Modular Coil Assembly Type-C

Final Design Review, Part III

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G. Lovett, B. Nelson, D. Williamson

June 30, 2005

Presentation Outline

- Specification of Type-C coil assembly – D. Williamson
- Lead blocks and winding sequence – P. Fogarty
- Drawing status and plans – D. Williamson

Charge Questions

NCSX
National Compact Stellarator Experiment

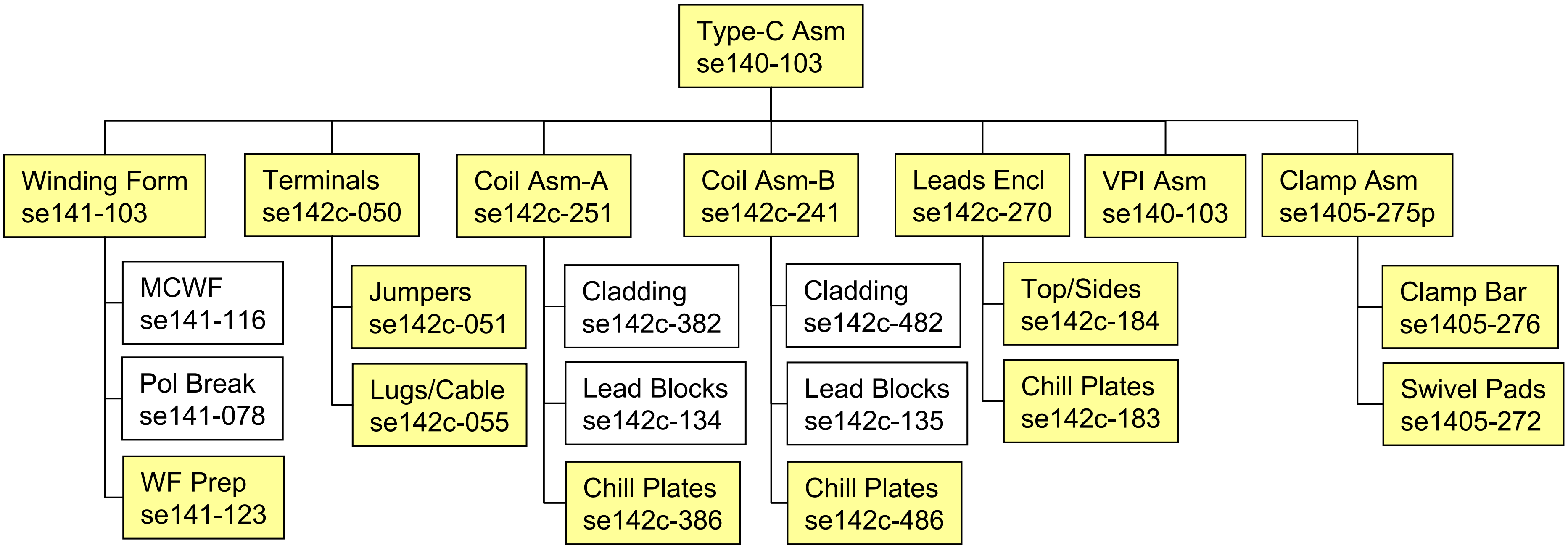
- Is the design of the Type-C coil assembly complete?
- Are the specifications and drawings ready to be issued?
- Is the schedule for remaining documentation achievable and consistent with project need dates?

FDR Part I,II Results

- Earlier reviews focused on the models and drawings needed for procurement of cladding and lower lead blocks
- Chits addressed TRC experience, procurement strategy, managing the large number of parts needed for Type-C assembly
- Comments have been resolved and fabrication of first needed parts is underway

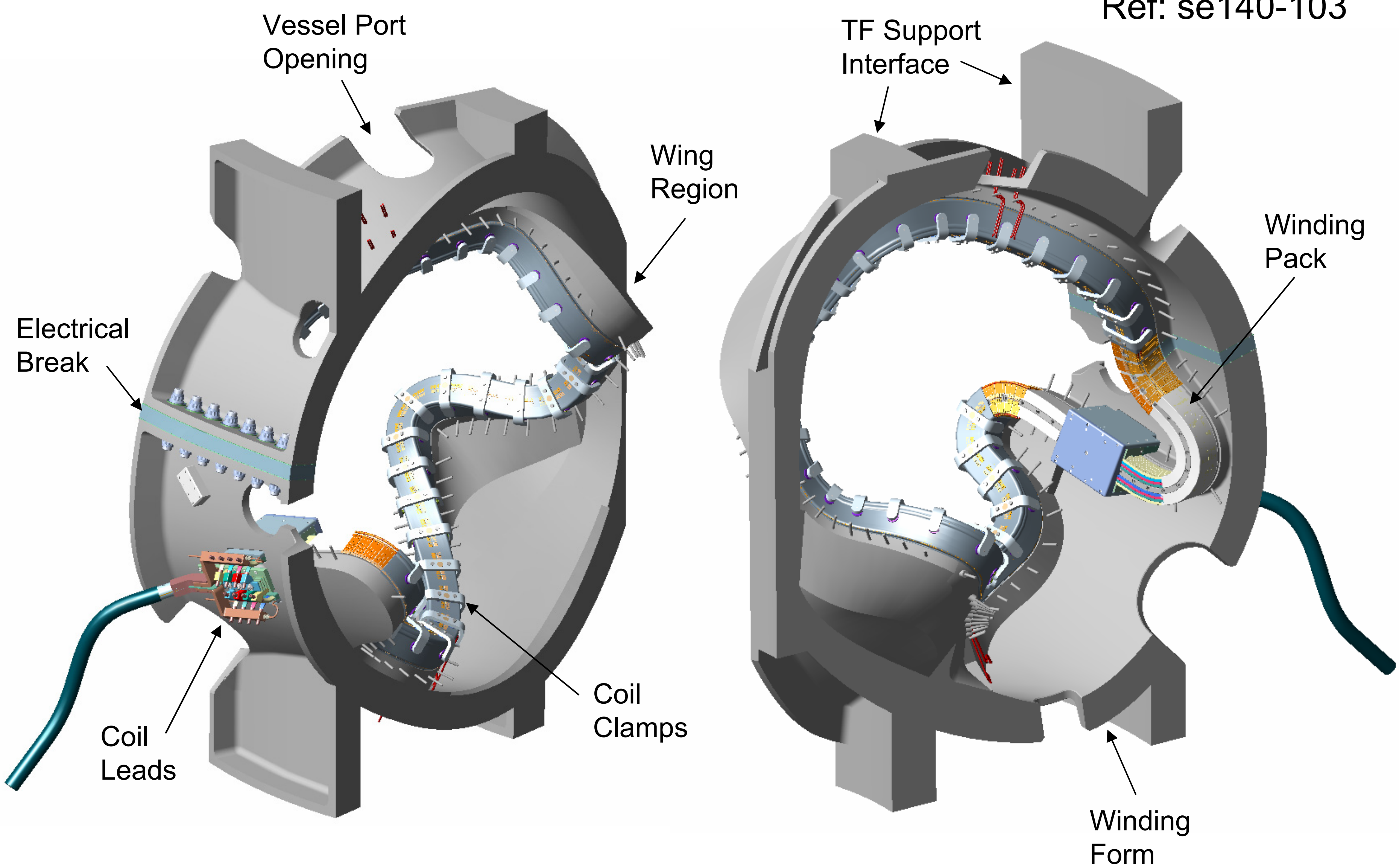
#	Chit/Audit Finding [Originator]	Review Board Recommendation	Status
1	Investigate ways of cleaning up drawing files. [Horner]	Concur	DXF/DWG output investigated, DXF appears best.
2	Consider process improvement for generating cladding/chill plate drawings for type A and type B. [Reiersen]	Concur	ProE family table method studied and found to be best approach.
3	Expedite resolution of terminal block height issue. Determine how much TF Structure can be relieved. Consider pre-bending prior to brazing replacing tow 90° bends with one gentle bend. [Reiersen]	Concur	Terminal design has been improved, TF clearance increased to about 3/4-in.
4	Revised lead block design should be evaluated by Art Brooks for field errors. [Reiersen]	Concur	Calculation shows that field errors are acceptable.
5	Need to articulate procurement plan and incorporate into DMB for chill plates and cladding. Issues need resolution. [Reiersen]	Concur	Fab first set of cladding and chill plates at PPPL, procure remainder.
6	Fabricate the first set of each cladding and chill plates at PPPL. The remaining plates would be ordered with outside vendor. Various options should be evaluated. [Chrzanowski]	Concur	See above.
7	Check cladding/chill plate design by jabbering just lot at PPPL before sending out for procurement. [Reiersen]	Concur	See above.
8	Identify side A and side B on the winding form when it comes through the door. [Nelson]	Concur	Included in MCWF Prep procedure, D-NCSX-MCF-001.
9	Add a number to the parts that correspond to the web hole numbering scheme. [Nelson]	Concur	Asm drawing correlates part and hole numbers.

