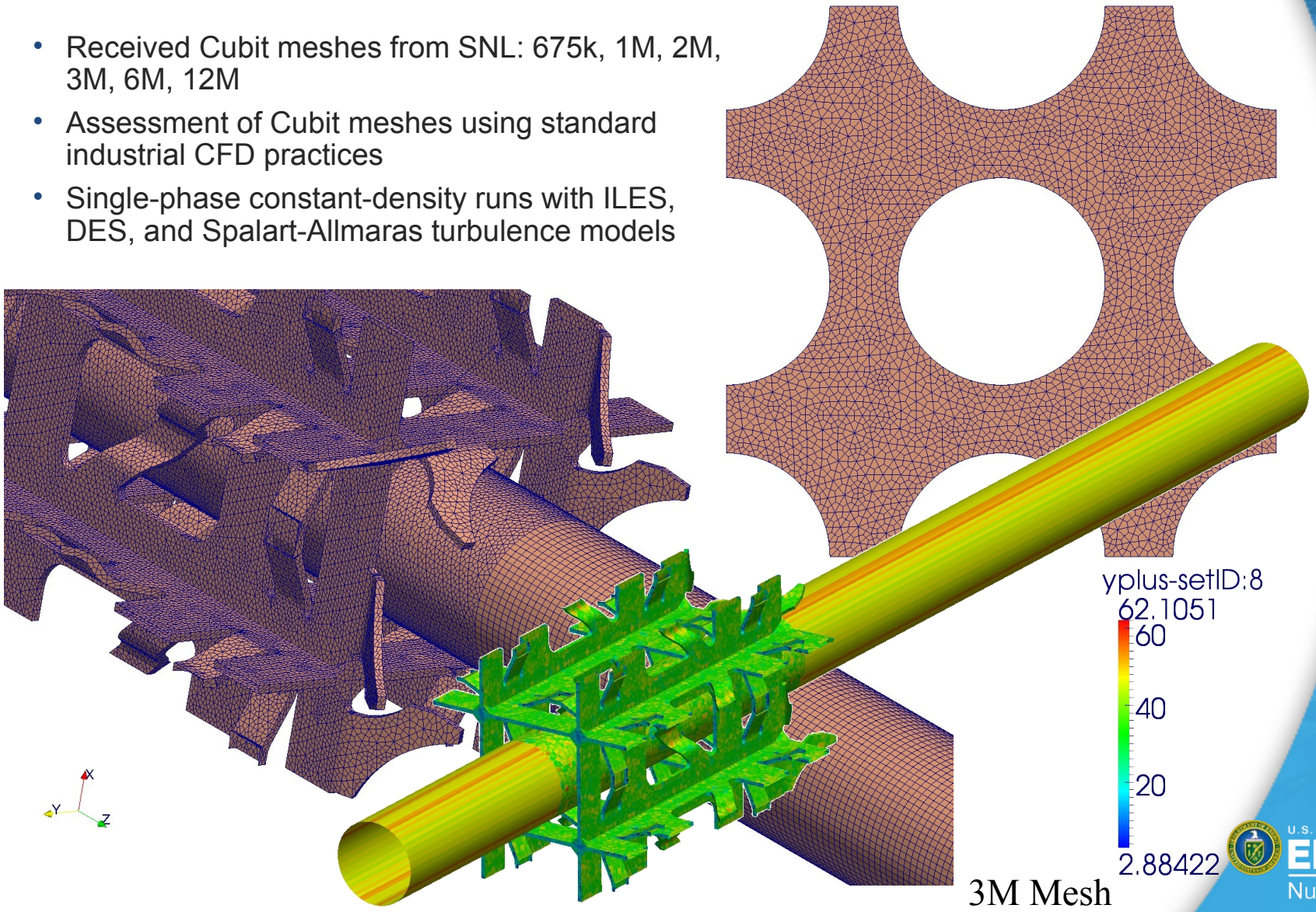
- Background
  - Our Dec. 2011 GTRF-milestone: *"Initial Assessment of Hydra-TH on GTRF Problems"* (THM.CFD.P4.01)
- Current work for L3 milestone THM.CFD.P5.05, Sept. 2012:
  - New hybrid meshes with Spider: 3x3, 5x5
  - New Hydra-TH runs, now collecting turbulence statistics
- Summary

Background

Background

Snapshots from THM.CFD.P4.01 L2 milestone from Dec. 2011

- Received Cubit meshes from SNL: 675k, 1M, 2M, 3M, 6M, 12M
- Assessment of Cubit meshes using standard industrial CFD practices
- Single-phase constant-density runs with ILES, DES, and Spalart-Allmaras turbulence models

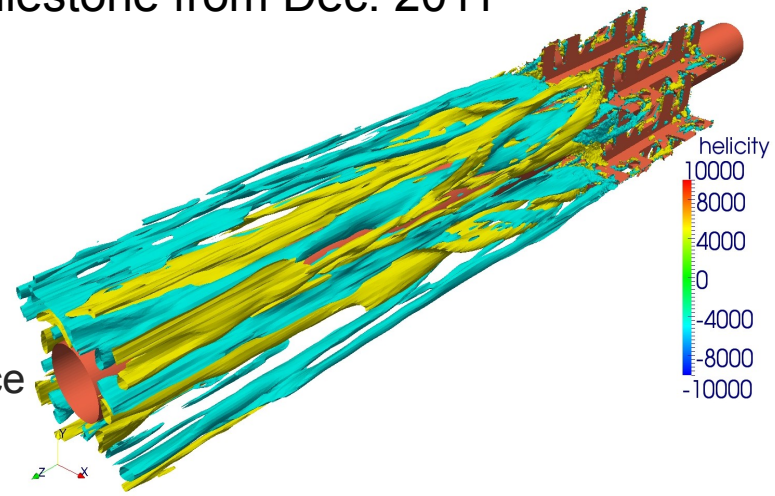


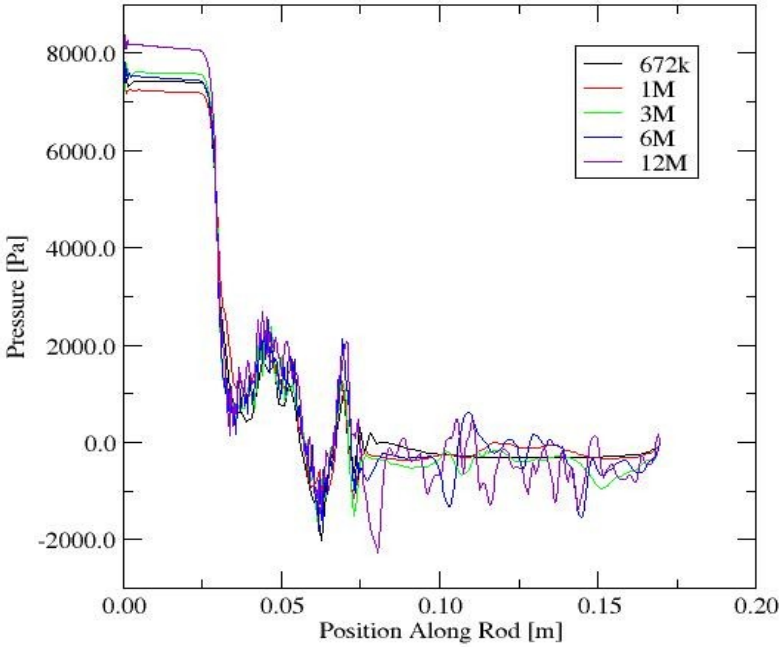
3M Mesh

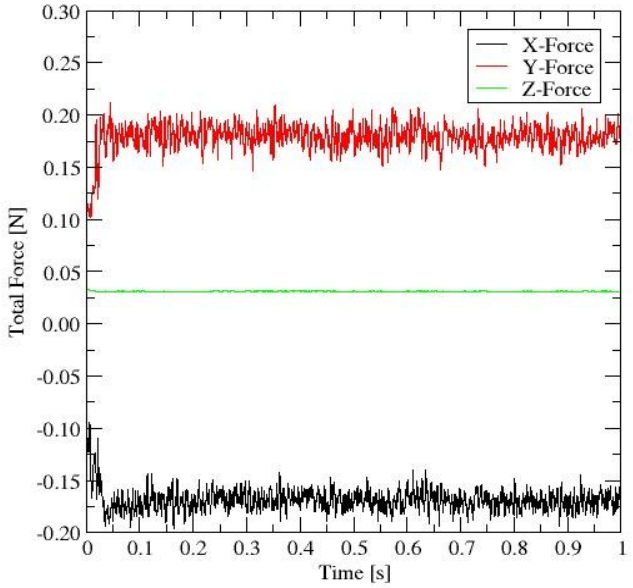
Background

Snapshots from THM.CFD.P4.01 L2 milestone from Dec. 2011

- Strong vortical structures captured
- Rod force time-histories suggest URANS may not be a good option for GTRF
- Largest Cubit mesh (at the time: 12M) suggests pressure drop not converged
- **Unresolved issues:** mesh quality, convergence, pressure drop, no turbulence statistics, which turbulence model to use, influence of periodic and outlfow BCs, domain length







