NSTX Vacuum Vessel Protection Armor for Neutral Beam Injection Heating

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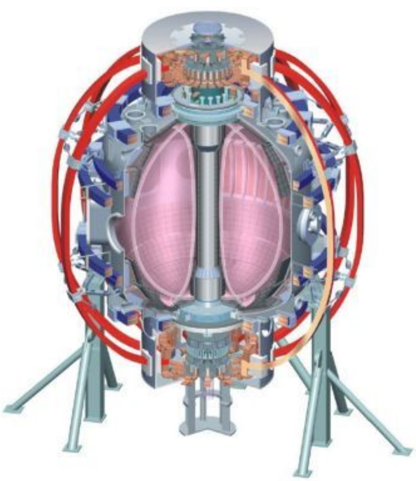
L. Bryant, T. Stevenson, and C. Priniski

13th International Workshop on Plasma-Facing Materials and Components for Fusion Applications Conference
Rosenheim, Germany
May 9-13, 2011



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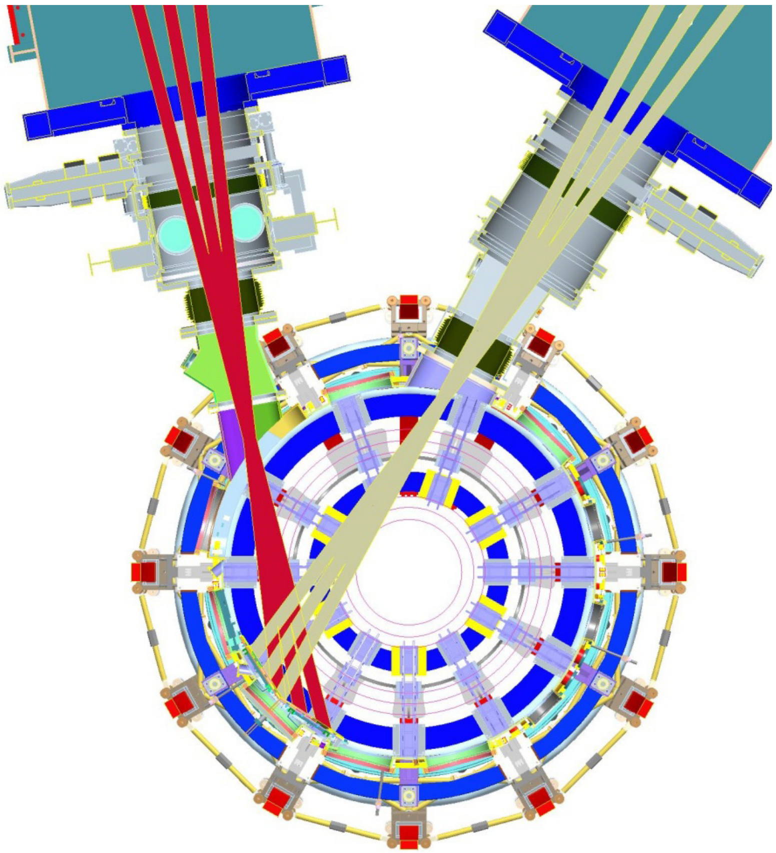
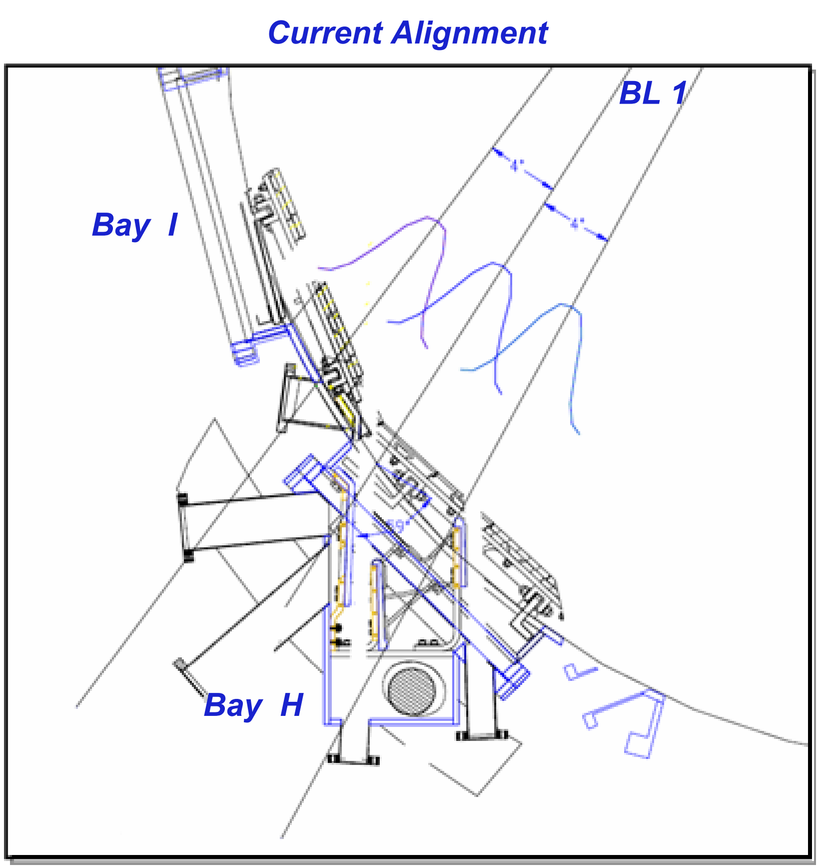
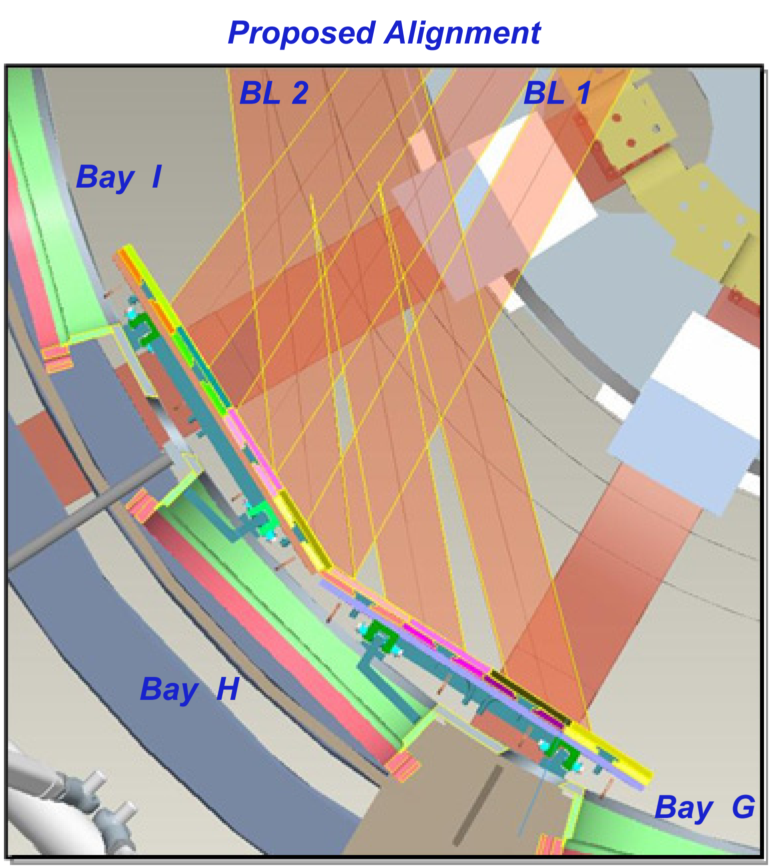
Neutral Beam Armor: Overview



