National Spherical Torus eXperiment Upgrade

ITER:
LFSR Transient Electromagnetic Analysis

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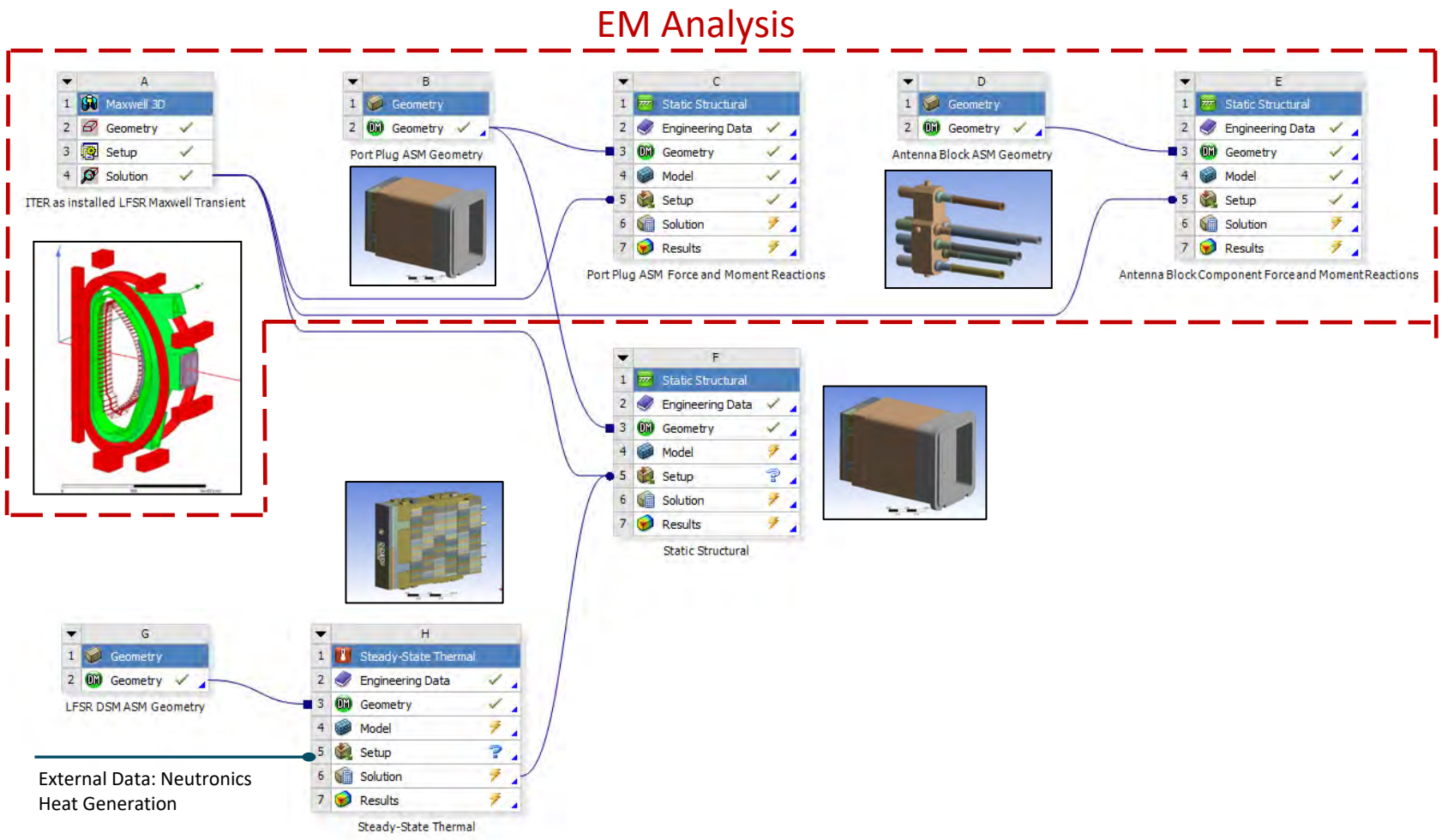
January 10, 2020

LFSR FEA WorkBench Project Page



List of LFSR *Maxwell* Transient EM Runs

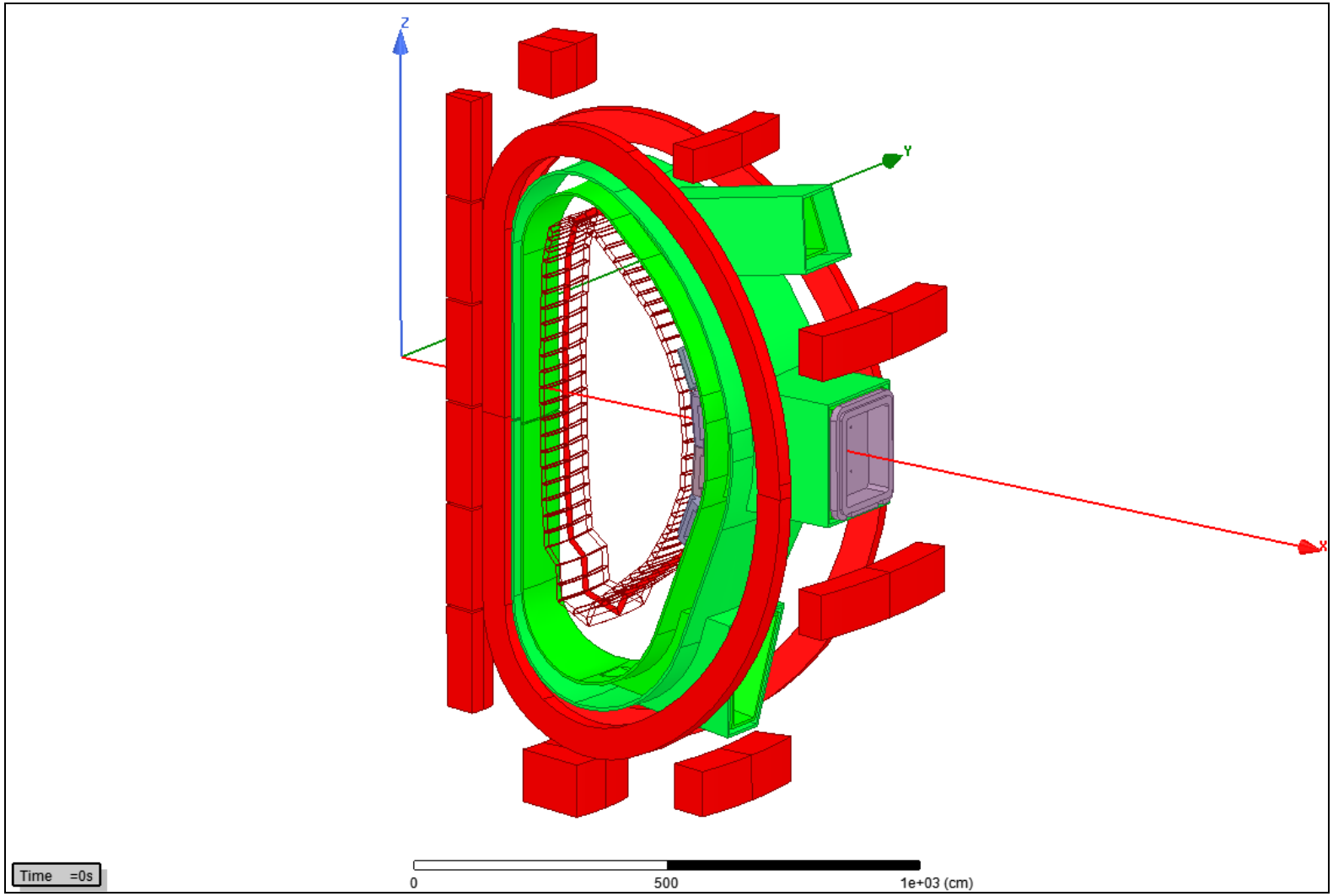
List of LFSR *Maxwell* Transient EM Runs

Run #	Material Assignments	LFSR ASM Fidelity	Port Plug Default Element Size	Total Mesh Size	ANSYS Release	Comments
1	Initial 09-26-19	Smeared-Properties	7.5 cm	3.3 E06	R19.2	Solved
2			10 cm	2.44E+06	2019R2	Solved
3			5 cm	5.40E+06	2019R3	Run aborted: est. time to solve > 600 hours
4	Revised 11-22-19		7.5 cm	3.30E+06	R19.2	Results provided for stress analysis [1]
5			10 cm	2.44E+06	2019R3	Solved: results used for mesh convergence study [2]
6			5 cm	5.40E+06	2019R3	Run aborted: est. time to solve > 600 hours
7		High Fidelity	10 cm	3.0E6 (est.)	2019R3	Model won't mesh; est. time to solve > 600 hours [3,4]

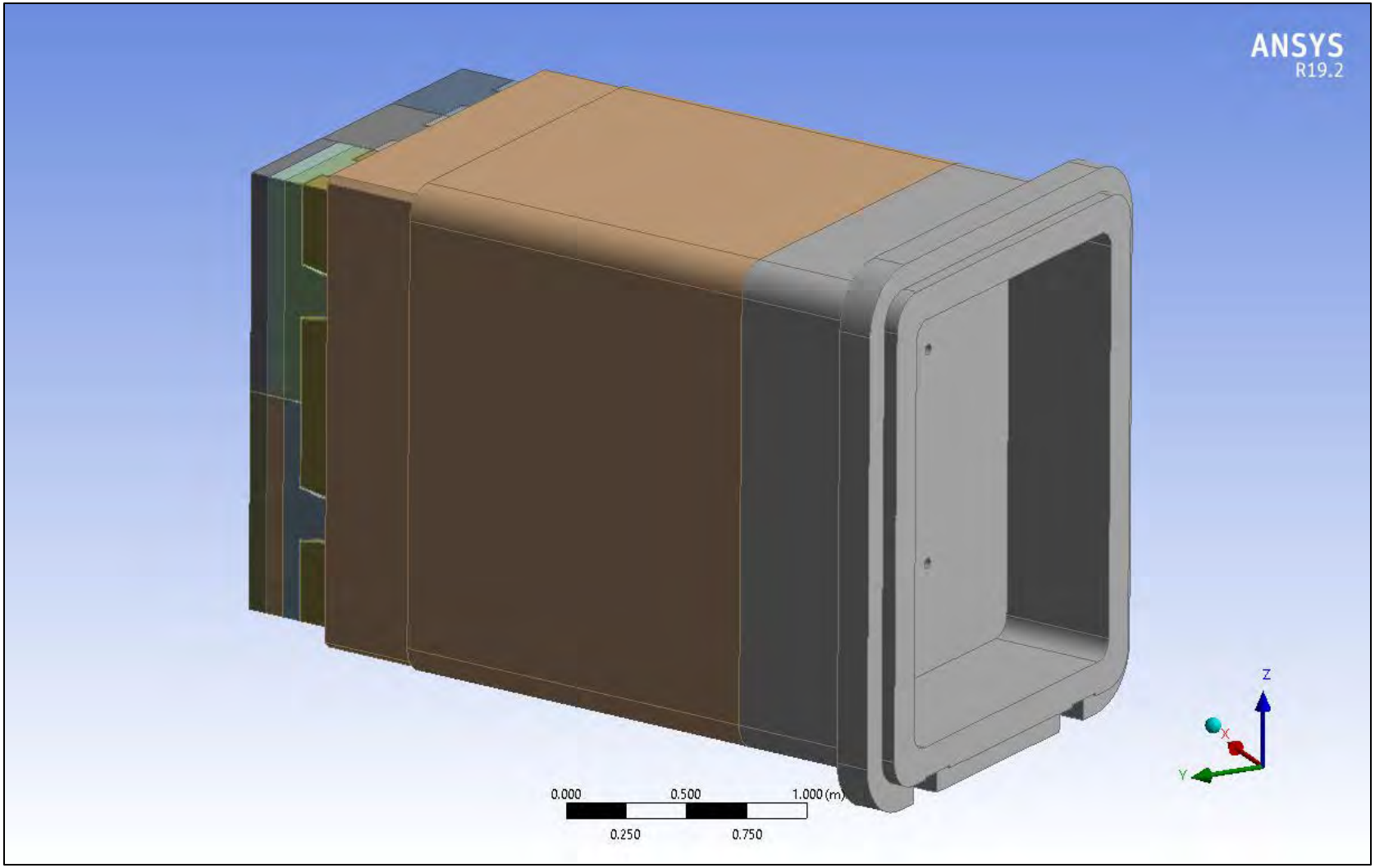
Notes:

1. ANSYS archive file: LFSR_Transient_EM_Medium_110719_2.wbpz (R19.2); coarse-mesh EPP Mechanical force and moment reaction results.
2. ANSYS archive file: LFSR_Transient_EM_Coarse_112319_2.wbpz (2019R3); coarse-mesh EPP Mechanical force and moment reaction results.
3. ANSYS archive file: LFSR_HF_010620.wbpz (2019R3). File provided to ANSYS Tech Support on 01-08-20 to resolve meshing issue.
4. High-fidelity model created from Run #5 model, replacing smeared-properties LFSR components with high-fidelity components from file: ANTENNA_BLOCK_ASM_MAX_121919.x_t. This isolated subassembly was meshed in Maxwell model file: HF_ANTENNA_BLOCK_ASM.wbpj (R19.2).

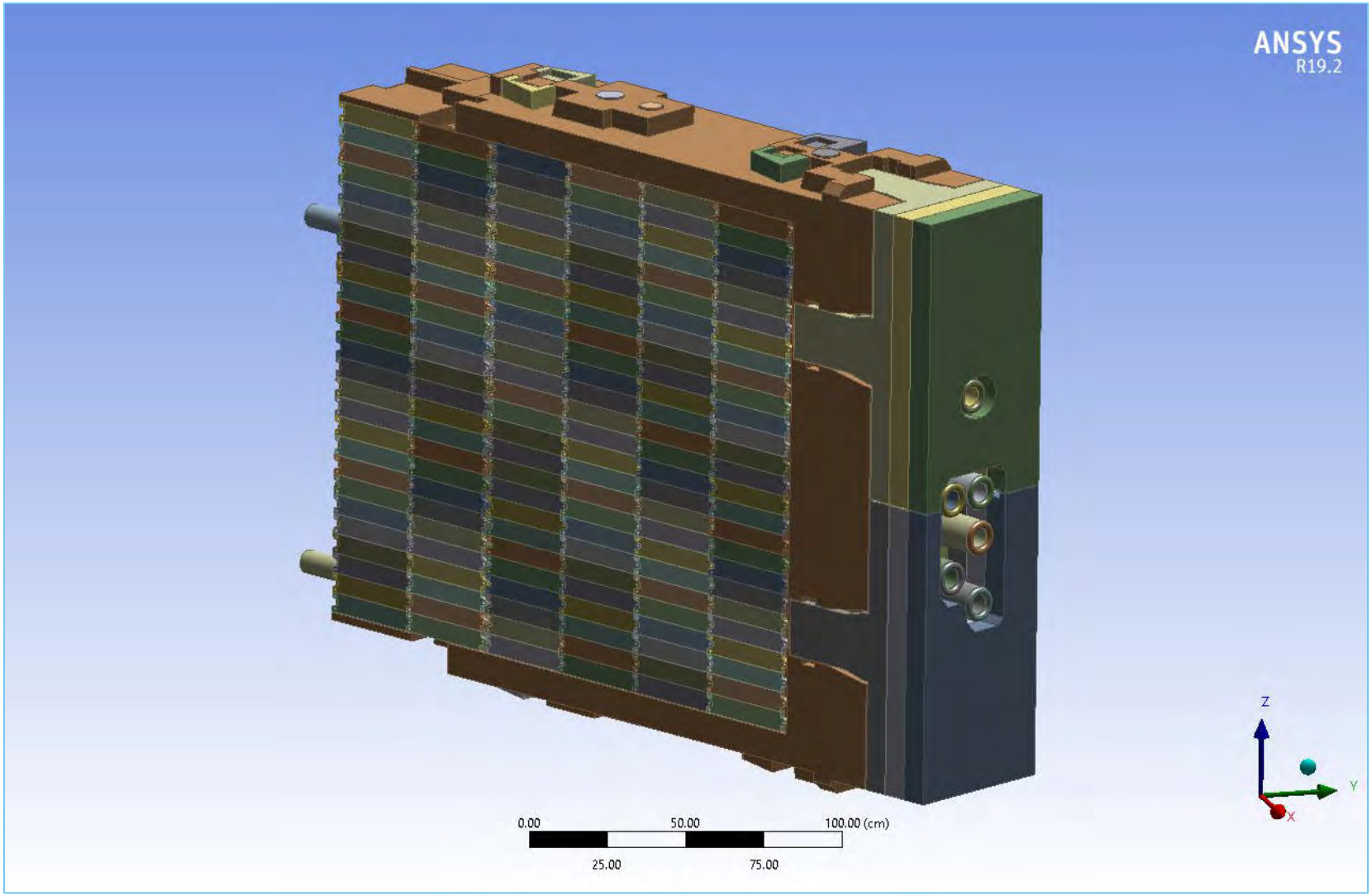
Maxwell: ITER TF, OH, and PF Coils with VV and EPP Solid Model



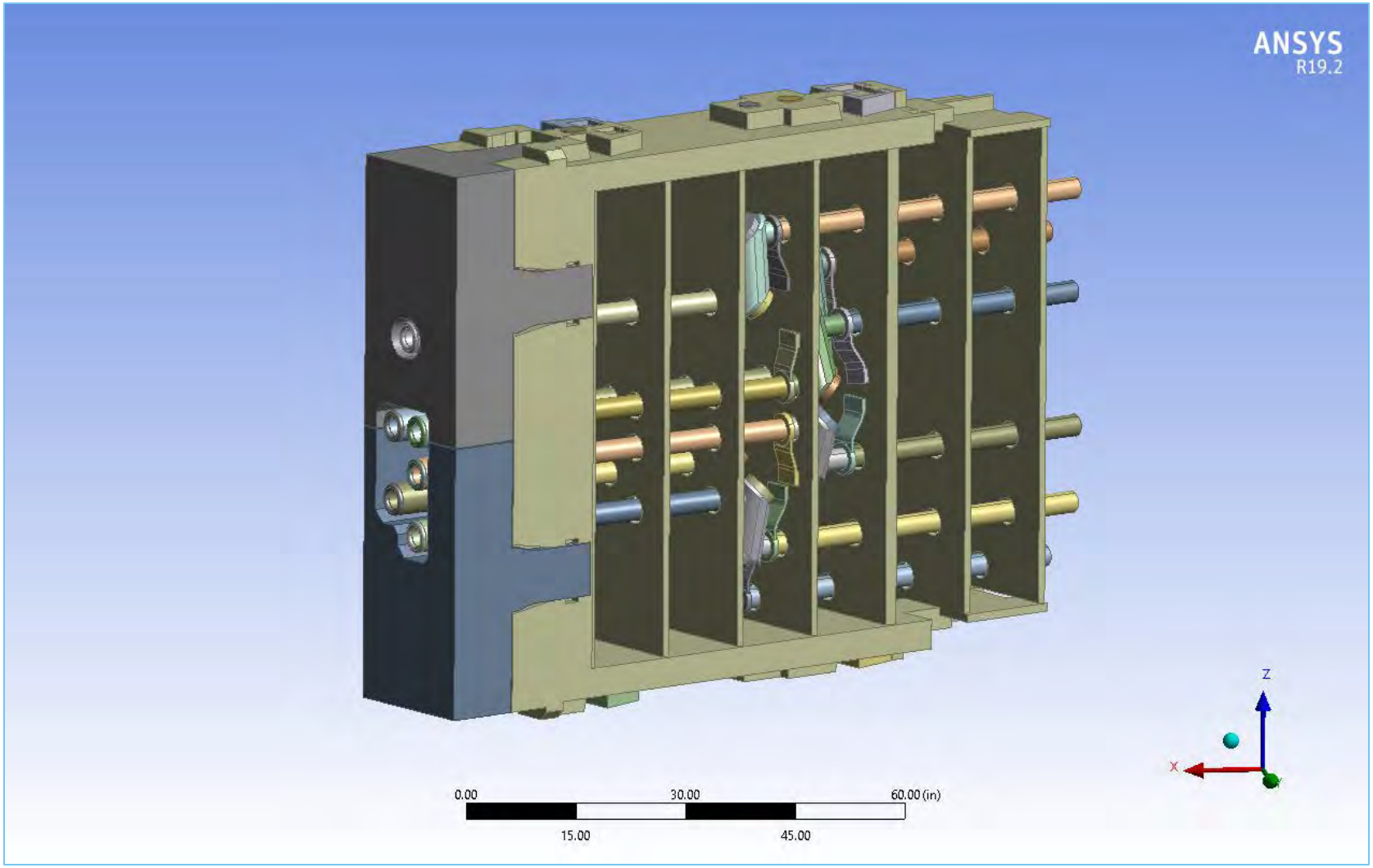
DesignModeler: LFSR Equatorial Port Plug (EPP) Solid Model