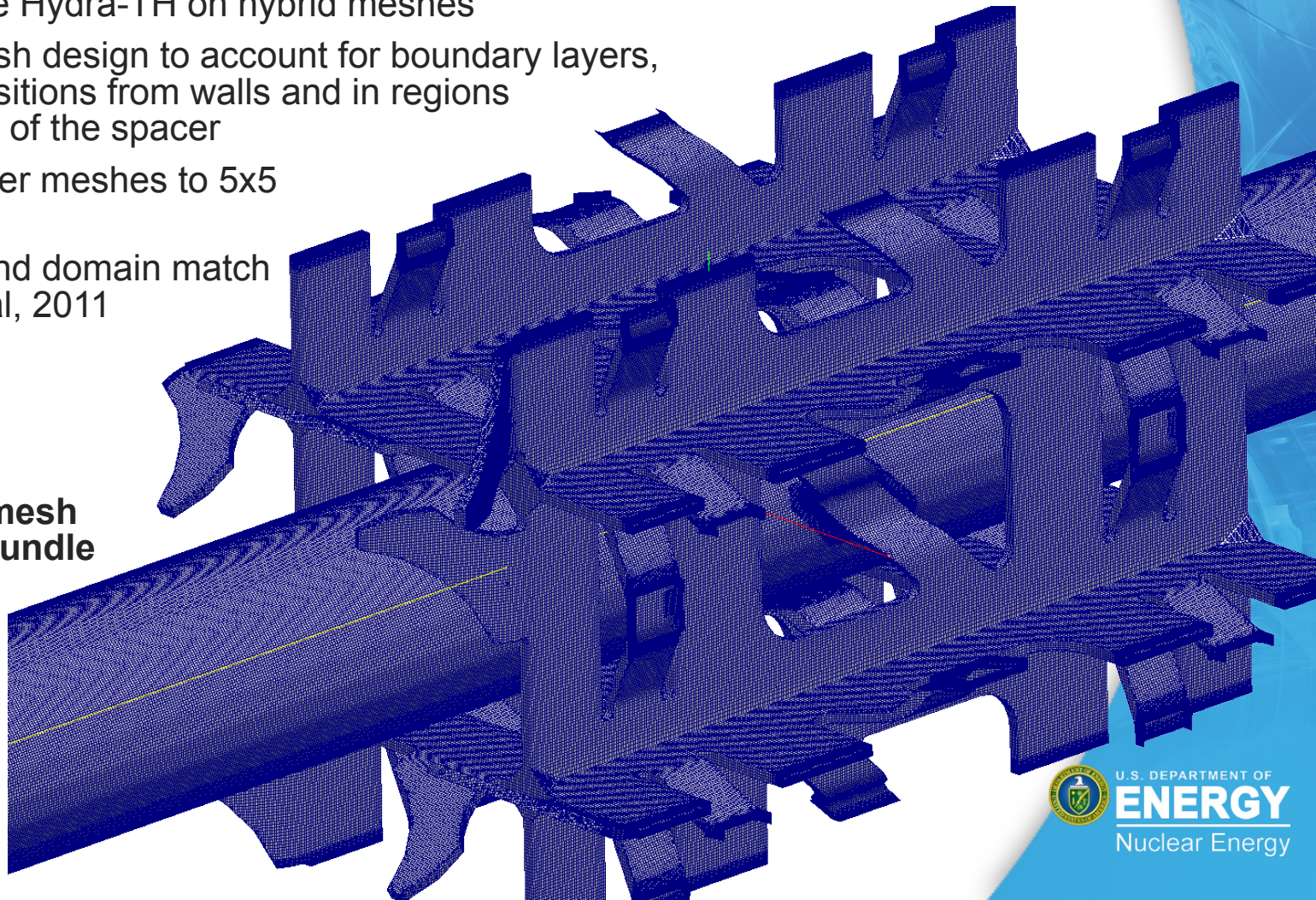
New meshes for GTRF

Ongoing work toward new L3 milestone, Sept. 2012

Meshing 3x3 rod-bundle with Spider

Goals:

- Demonstrate Numeca's Hexpress/Hybrid (a.k.a. “Spider”) automatic hybrid meshing technology on GTRF
- Demonstrate Hydra-TH on hybrid meshes
- Improve mesh design to account for boundary layers, smooth transitions from walls and in regions downstream of the spacer
- Extend Spider meshes to 5x5 rod bundle
- Geometry and domain match Elmahdi et al, 2011



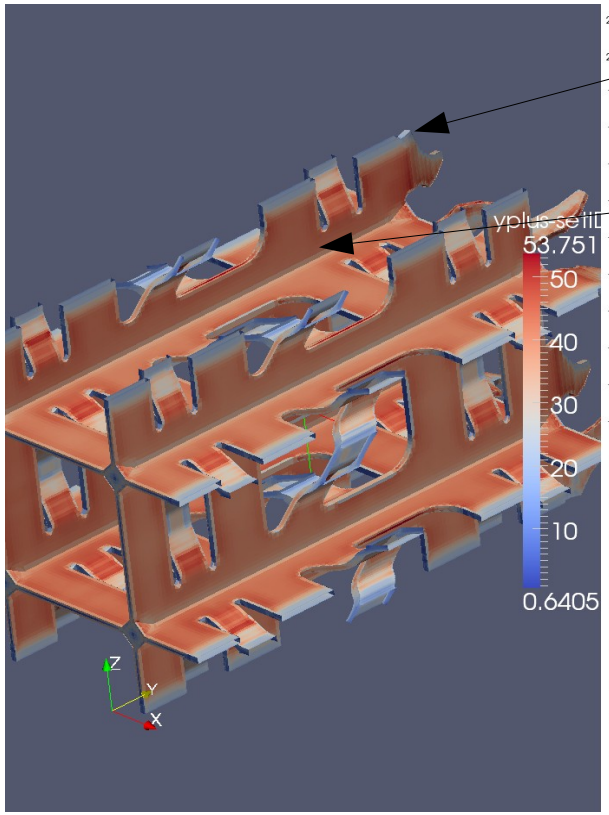
47M Spider mesh for 3x3 rod bundle

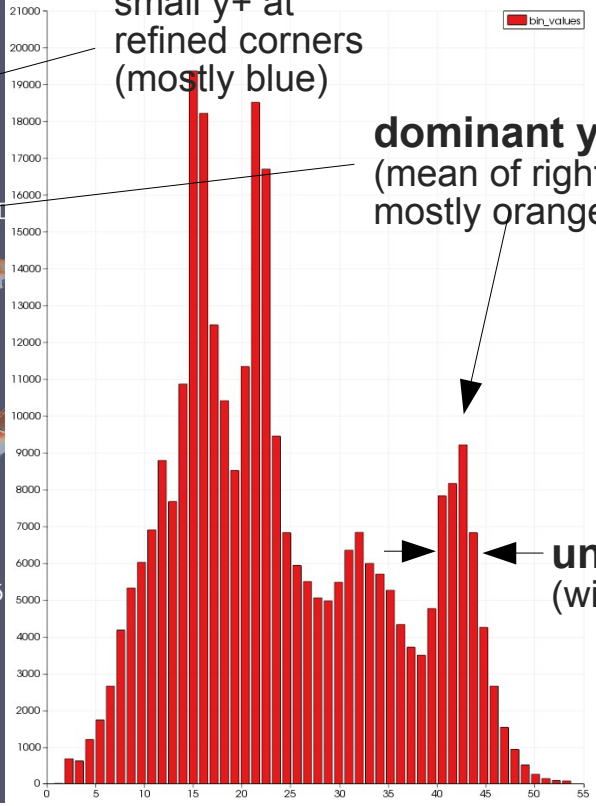
3x3 status

- Generated meshes for 3x3 with cell counts: 2M, 7M, 30M, 47M, 80M, 185M
- Initial runs with Hydra-TH to determine y+ on no-slip walls
- 2-47M ILES runs underway with 96-1920 compute cores at LANL

Mesh assessment using y+

$$y^+ = \frac{y}{\nu}\sqrt{\frac{\tau_w}{\rho}}$$





small y+ at refined corners (mostly blue)

dominant y+ ~ 42 (mean of rightmost spike, mostly orange)