This Review: Balance of Coil Asm



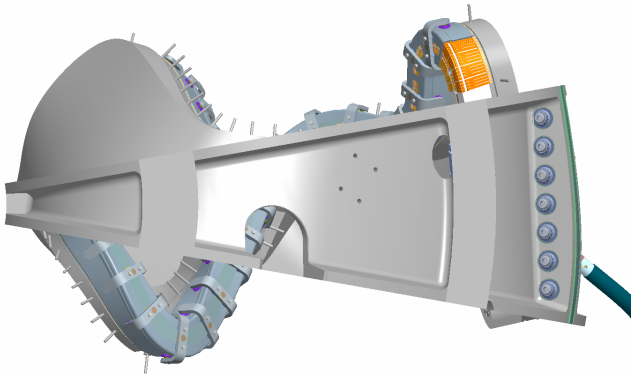
Coil Assembly

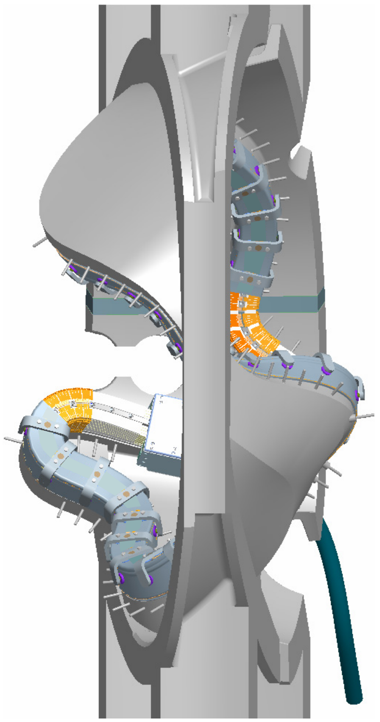
Ref: se140-103

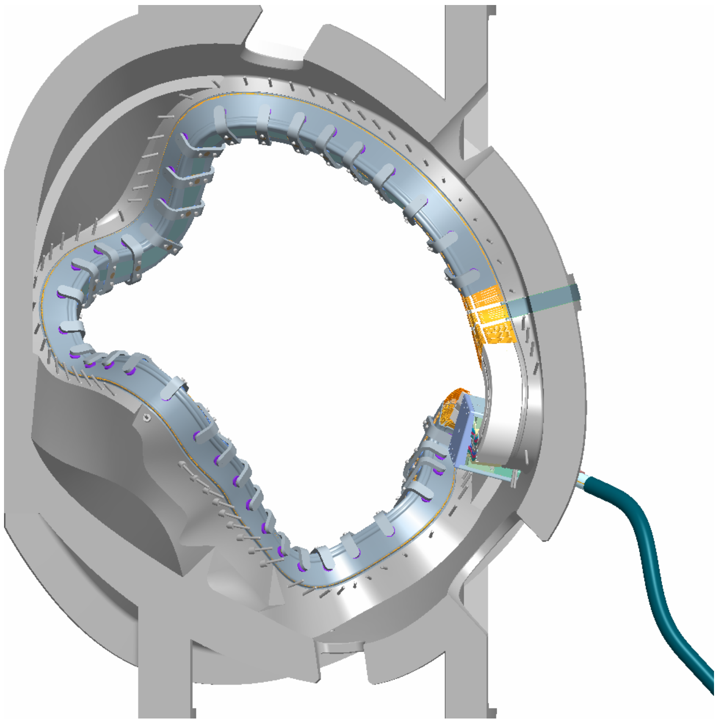


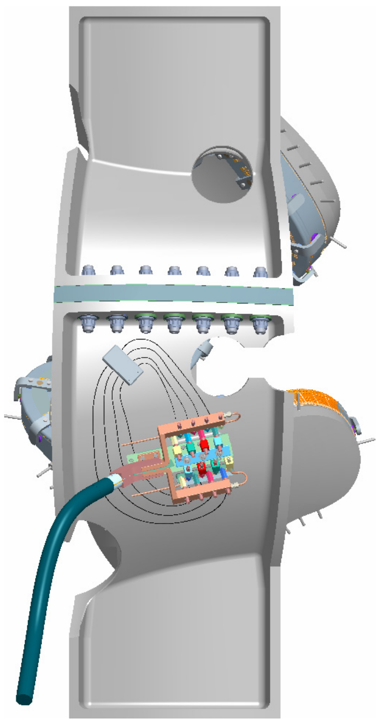
Coil Assembly

Ref: se140-103

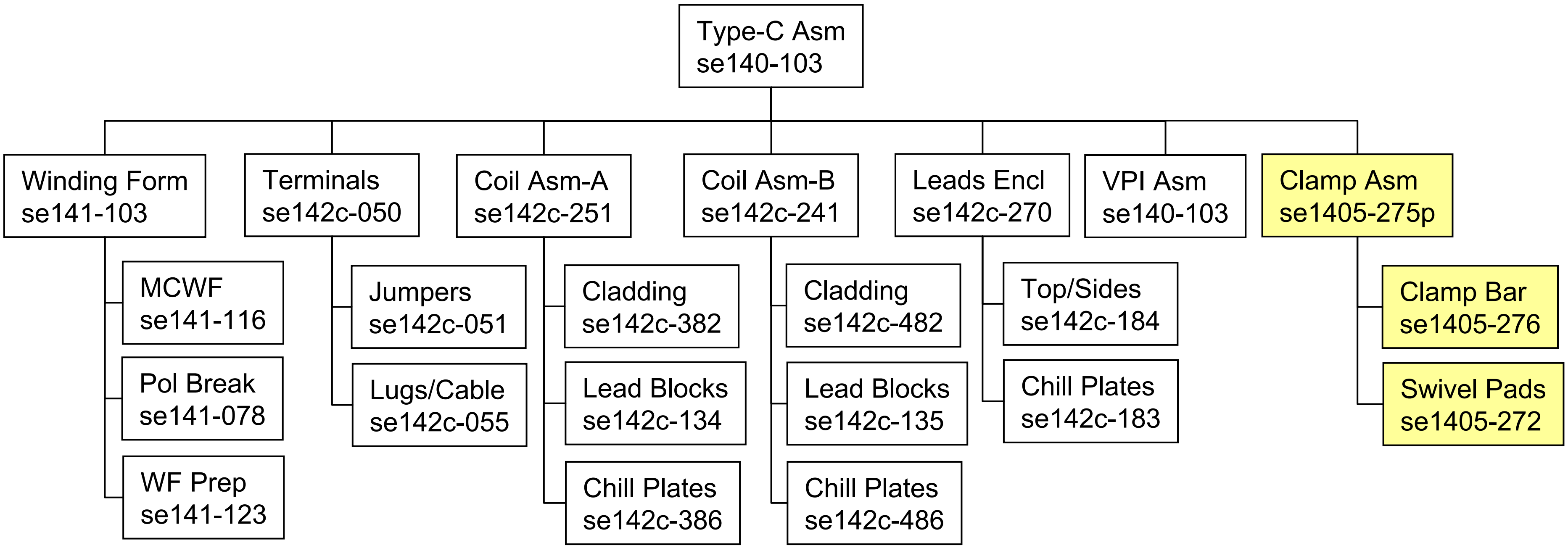






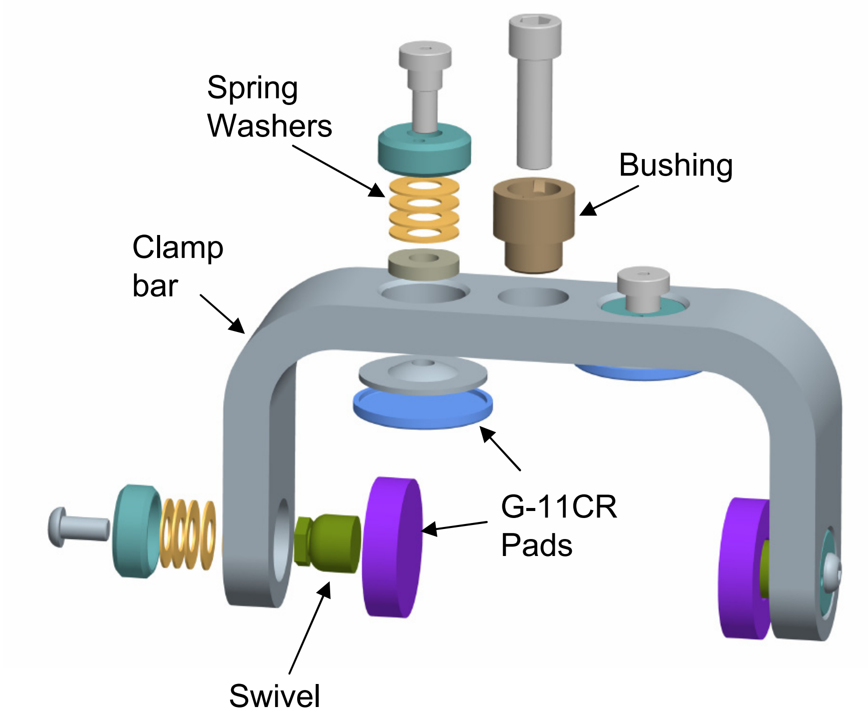


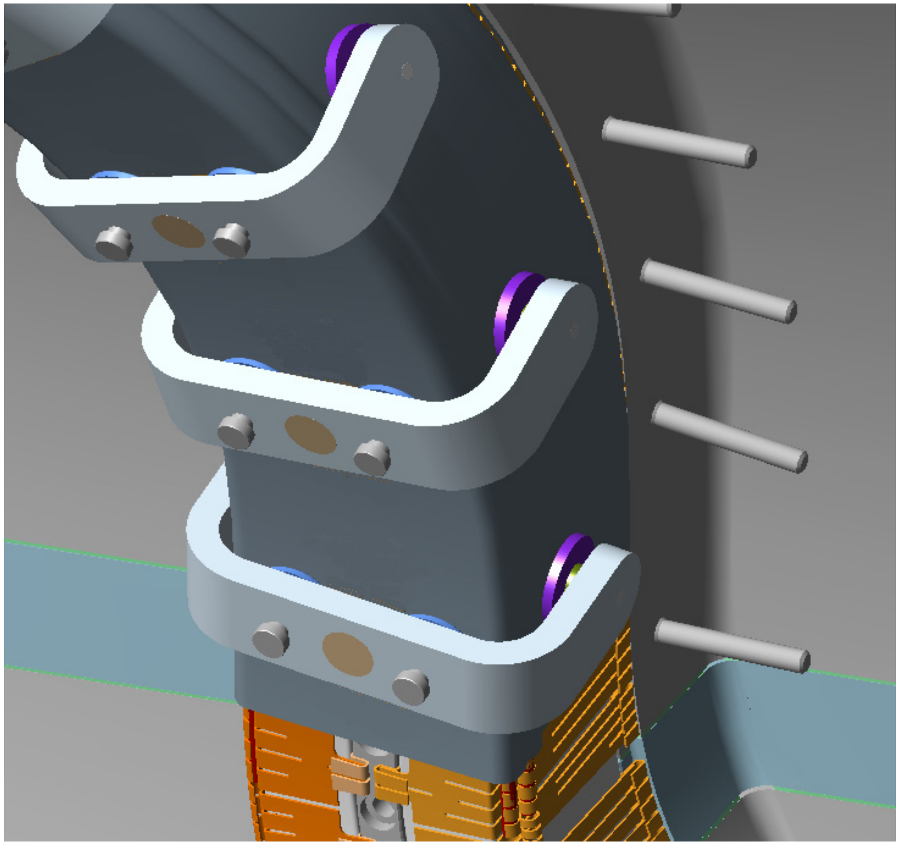
Clamp Subassembly



Clamp Subassembly

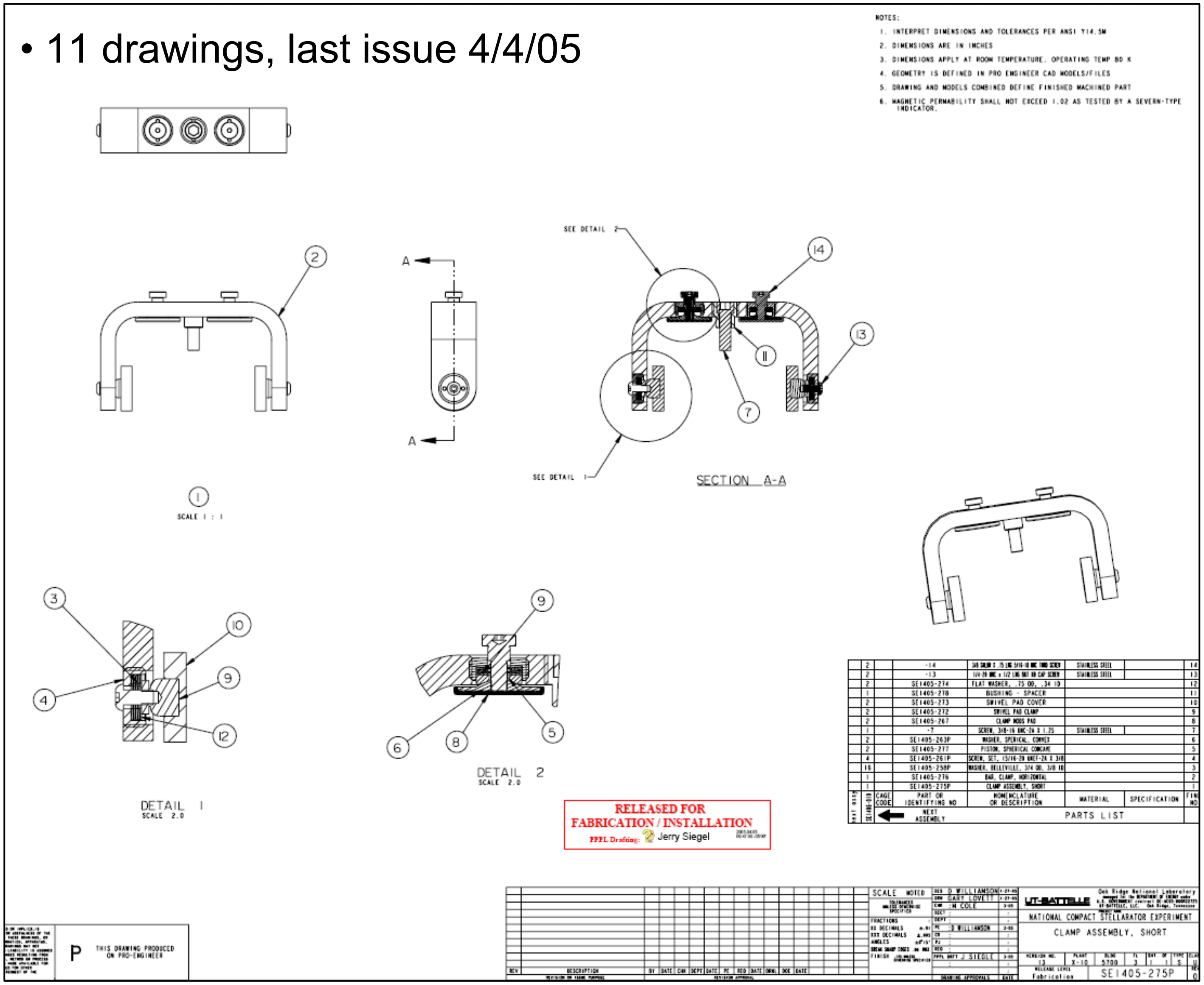
- Function is to provide ~100-lb preload per pad to react thermal, EM loads
- Clamp bar dimensions = .75-in thk x 1.5-in depth, 5.22-in wide for TRC
- Type-C requires 44 clamp assemblies, ref: se1405-275p rev1 (TRC), rev2 pending





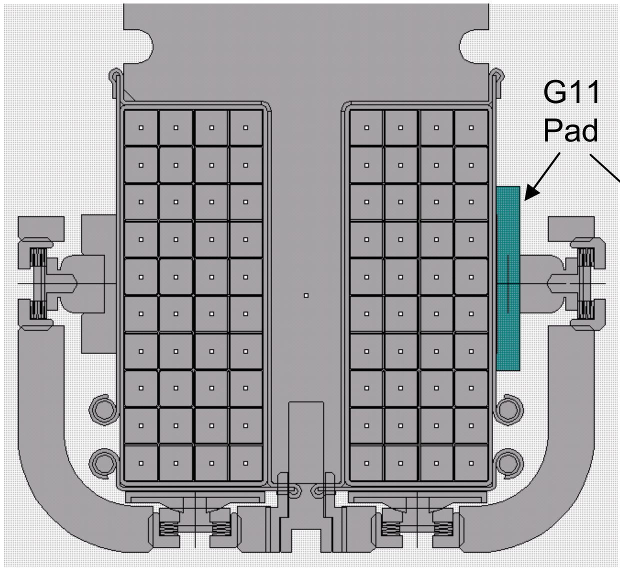
Clamp Asm Drawing

- 11 drawings, last issue 4/4/05

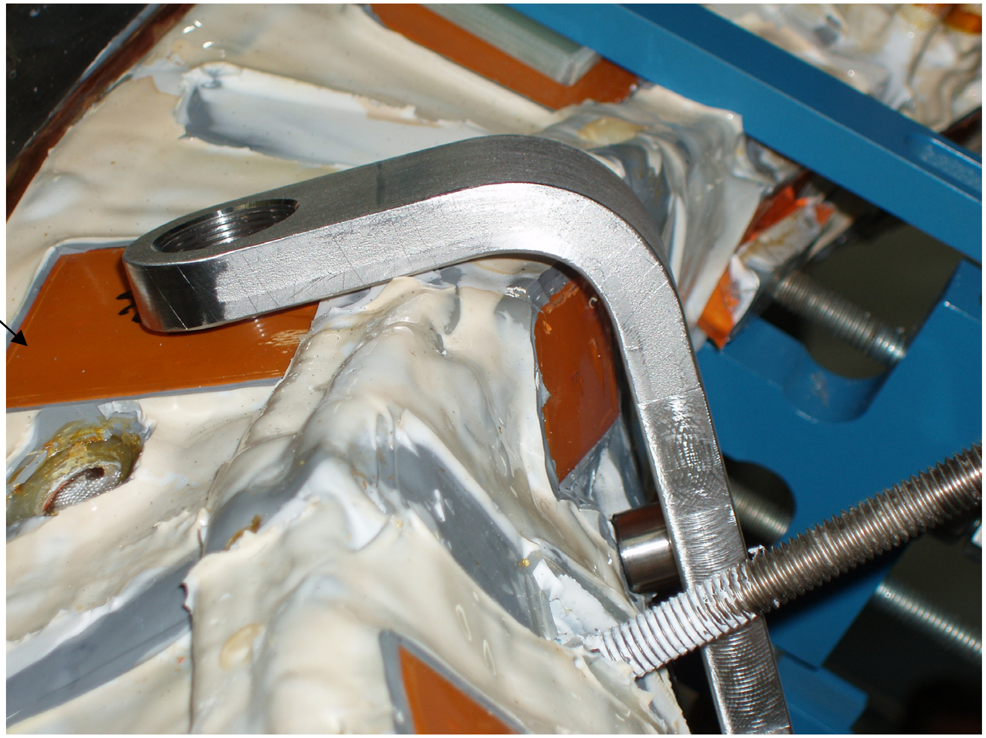


TRC Experience

- About 20 of 25 clamps fit ok, others were modified by chamfering edges or cutting off a leg to prevent interference with cooling tubes
- Stress analysis indicates max winding pack - tee gap = .006-in, max clamp stress = 10-ksi at bushing interface for altered clamp (Side-A pusher left off)
- Issues of coil lateral build, twist, and G11 pad thickness and fit suggest increasing width of Type-C clamp by .25-in