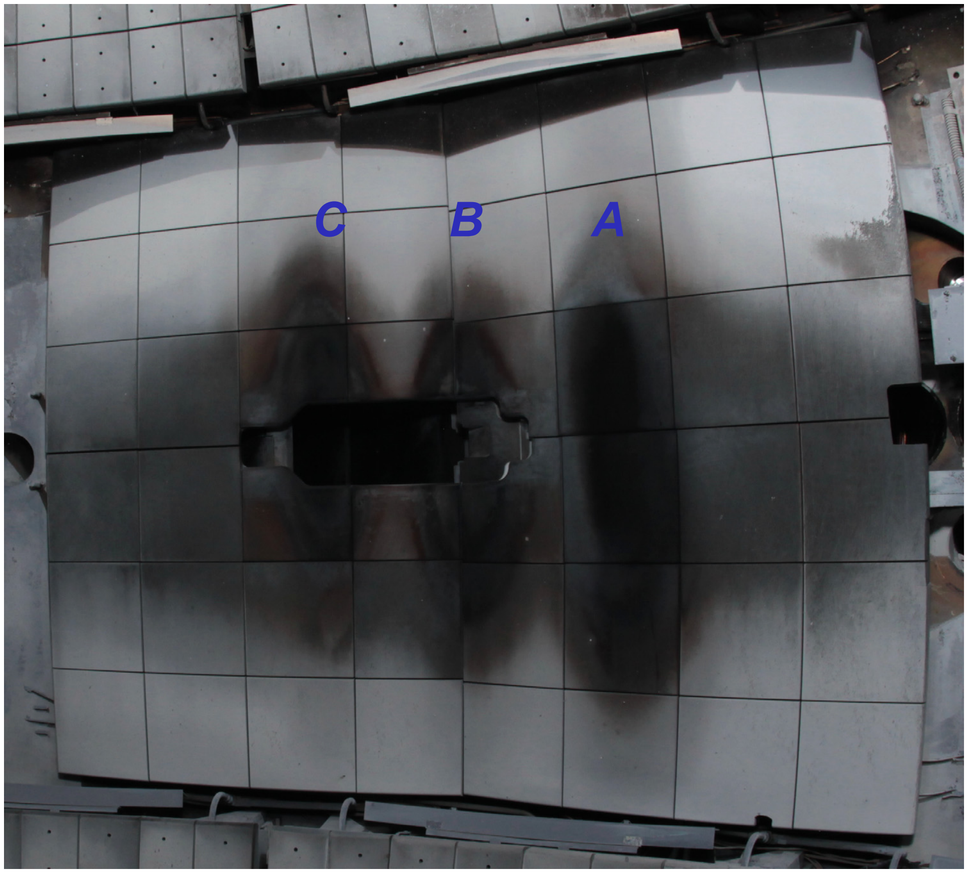
- Armor Relocation
  - Shift armor counterclockwise
    - To fit both beamlines on surface
  - Use ATJ graphite in non-crucial areas of armor
    - Use Carbon Fiber Composite (CFC) in areas of intense beam overlap
  - Upgrade mounting hardware to maximize port functionality and installation/removal
    - Evaluate disruption forces and resulting stresses on armor mounts