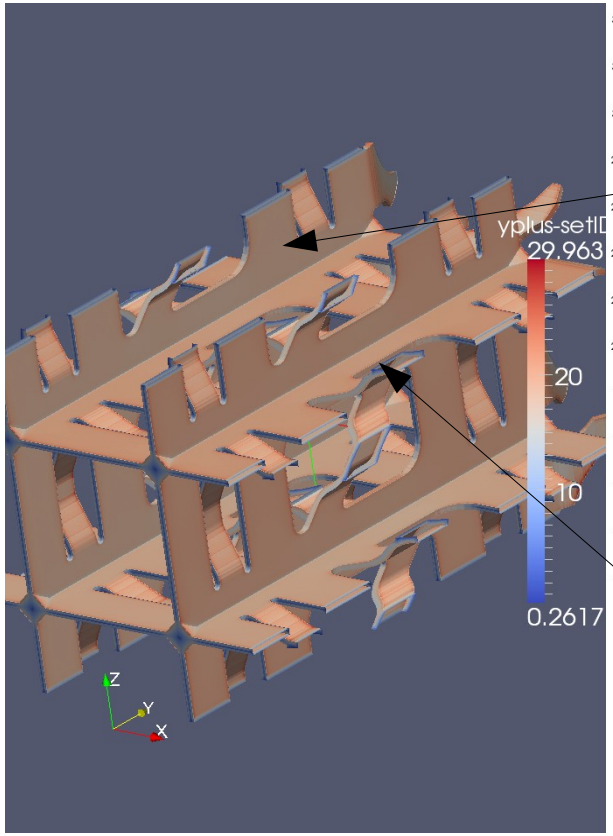
uniformity of y+ (width of rightmost spike)

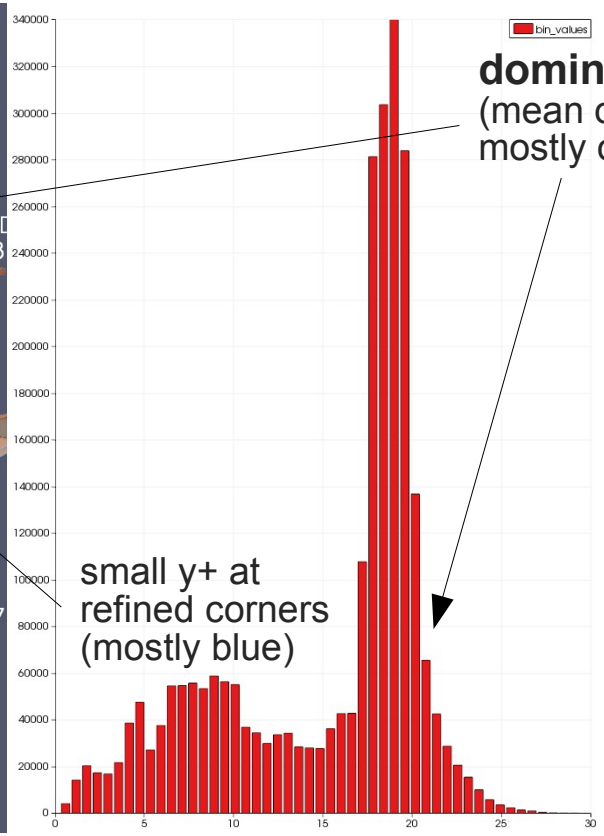
y+ spatial distribution on 7M spacer

y+ histogram

Mesh assessment using y+

- Another example: 185M cells
- y+ = 1 required for full wall-resolution
- Mesh assessment:
  - **dominant y+** ~ How well the boundary layer is resolved?
  - **uniformity of y+** ~ How good is the mesh quality at walls?





dominant y+ ~ 18
(mean of rightmost spike, mostly orange)

small y+ at refined corners (mostly blue)

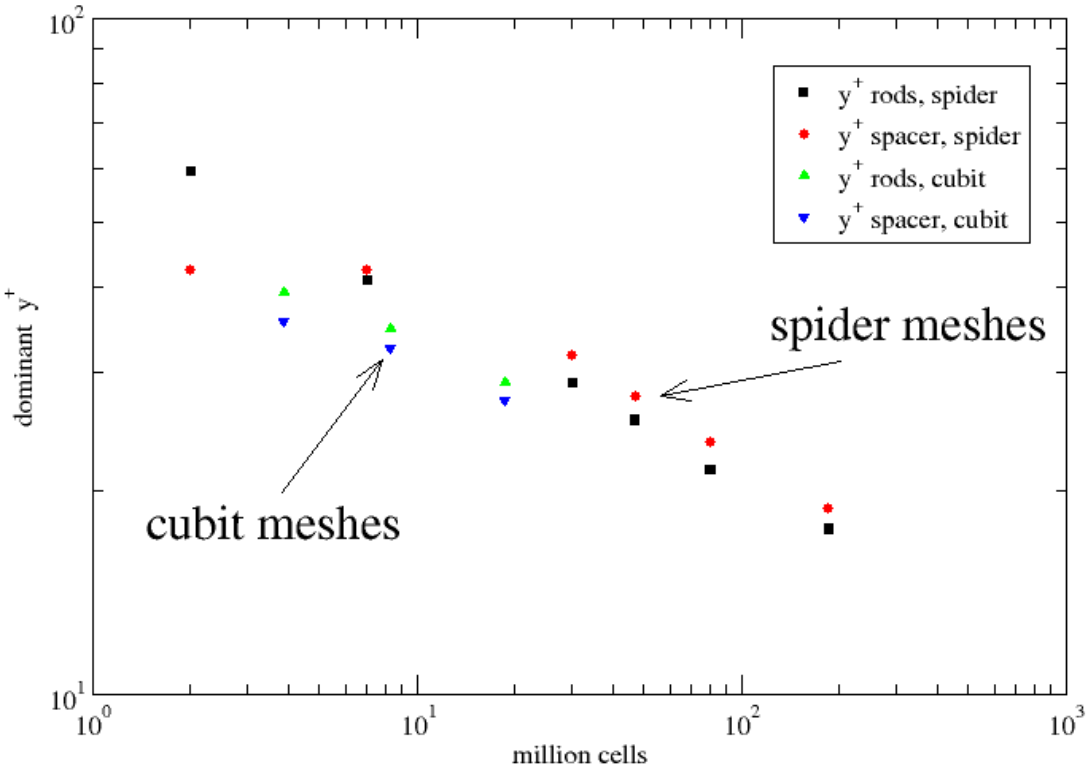
y+ spatial distribution on 185M spacer

y+ histogram

Mesh assessment using dominant y+

Dominant y+ on spacer and rods vs. number of cells for

- Spider (2M, 7M, 30M, 47M, 80M, 185M)
- Cubit (3.9M, 8.3M, 18.6M)

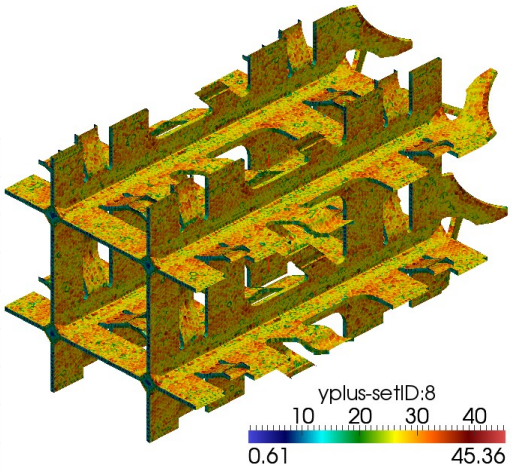


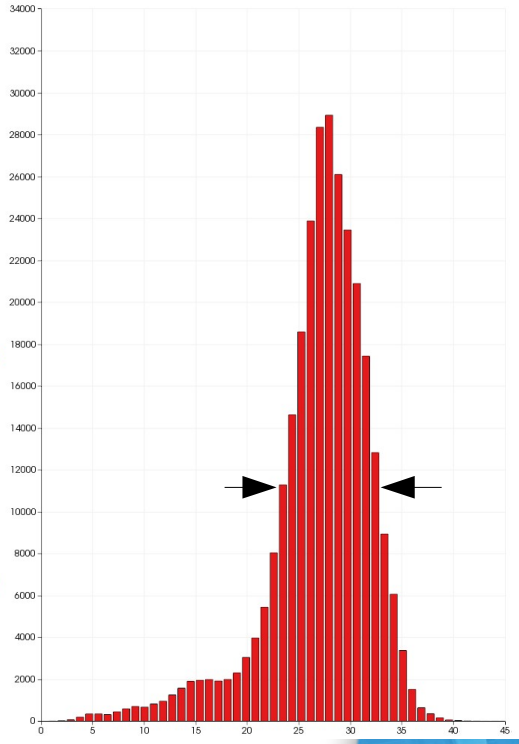
- Both Spider and Cubit meshes exhibit monotonic decrease in y+ with increasing cell count
- Logarithmic trend: **None of these are boundary-layer meshes; trying to achieve y+~1 with this strategy would require 10^12 cells**
- Next step: add (power law) boundary layer refinement