TRC Cross-Section

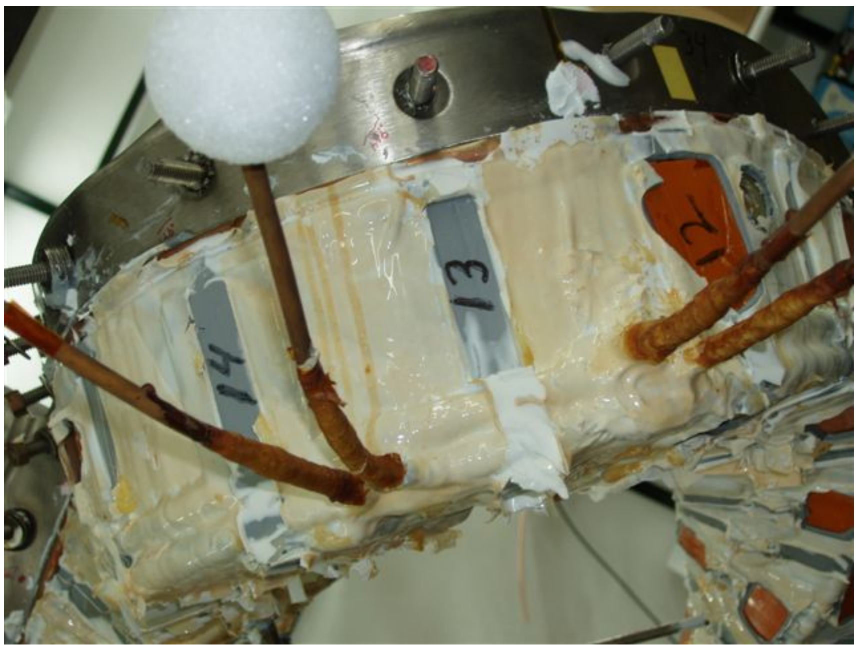


VPI Mold Assembly

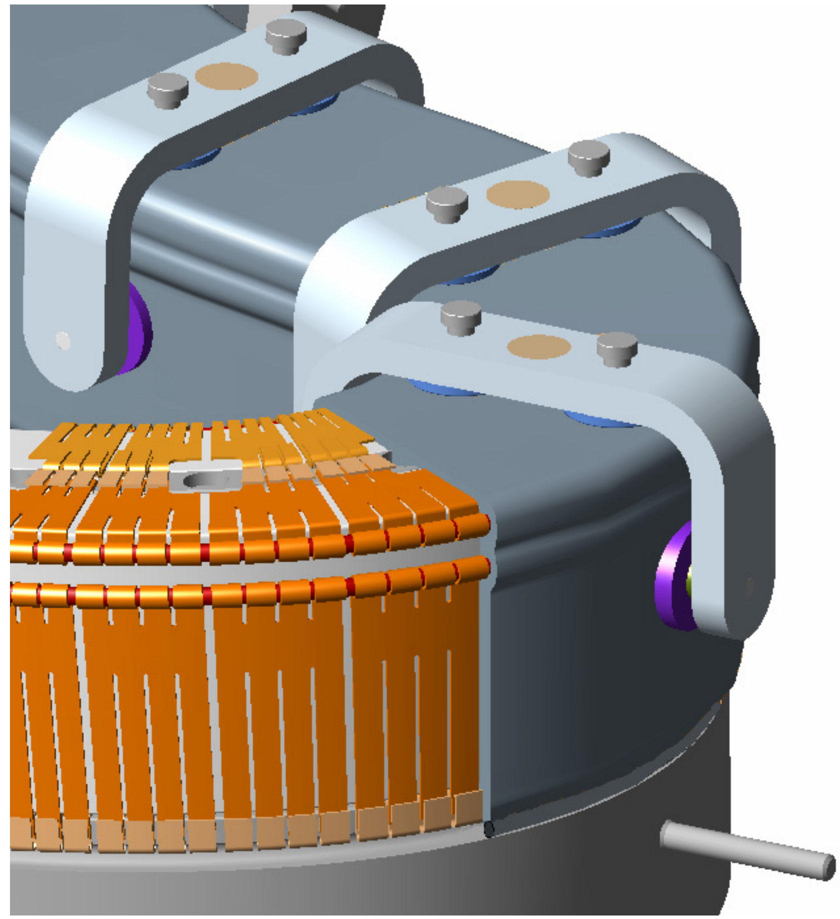
- Type-C Asm se140-103
  - Winding Form se141-103
    - MCWF se141-116
    - Pol Break se141-078
    - WF Prep se141-123
  - Terminals se142c-050
    - Jumpers se142c-051
    - Lugs/Cable se142c-055
  - Coil Asm-A se142c-251
    - Cladding se142c-382
    - Lead Blocks se142c-134
    - Chill Plates se142c-386
  - Coil Asm-B se142c-241
    - Cladding se142c-482
    - Lead Blocks se142c-135
    - Chill Plates se142c-486
  - Leads Encl se142c-270
    - Top/Sides se142c-184
    - Chill Plates se142c-183
  - VPI Asm se140-103
  - Clamp Asm se1405-275p
    - Clamp Bar se1405-276
    - Swivel Pads se1405-272

VPI Mold Assembly

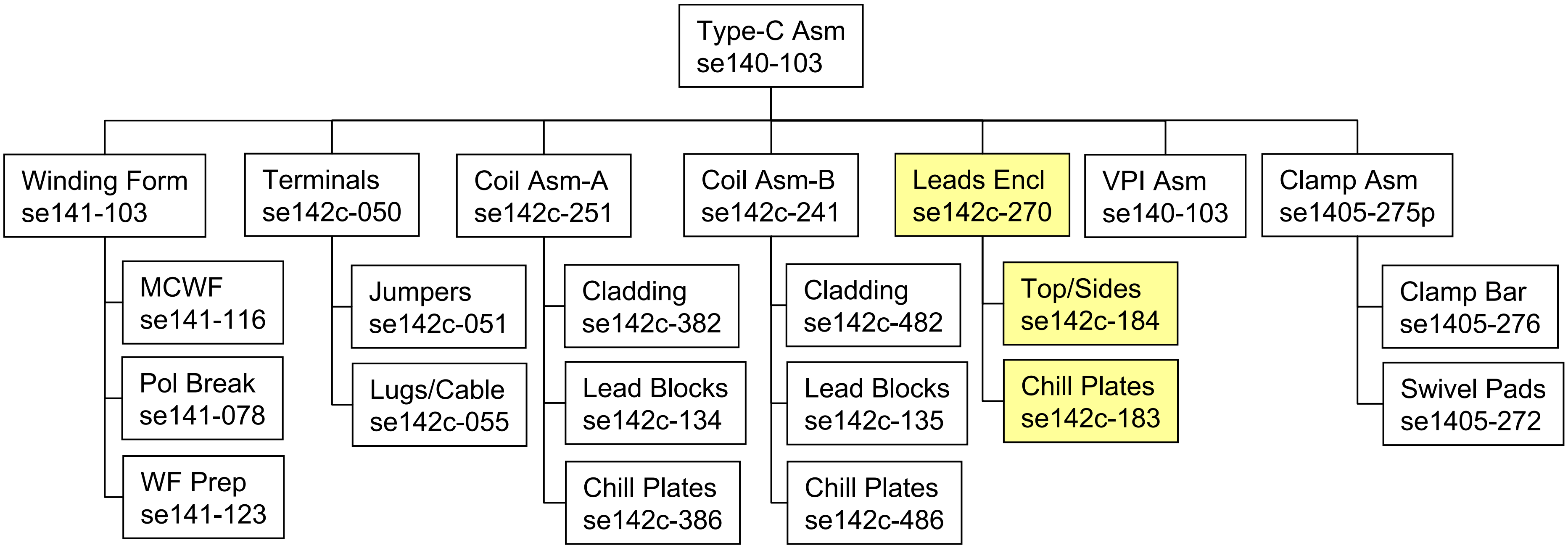
- Function is to provide vacuum-pressure boundary over ~30-ft2 surface area
- Composed of self-fusing silicone tape, chopped glass and Hysol resin/hardener
- Sealing groove is same as TRC, continuous on both sides for Type-C
- Bill of material callout on se140-103