Armor Move


Current Alignment
BL 1
Bay I
Bay H


Proposed Alignment
BL 2
BL 1
Bay I
Bay H
Bay G

Armor Move: Beamline Fit



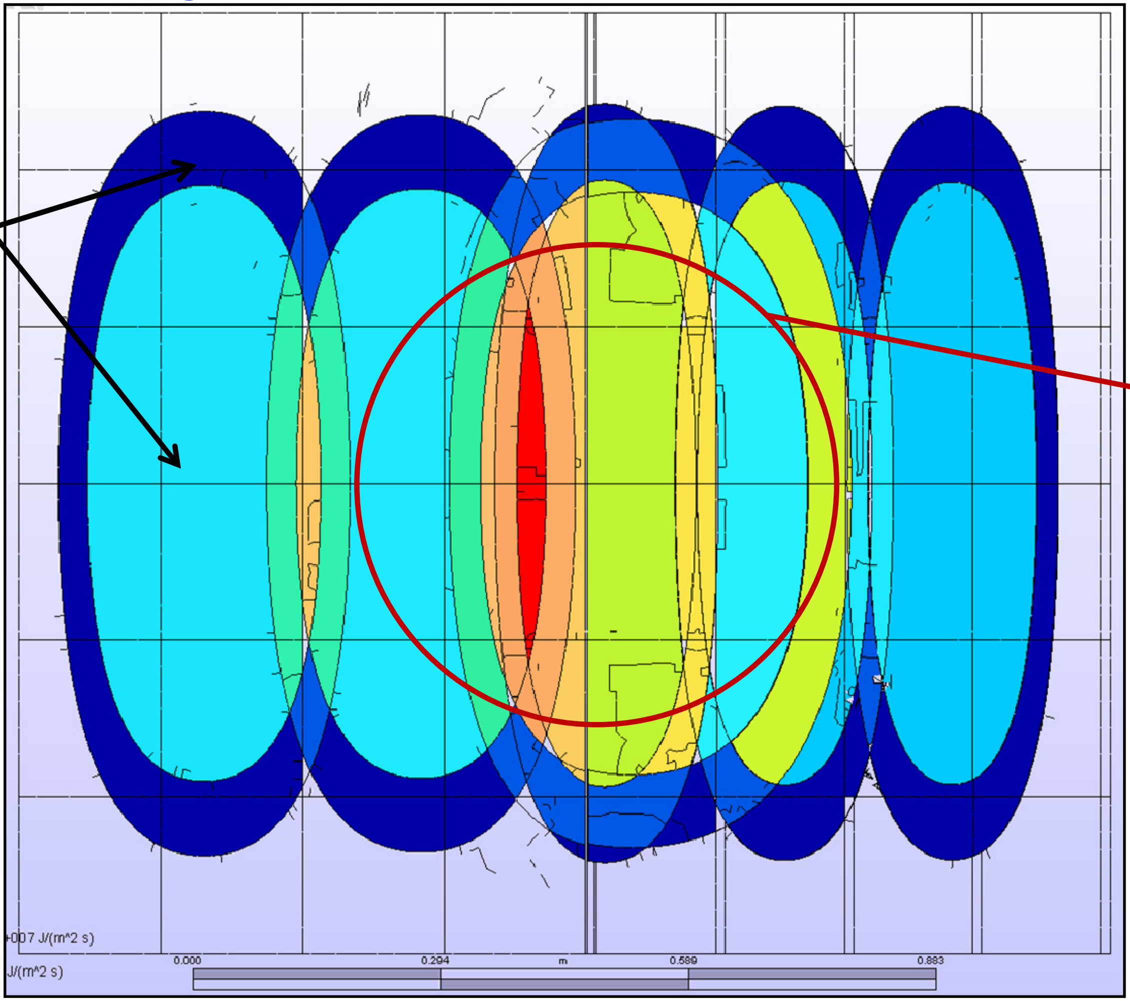
Used combination of empirical data and analysis to create beam "footprints"

- Beam photo shows rough ellipse shape from conditioning shots
- Assumed beam dispersion of .5 deg horizontal, 1.5 deg vertical
- Used calculated "Smear" areas for beam profiles (incident angle effects)
- Taking these areas, built ellipses and applied them to a simple armor shape, showing beam layout and overlaps

Armor Move: Beamline Fit

Resulting Source Profiles on Armor Face Confirms Fit!

- ***Outer ring:***
  20% total source power
- ***Inner "hotspot":***
  80% total source power



- ***Beam overlaps create areas of intense flux***
- ***Area of thermal investigation and probable material upgrade to 3D CFC***

Armor Tile Thermal Analysis

- Model accuracy check
  - Data from MSE shots
    - ATJ tiles
    - 90 kV, 19 MW/m^2 source heat flux, 400 ms
    - 50 – 80 C bulk temp change
      - Confirmed that ALGOR model behaved similarly

- 1 NB "fault" testing
    - Temperature and Stress under full power, full length of shot
      - » 80 kV, 7.7 MW/m^2, 5 sec
      - » 90 kV, 9.2 MW/m^2, 3 sec
      - » 110 kV, 13.9 MW/m^2, 1 sec
    - Baseline Material properties of ATJ Graphite
      - Max Tensile Stress: 26 MPa
      - Max Temp : 2600 ° C*

*This is the temperature at which the sublimation rate rapidly accelerates. Sublimation does begin at lower temperatures in vacuum, but the effect is less. Attempting to capture an acceptable maximum temperature.

Armor Tile Thermal Analysis

	Run #	Run Description	T (deg C)	Time @ T (s)	Tslot Von Mises (MPa) Free exp.
1 Beamline	1	**MSE, 90 kV, .400 ms, 9.24 MW/m^2 applied**			
	2	Stress analysis	544.6	0.433	8.91
	3	**80 kV, 5 s, 7.70 MW/m^2 applied**			
	4	Stress analysis	1893.7	5.5	16.16
	5	**90 kV, 3 s, 9.23 MW/m^2 applied**			
	6	Stress analysis	1611.3	3.08	16.76
	7	**110 kV, 1 s, 13.86 MW/m^2 applied**			
	8	Stress analysis	1220.3	1.05	16.42
	9	Stress analysis	956.4	1.2	17.78

Armor Tile Thermal Analysis

- 2 NB “fault” testing
  - Temperature and Stress under full power of two beams
    - Looking at an overlap tile that sees greatest flux
    - Finding time limit to max temp and max stress
      - » 80, 90, 110 kV

	Run #	Run Description	T (deg C)	Time @ T (s)	Tslot Von Mises (MPa) Free exp.
2 Beamlines	11	**80 kV, max q: 23.9 MW?m^2**			
	12	Stress analysis, TS 14	2693.9	1.68	36.6
	13	Stress analysis, TS 8	1965.2	0.96	25.6
	14	**90 kV, max q: 35.8 MW/m^2**			
	16	Stress analysis, TS 18	2643.3	1.08	37.88
	15	Stress analysis, TS 10	1905.54	0.6	26.1
	17	**110 kV, max q: 35.84 MW/m^2**			
	18	Stress analysis, TS 18	2649.4	0.675	38.68
	19	Stress analysis, TS 10	1879.7	0.375	26.86