Mesh assessment using uniformity of y+

- Spider meshes on spacer are consistently more uniform
- A quantitative metric: entropy of the cell-area-weighted histograms (future work)

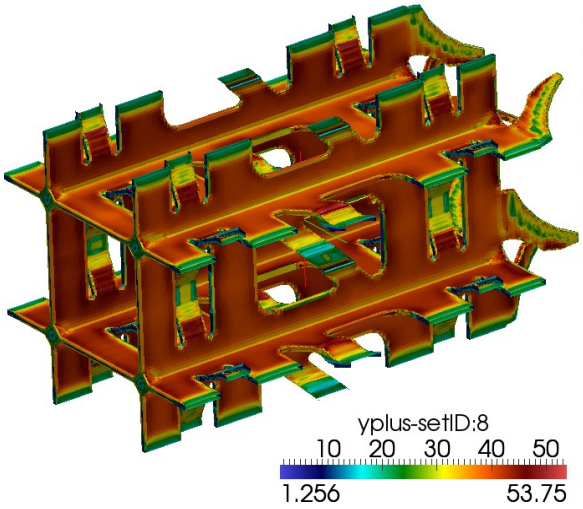
18.6M Cubit

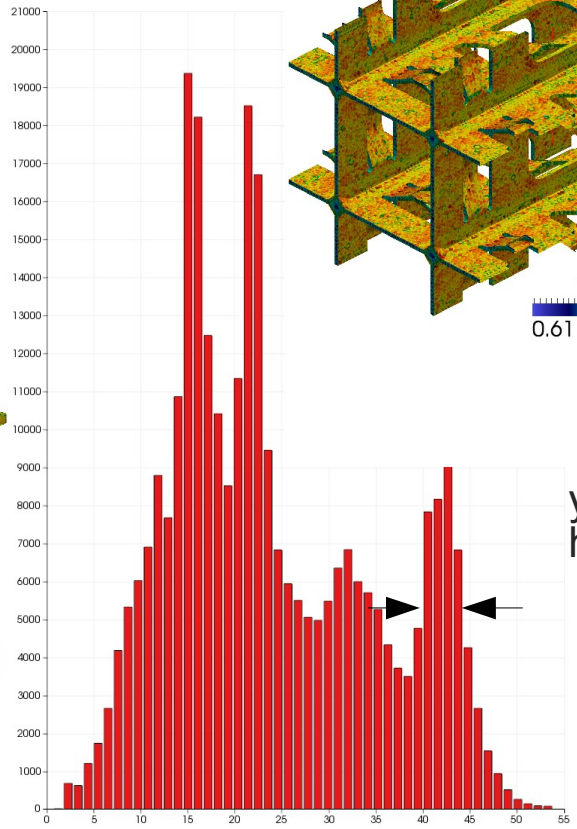




y+ spatial distribution and histogram on **18.6M Cubit** spacer