Twisted Racetrack Bag Mold

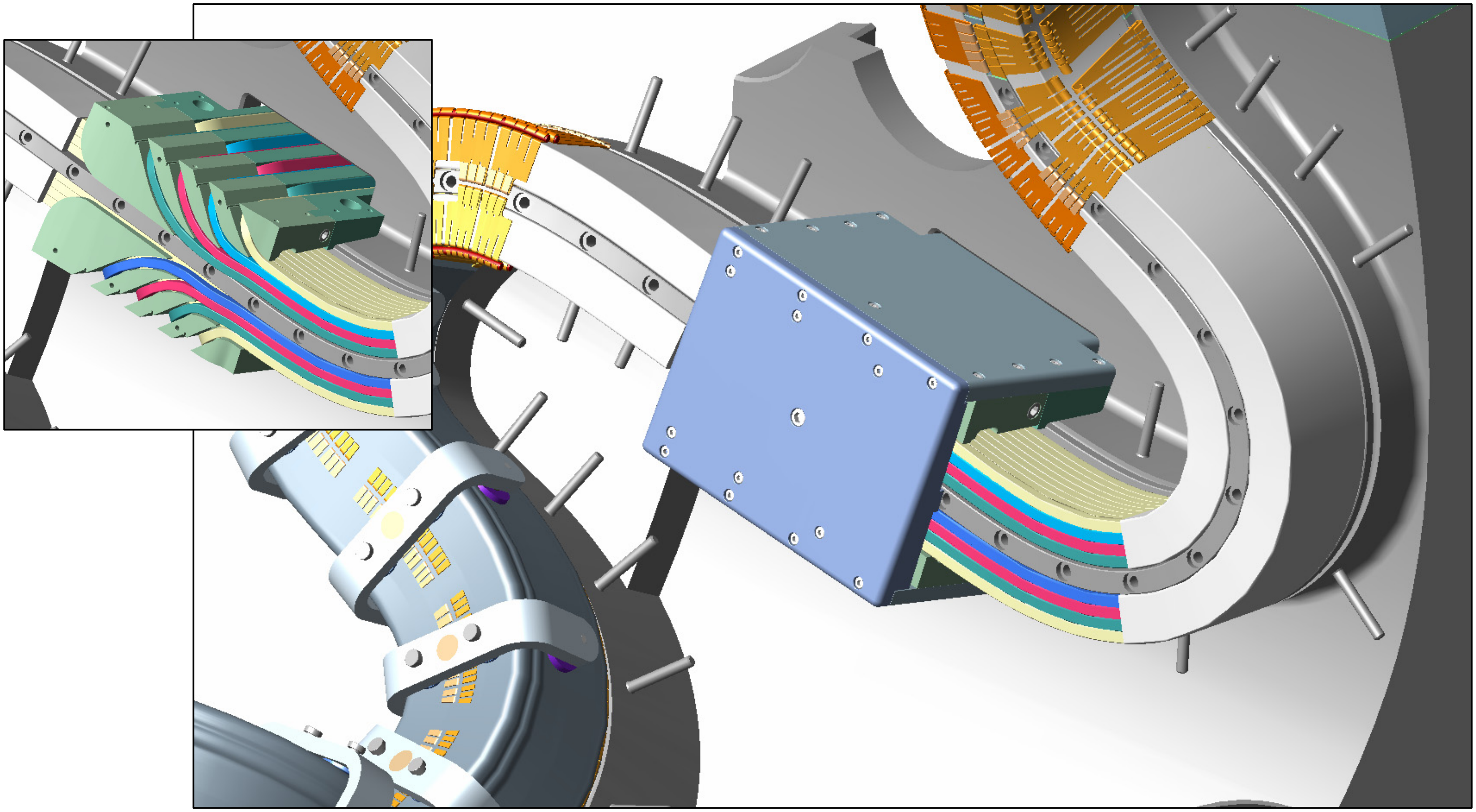


Leads Enclosure

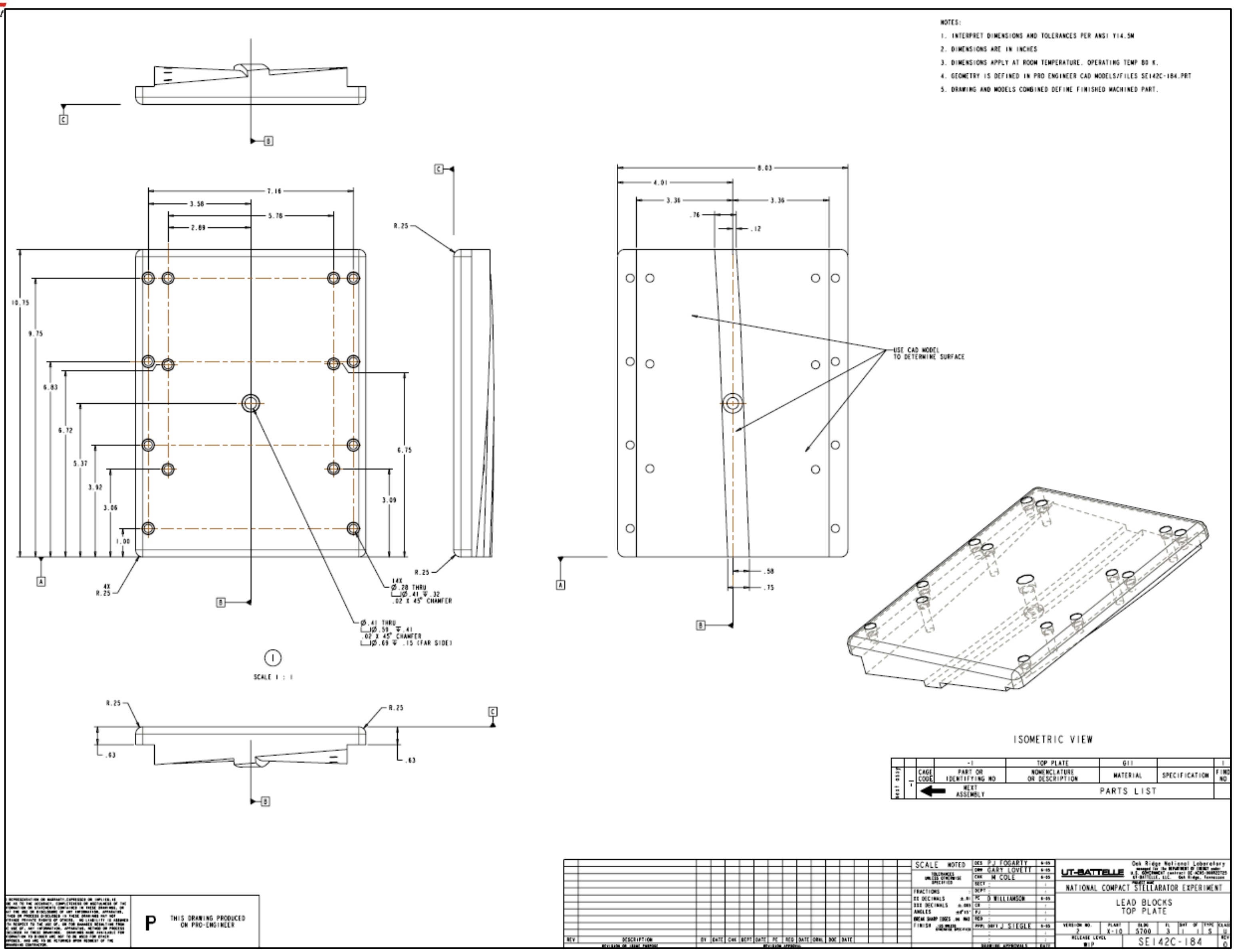


Leads Enclosure

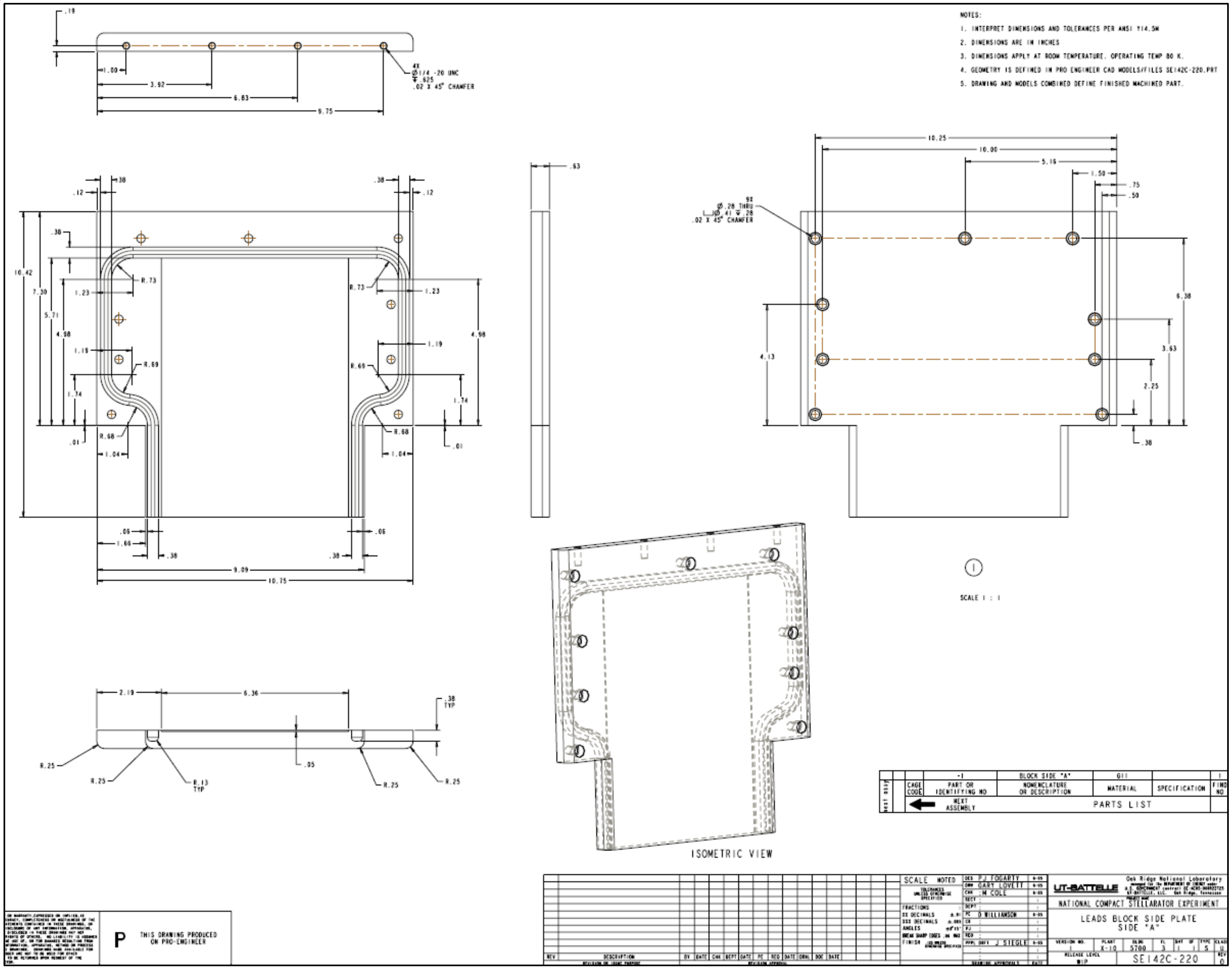
- G-11CR plates tie winding packs together in ~8 x 10 x 12-in enclosure
- Pre-fit features ensure proper alignment of starting lead blocks
- Top plate requires some contour machining



Leads Enclosure Top Plate



Leads Enclosure Side Plate



Chill Plates Subassembly

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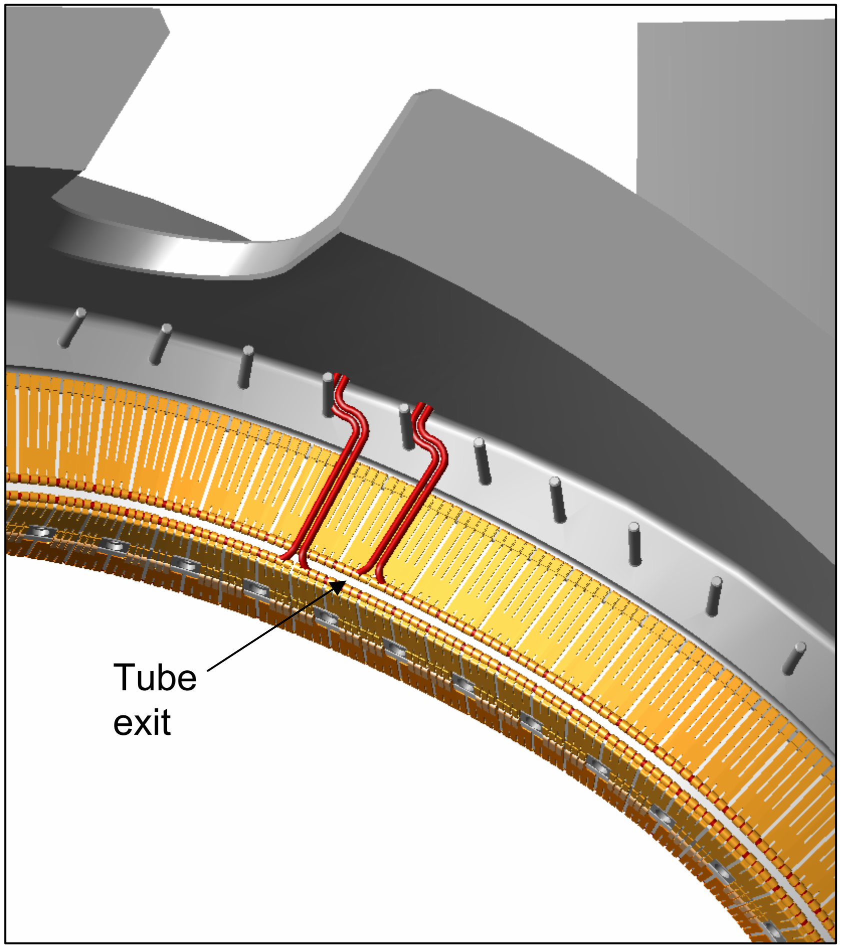
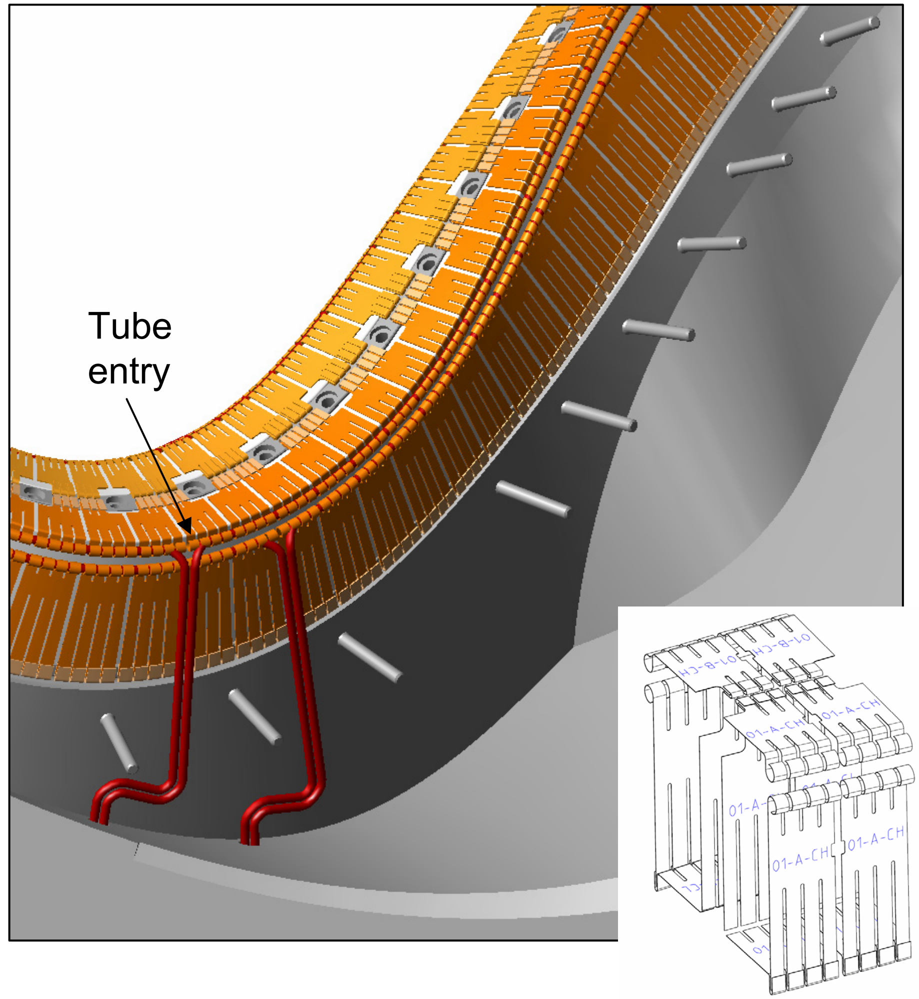
  - VPI Asm se140-103
  - Clamp Asm se1405-275p
    - Clamp Bar se1405-276
    - Swivel Pads se1405-272

Chill Plates Subassembly

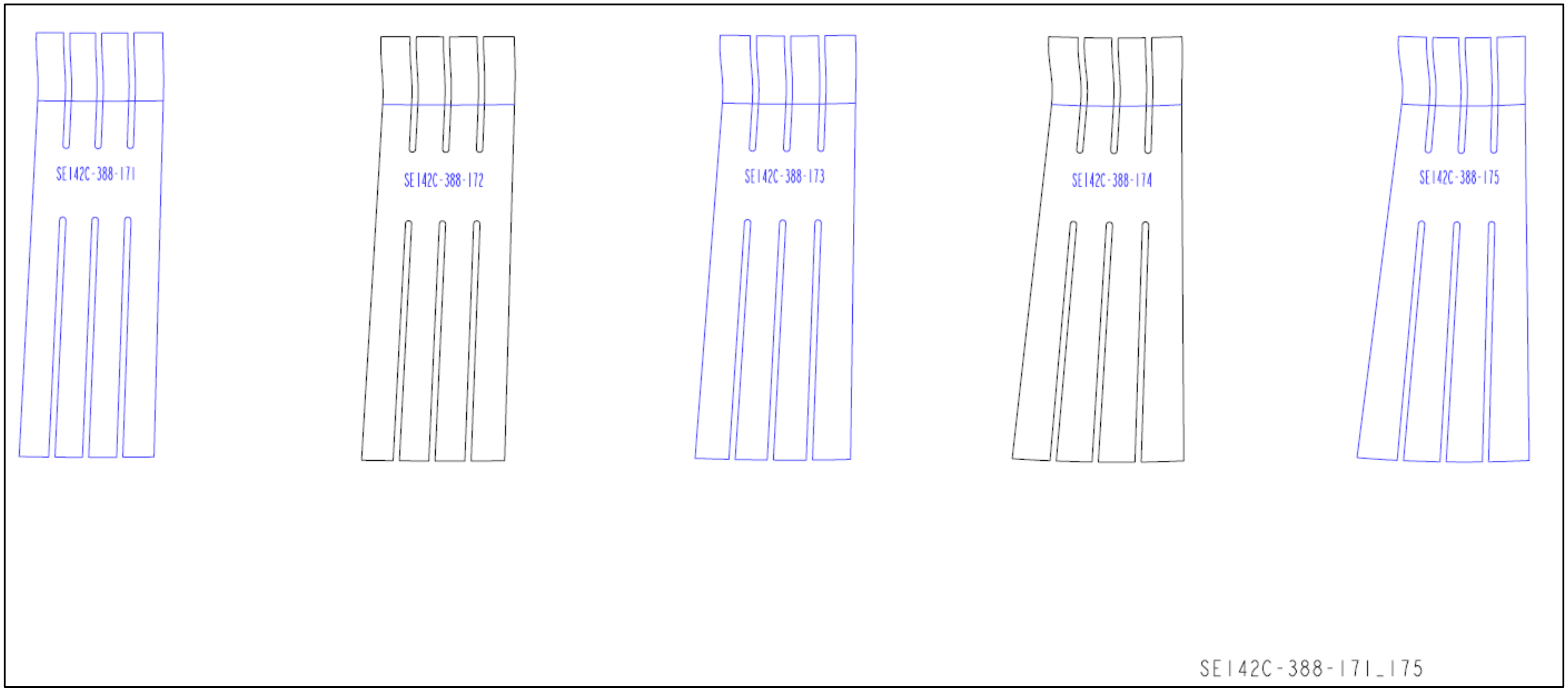
- 384+ chill plate parts per winding pack, average dimensions 1.5 x 4 x 4-in





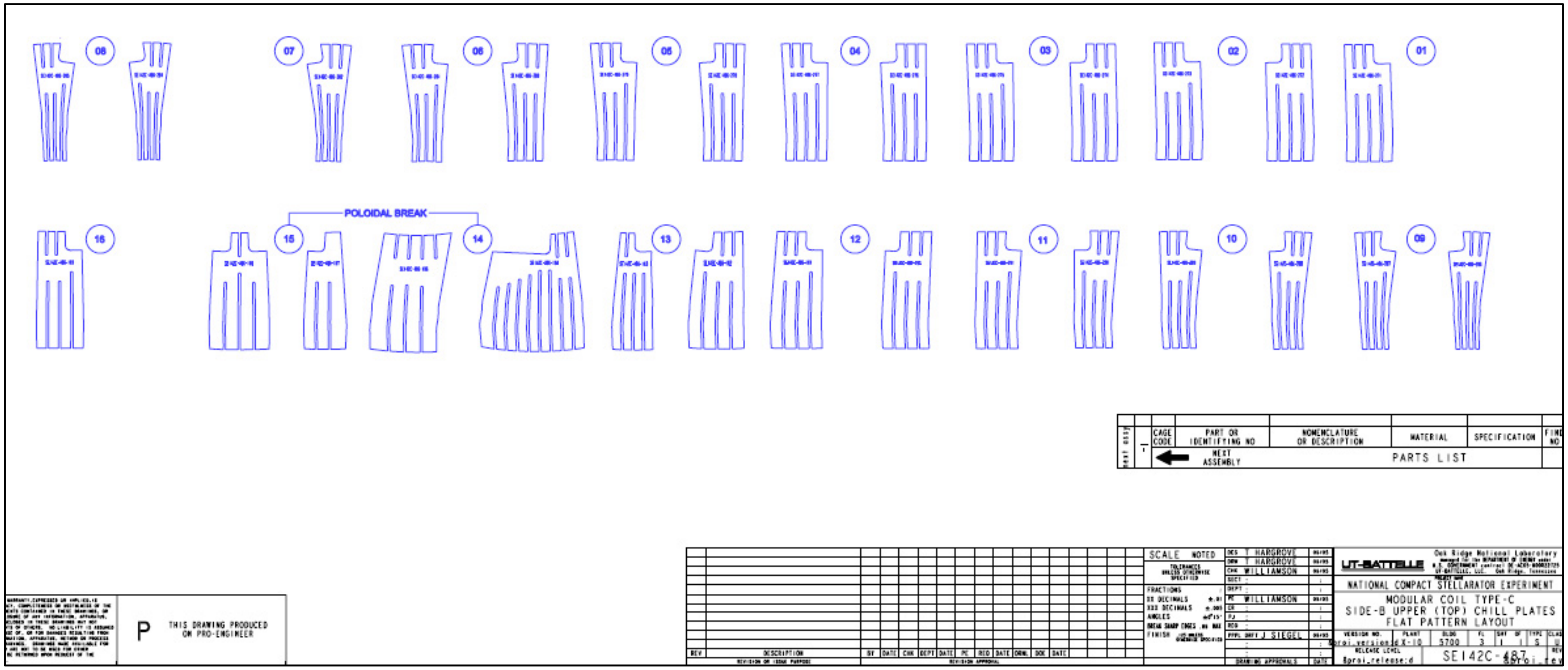
Chill Plate Drawings

- About 76 flat pattern drawings per winding pack, no format, DXF and PDF output



Chill Plates Asm Drawing

- Flat pattern layout drawing correlates part number with hole number
- Useful for QA check of parts before installation