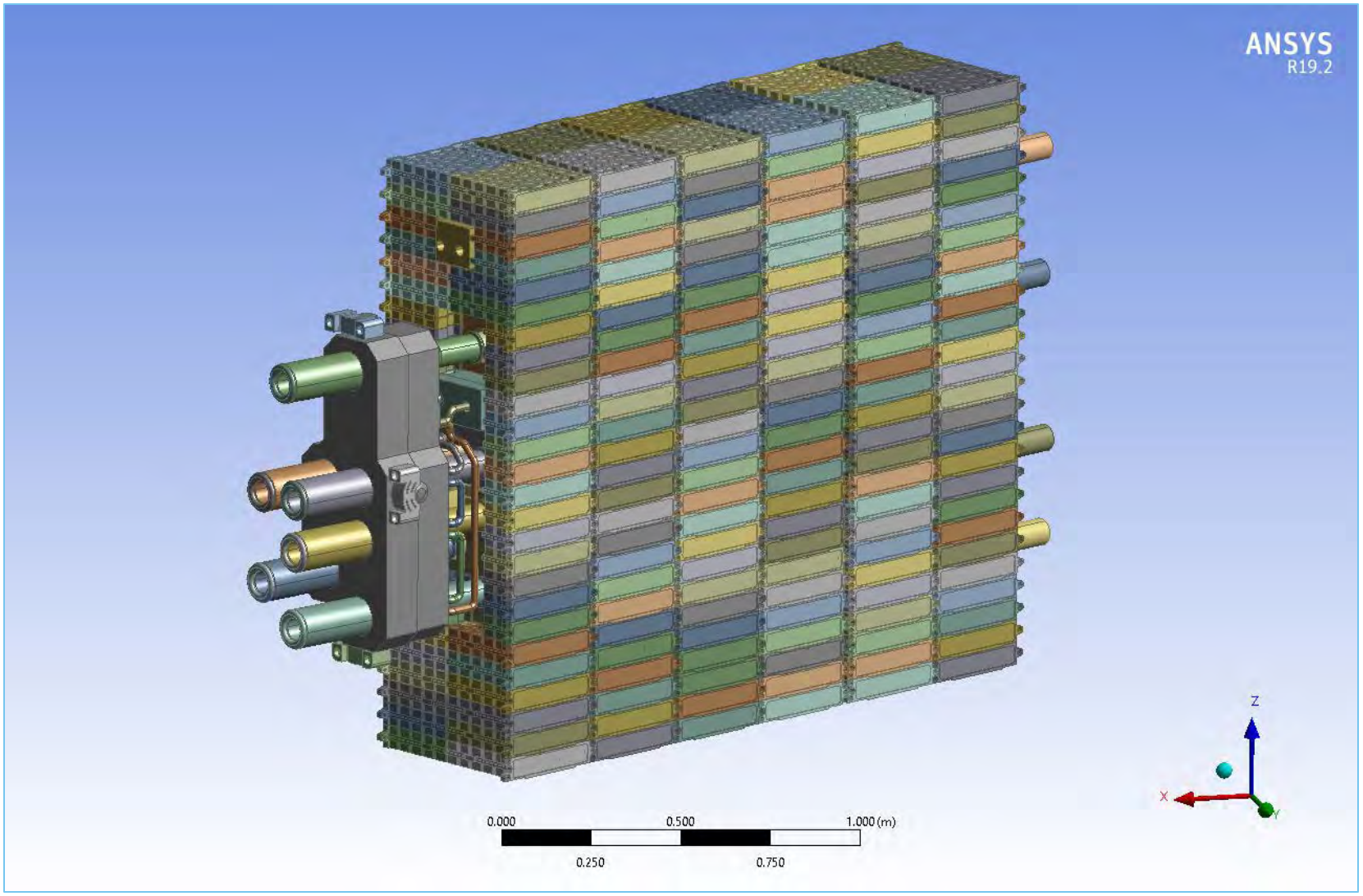
DesignModeler LFSR EM Solid Model:



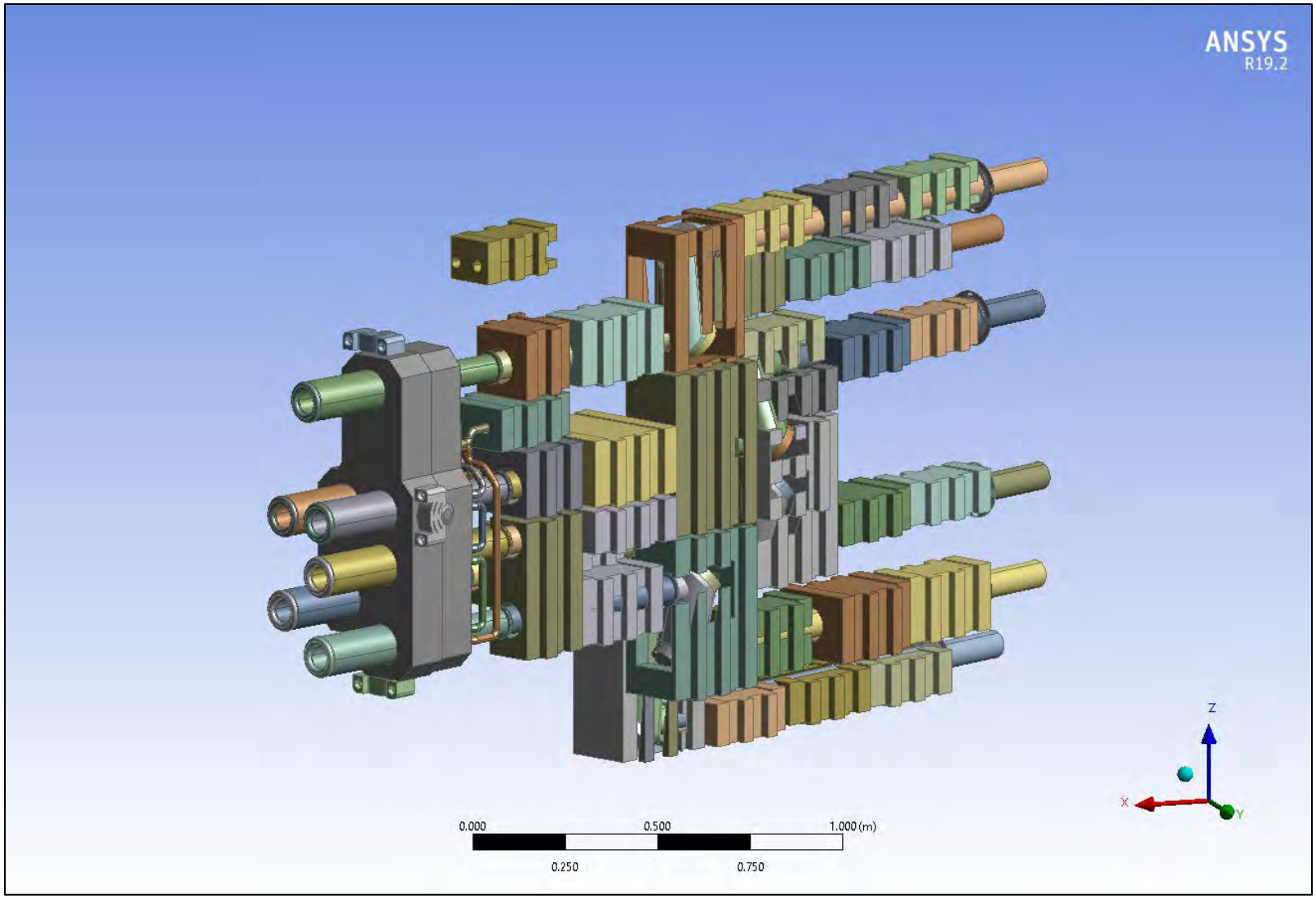
LFSR Diagnostic + DSM: *DM* Solid Model
Shielding Trays Not Shown



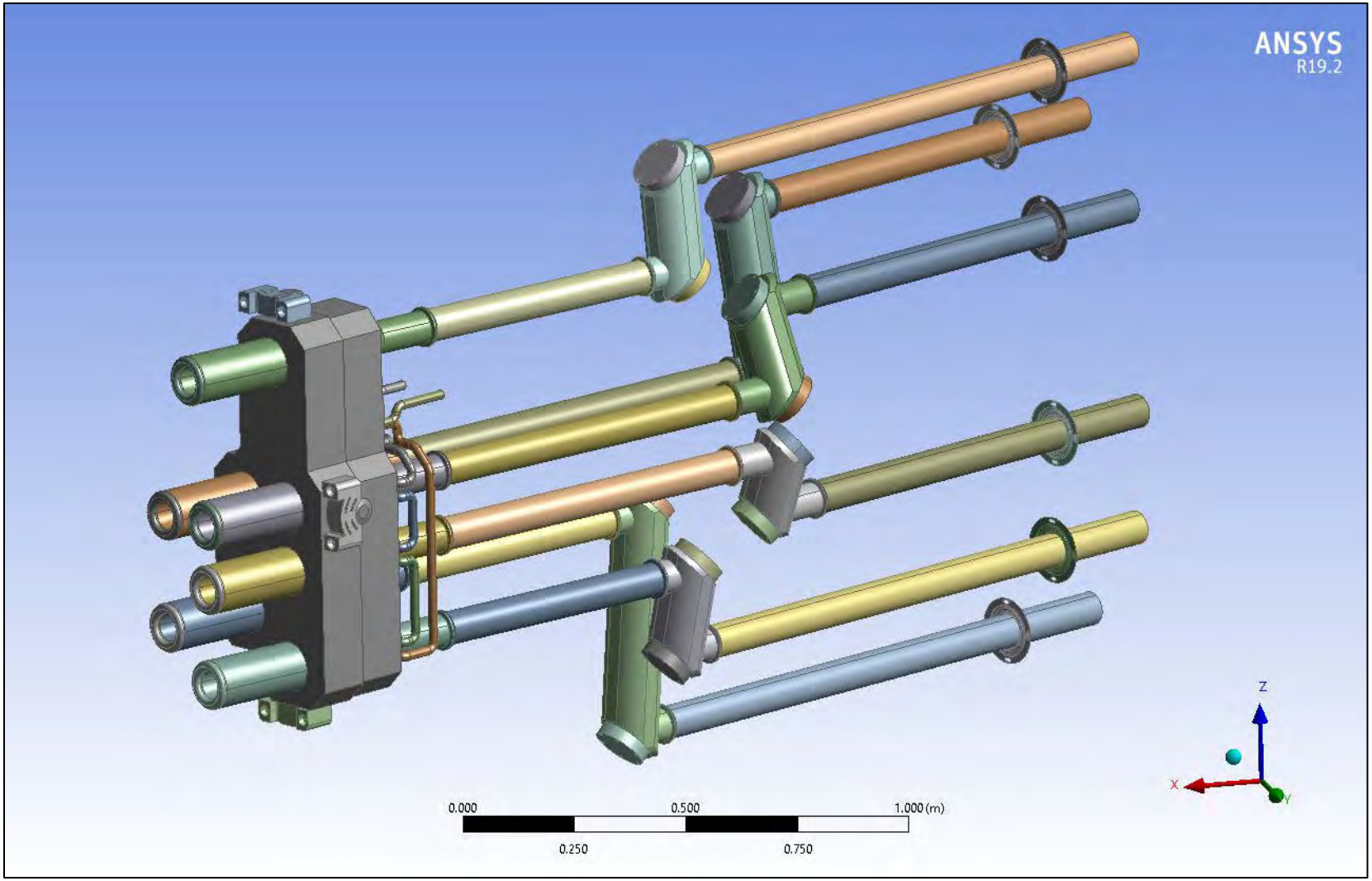
DesignModeler: LFSR Diagnostic + Tray Stack Solid Model
DSM Frame and DFWs not shown



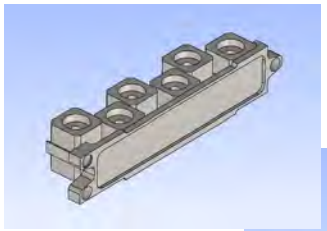
DesignModeler: LFSR Diagnostic+Backfill Solid Model
Shielding Trays, DFWs, and DSM Frame not shown



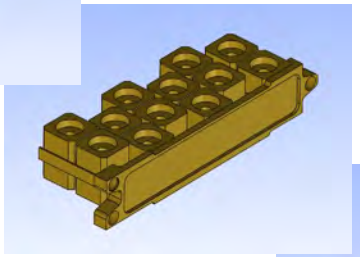
DesignModeler: High-Fidelity LFSR ASM Solid Model



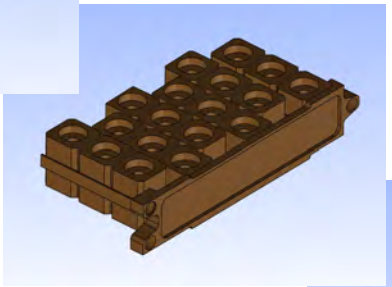
SolidWorks: High Fidelity (HF) Tray Configurations