Armor Tile Thermal Analysis

- **Results**
  - Single NBL "fault" is acceptable
    - Temperatures and stresses within capabilities of ATJ graphite
    - Possible surface cracks, ablation
      - If occurs, should attempt to visually inspect surface for damage
  - Double NBL "fault" is not acceptable with <u>only</u> ATJ
    - Stresses on surface and in T-slot exceed material limit
      - Risk critically cracking tile. Need to prevent this.
        - » Use available CFC in needed zones. Tensile strength 3x that of ATJ
      - Temperatures will surpass 2600 ° C and carbon will rapidly sublimate.
        - » Material mass will be sufficient to protect for length of "fault" (Stainless backing plates added protection)
        - » Armor will be damaged, needs visual inspection, but will perform its duty as a sacrificial protective surface
      - Increased safety:
        - » Additional Plasma interlock
        - » Increasing SS backing plate coverage
        - » Increased administrative caution while using both NBLs

Thermal Analysis for Between-Shot Cooling

- Worst case heat load on tile and backing plate
  - Ran test sample in ALGOR, simple shape
    - "Back of the envelope" analysis
    - 3"x1" slice of armor (tile and backing plate), 3/8" cooling tube, 20 minutes between shots
    - Determined time constant for cooling: ~70 seconds
  - Preliminary results suggest cooling system adequate for in-between shot cooling
    - More tests needed to confirm. Numbers will be updated for FDR as analyses are completed

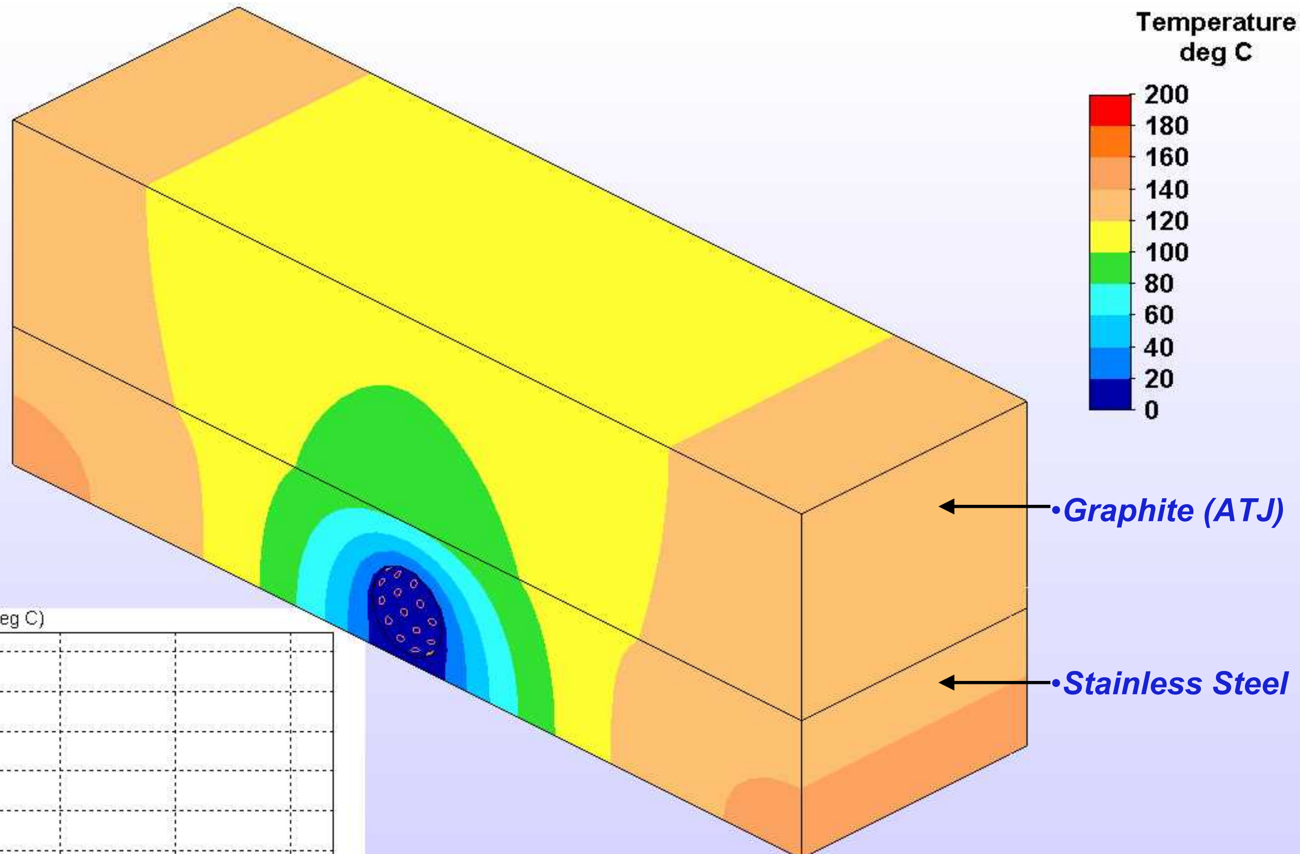
Thermal Analysis for Between-Shot Cooling