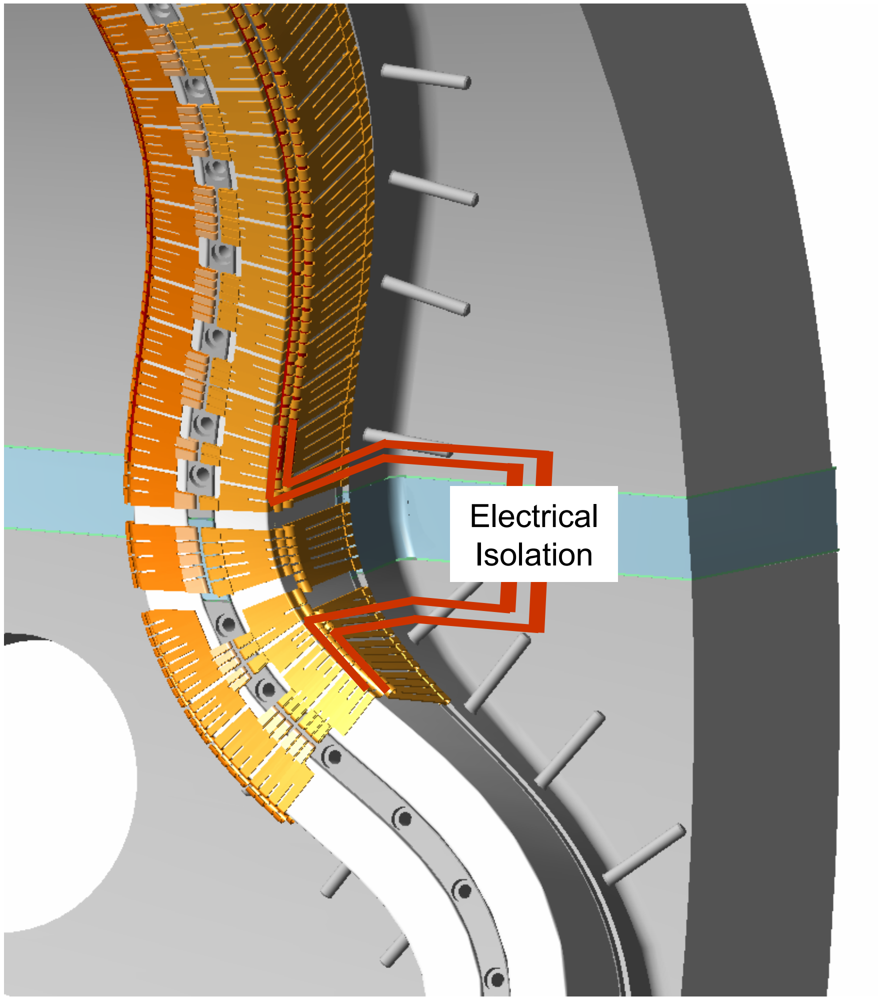
Improvements, New Issues

Type-C chill plates incorporate TRC input:

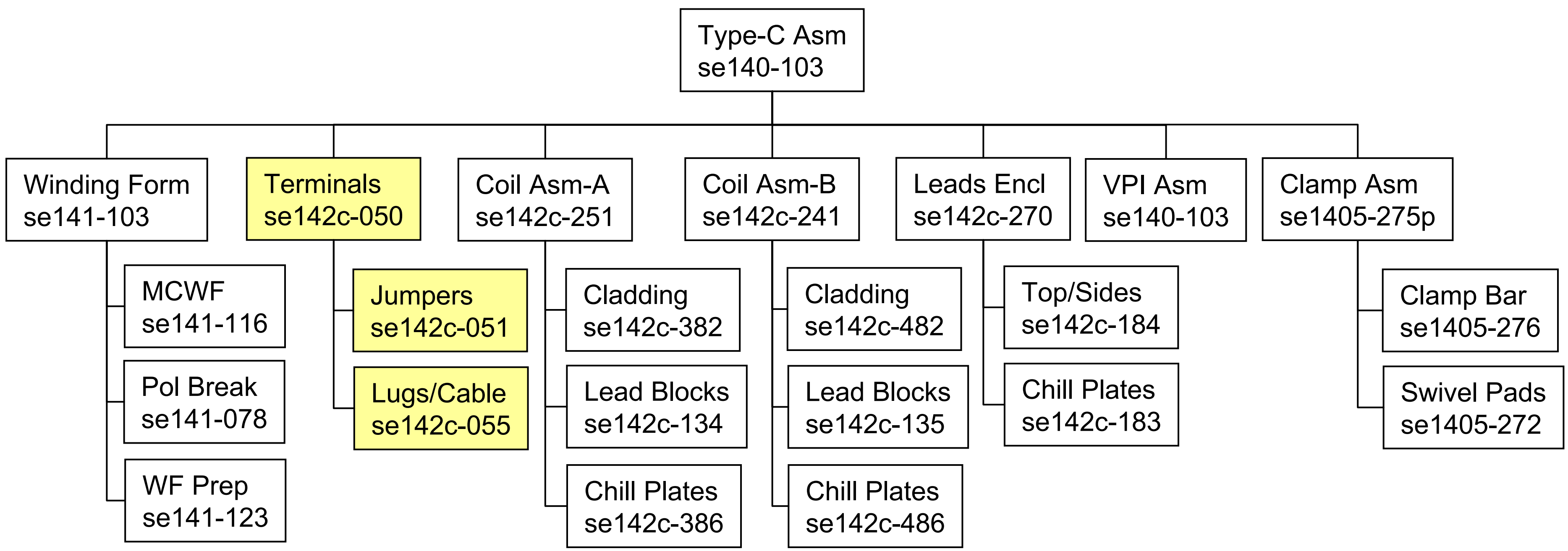
- Increase part spacing to .125-in, tab gap = .060-in
- Reduce number of slits, make min tab width > .2-in
- Increase tab length, trim at assembly
- Number parts according to hole position
- Replace cladding with strips in tight bends (test)
- Reduce radius of clamp cutout
- Modify staking tools and procedure

New issues involve:

- Poloidal break
- Routing of cooling tubes

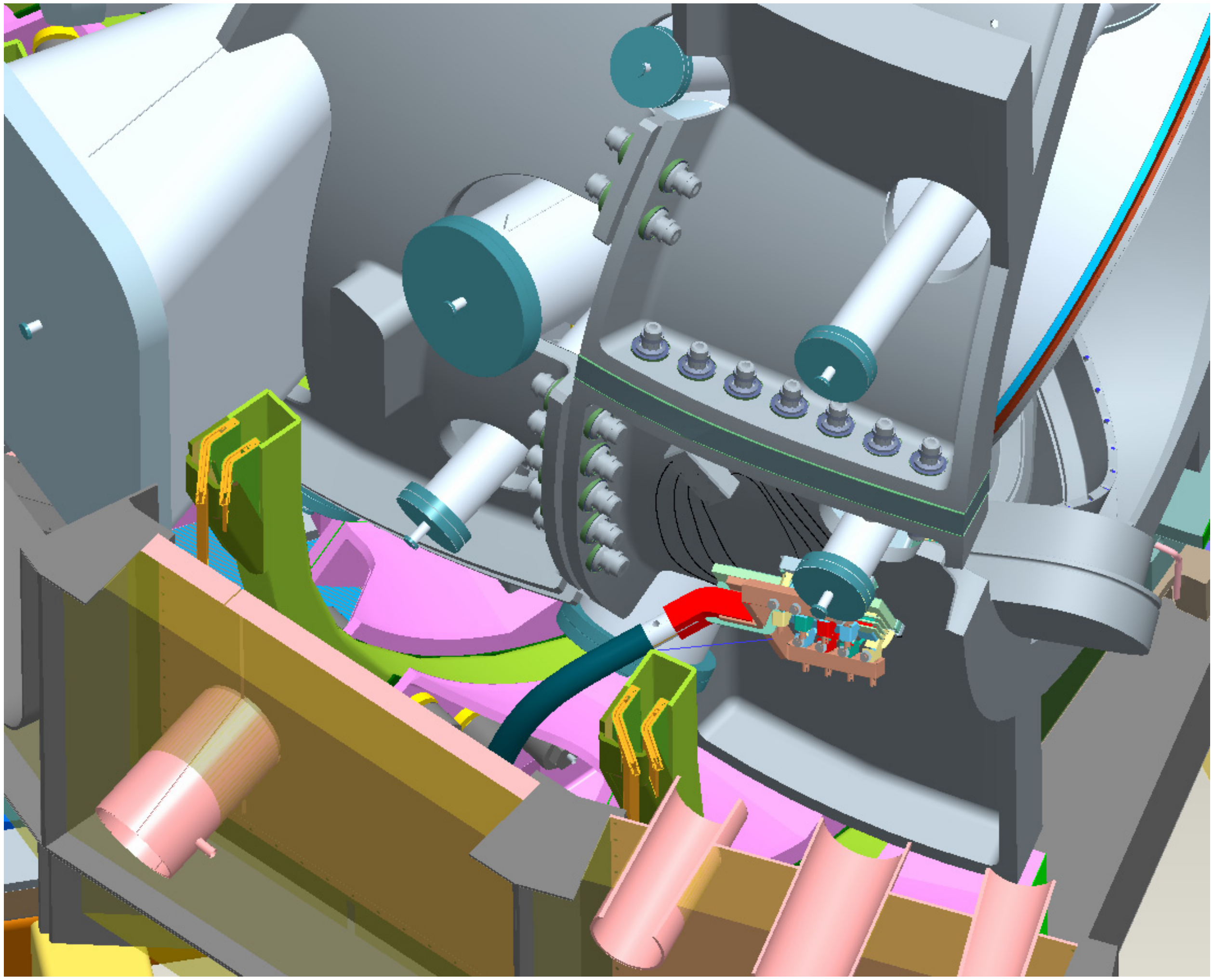


Leads Terminal Subassembly



Leads Terminal Subassembly

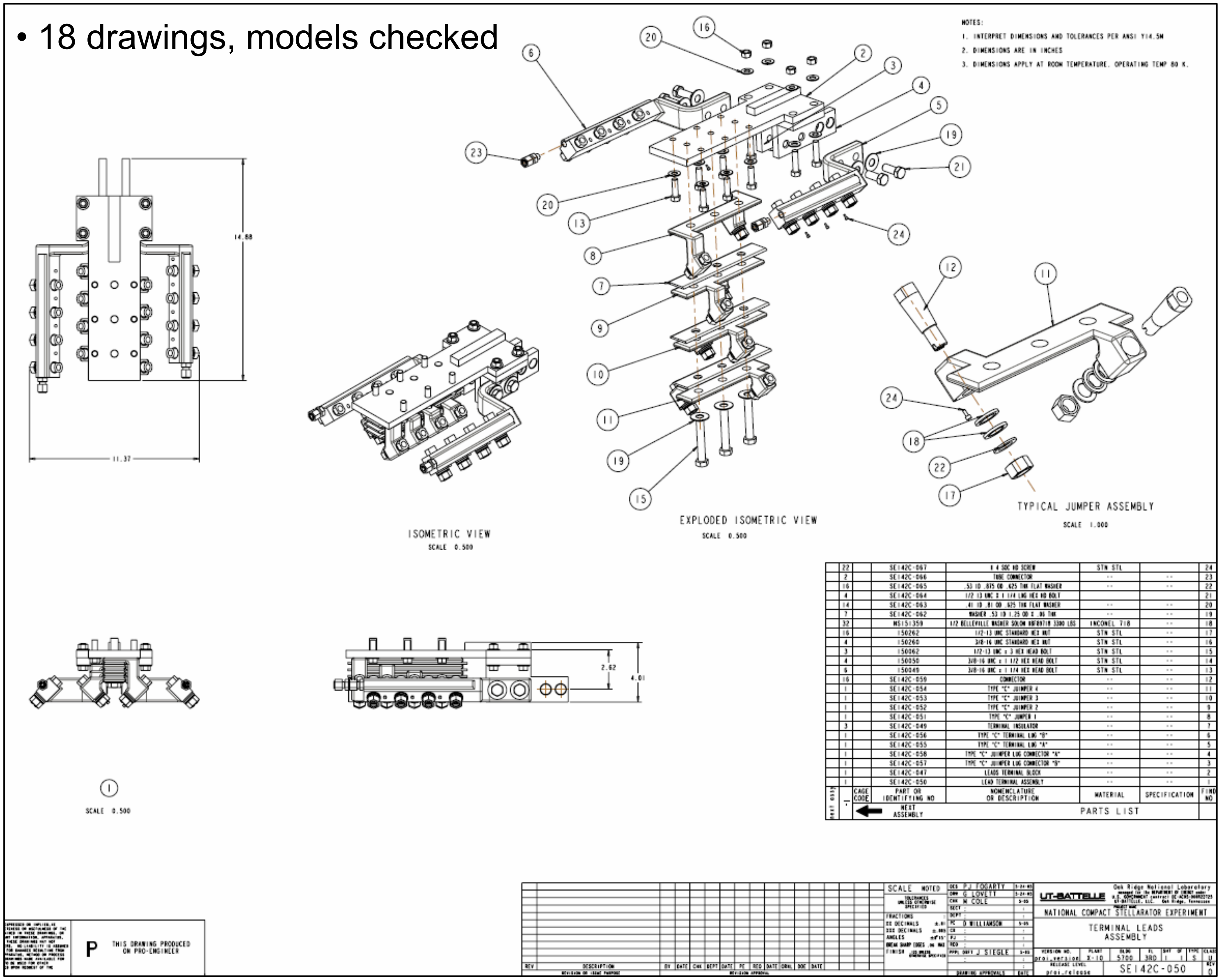
- Revised design addresses issues of installation, clearance, and field errors