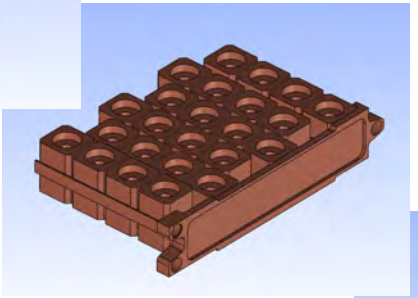
1 Block Deep



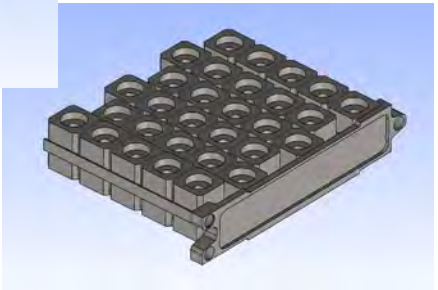
2 Blocks Deep



3 Blocks Deep

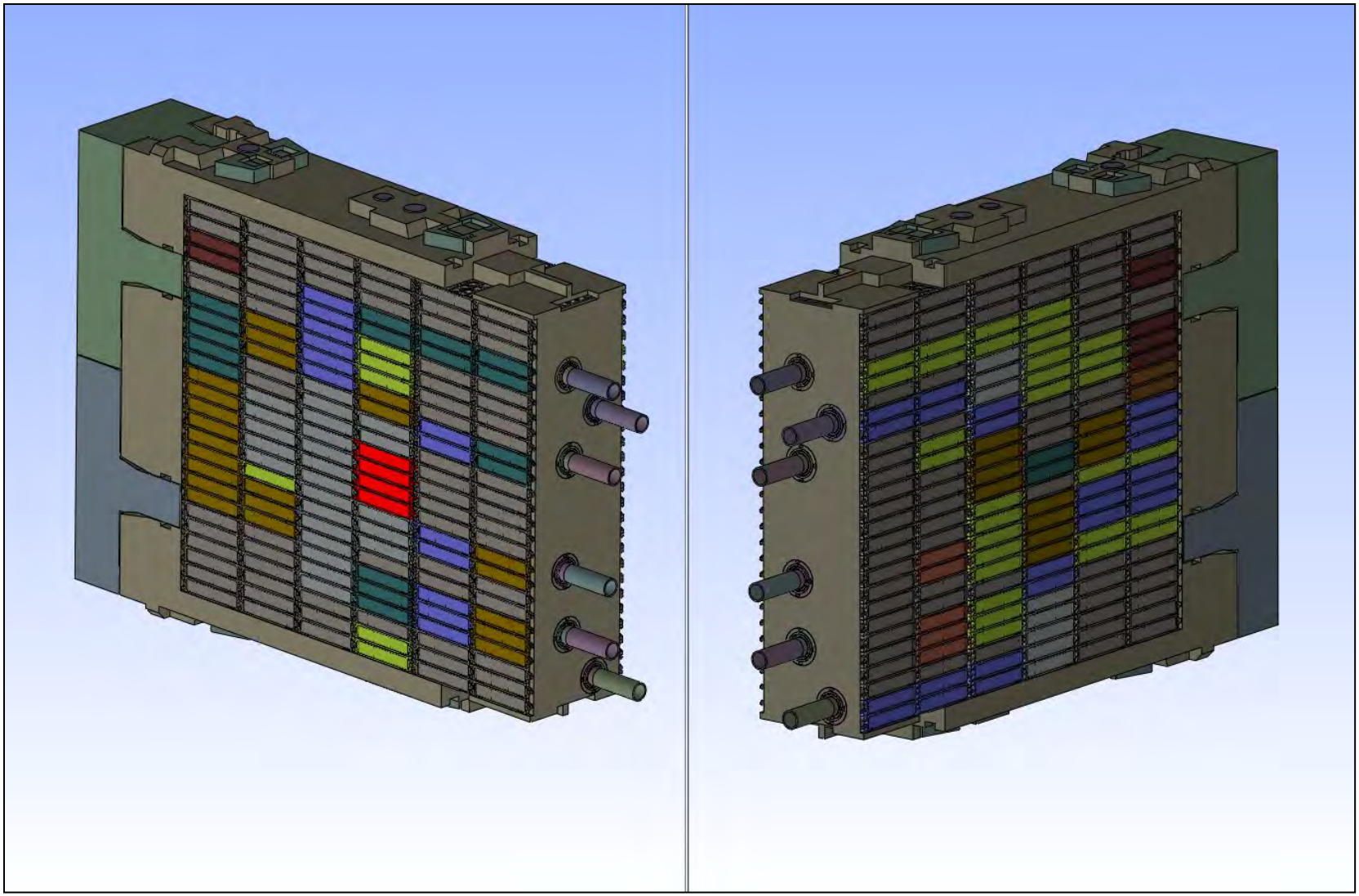


4 Blocks Deep

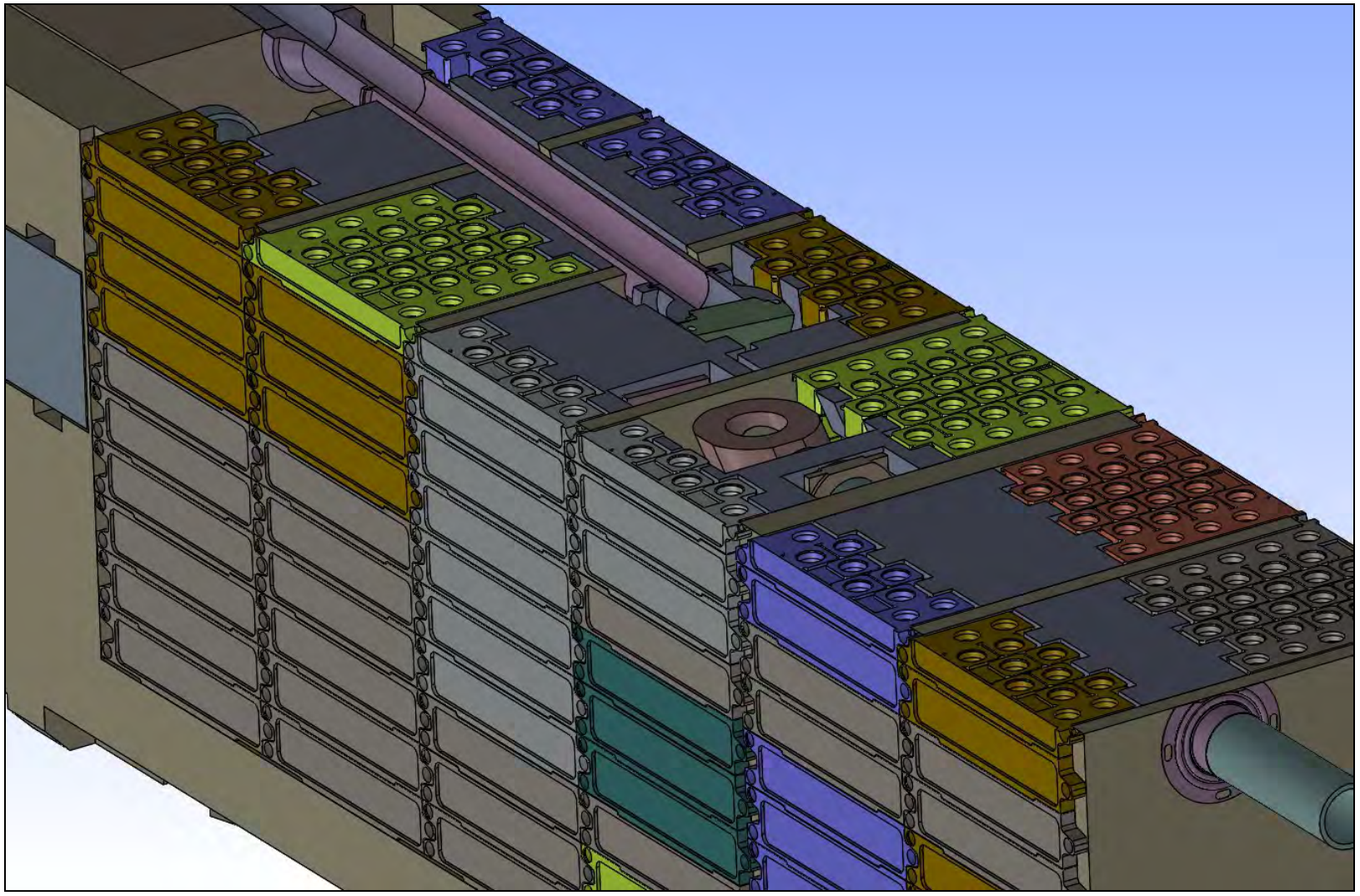


5 Blocks Deep

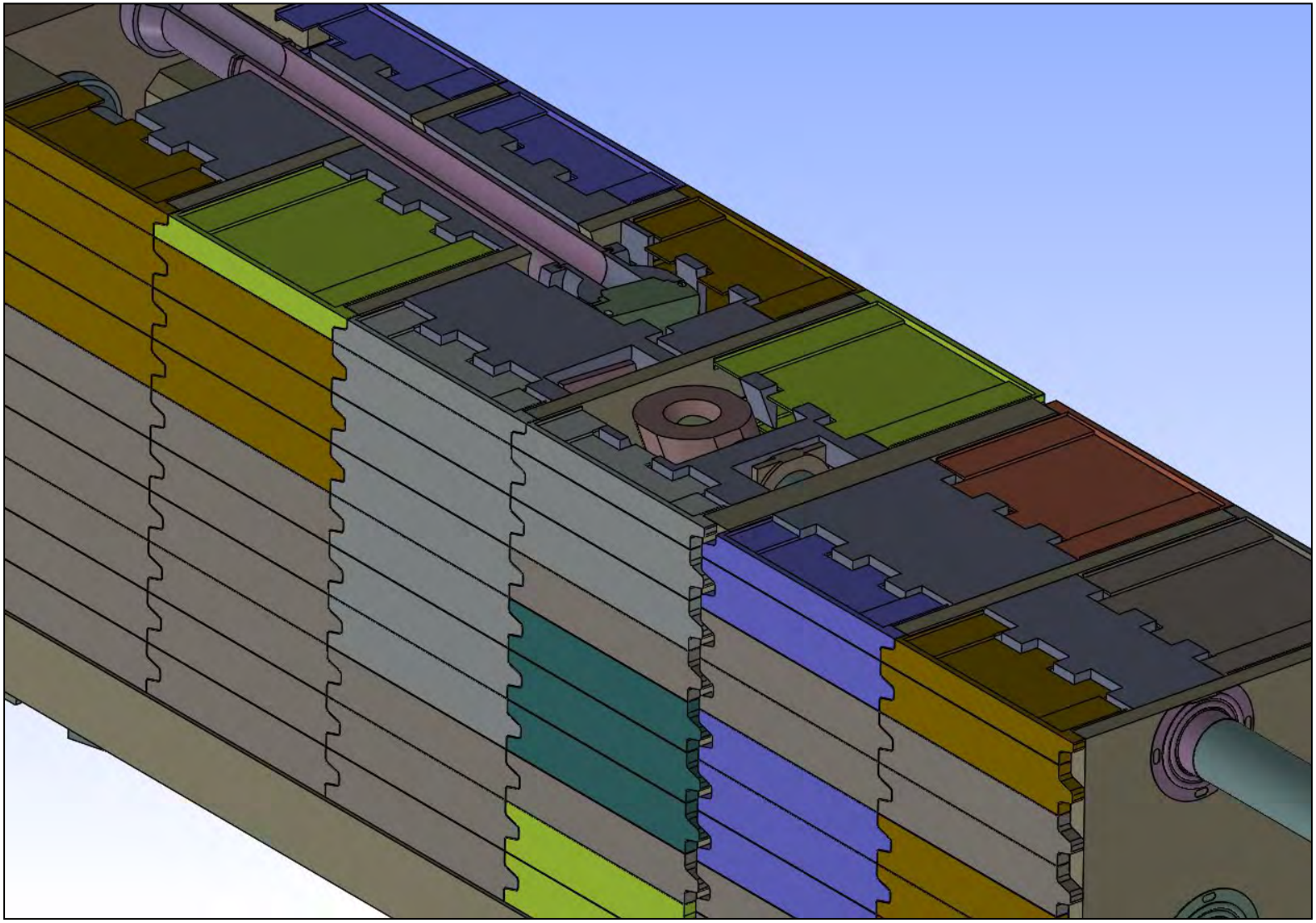
SolidWorks: Left and Right Tray Configuration Selection:
10 Tray Configurations



SolidWorks: Left and Right Side Tray Configuration Selection:
10 High-Fidelity Tray Configurations



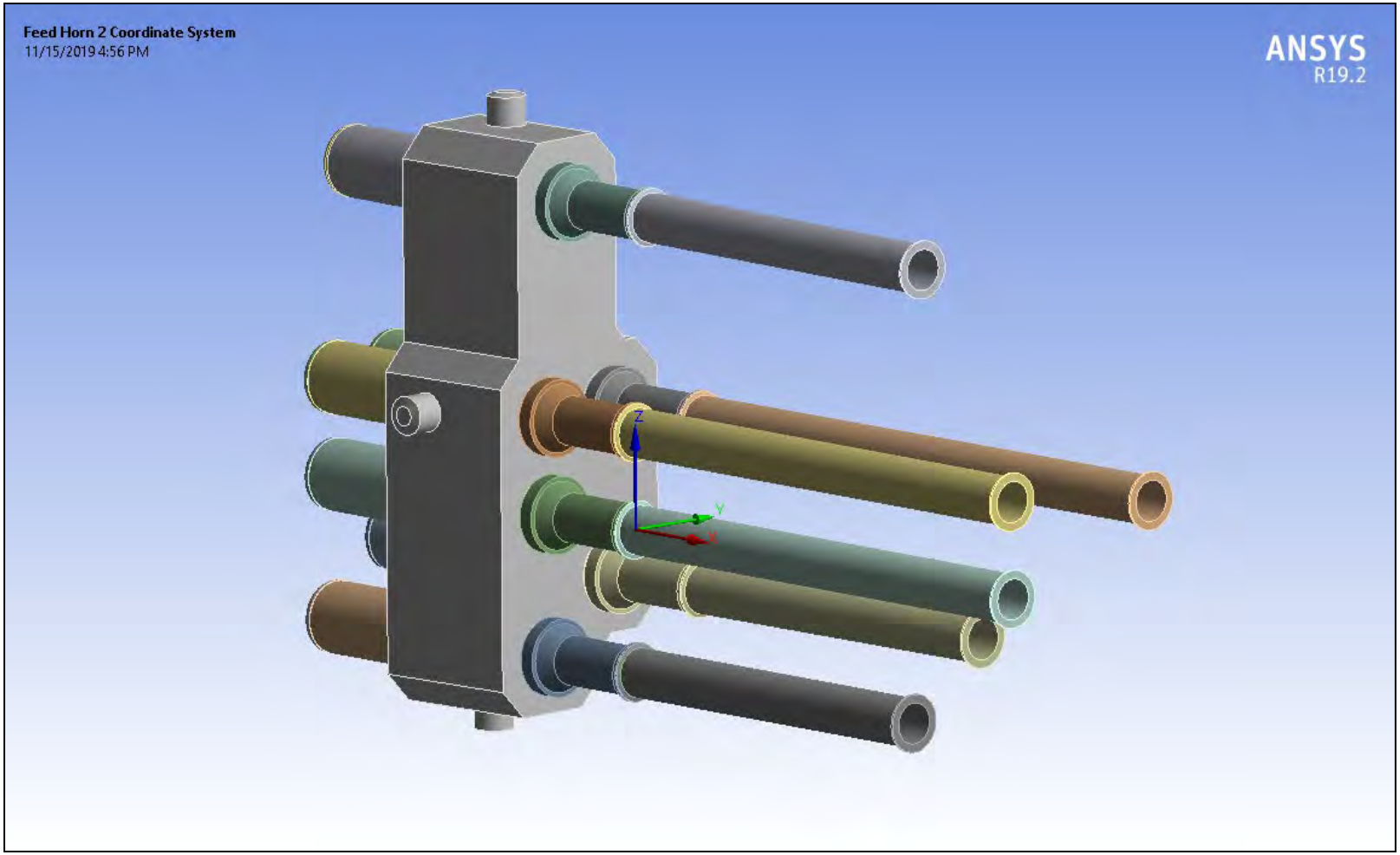
SolidWorks: Left and Right EM Tray Configuration Selection:
10 Simplified Tray Configurations



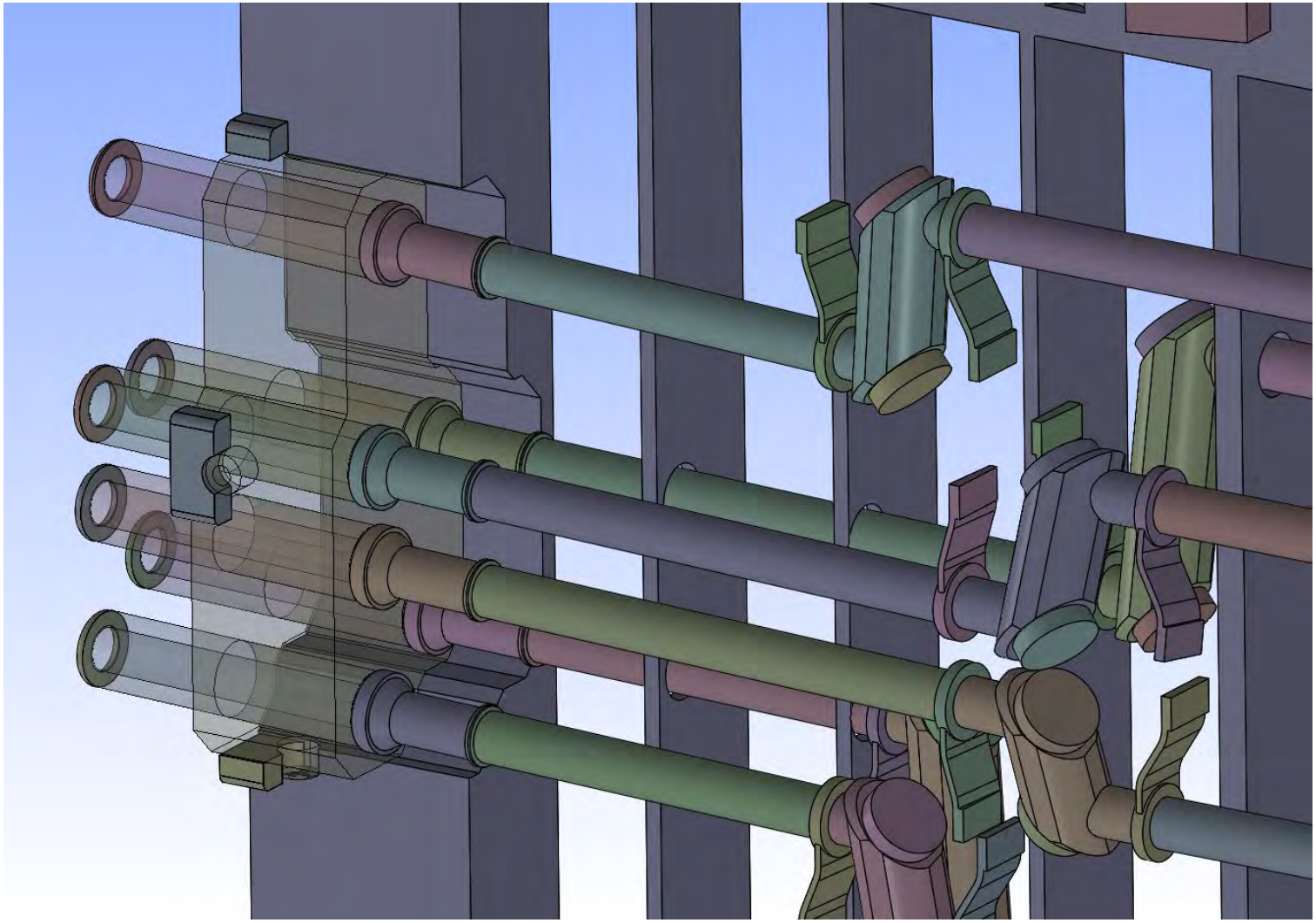
Smeared-Properties EM Analysis

- Internal cooling passages filled, electrical conductivity reduced based on volume fraction for:
  - End Caps
  - Feed Horns
  - Antenna Block
  - DFWs
- Cooling tubes excluded from EM analysis