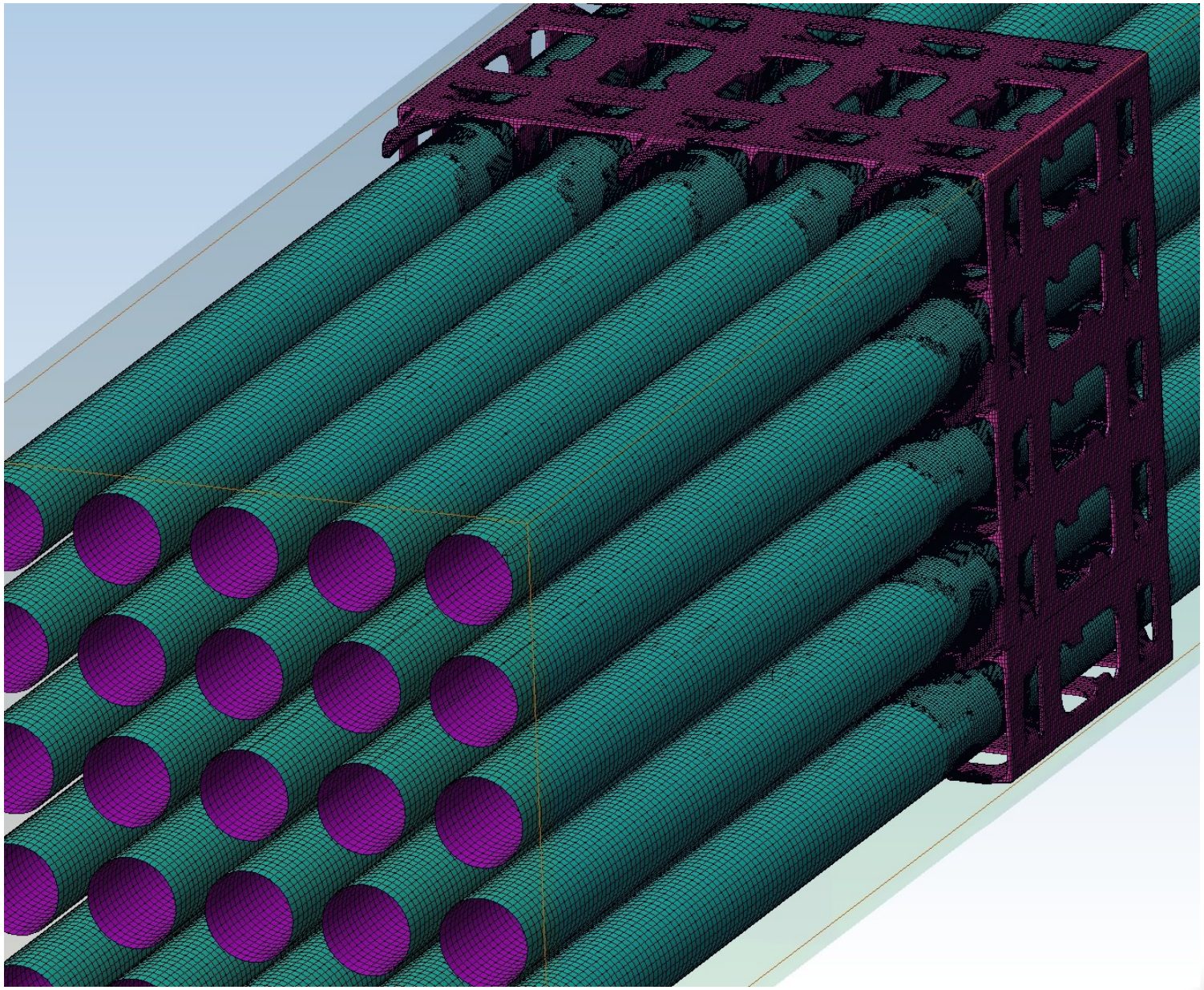
7M Spider



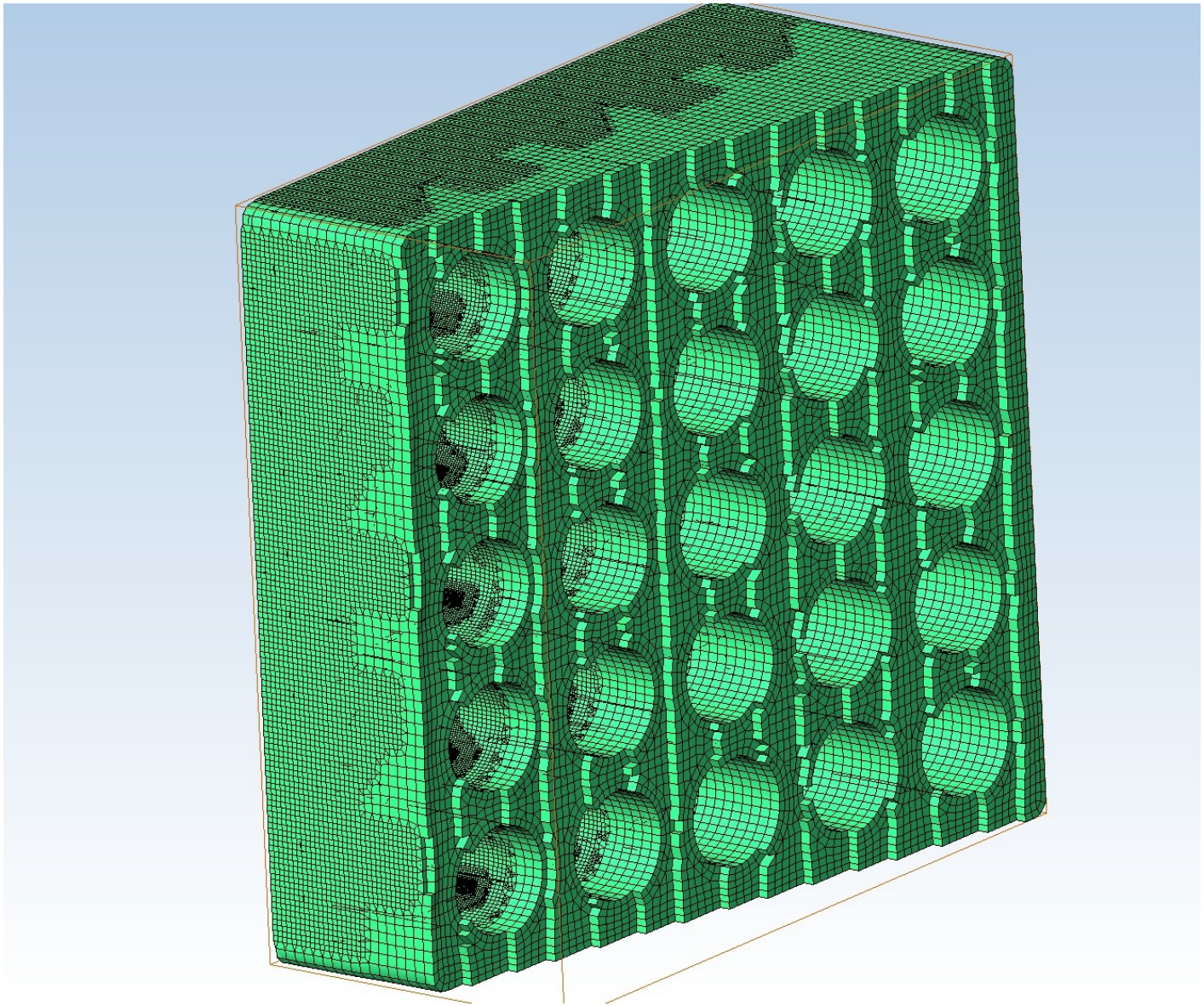


y+ spatial distribution and histogram on **7M Spider** spacer

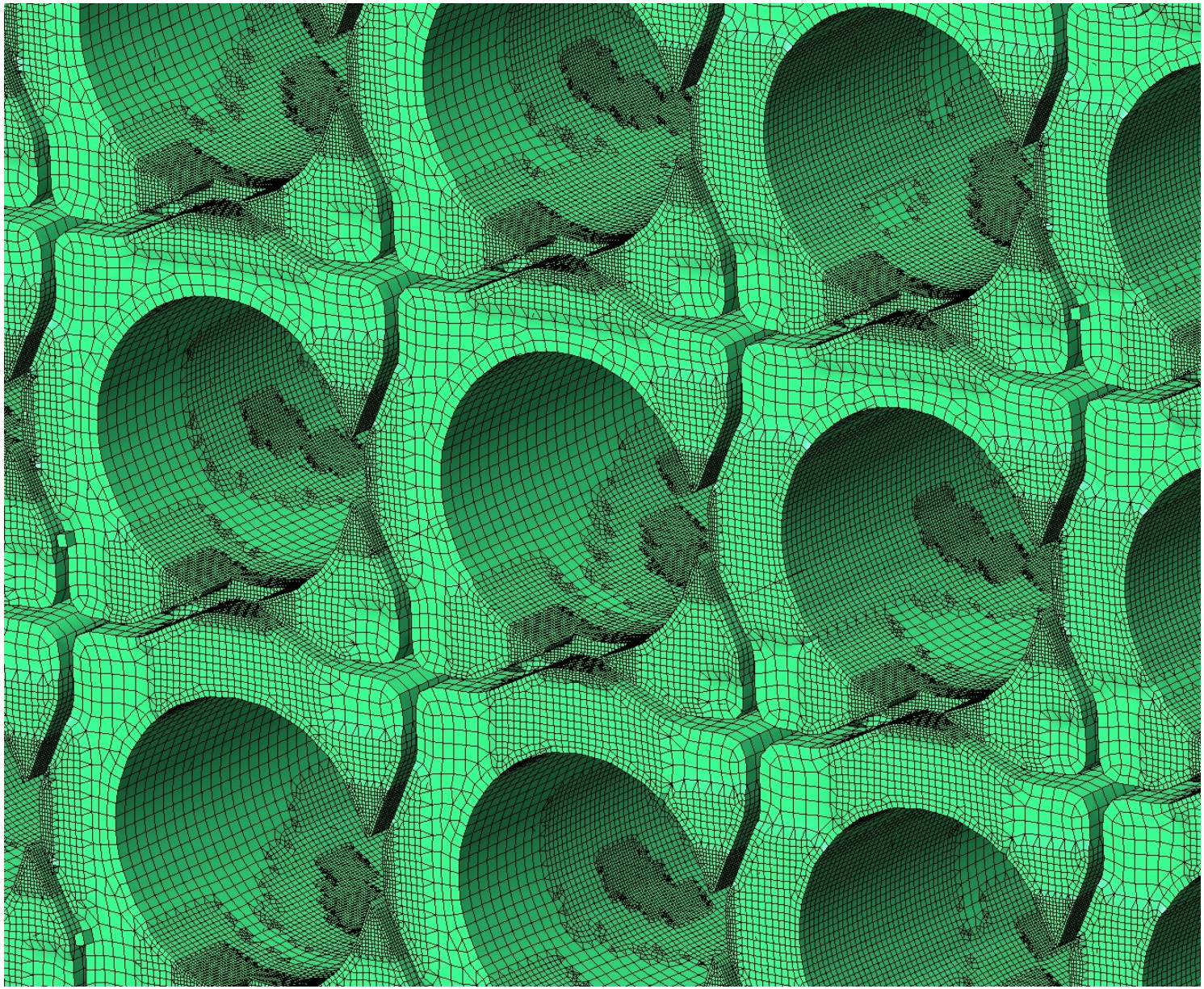
Spider mesh for 5x5: 14M, (96M)



Spider mesh for 5x5: 14M, (96M)



Spider mesh for 5x5: 14M, (96M)



Spider mesh for 5x5: 14M, (96M)