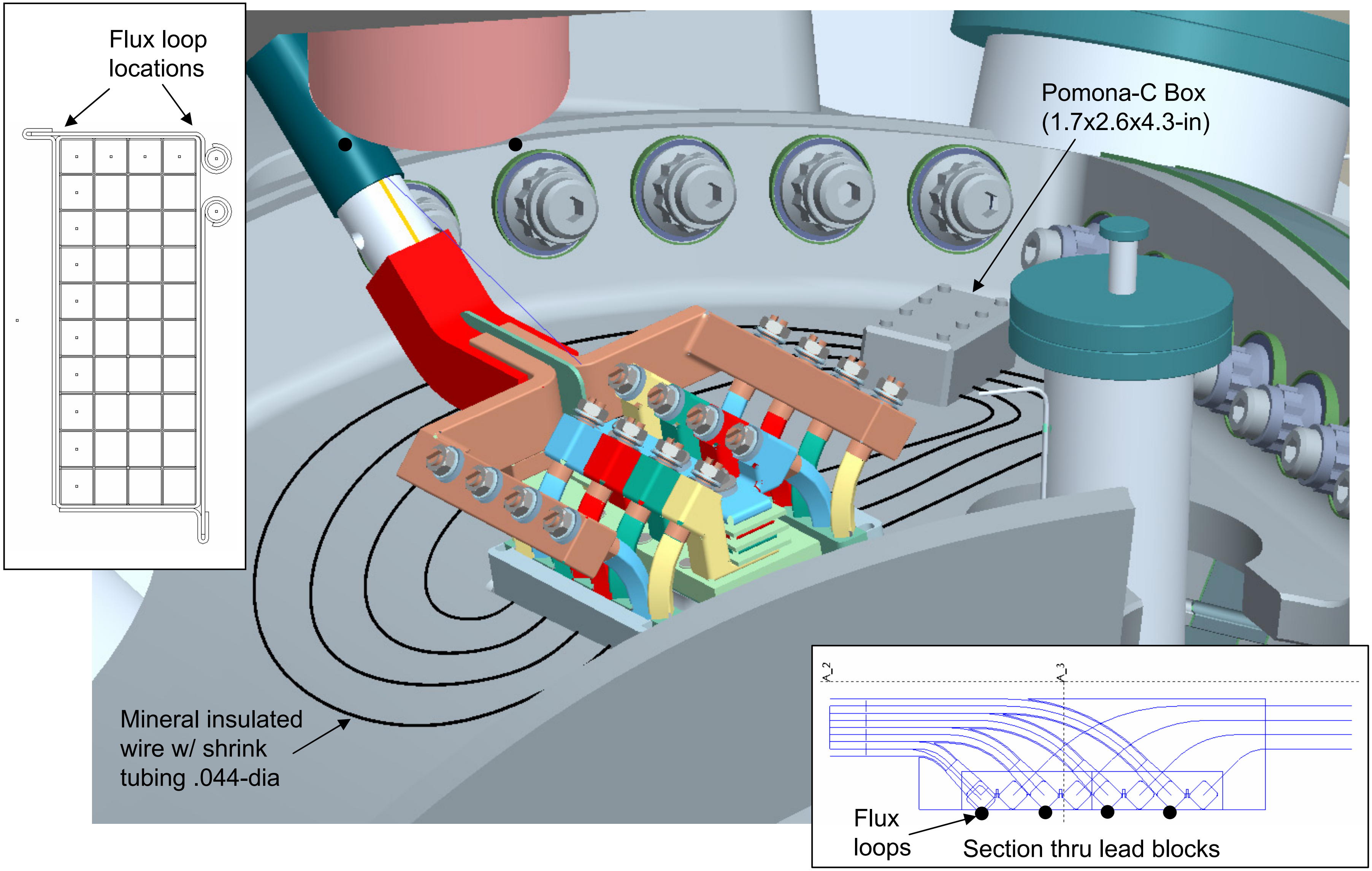
Leads Terminal Asm Drawing

NCSX National Compact Stellarator Experiment

- 18 drawings, models checked



Flux Loop Termination Concept



Winding Form Prep

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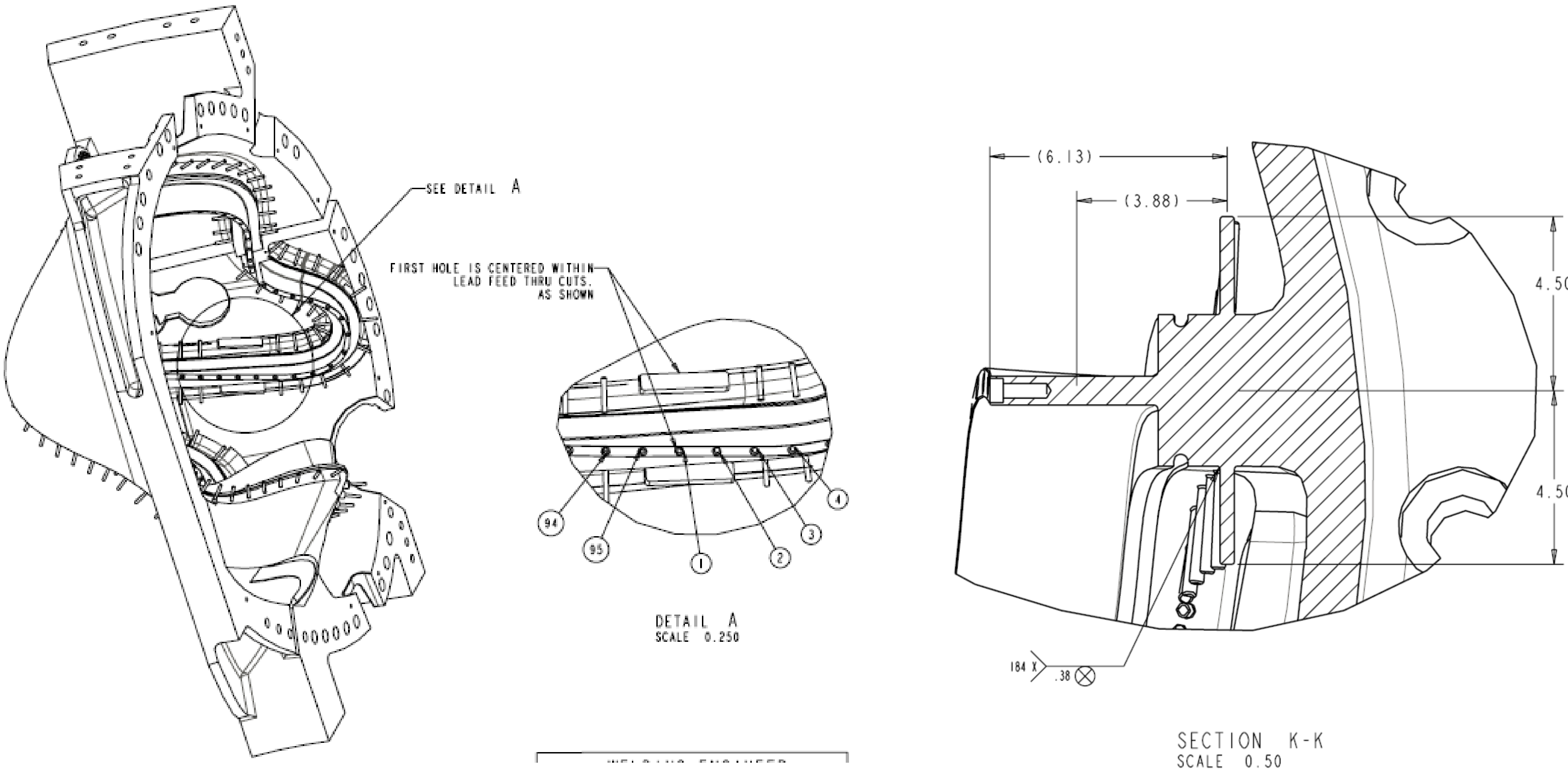
  - Clamp Asm se1405-275p
    - Clamp Bar se1405-276
    - Swivel Pads se1405-272

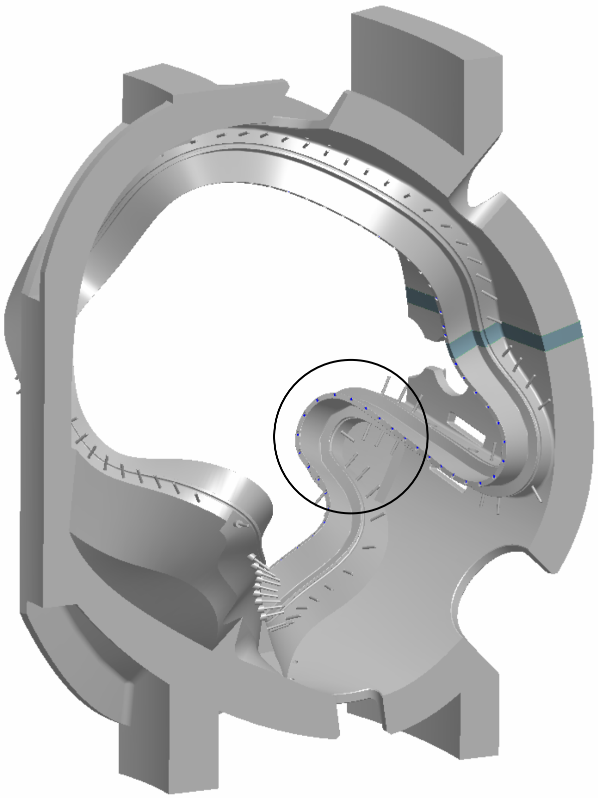
Winding Form Prep

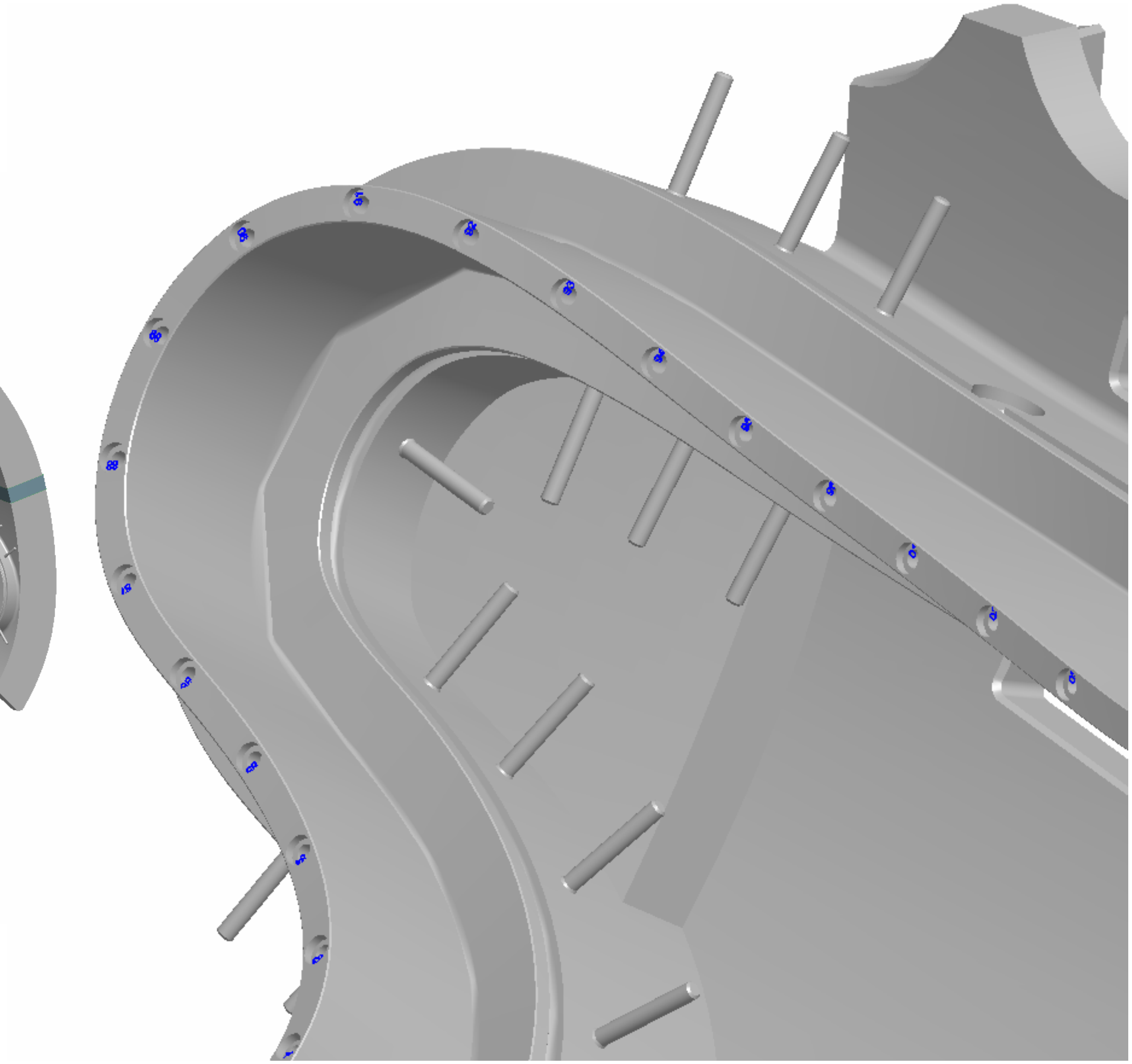
- Winding form prep includes hole numbering, installation of winding clamp studs
- Drawing se141-123 ready after checking changes are made