Mechanical: LFSR Feed Horn, Block, Waveguide ASM



SolidWorks: LFSR Smeared-Properties Antenna ASM
Internal cooling passages filled

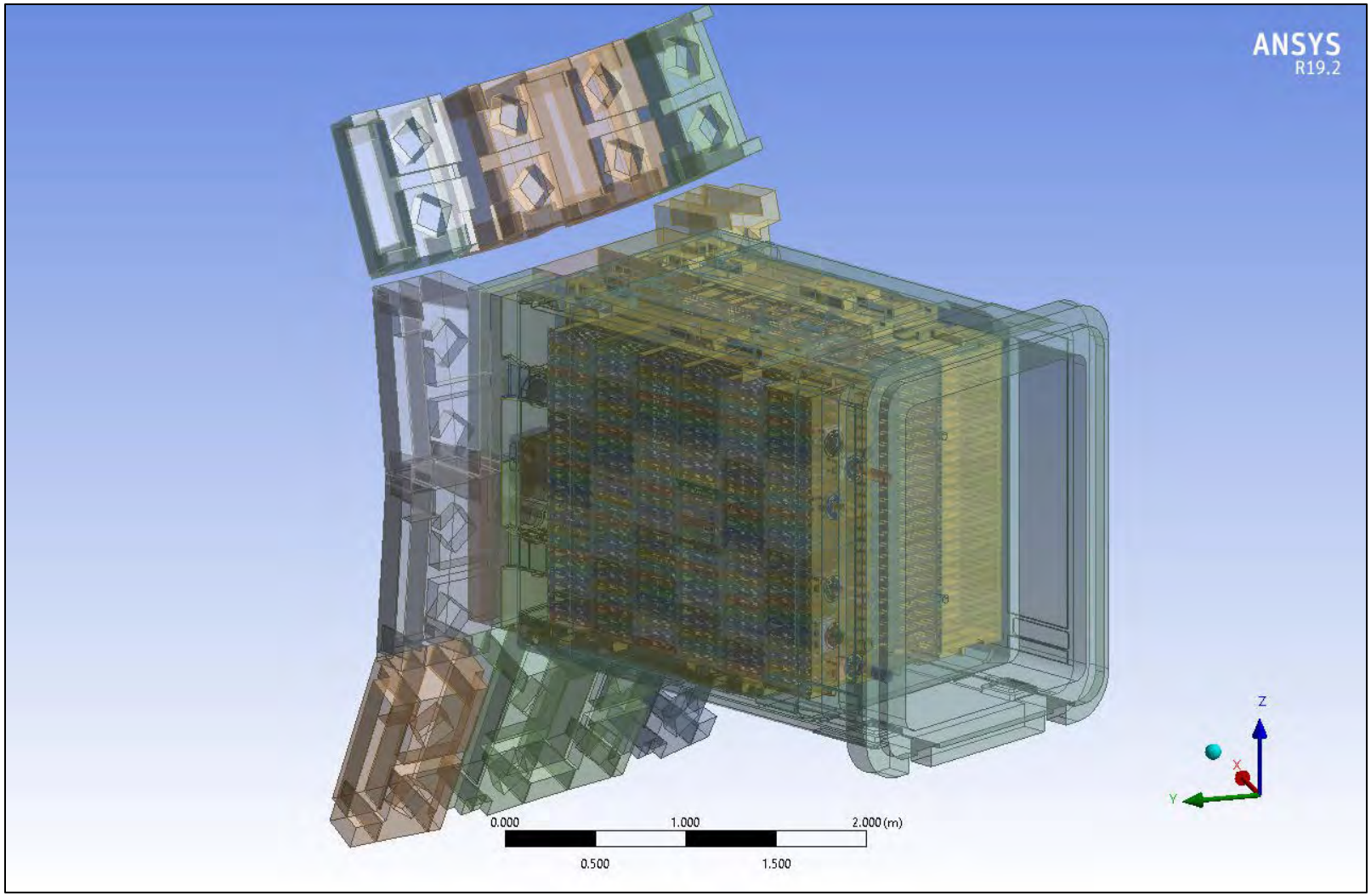


Maxwell LFSR Smeared-Properties EM Analysis:
Material Conductivity

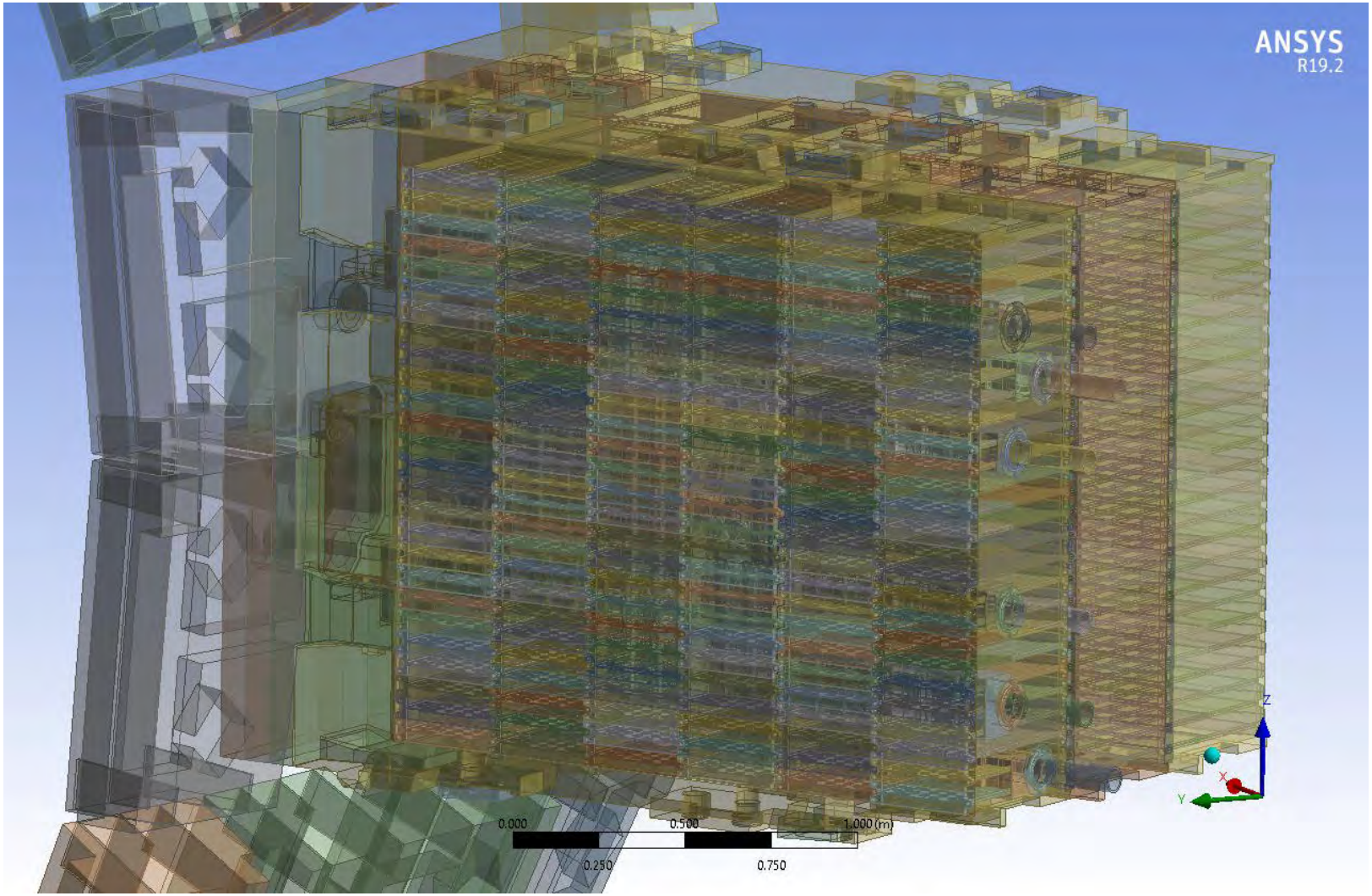
LFSR Materials: Component Smeared Properties Electrical Conductivity					
Item	Material Designation	Components	ρ X Real Ω*m	ρ X ANSYS Ω*m	σ X ANSYS s/m
1	316LN	VV, port plug, rear waveguides, periscopes, back fill pieces	7.76E-07	7.76E-07	1.29E+06
2	316LN 64% End Cap	End caps	7.76E-07	1.21E-06	8.25E+05
3	316LN 75% Feed Horn	Horn bodies	7.76E-07	1.03E-06	9.71E+05
4	316LN 78% Blanket	Blankets	7.76E-07	1.00E-06	1.00E+06
5	316LN 79% DFW1	DFW1 front section	7.76E-07	9.88E-07	1.01E+06
6	316LN 86% DFW23	DFW23	7.76E-07	9.02E-07	1.11E+06
7	316LN 87% DFW1	DFW1 middle section	7.76E-07	8.94E-07	1.12E+06
8	316LN 93% DFW1	DFW1 rear section, DSM123	7.76E-07	8.39E-07	1.19E+06
9	316LN 93% Block	Antennae block	7.76E-07	8.34E-07	1.20E+06
10	S660 Steel	Pins	7.76E-07	7.76E-07	1.29E+06
11	Aluminum Bronze	Pads	2.46E-07	2.46E-07	4.07E+06
12	CuCrZr	Shield trays, front waveguides, clamps, mitered caps	2.71E-08	2.71E-08	3.69E+07

DesignModeler LFSR PP ASM Solid Model:

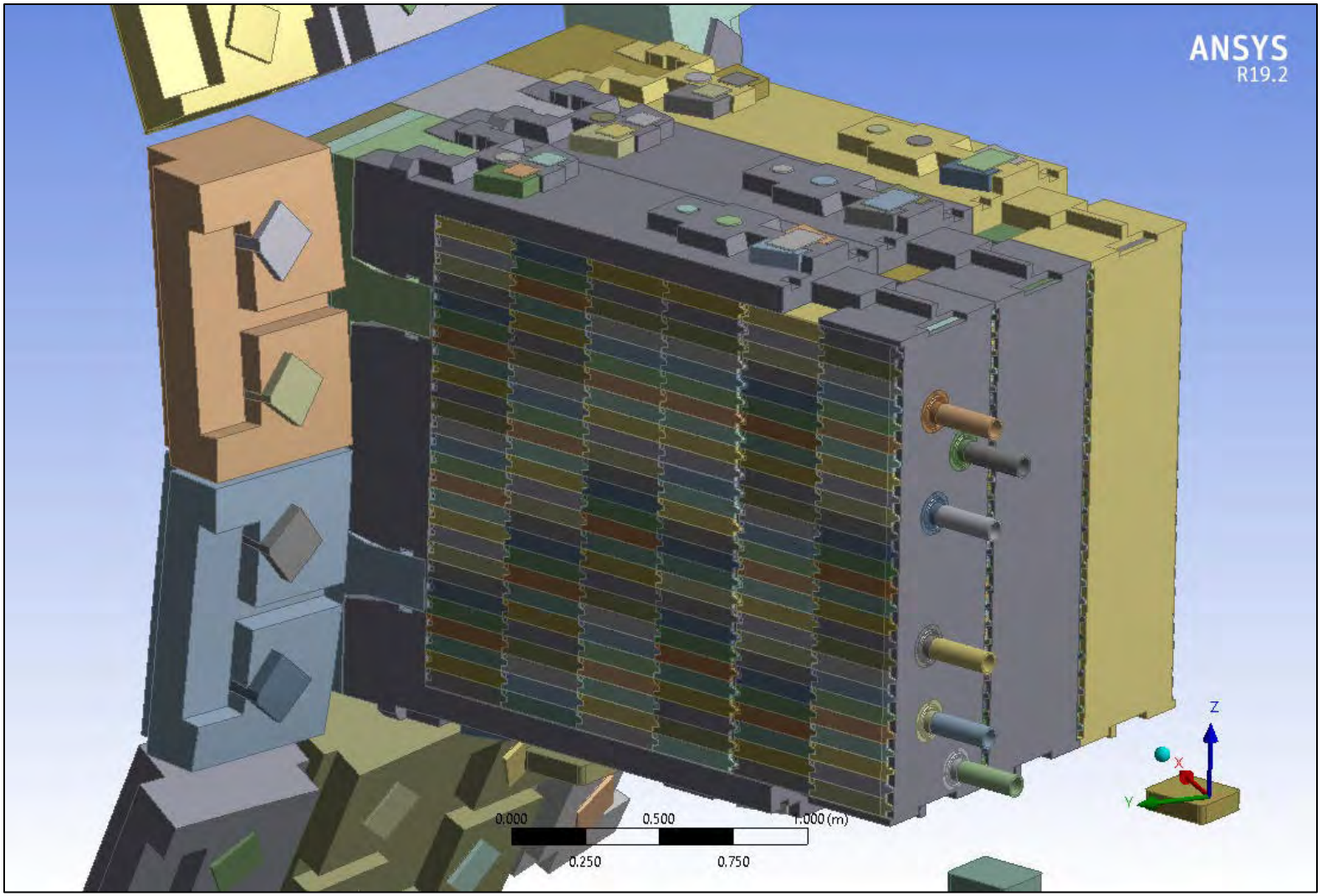
DSM1: LSMR ASM; DSM2/3: Simplified EM Shielding Trays



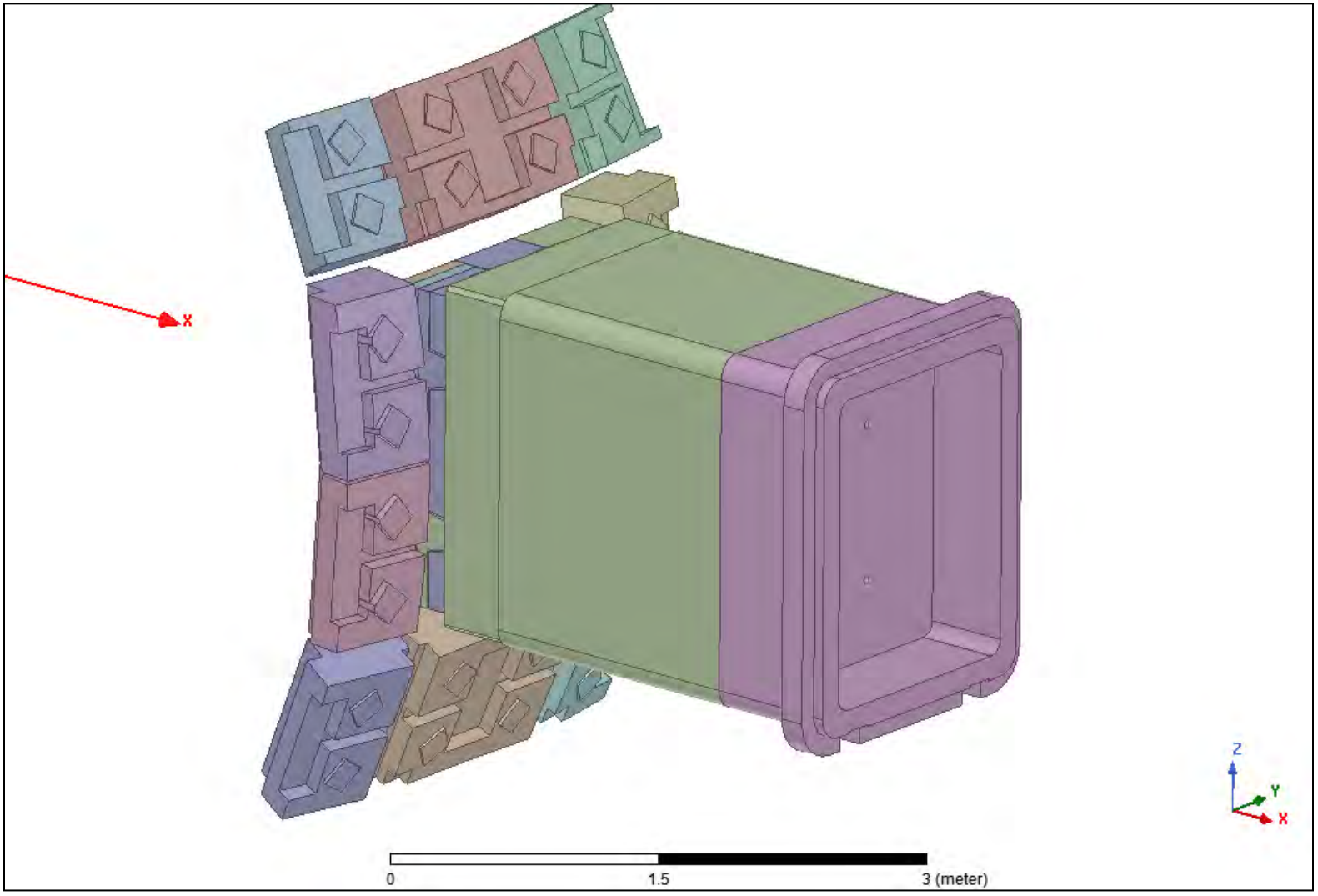
DesignModeler LFSR PP ASM Solid Model:
DSM1: LFSR ASM; DSM2/3: Simplified EM Shielding Trays



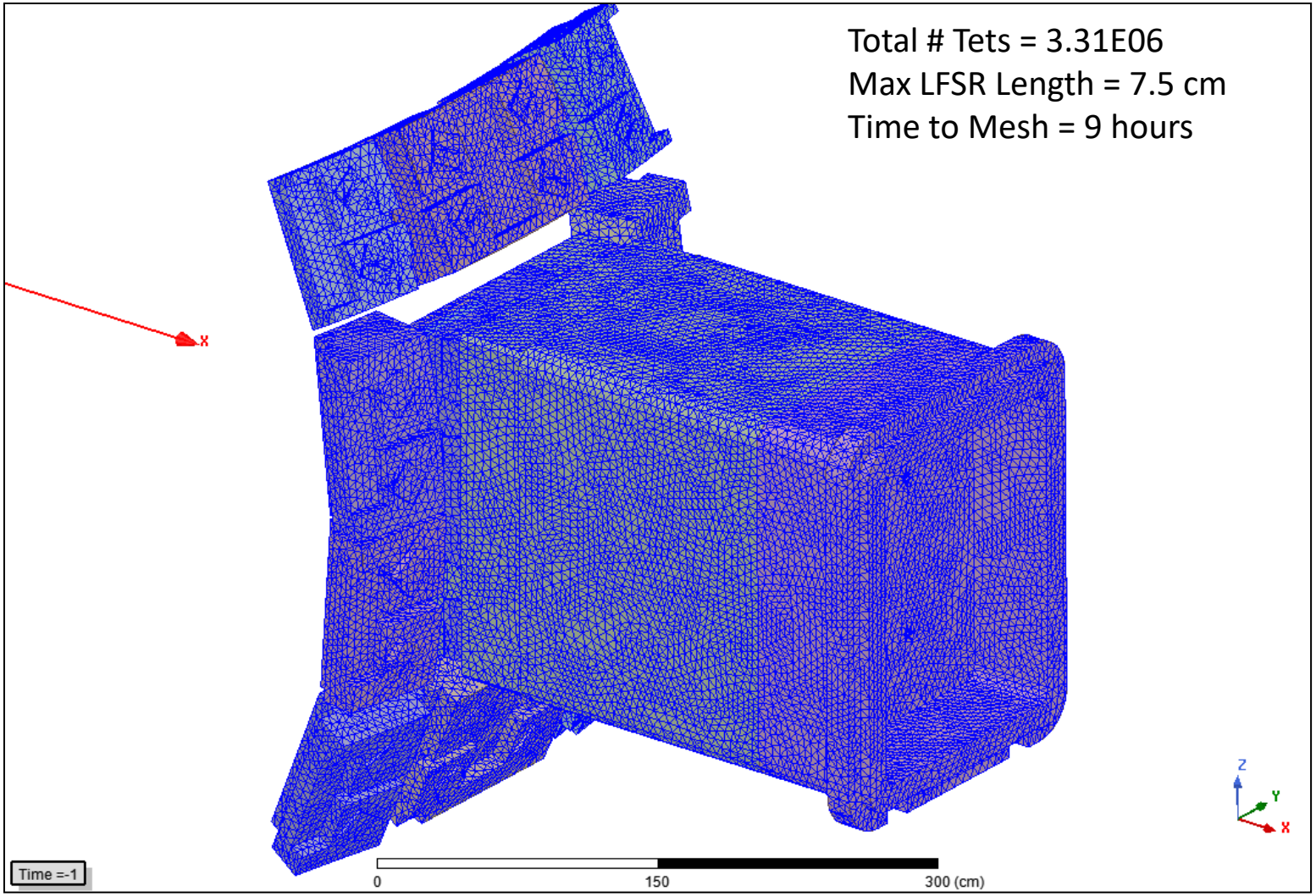
DesignModeler LFSR PP ASM: Aluminum Bronze Pads



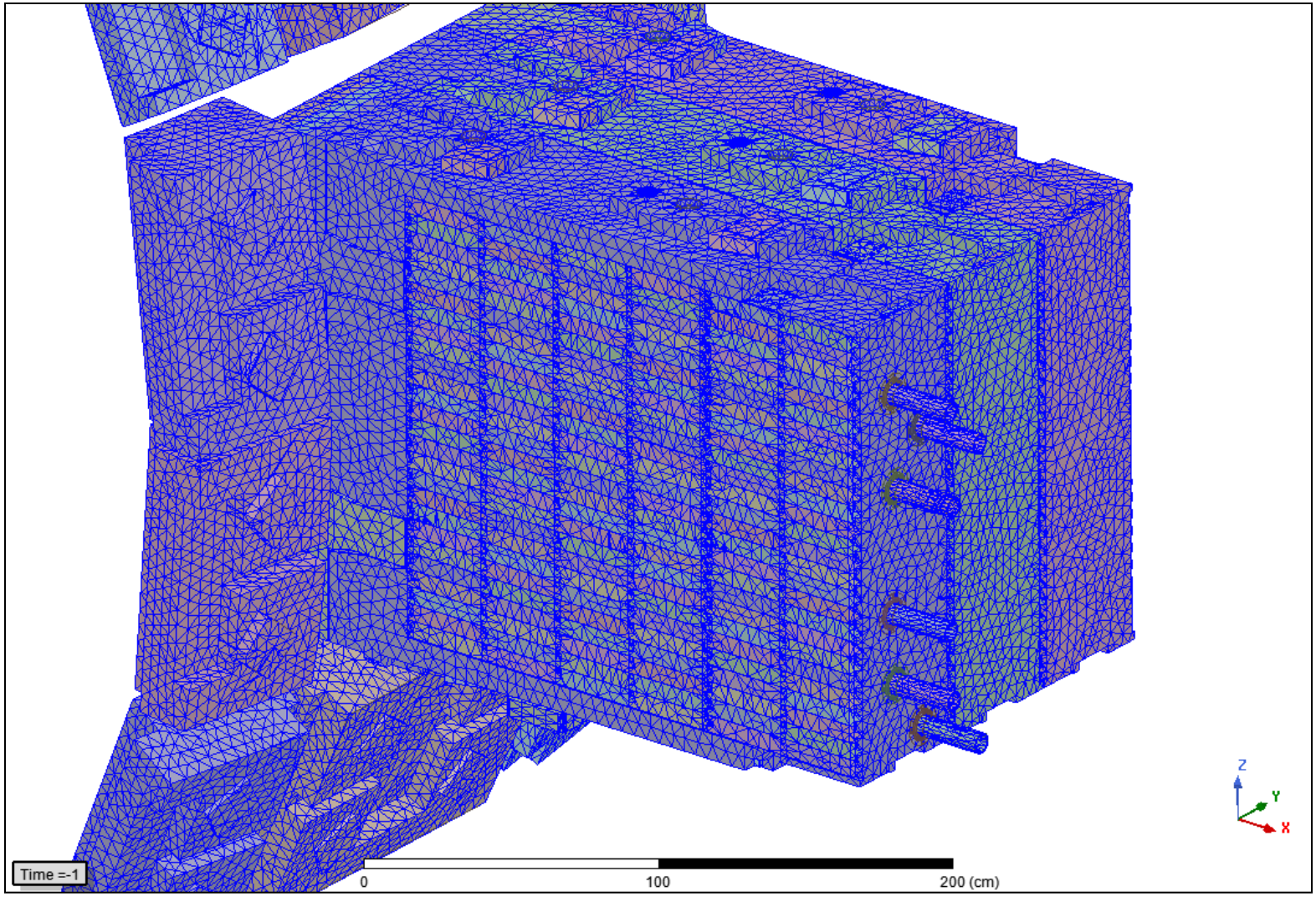
Maxwell LFSR PP ASM Solid Model:
DSM1: LFSR ASM; DSM2/3: Simplified EM Shielding Trays