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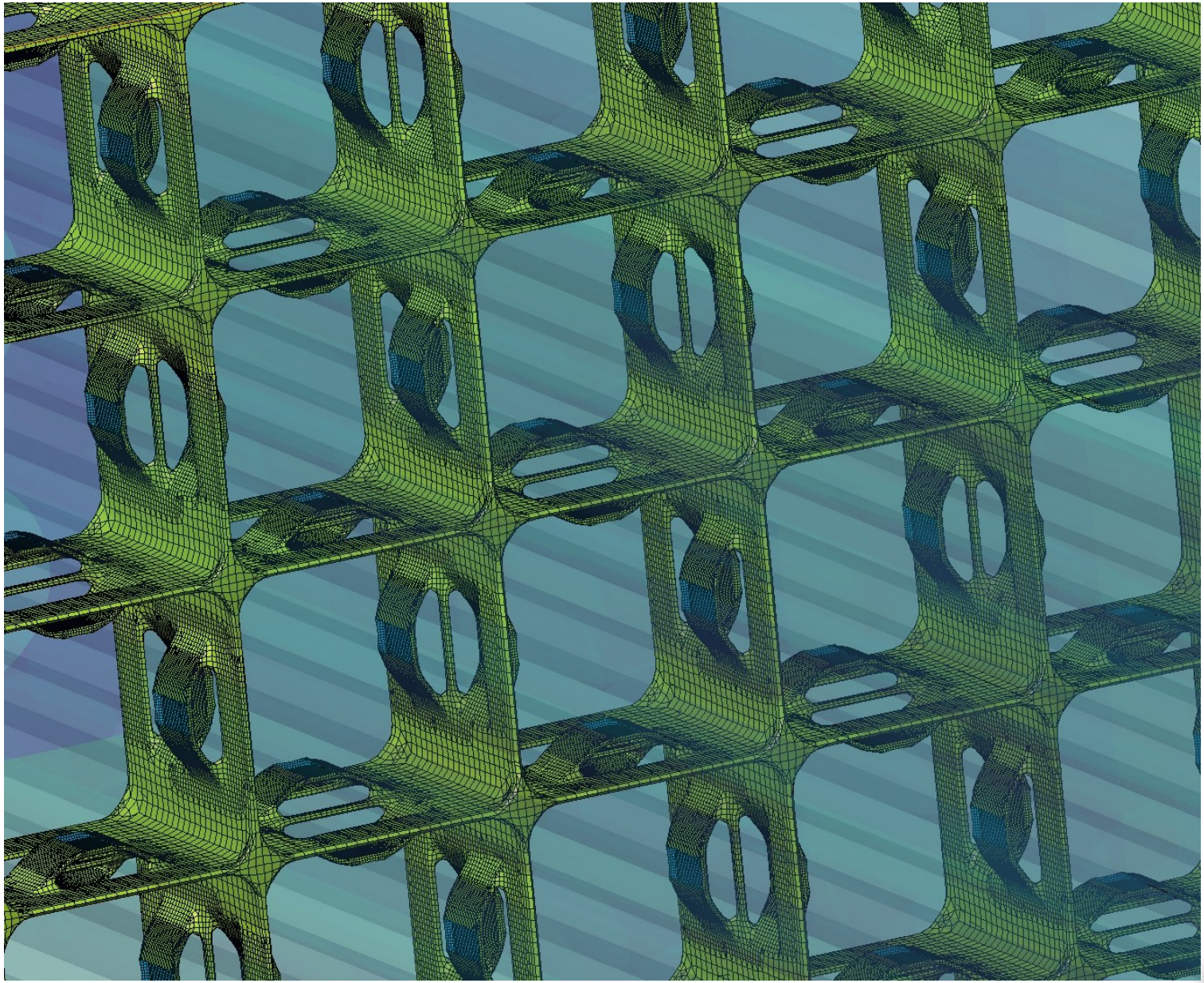
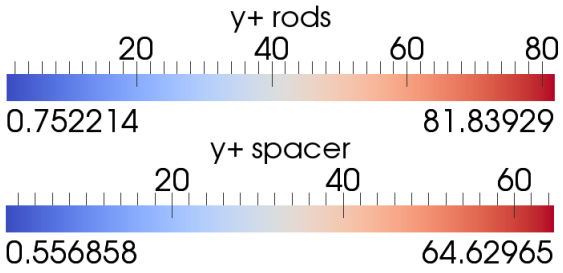
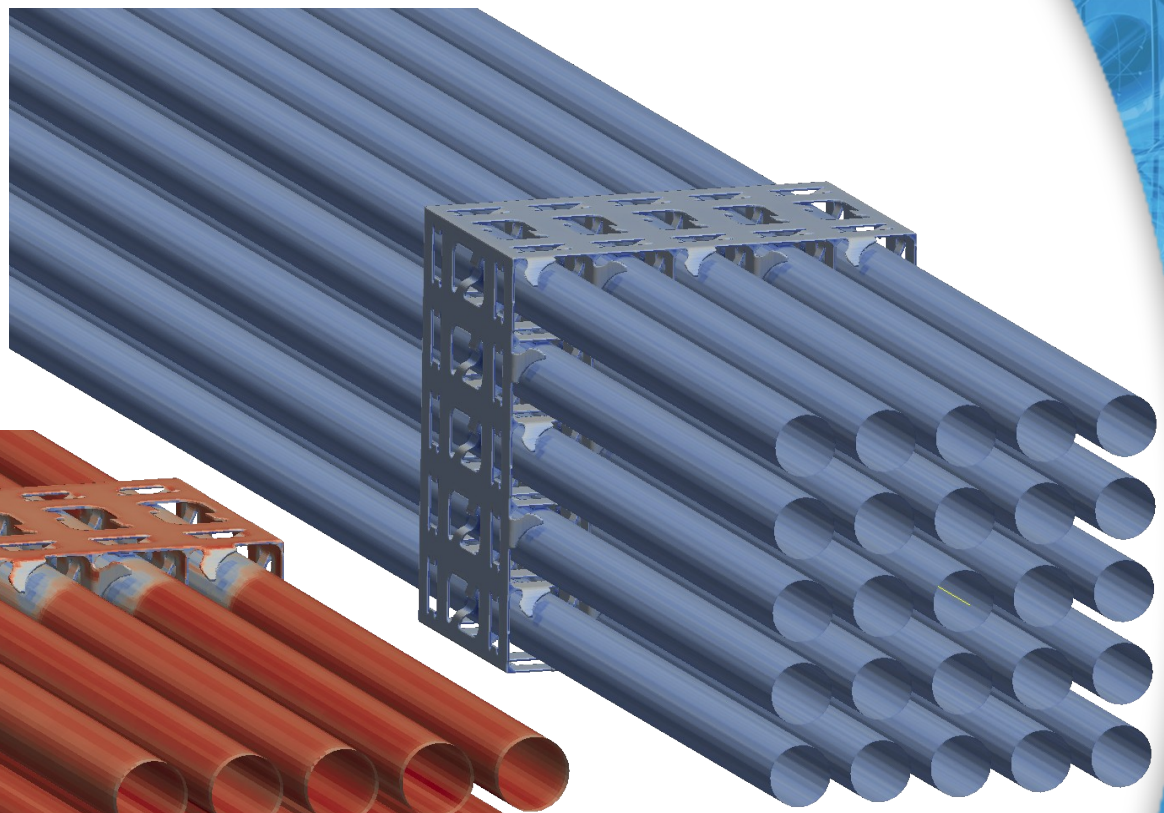
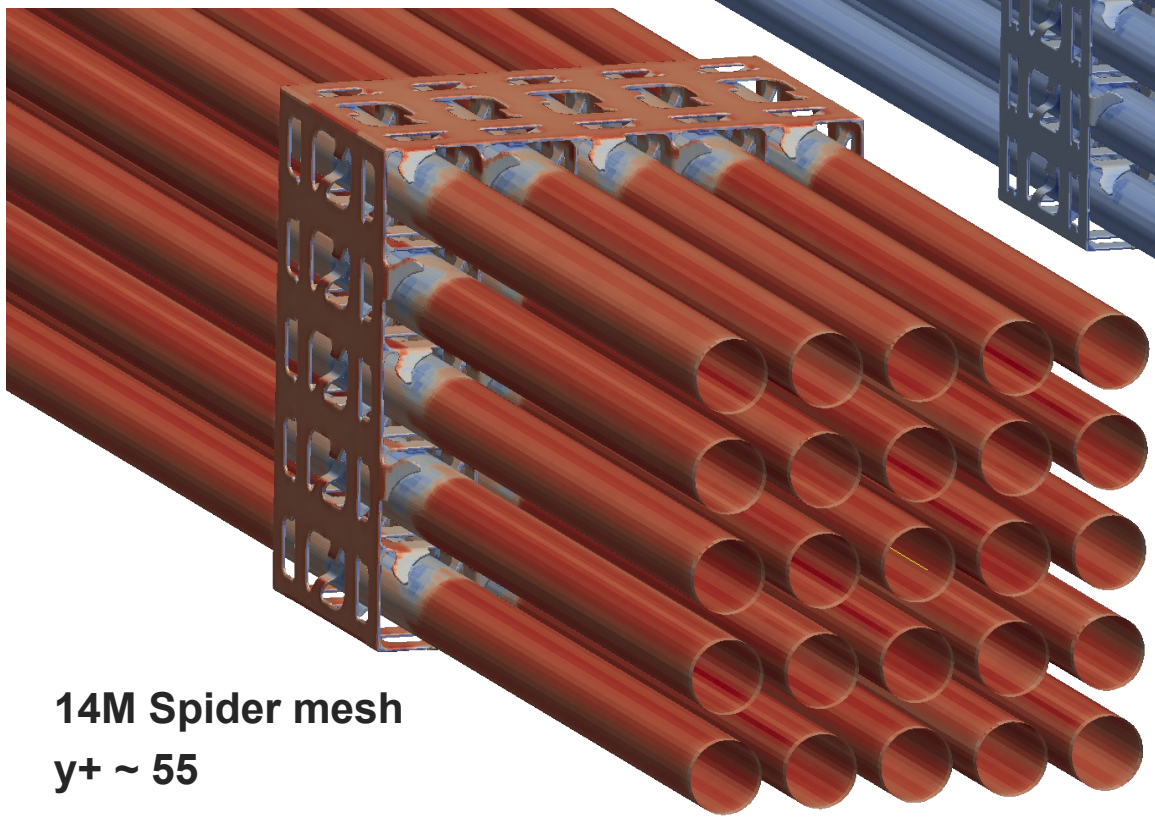


y+ on 5x5





96M Spider mesh
y+ ~ 18



14M Spider mesh
y+ ~ 55

CASL
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Nuclear Energy

Numeca's Hexpress/Hybrid (a.k.a. Spider) meshing technology

- **Fully automatic** mesh generation; text config file; batch mode
- Unstructured, hex-dominant, conformal hybrid meshes
- High quality viscous layers
- Hole searcher in CAD geometry
- Shared-memory parallel
- Memory requirements: 0.5GB / million cells