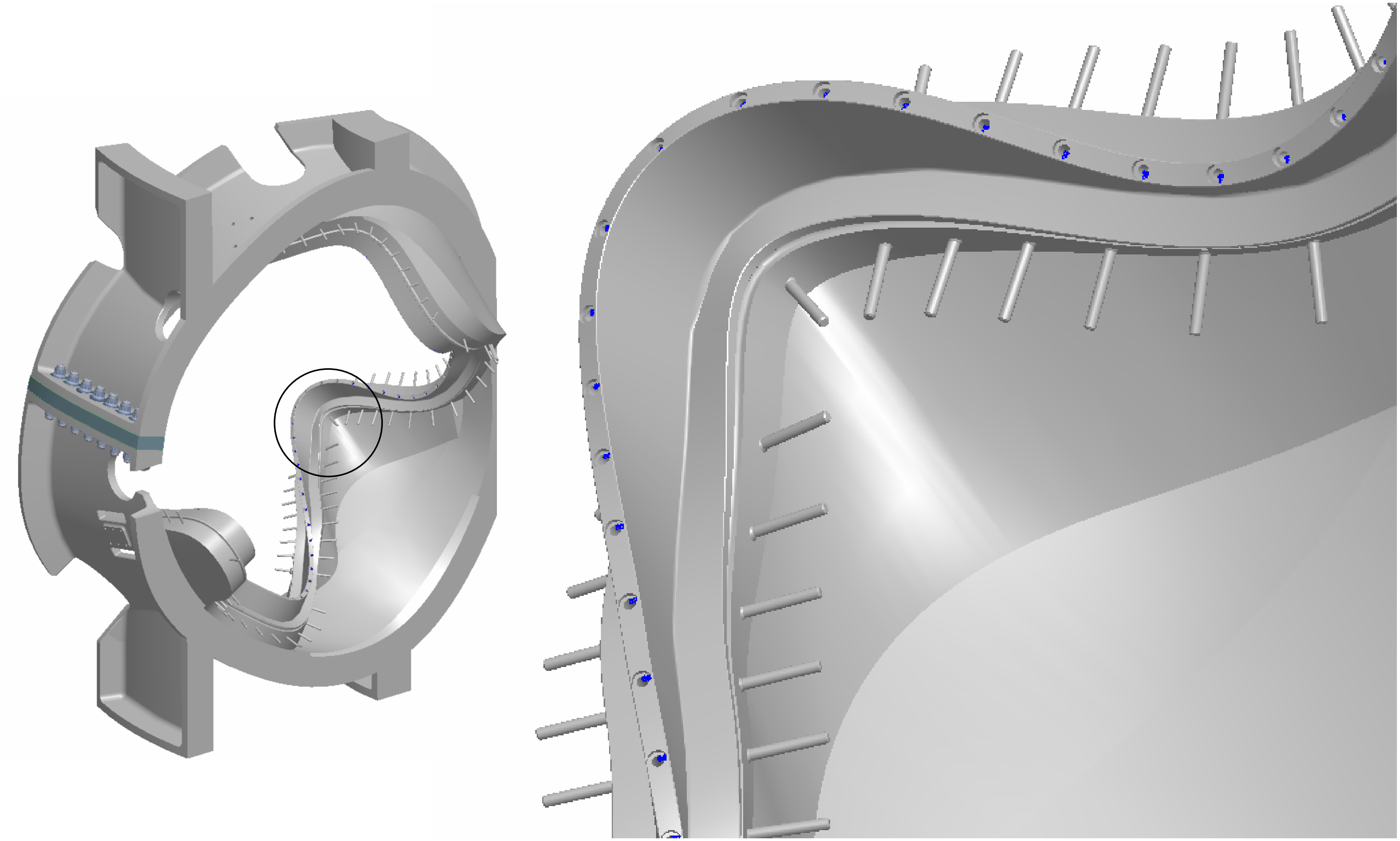
Ref: se141-123

Winding Clamp Studs



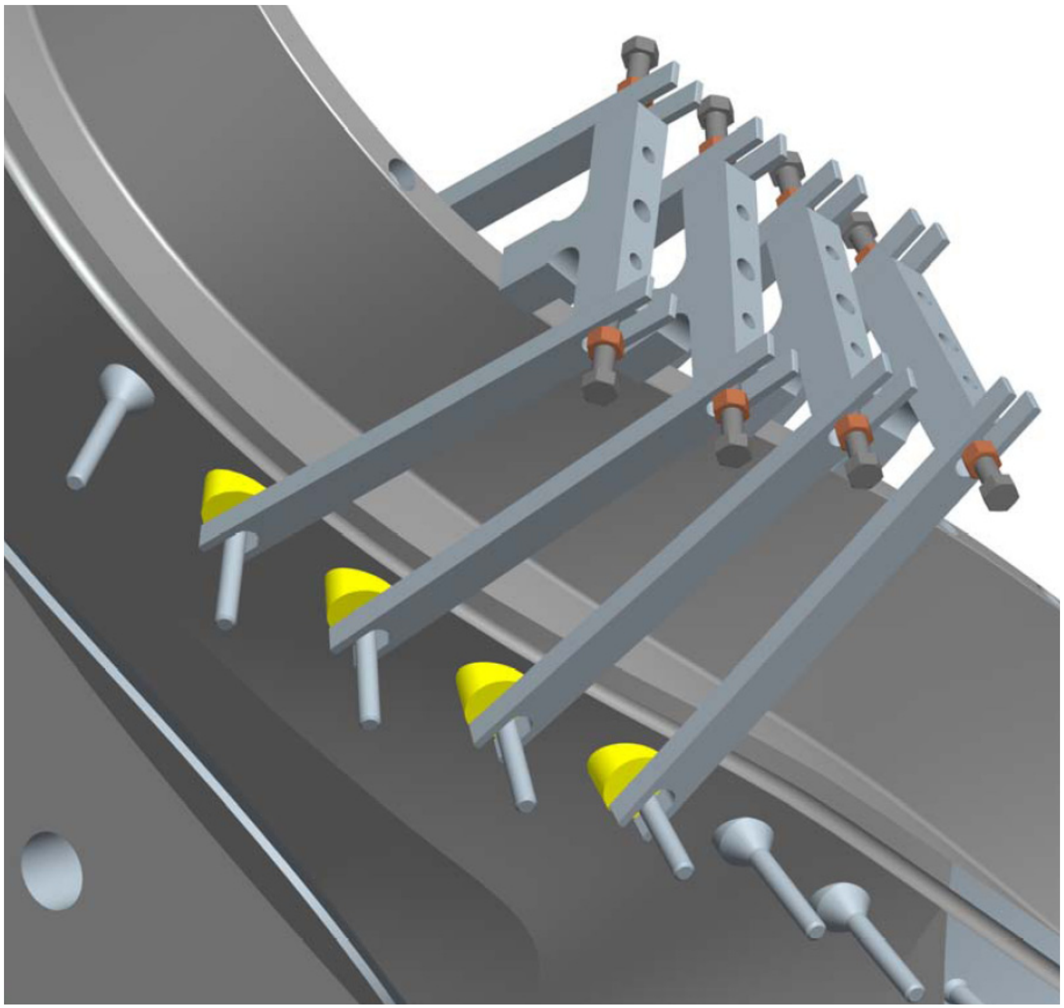


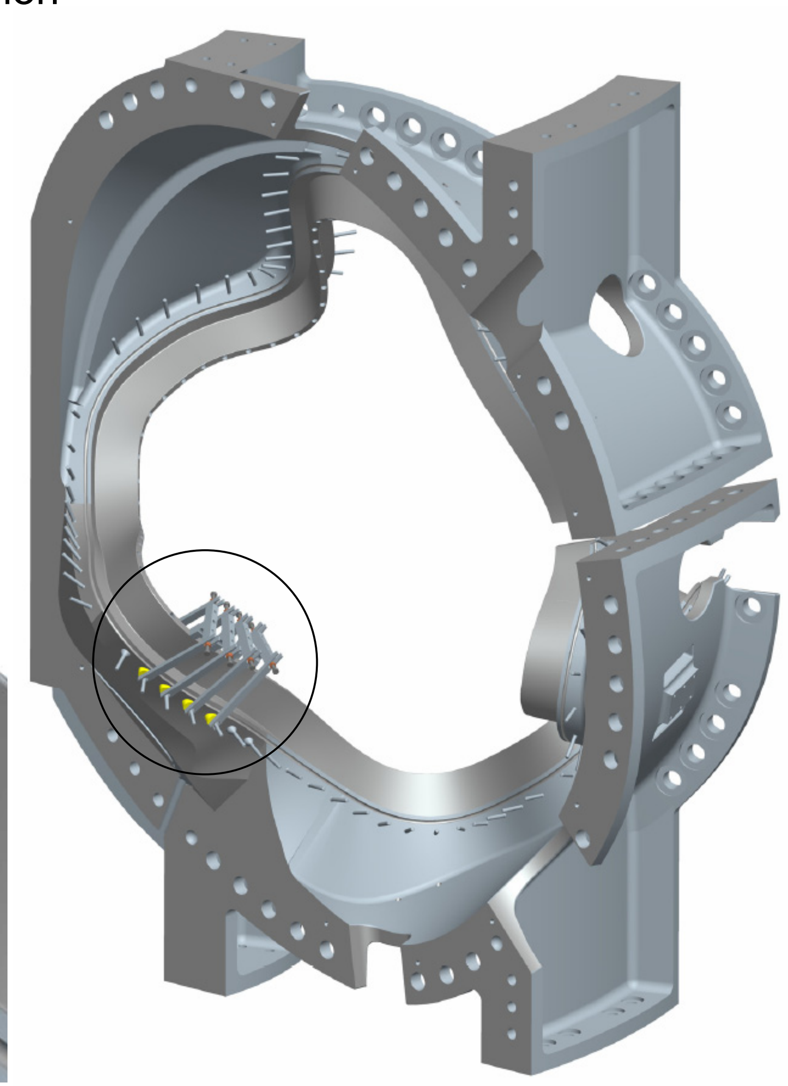
Winding Clamp Studs



Clamp Stud Adapter

- Adapter, 1.25-in dia x 2 lg required in cutaway region
- Approximates MCWF surface with flat cut





Go to Paul Fogarty's slides

Drawing Status and Plans

- Type-C drawing package includes 362+ drawings, of which 176 have been released for fabrication
- Status of remaining drawings:
  - Top level asm and layouts
    - Major cleanup in progress, schematics not started, issue all by Jul-27
  - Winding form assembly
    - Making checking changes to stud drawing, issue by Jul-11
  - Side-A winding pack assembly (incl lead blocks)
    - Approx 78 chill plate drawings in progress, check and issue by Jul-20
    - Issue upper lead block, misc G11 parts by Jul-13
  - Side-B winding pack assembly (incl lead blocks)
    - Approx 78 chill plate drawings in progress, check and issue by Jul-20
    - Issue upper lead block, misc G11 parts by Jul-13
  - Leads terminal assembly
    - Model check complete, drw check in progress, issue by Jul-15
    - If schedule problems, use STL mockup to start C1 winding
  - Lead blocks enclosure
    - Model check complete, drw check in progress, issue by Jul-13
    - If schedule problems, use STL mockup to do C1 pre-fit
  - Clamp assembly
    - Rev to clamp bar complete, check and issue by Jul-15

Conclusion

- Is the design of the Type-C coil assembly complete?
  - All components have been modeled, incorporating design requirements and TRC recommendations
  - Some work remains to complete lead area chill plates, cooling tube routing at poloidal break, and flux loop wire termination
- Are the specifications and drawings ready to be issued?
  - Assembly specification has been issued for comment
  - Remaining lead blocks have been detailed and checked, chill plates are being checked in parallel with drawing preparation
  - Clamp drawing revision is complete
- Is the schedule for remaining documentation achievable and consistent with project need dates?
  - First priority given to long lead outside procurement: lead blocks, terminal parts, clamps
  - Second priority to water-jet cutting: chill plates for C1, then shift to outside procurement

Backup Slides

Comparison of Twisted Racetrack analysis to Global NCSX Modular Coil analyses

Non-linear Modular Coil analyses [2T high Beta loading applied.]				
Coil	Winding Stress (ksi)	Shell/Tee Stress (ksi)	Max Principal Strain (in/in)	Gap [Laterial] (mm)
Mechanica A	10.5	24.7	0.0011	0.0889
Mechanica B	11.5	39.0	0.00012	0.5842
Mechanica C	12.9	32.0	0.0015	0.8128
Ansys A	11.5	33.5	0.0013	0.2
Ansys B	9.6	36.1	0.001	0.5
Ansys C	11.0	32.9	0.0012	0.6

Modular coil analysis 11/1/04 (2T High Beta and Thermal Stress effects)

$E_{Winding}$ = 9 E6 psi

E_{Shell} = 23 E6 psi

Ranges for expected max stress/strain on the TRC tee and windings

Twisted Racetrack Summary							
	Current (kAmps)	Estimated range for max stress in tee (ksi)		Estimated range for max stress in winding (ksi)		Estimated range for max strain in winding (in/in)	
Linear	42	43	58	18	24	3.0E-03	4.0E-03
Linear	31.5	24	32	10	14	1.7E-03	2.3E-03
non-linear	42	71	96	13	18	3.0E-03	4.0E-03
non-linear	31.5	40	54	8	11	1.8E-03	2.4E-03

Twisted Racetrack Non-linear Coil Analysis (magnetic pressure and thermal stress)
[$E_{Winding}$ = 9 E6 psi E_{Shell} = 23 E6 psi]

Property Comparison on the Twisted Racetrack Analysis

The latest test data suggests that the assumed modulus values used in the analysis for the tee and winding were slightly higher than needed.

Twisted Racetrack Summary

Analysis Type	Current (kAmps)	Winding Modulus (Mpsi)	Shell Modulus (Mpsi)	Max Stress Tee (ksi)	Max Stress winding (ksi)	Max Clamp Stress (ksi)	Max gapoff tee (in)	Max principle strain (in/in)
non-linear	31.5	**9**	**23**	46.7	9.5	8.8	-0.00519	0.002096
non-linear (new Mat. Props.)	31.5	**8.5**	**22**	47	8.9	8.7	-0.00537	0.002106

Twisted Racetrack Summary

	Current (kAmps)	Winding Modulus (Mpsi)	Shell Modulus (Mpsi)	Estimated range for max stress in tee (ksi)		Estimated range for max stress in winding (ksi)		Estimated range for max strain in winding (in/in)	
non-linear	31.5	**9**	**23**	40	54	8	11	1.8E-03	2.4E-03
non-linear (new Mat. Props.)	31.5	**8.5**	**22**	40	54	8	10	1.8E-03	2.4E-03

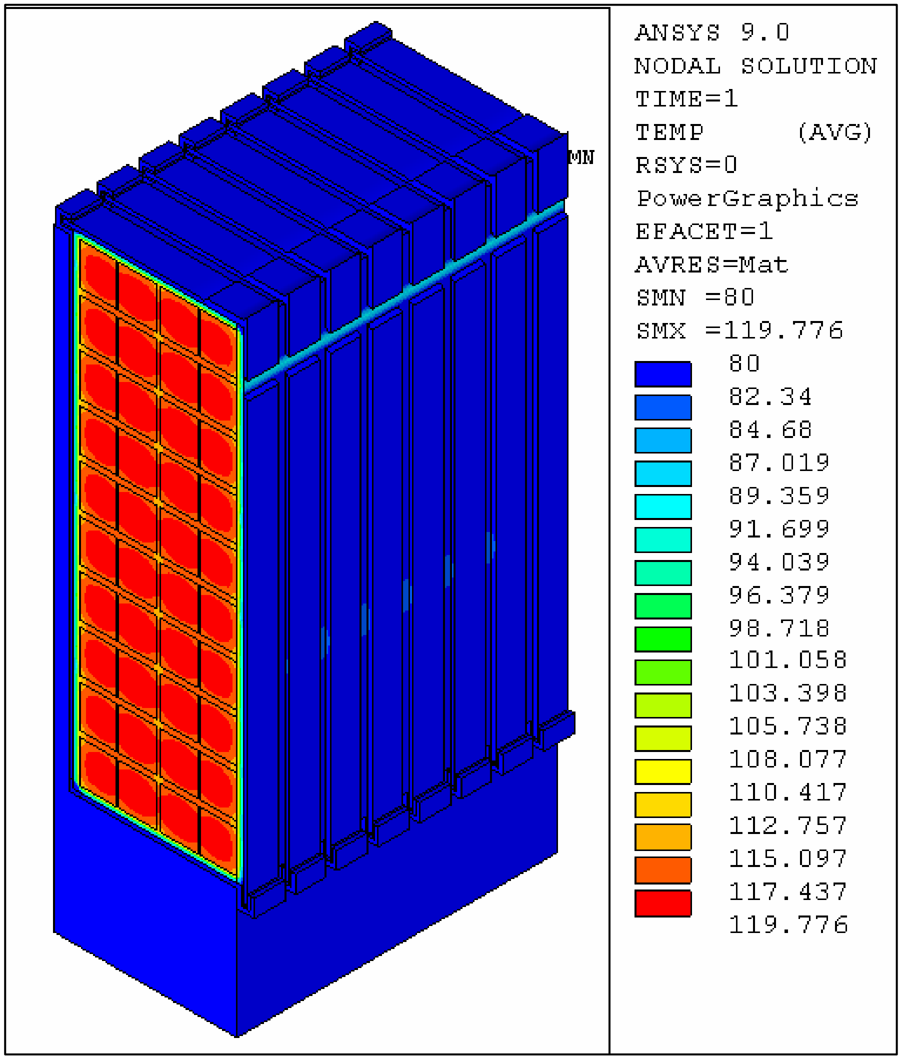
The difference in property values has little effect on the Twisted Racetrack Analysis and thus the lower modulus is not expected to impact the Global NCSX Modular Coil Analysis.