Maxwell LFSR PP ASM: EM Medium-Mesh Transient Mesh
DSM1: LFSR ASM; DSM2/3: Simplified EM Shielding Trays



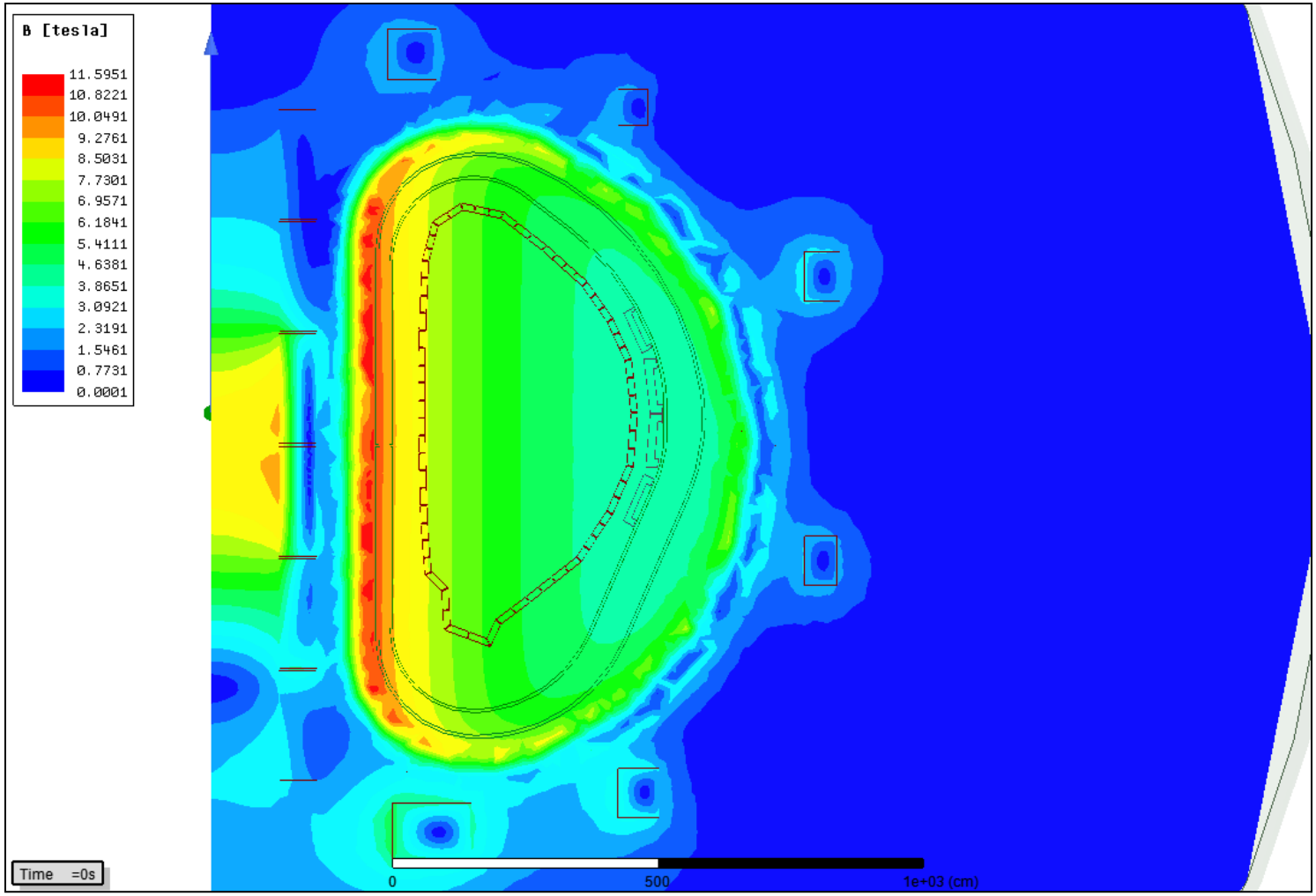
Maxwell LFSR PP ASM: EM Medium-Mesh Transient Mesh
DSM1: LFSR ASM; DSM2/3: Simplified EM Shielding Trays



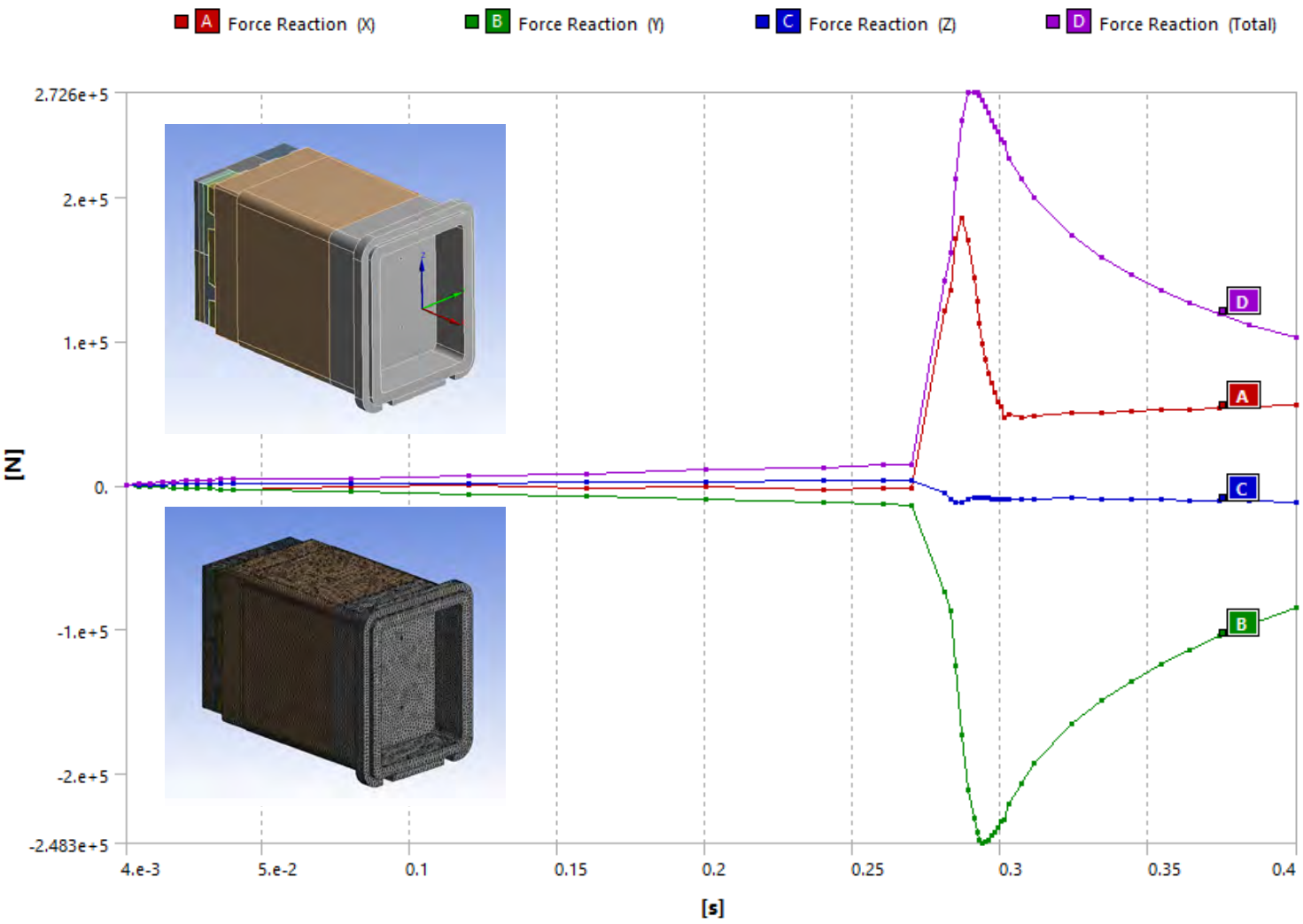
Maxwell LFSR PP ASM: EM Medium –Mesh (7.5 cm) Transient Results

Time: 0s; DSM1: LFSR ASM; DSM2/3: Simplified EM Shielding Trays

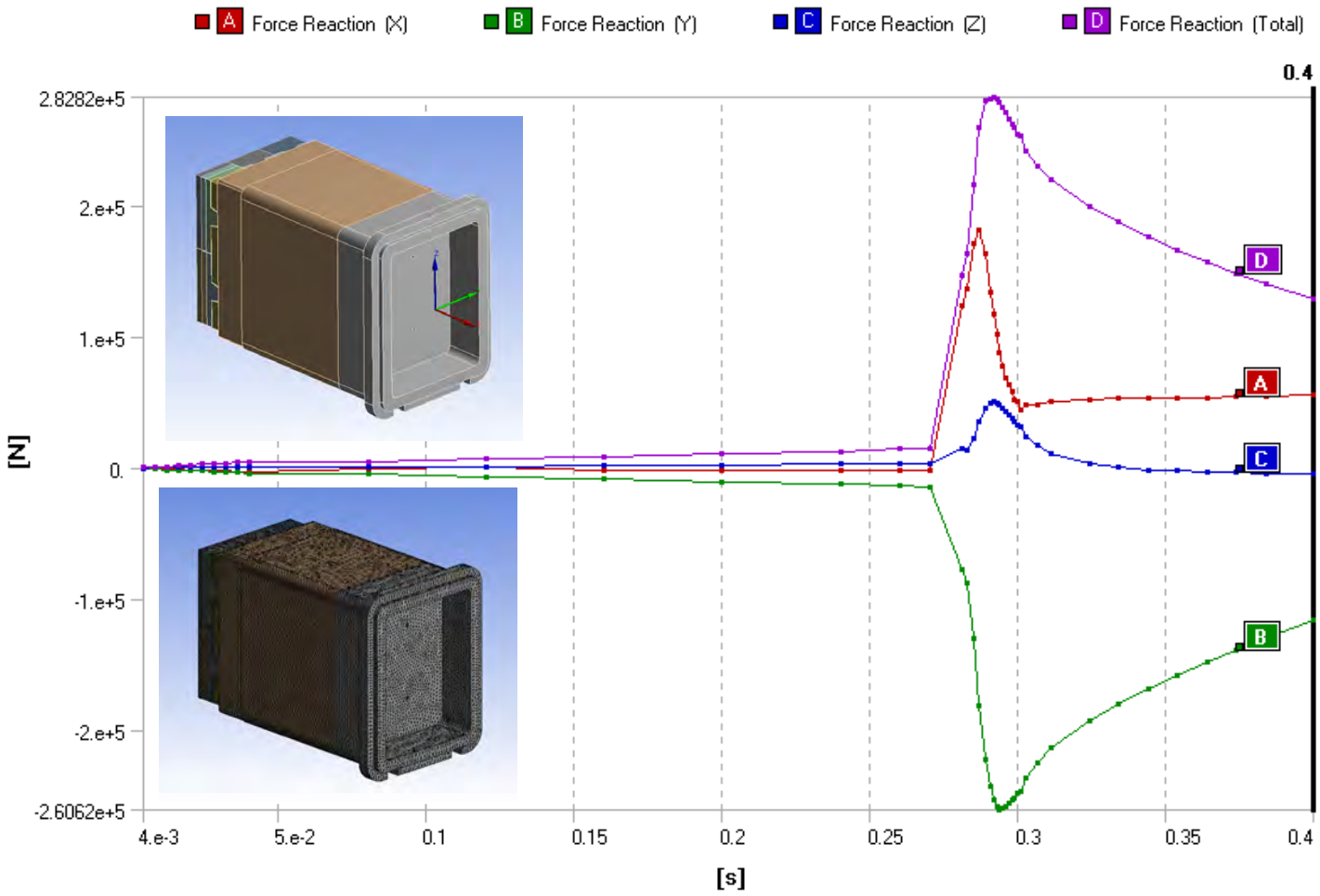
Current Scenario: MD_DW16_OT_2010



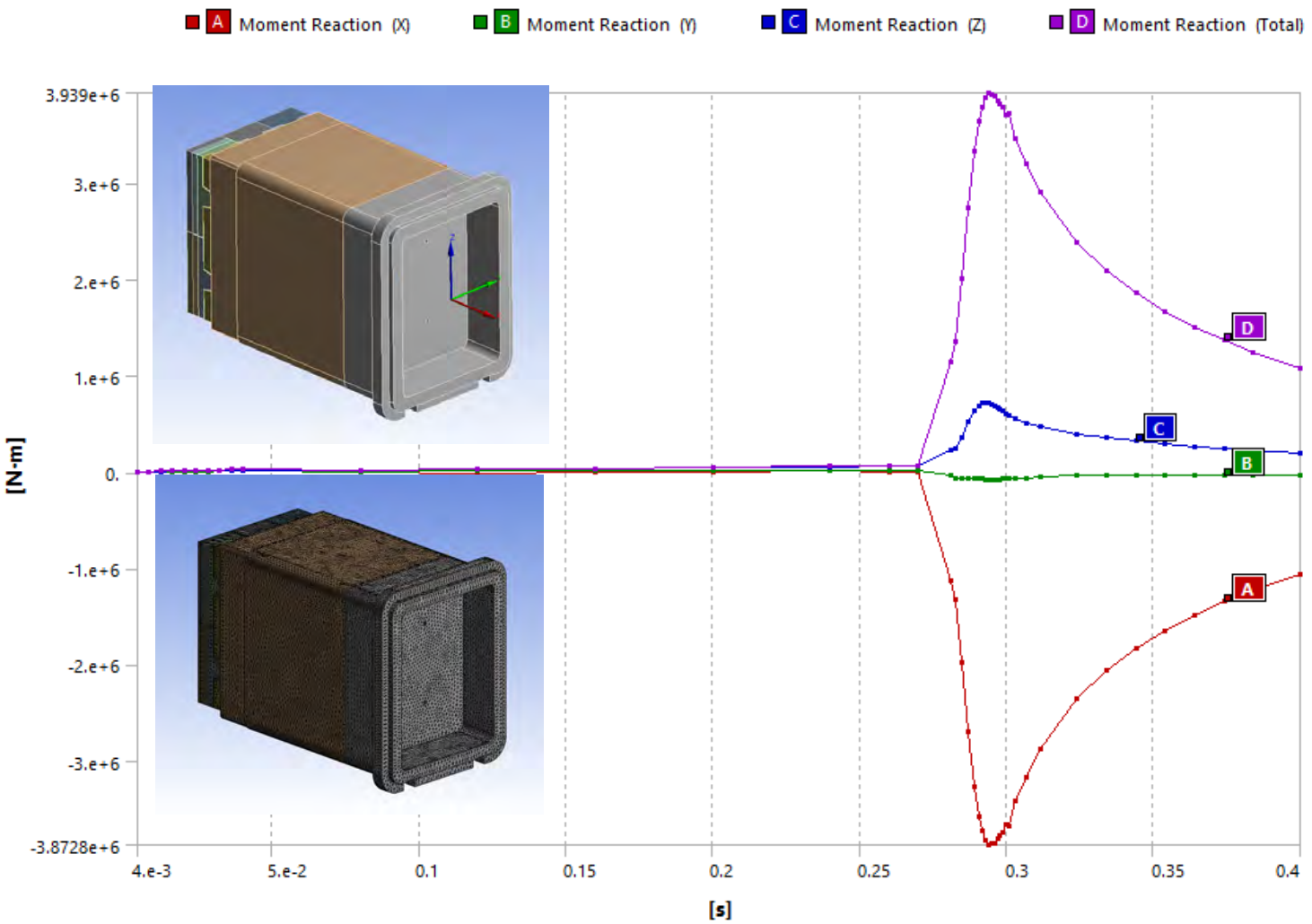
Mechanical LFSR EPP ASM: EM Medium-Mesh (7.5 cm) Transient Results
Force Reactions vs Time