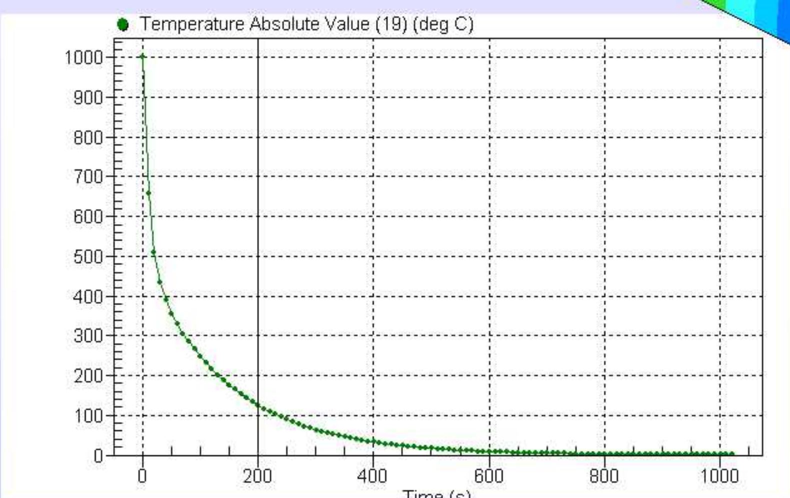
Time: 200 s

Time Step: 20 of 200

Maximum Value: 143.573 deg C

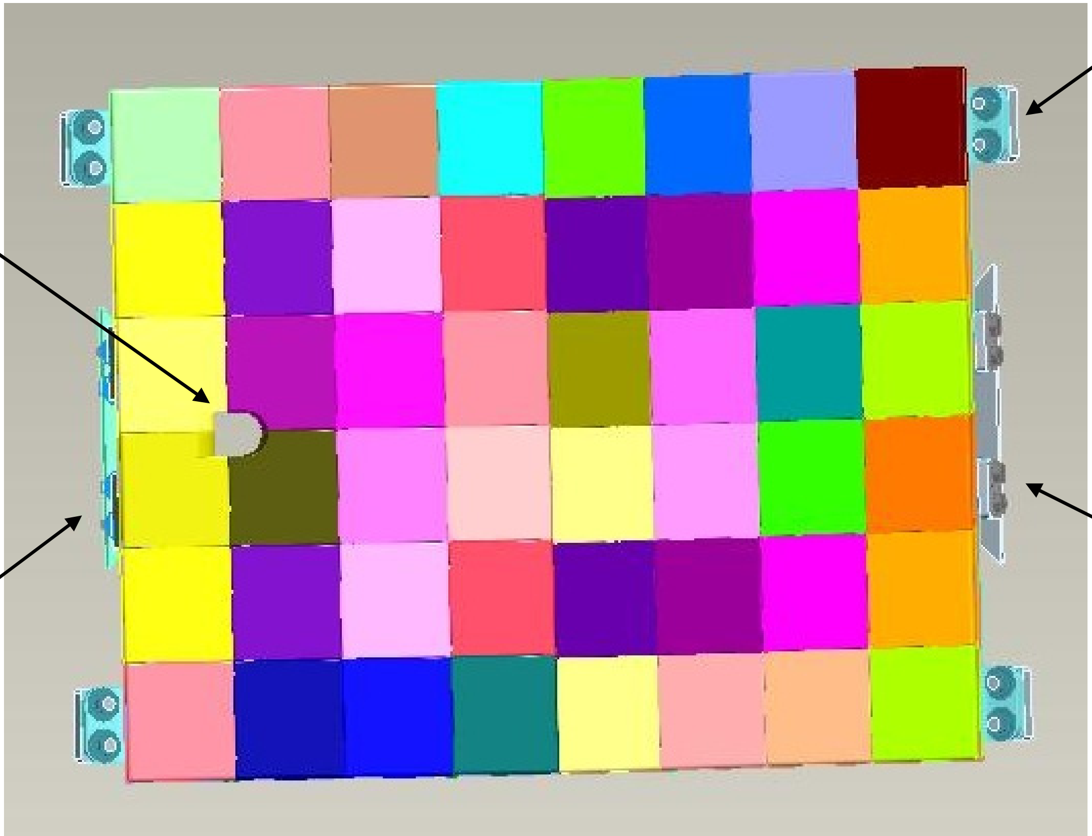
Minimum Value: 1.21787 deg C





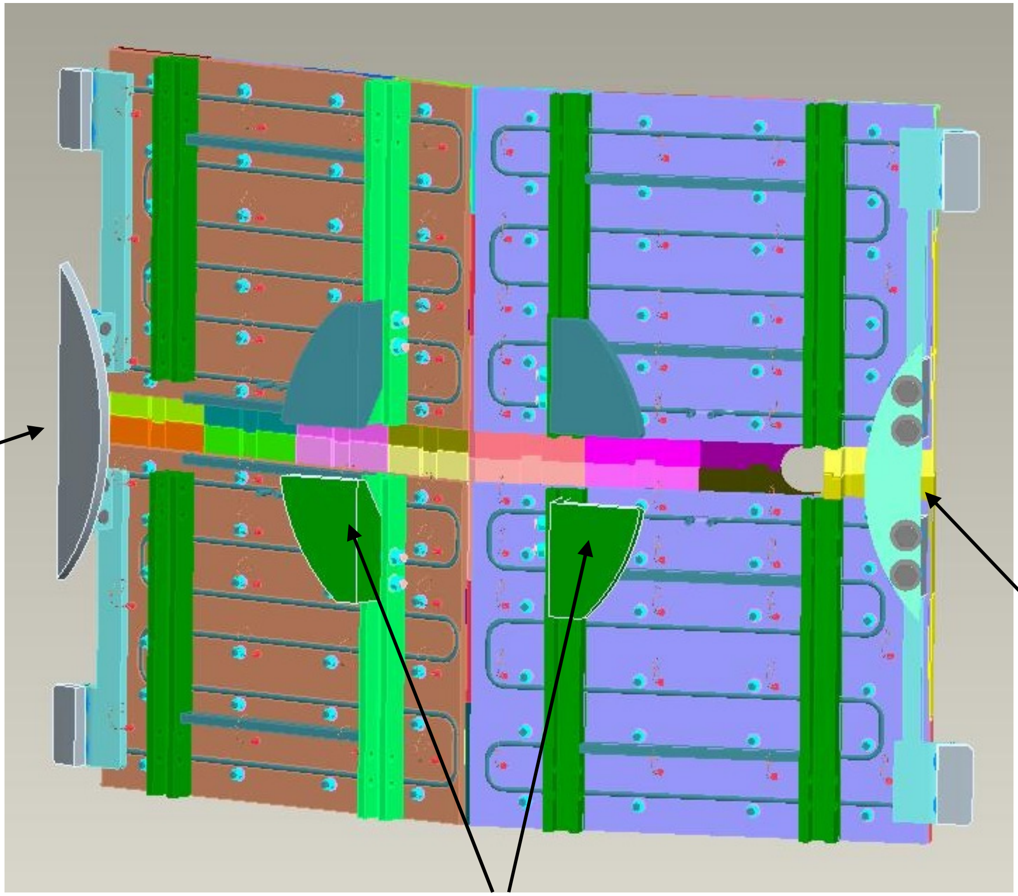