5x5 status

- 5x5 meshes generated: 14M, 96M
- **96M mesh in 80 mins** on 8-core workstation with 48GB RAM
- Initial runs with Hydra-TH to assess y+
- 14M ILES run underway with 1200 compute cores at LANL

New GTRF runs with turbulence statistics

Ongoing work toward new L3 milestone, Sept. 2012

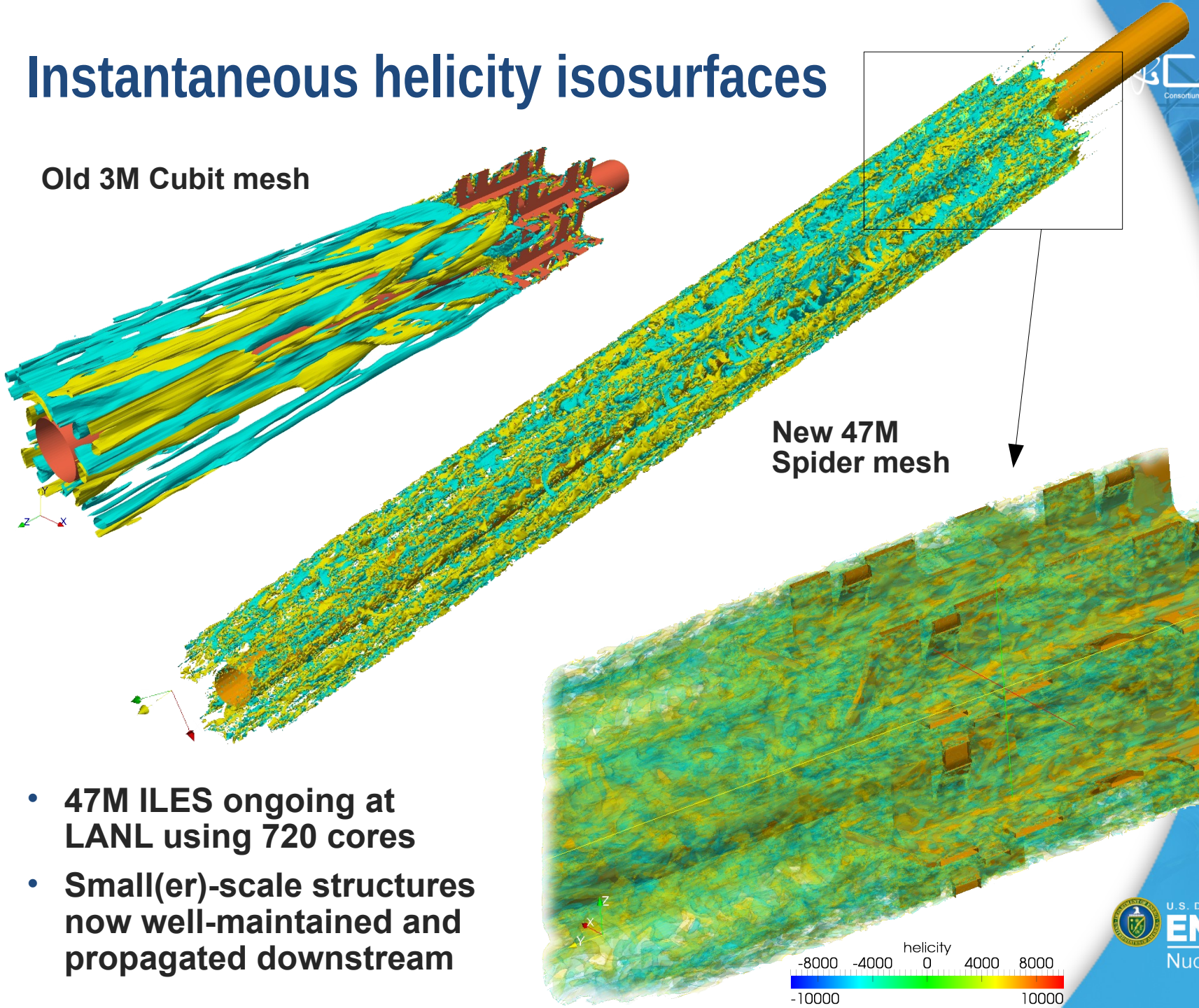
New GTRF runs with Hydra-TH

- Single-phase, incompressible NS
- ILES, collecting turbulence statistics
- Re-run 3x3 Cubit meshes: 672k, 1M, 2M, 3M, 6M, 12M
- 3x3 Spider meshes: 2M, 7M, (30M), (47M)
- 5x5 Spider mesh: 14M
- Larger meshes (80M, 185M, 96M): investigating memory allocation problems with PETSc using >5k cores

Ongoing work for Sept. L3 milestone

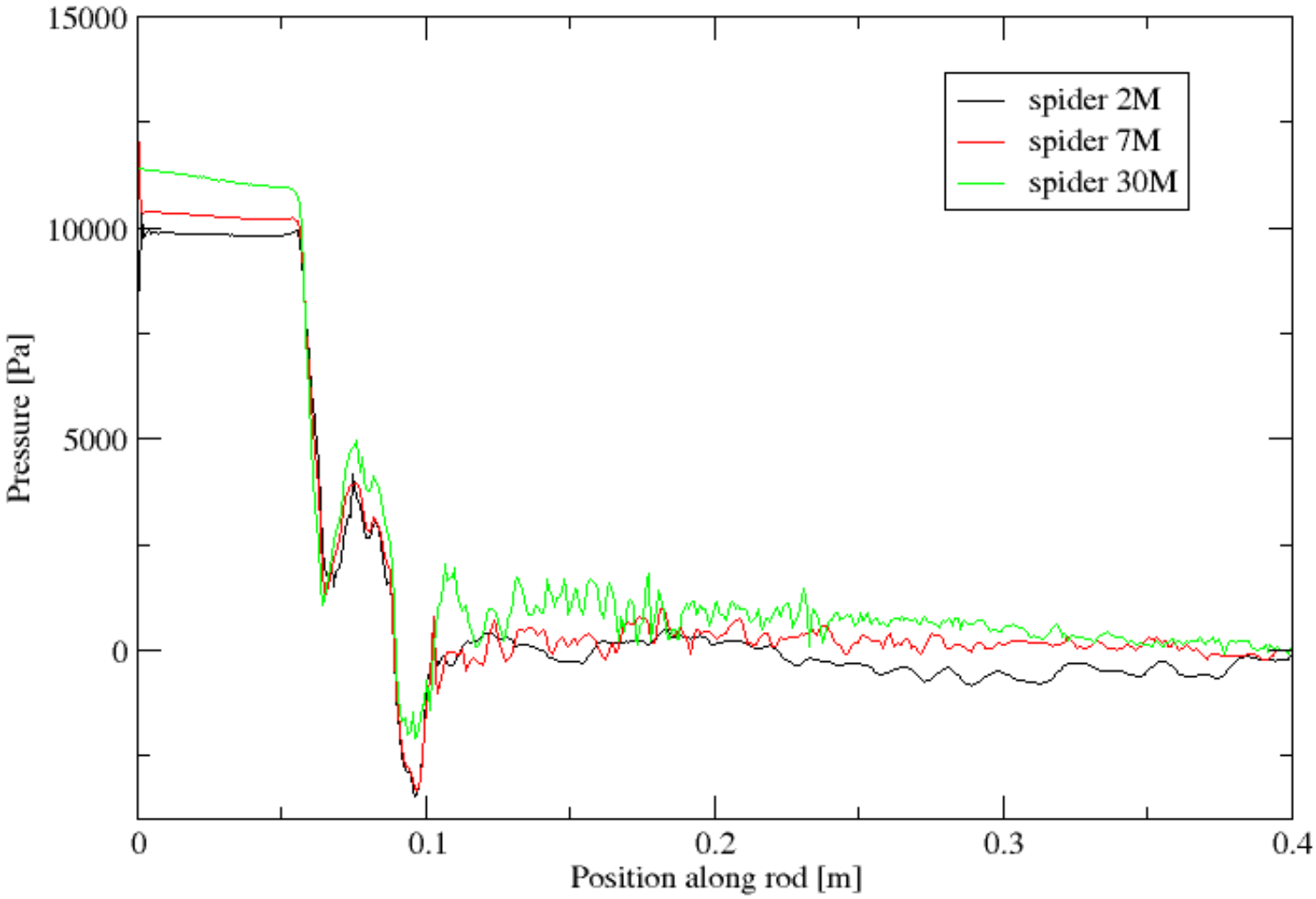
- Further assessment of mesh quality
- V&V of Hydra-TH with simpler turbulent flows: channel, lid-driven cavity, T-junction
- Turbulence models: ILES, DES, WALE, Spalart-Allmaras, Smagorinksy, k-ε
- Analyze turbulence statistics from GTRF runs
- Mesh convergence and HPC scaling study at LANL and Jaguar