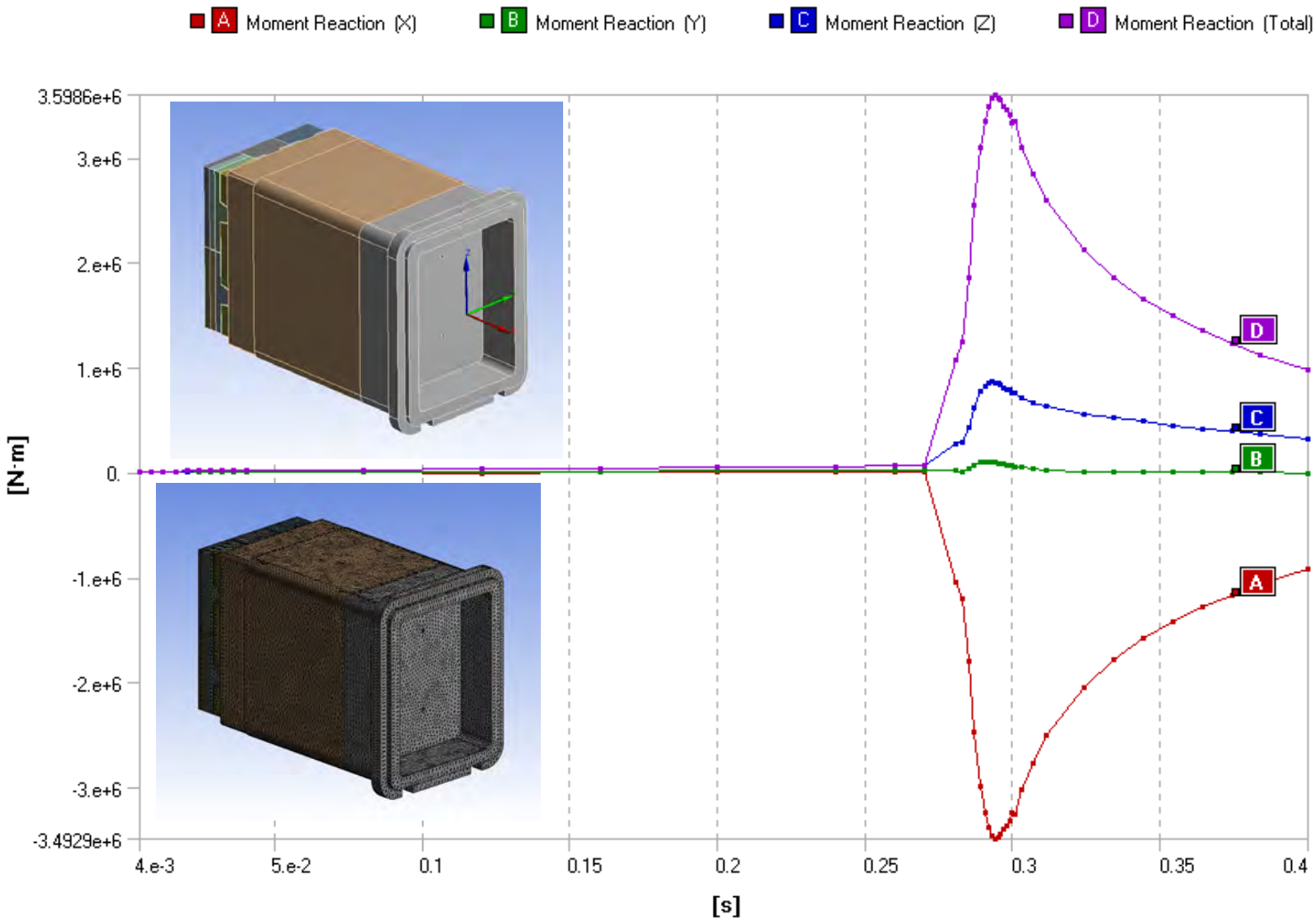
Mechanical LFSR EPP ASM: EM Coarse-Mesh (10 cm) Transient Results
Force Reactions vs Time



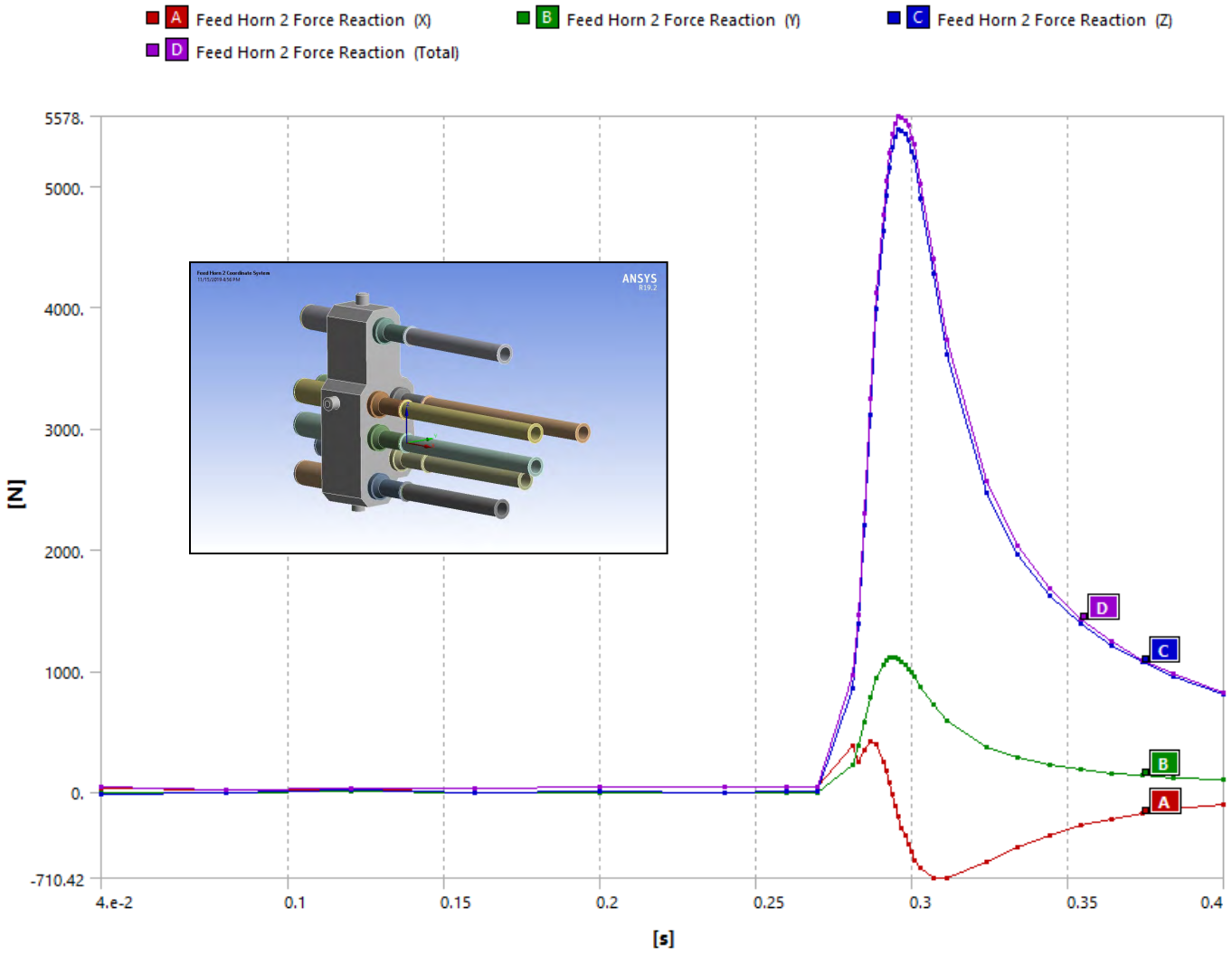
Mechanical LFSR EPP ASM: EM Medium-Mesh (7.5 cm) Transient Results
Moment Reactions vs Time



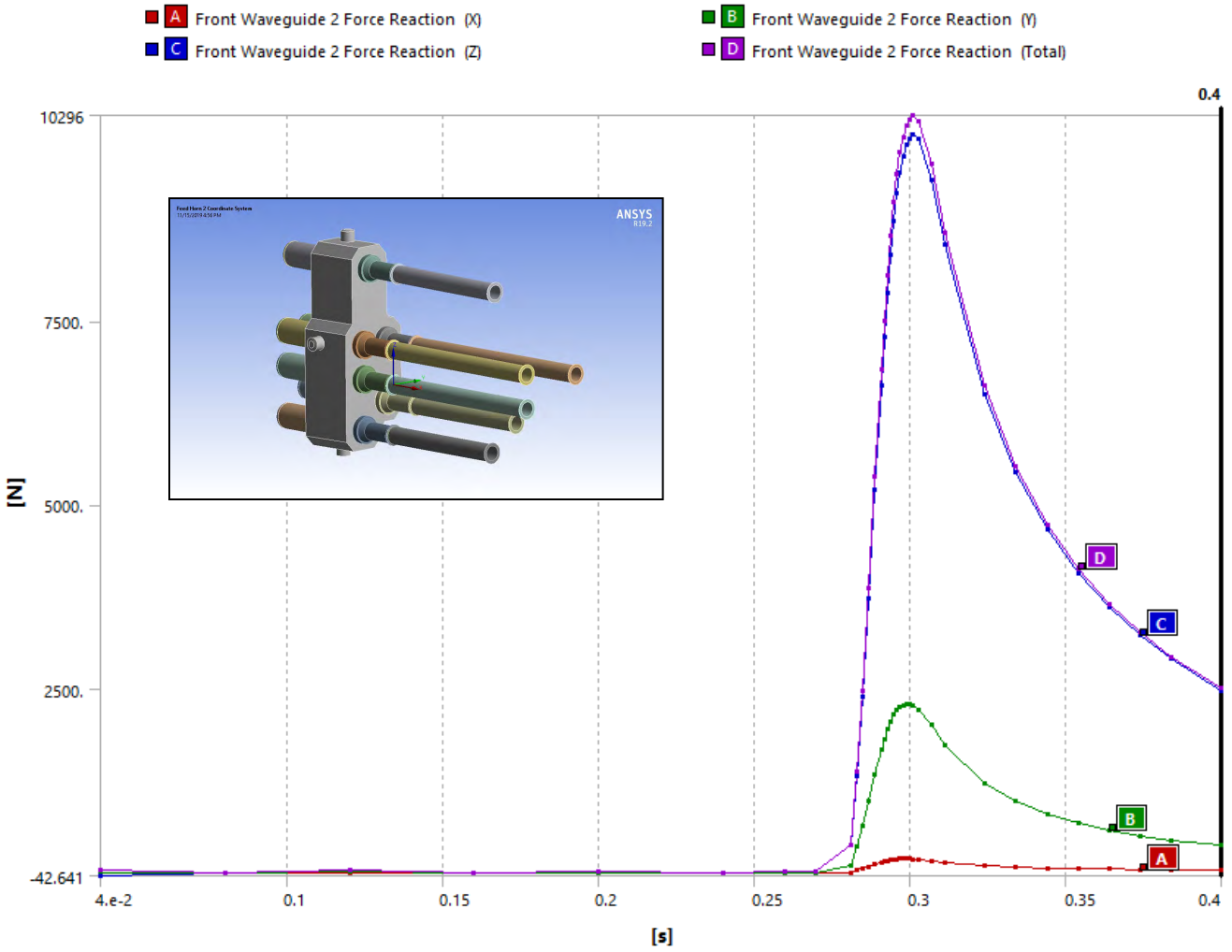
Mechanical LFSR EPP ASM: EM Coarse-Mesh (10 cm) Transient Results
Moment Reactions vs Time



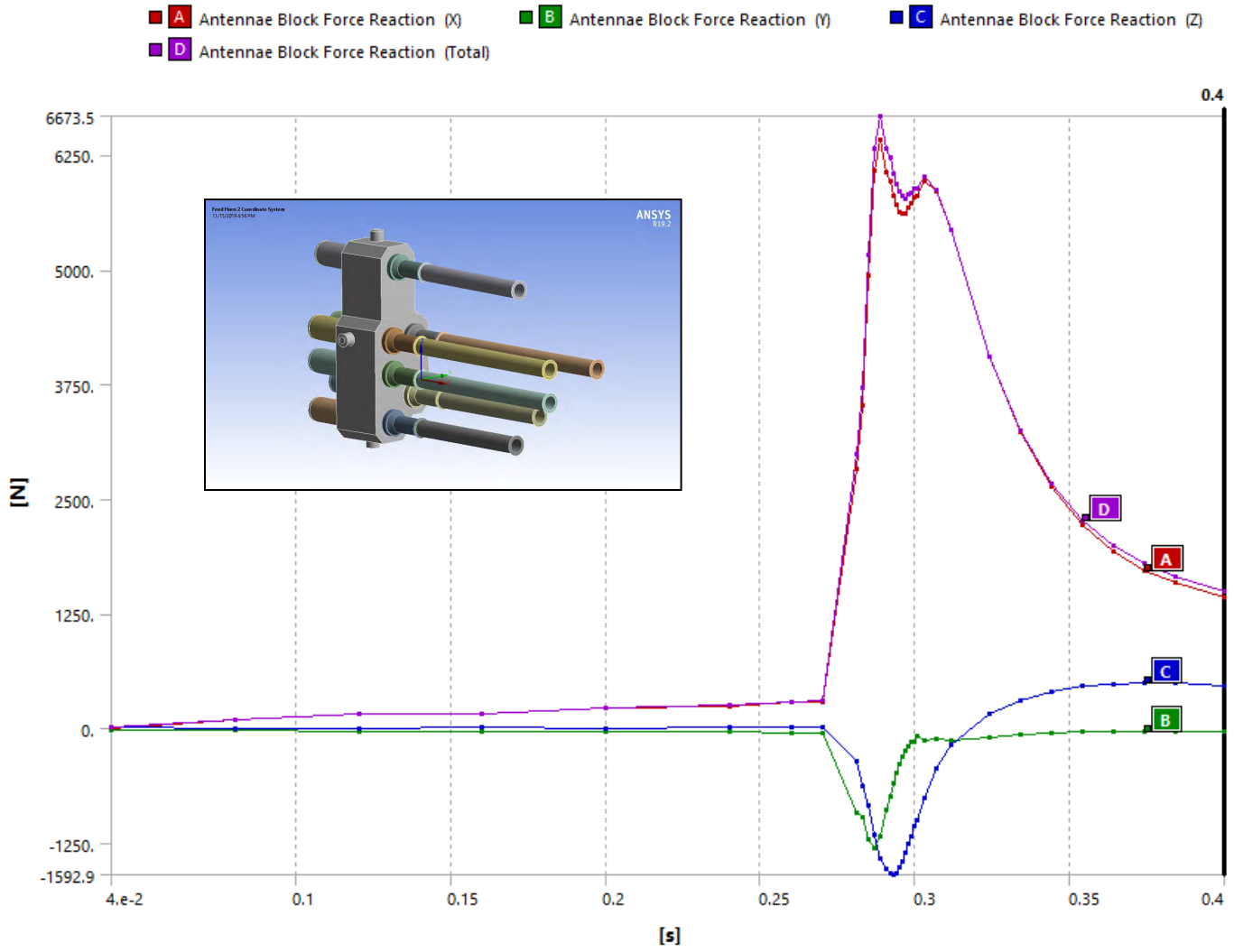
Mechanical LFSR Feed Horn: EM Medium-Mesh (7.5 cm) Transient Results
Force Reactions vs Time



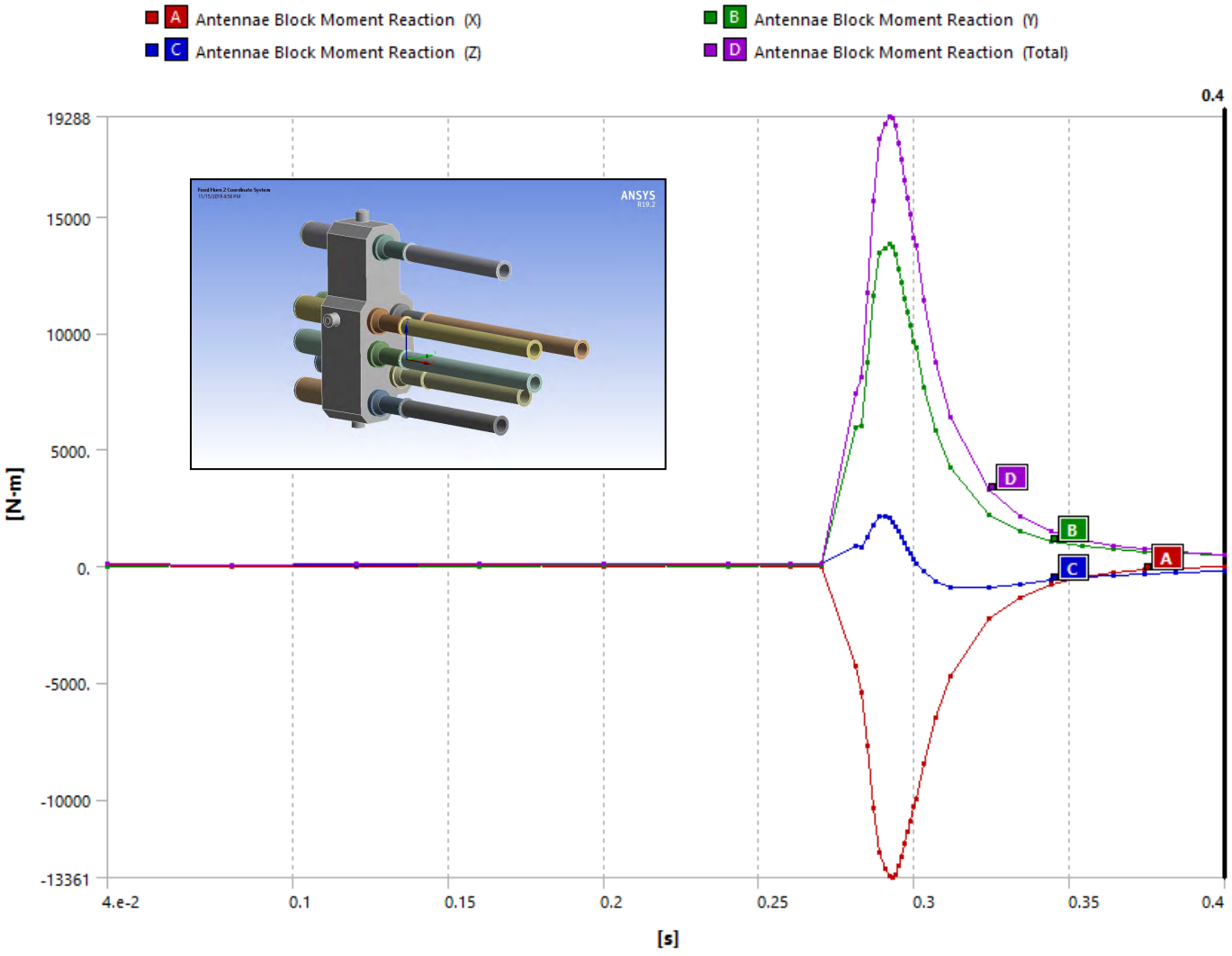
Mechanical LFSR Front Waveguide: EM Medium-Mesh Transient Results
Force Reactions vs Time



Mechanical LFSR Antenna Block: EM Medium-Mesh Transient Results
Force Reactions vs Time



Mechanical LFSR Antenna Block: EM Medium-Mesh Transient Results
Moment Reactions vs Time