Armor Support System

Front



Armor Support System

Back

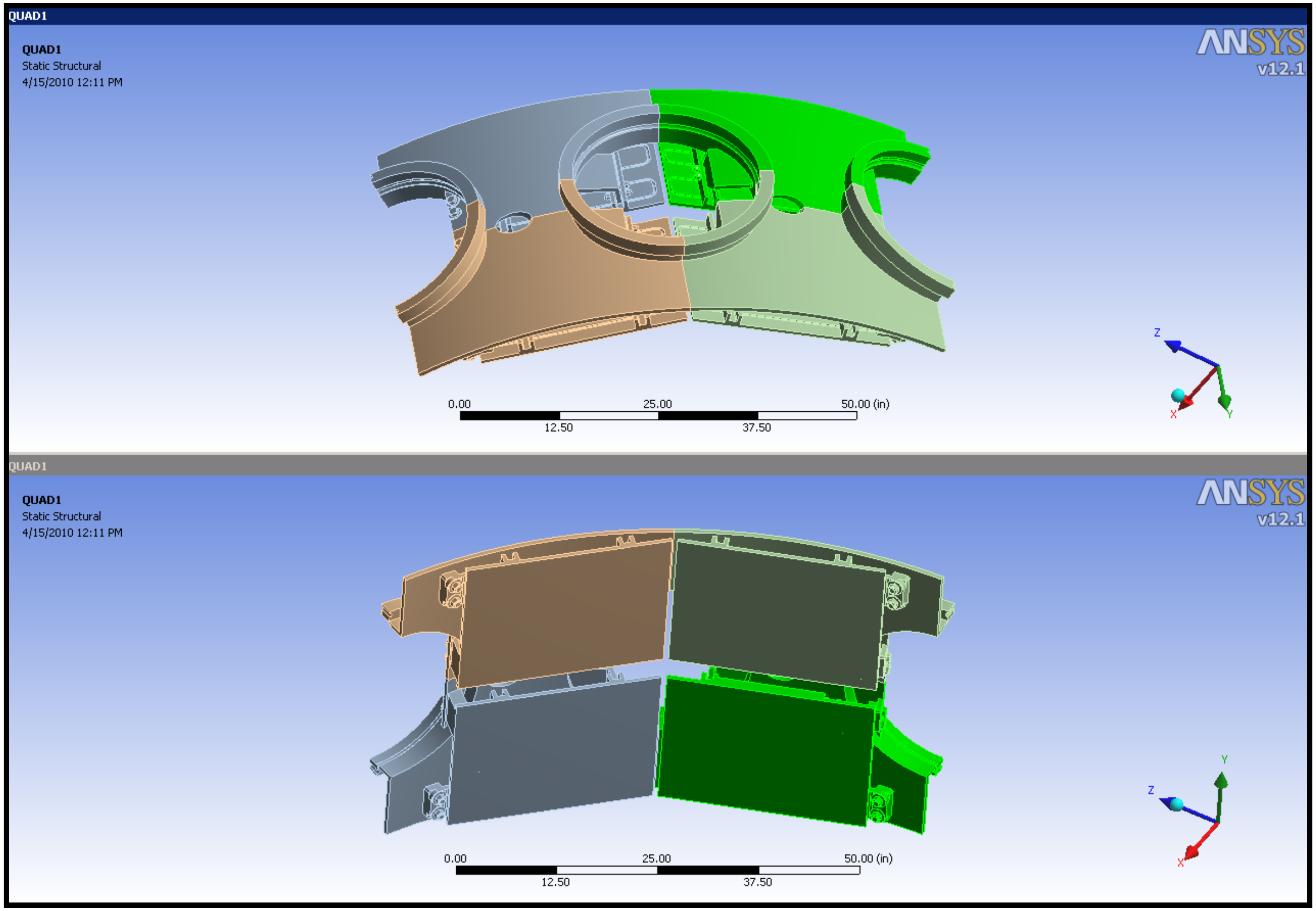


Bay I support

Redesigned Bay H supports

Bay G support

Neutral Beam Armor Solid Model