Instantaneous helicity isosurfaces



- 47M ILES ongoing at LANL using 720 cores
- Small(er)-scale structures now well-maintained and propagated downstream

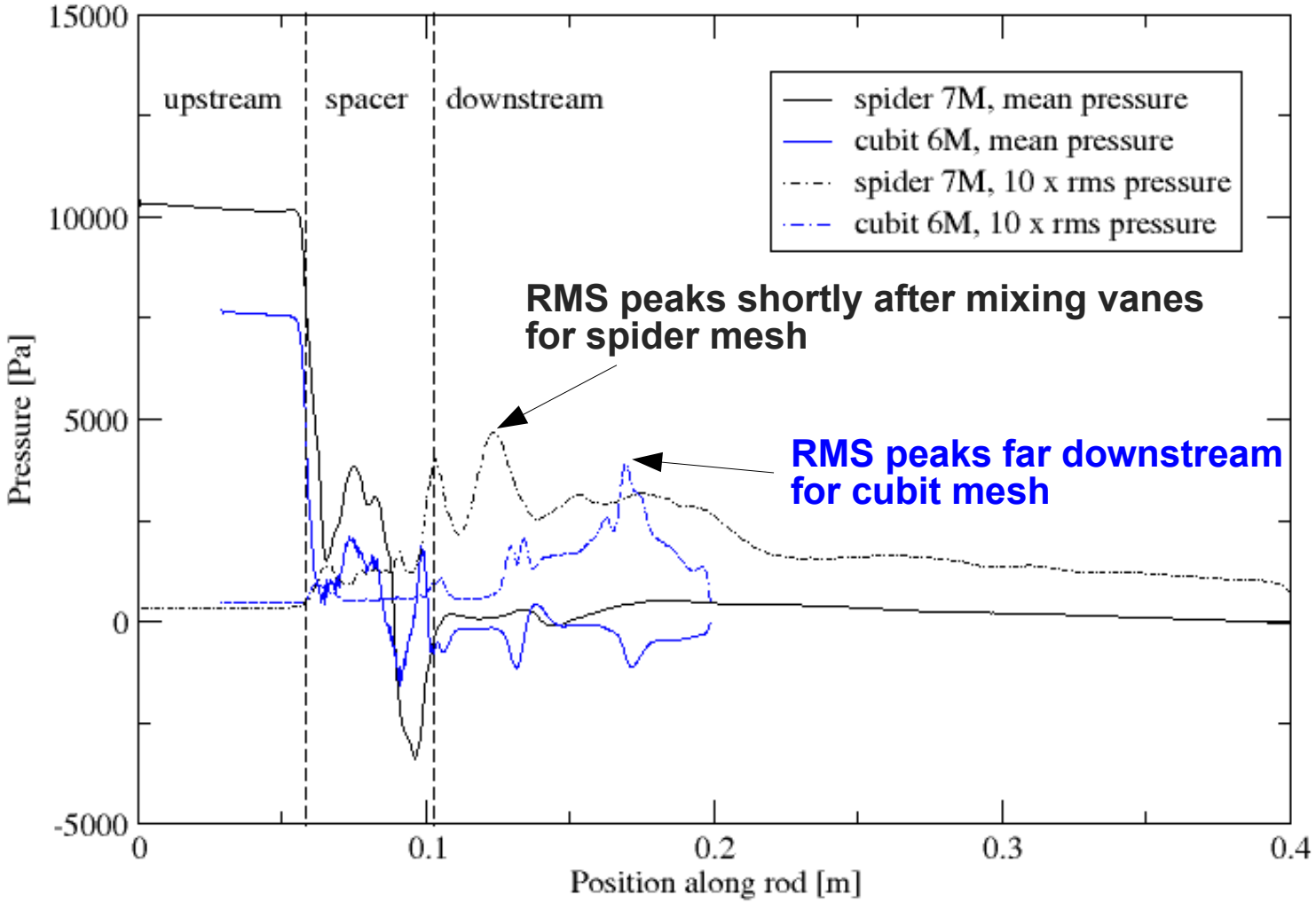
Instantaneous pressure along rod



- 47M running; 80M and 185M needs further work
- Pressure drop not yet converged

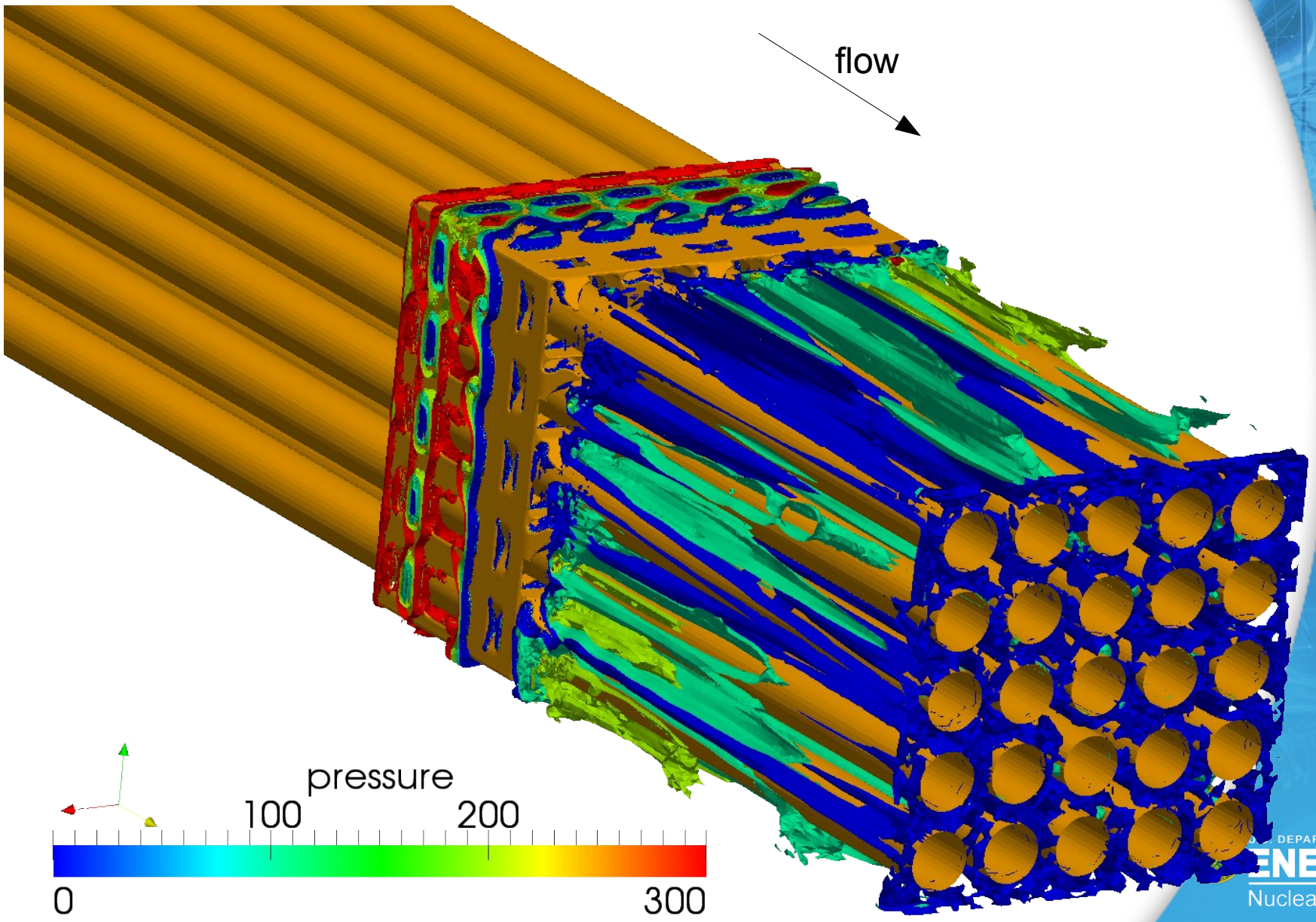
Mean and RMS pressure along rod

RMS pressure ~ “energy in pressure force”



Mean and fluctuation pressure very different for Cubit and Spider for similar mesh resolution

Instantaneous pressure on 14M 5x5



Summary

- Numeca's Hexpress/Hybrid ("Spider") is an excellent mesh generator for GTRF
- Automatic, simple to use

- Long domain, good quality mesh required for GTRF
- Next GTRF meshes: with boundary-layers, 0.5~1 billion cells

- Hydra-TH is (almost) ready for large-scale industrial CFD
- **More to come in L3.THM.CFD.P5.05, Sept. 2012**