High-Fidelity EM Analysis

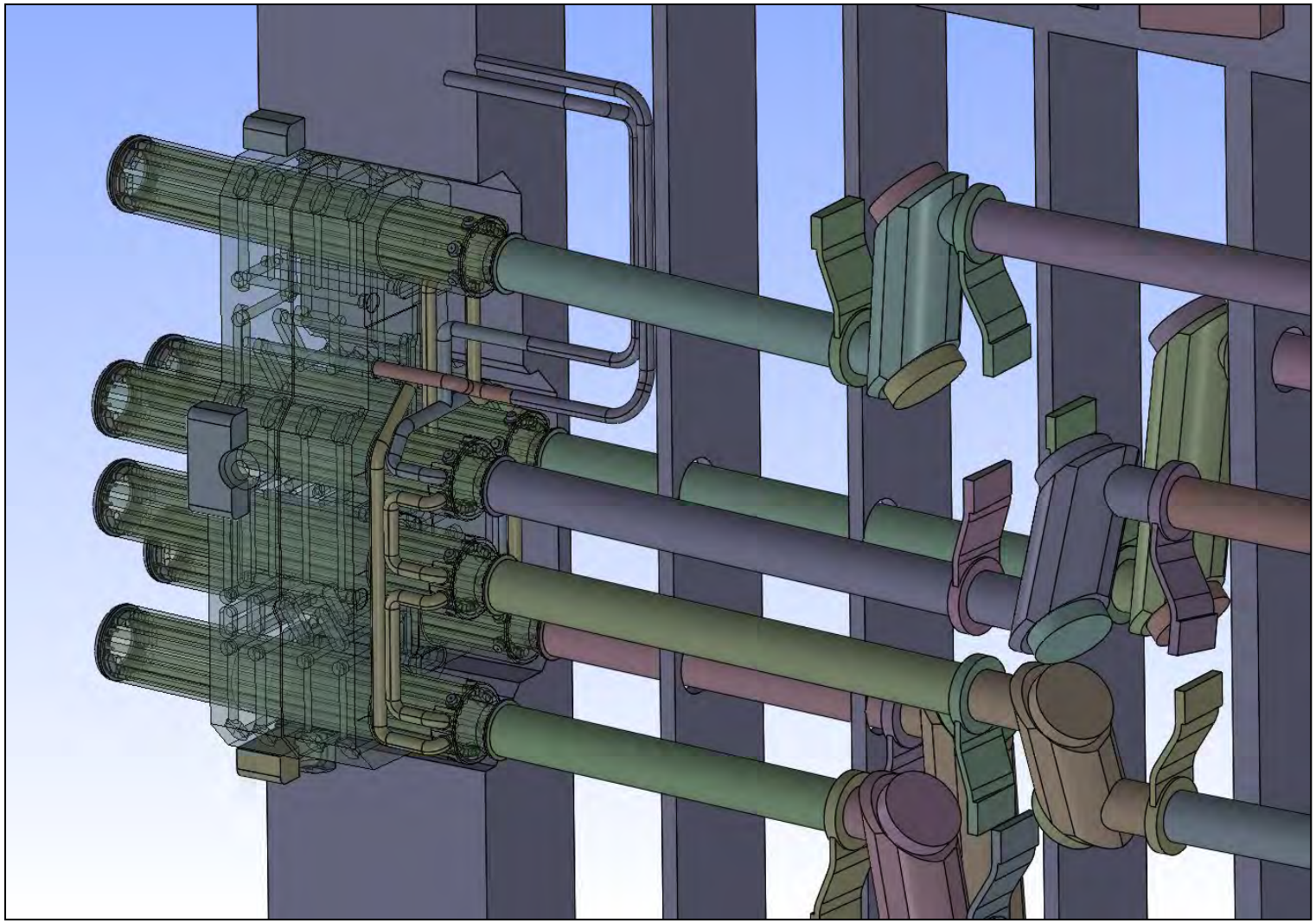
- Assume detailed stress analysis required for all components PPPL has design control over.
- Internal cooling passages restored for:
  - End Caps
  - Feed Horns
  - Antenna Block
- Cooling tubes included in EM analysis
- Initial Periscope Clamp Design used
  - Clamp electrical resistance increased by 2.2x to account for additional conduction length in latest design

Maxwell LFSR High-Fidelity EM Analysis:
Material Conductivity

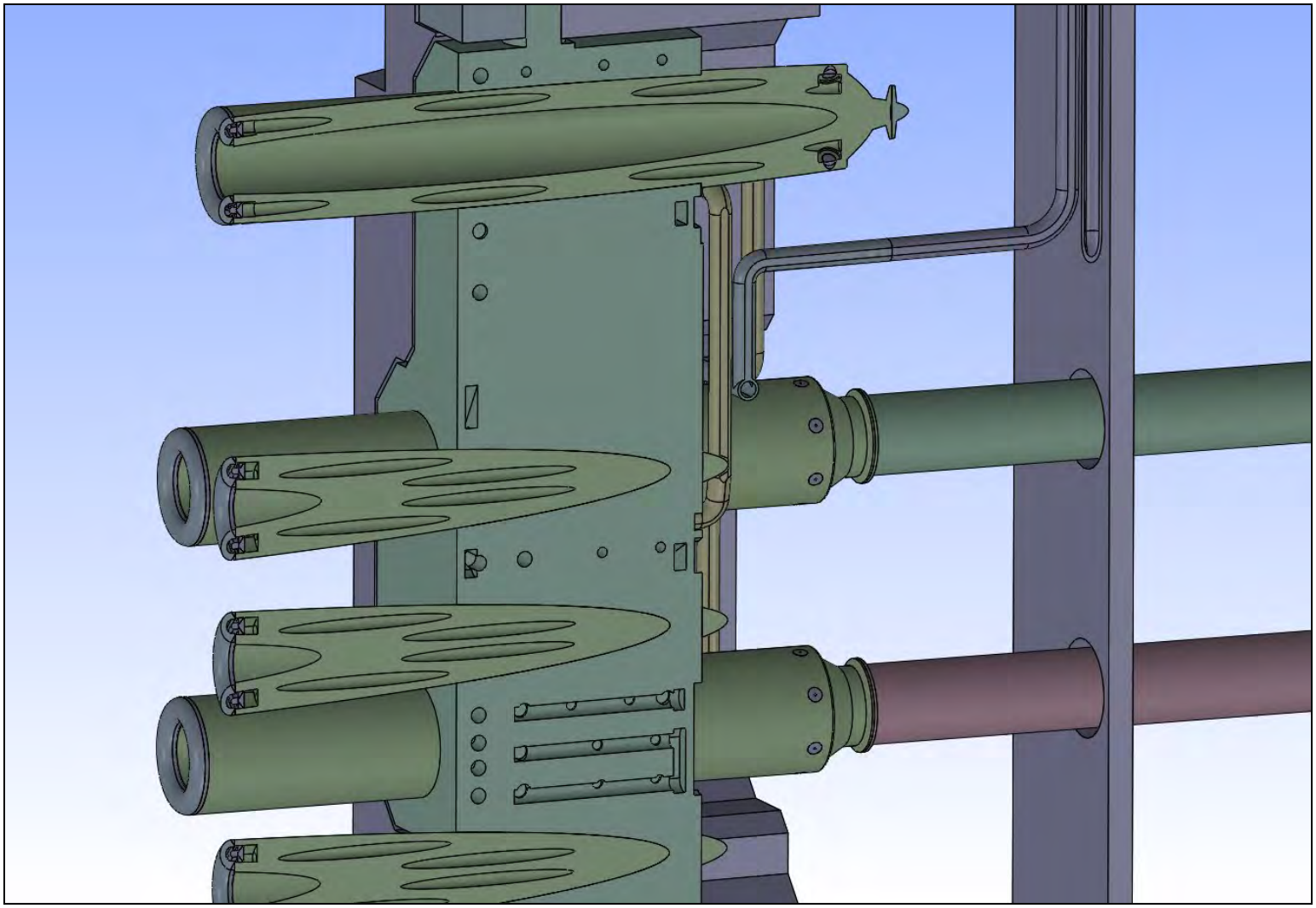
LFSR Materials: Component High-Fidelity Model Electrical Conductivity					
Item	Material Designation	Components	ρ X Real Ω*m	ρ X ANSYS Ω*m	σ X ANSYS s/m
1	316LN	VV, port plug, rear waveguides, periscopes, back fill pieces, end caps, feed horns, antenna block	7.76E-07	7.76E-07	1.29E+06
2	316LN 78% Blanket	Blankets	7.76E-07	1.00E-06	1.00E+06
3	316LN 79% DFW1	DFW1 front section	7.76E-07	9.88E-07	1.01E+06
4	316LN 86% DFW23	DFW23	7.76E-07	9.02E-07	1.11E+06
5	316LN 87% DFW1	DFW1 middle section	7.76E-07	8.94E-07	1.12E+06
6	316LN 93% DFW1	DFW1 rear section, DSM123	7.76E-07	8.39E-07	1.19E+06
7	S660 Steel	Pins	7.76E-07	7.76E-07	1.29E+06
8	Aluminum Bronze	Pads	2.46E-07	2.46E-07	4.07E+06
9	CuCrZr	Shield trays, front waveguides, mitered caps	2.71E-08	2.71E-08	3.69E+07
10	CuCrZr 45% Clamps	Periscope clamps	2.71E-08	1.22E-08	8.20E+07
11	CuCrZr 78% Braided	Braided WG support rings	2.71E-08	2.11E-08	4.73E+07

SolidWorks: LFSR High-Fidelity Antenna ASM

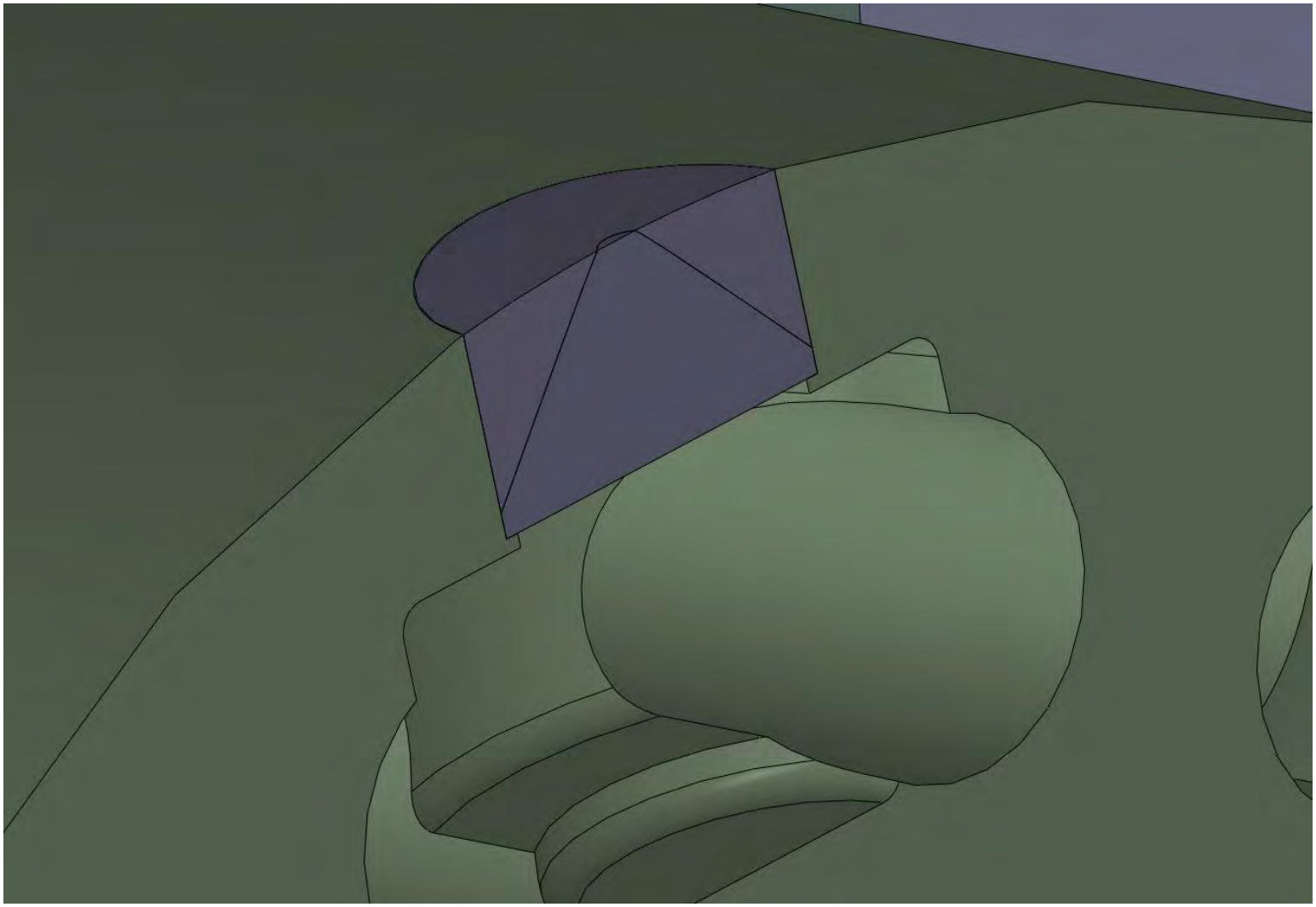
Internal cooling passages preserved



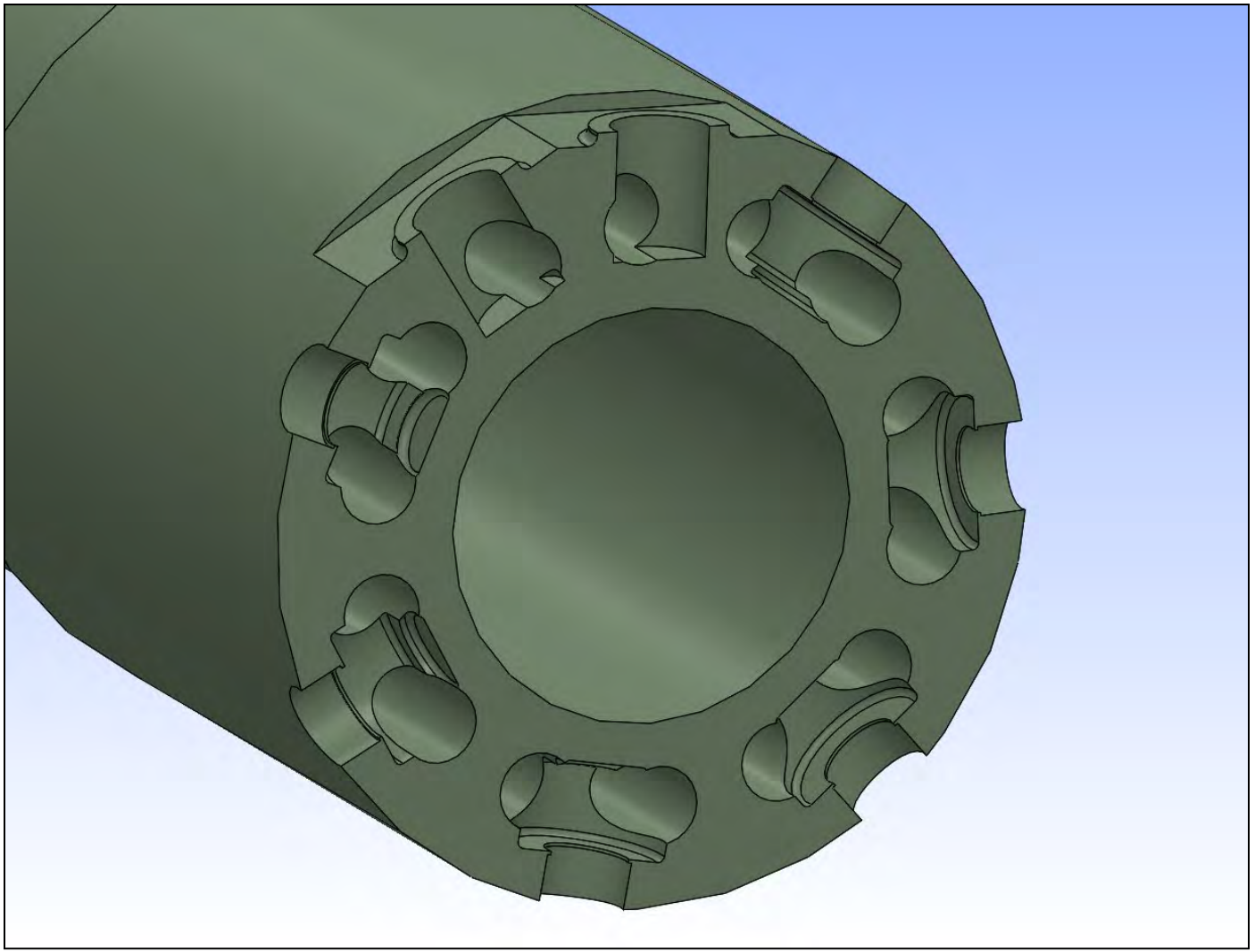
SolidWorks: High-Fidelity Antenna ASM:
Cross Section



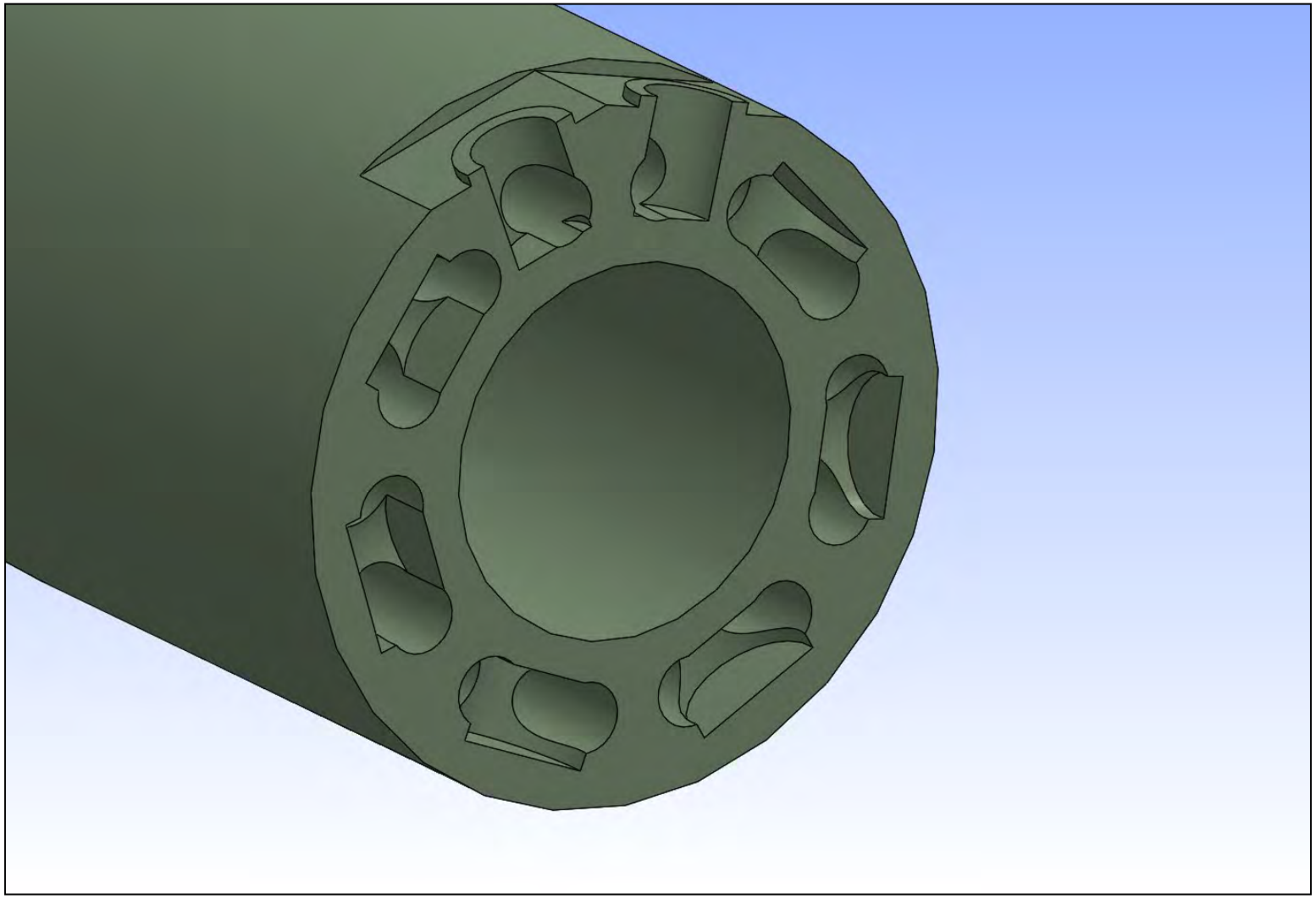
SolidWorks: High-Fidelity Antenna ASM:
Typical Simplification: Weld Plug to be Replaced with Filled Hole