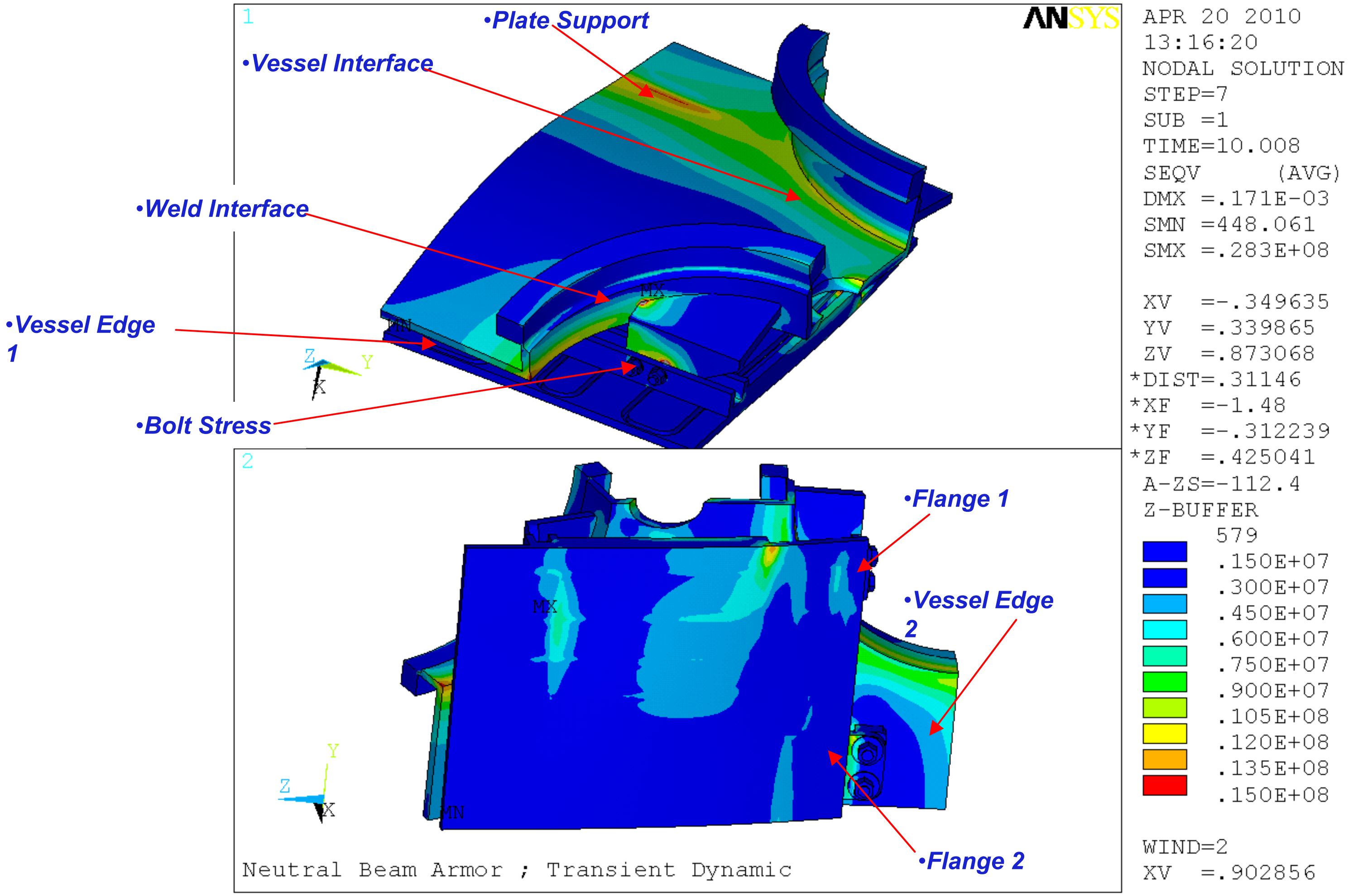


•The Solid Model is Symmetric about 2 planes

•Only ¼ of Armor model will be included in the FE analysis

Transient Dynamic Von Mises Stress

(Outboard Displacement Disruption)