Winding Pack Thermal Analysis

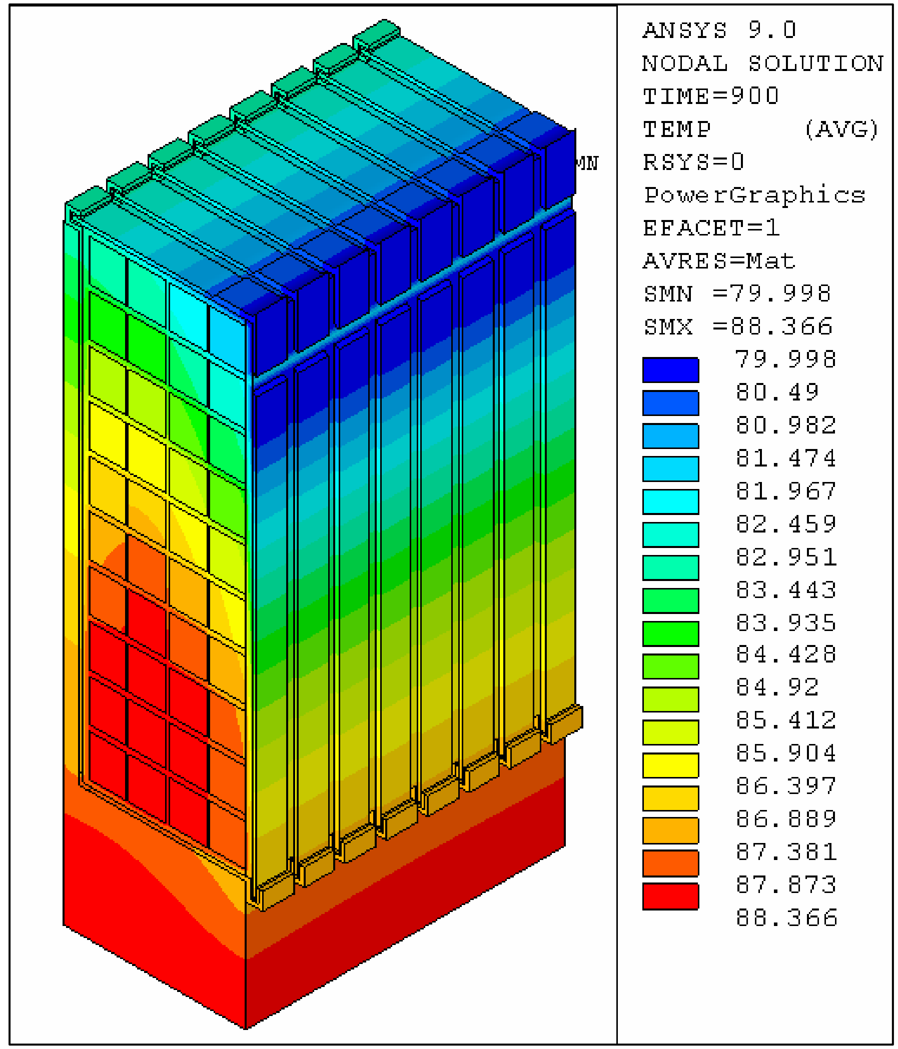
NCSX

- Temperature dependent heat generation (see next slide)
- Crimp conductivity set to 100 W/m-K
- Groundwrap overlap is reduced from 2X to 1.3X.
- Copper thickness is 0.04 in.
- Pulse shot is still 2T, high beta, 10,390 Amps/cable.
- Cool down time is still 15 minutes.

First Cycle

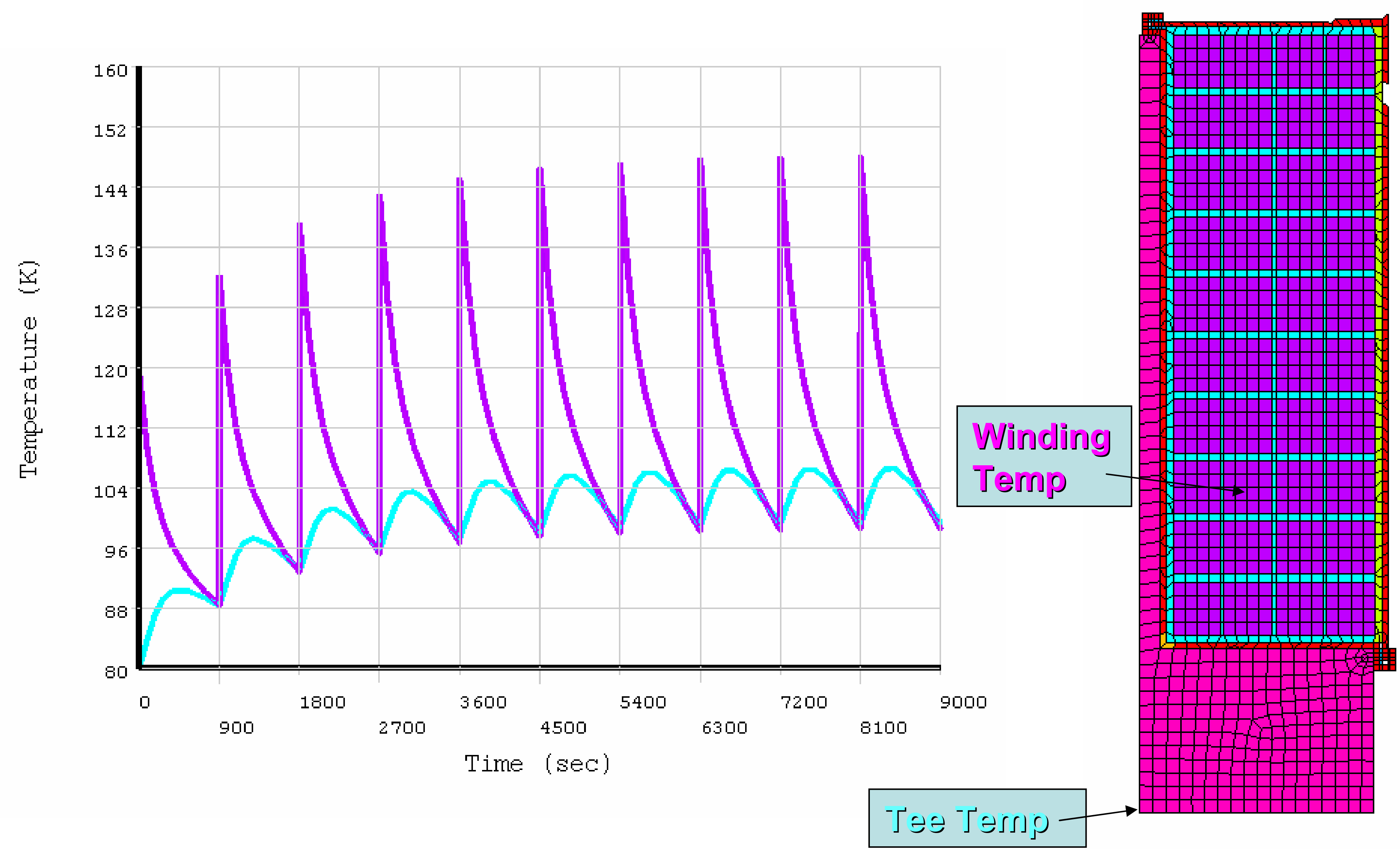


Immediately after pulse



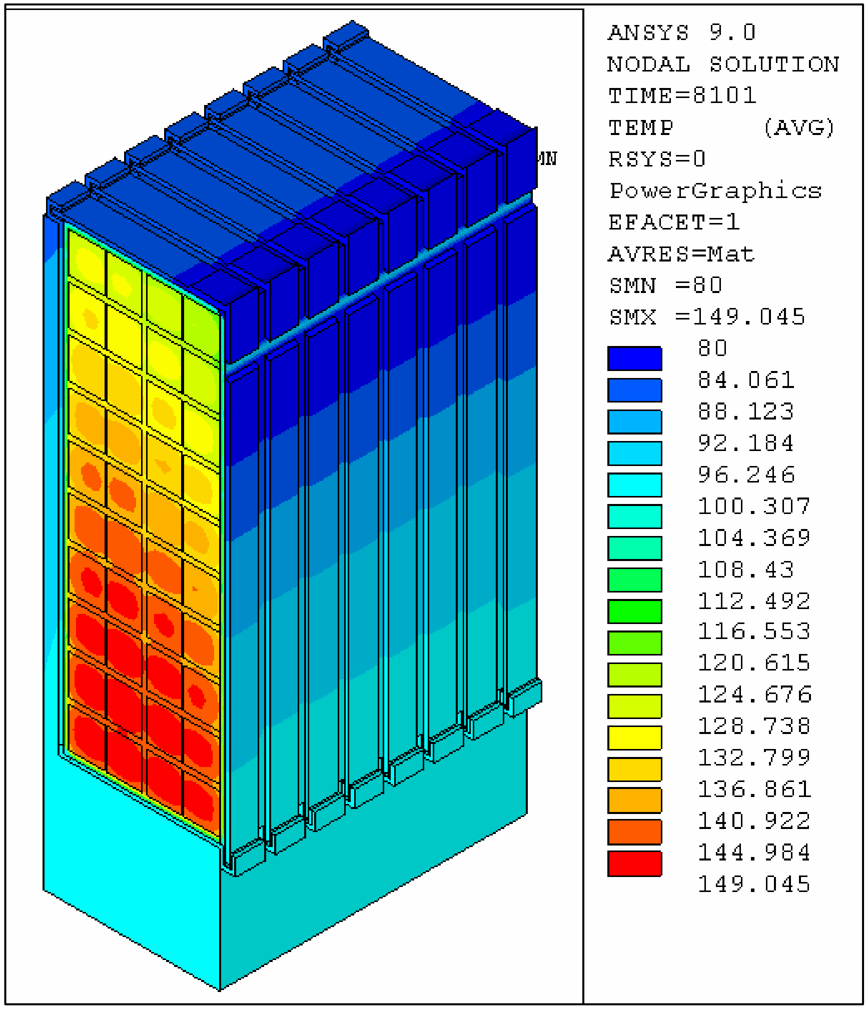
T = 15 minutes (after cool down)

Ten Cycles

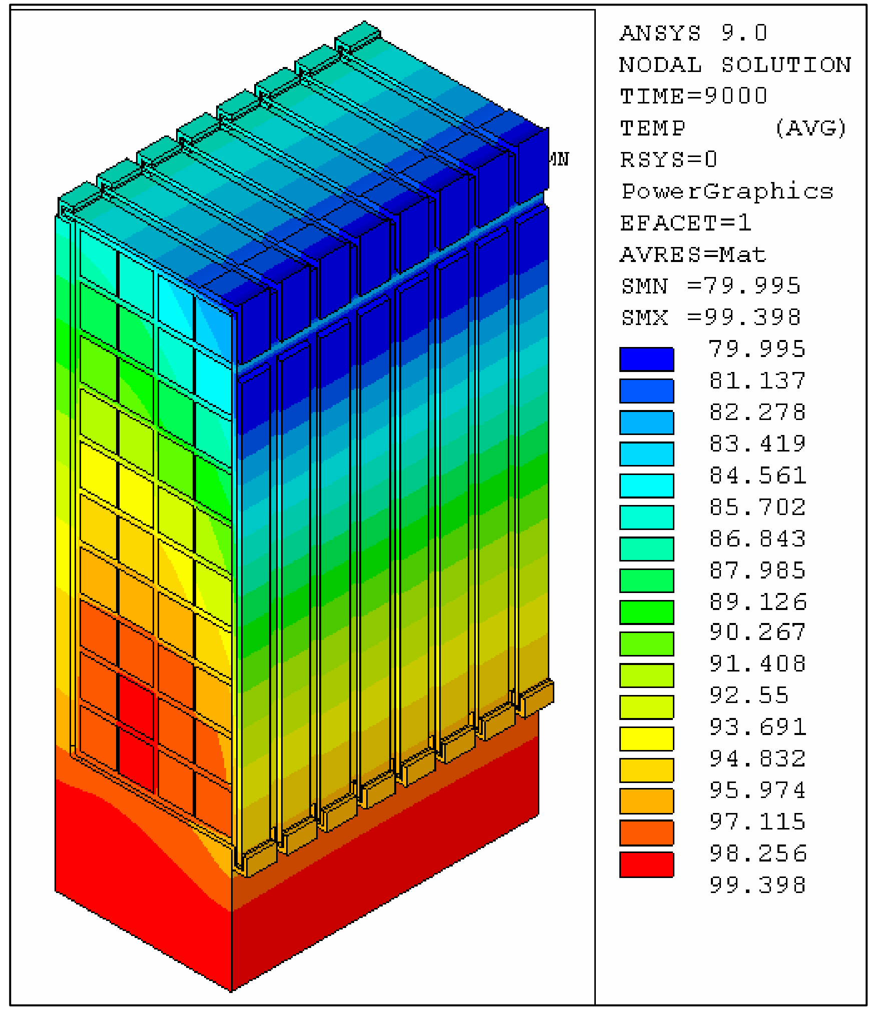


160
152
144
136
128
120
112
104
96
88
80
Temperature (K)
0
900
1800
2700
3600
4500
5400
6300
7200
8100
9000
Time (sec)
Winding Temp
Tee Temp

NCSX



Temperature after the 10th shot



Temperature after the 10th cool down

After 10th cycle (winding and tee isolated)

NCSX