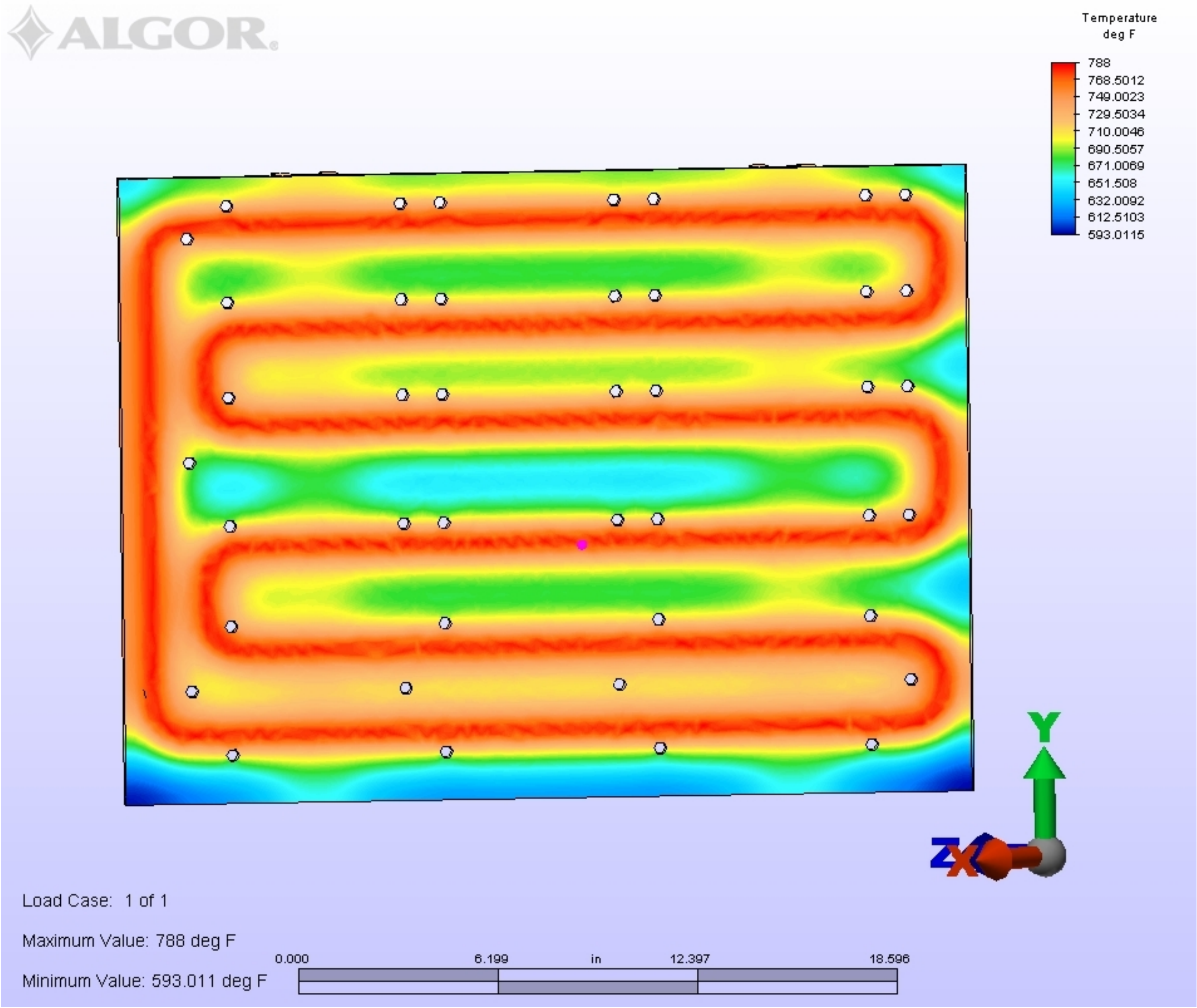


•The Transient Equivalent Stress at Max Current is less than 10 Ksi

•and well within the material strength capacity ***(Based on Merged Solids)***

Thermal Growth

- Addressed potential thermal growth issues with the new armor constraints
  - Used bake-out temps as an example
  - Shows that SS plates grow "up and out"
  - Do not cause tile interference



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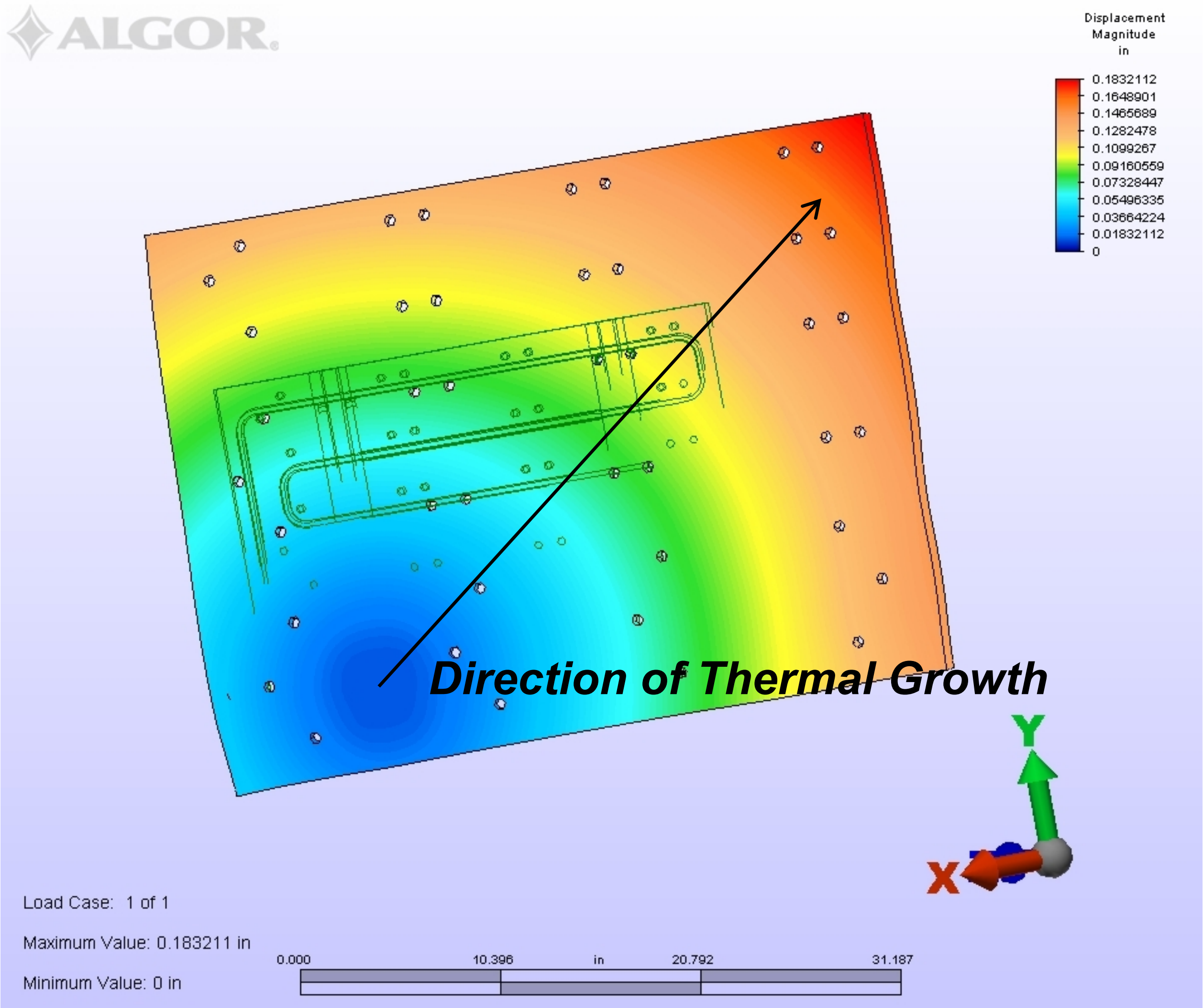

Conclusions

- **Armor Relocation: Thermal**
  - 6 sources fit adequately upon armor face
  - In areas of high heat flux (source overlaps), tile material will be replaced with 4D CFC
    - CFC has multi-plane high k, thermal shock resistance, good mechanical properties
  - Armor will sufficiently protect the VV from NB exposure, even with increased heat flux from source overlap
  - Cooling lines will be adequate for heat removal between shots

- **Armor Relocation: Mechanical**
  - New mounting scheme improvement to accessibility
    - Employing bay H and G as access points
  - Disruption analyses show that forces in the mounts are low, material and fasteners are adequate for loading
    - Consider final analysis with updated load scenarios and non-merged model
  - Thermal growth in plates will not cause issues with tiles
  - Installation procedure is being created
  - Armor drawings are complete (barring any other changes to design)