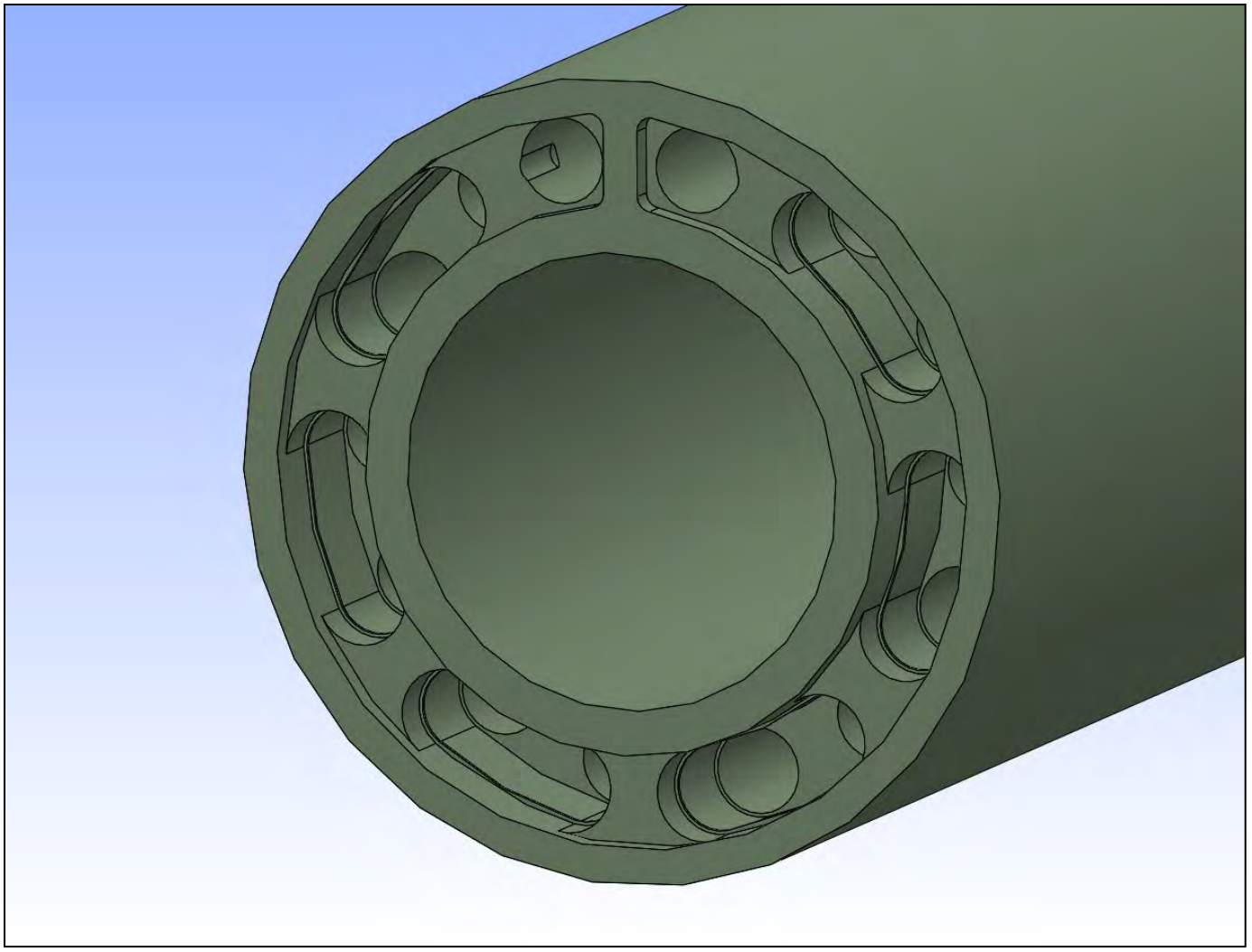
SolidWorks: High-Fidelity Feed Horn:
I/O End Full Featured Model



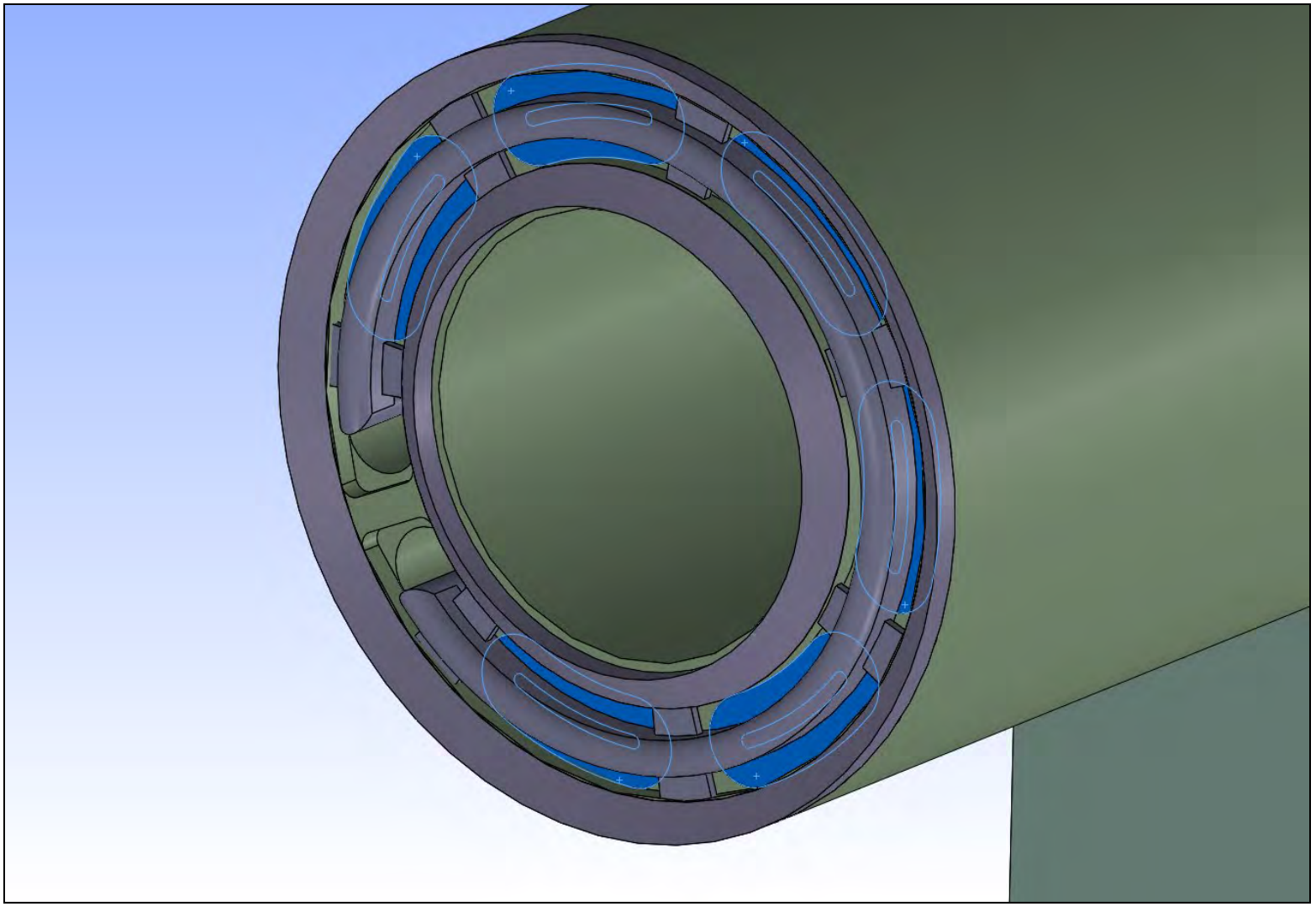
SolidWorks: High-Fidelity Feed Horn:
I/O End Simplified Model



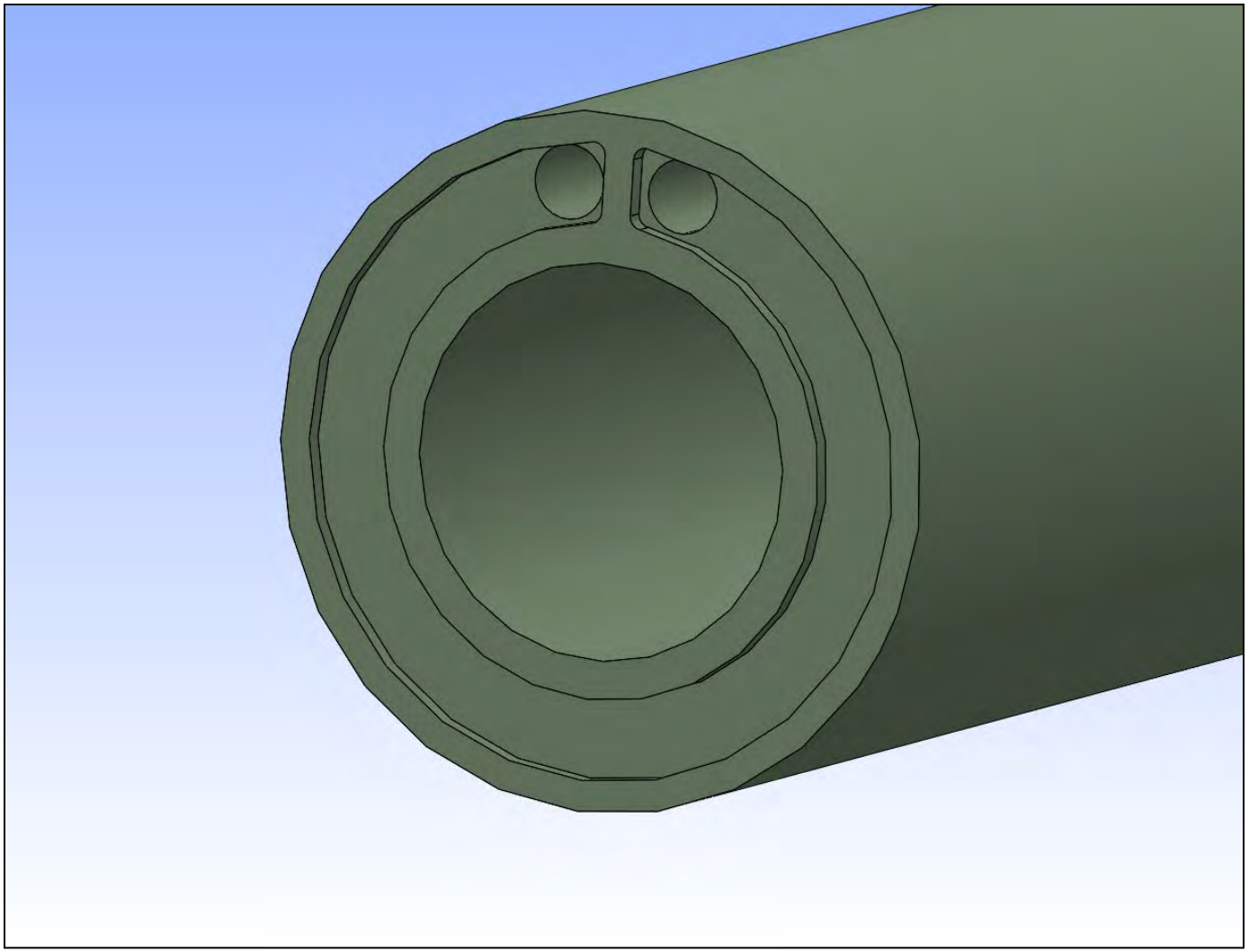
SolidWorks: High-Fidelity Feed Horn:
End Cap-End Full Featured Model



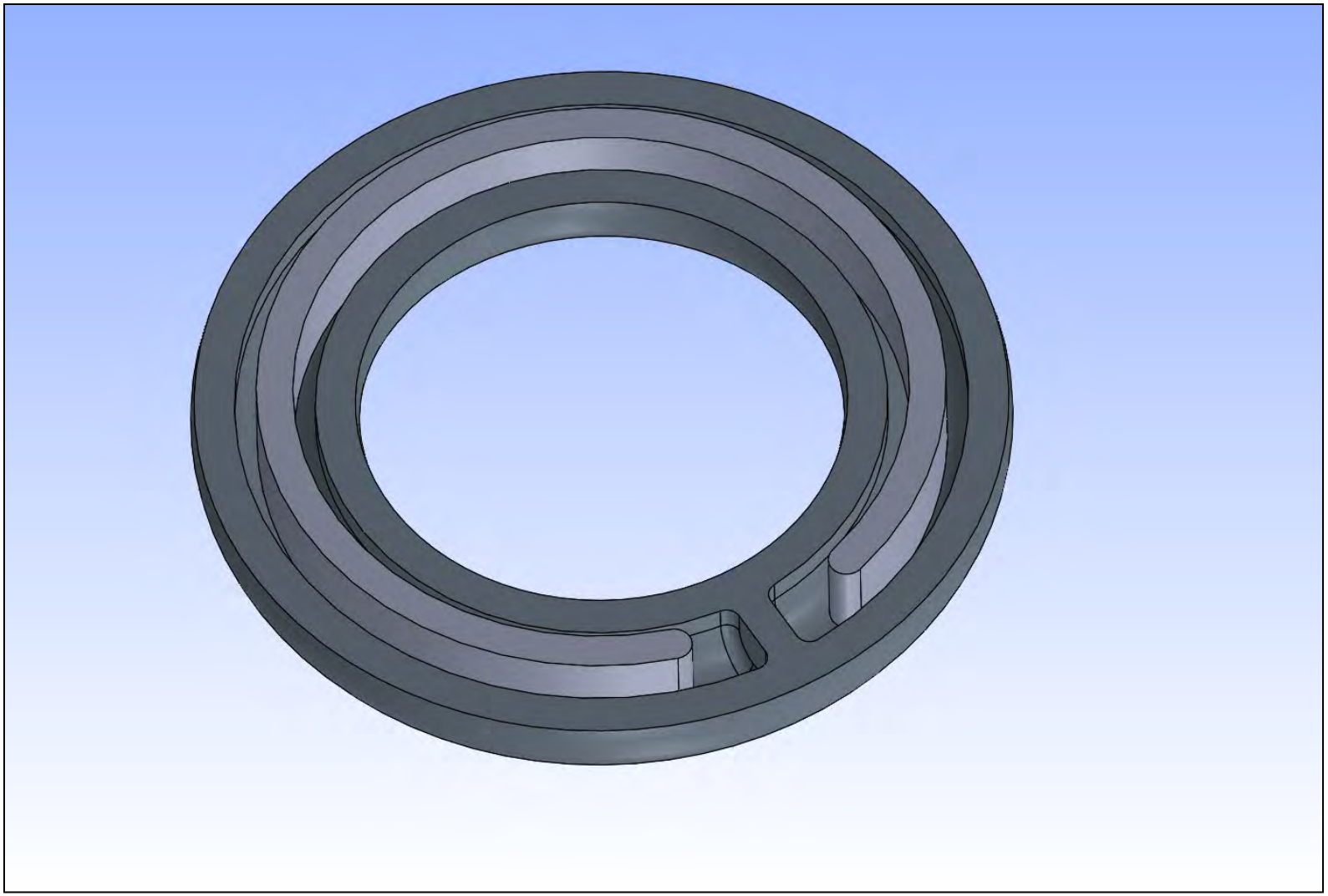
SolidWorks: High-Fidelity Feed Horn, End Cap, Spacer Ring ASM:
End Cap-End Simplified Model: Plug Welds (Blue) part of Feed Horn



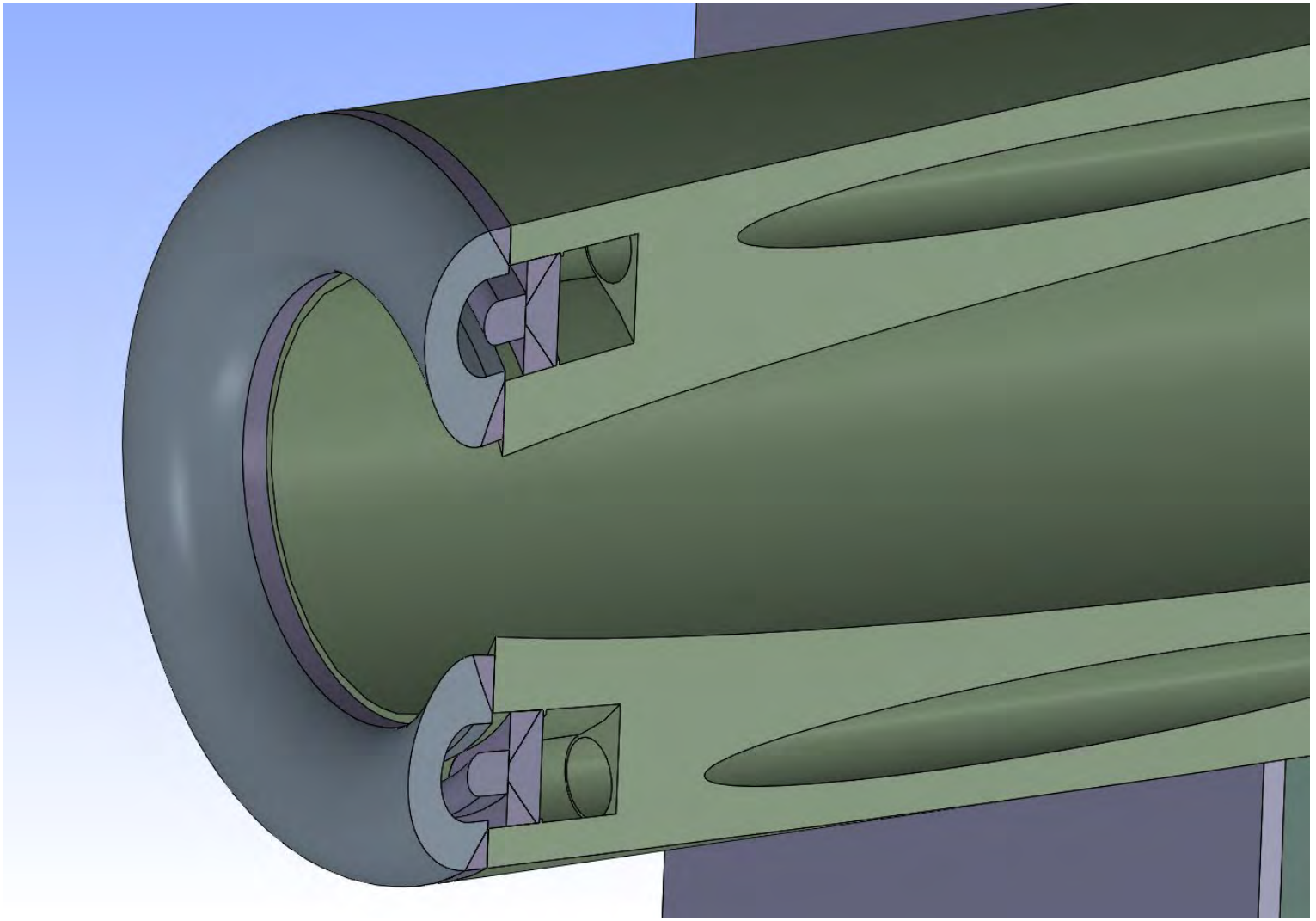
SolidWorks: High-Fidelity Feed Horn:
End Cap-End Simplified Model



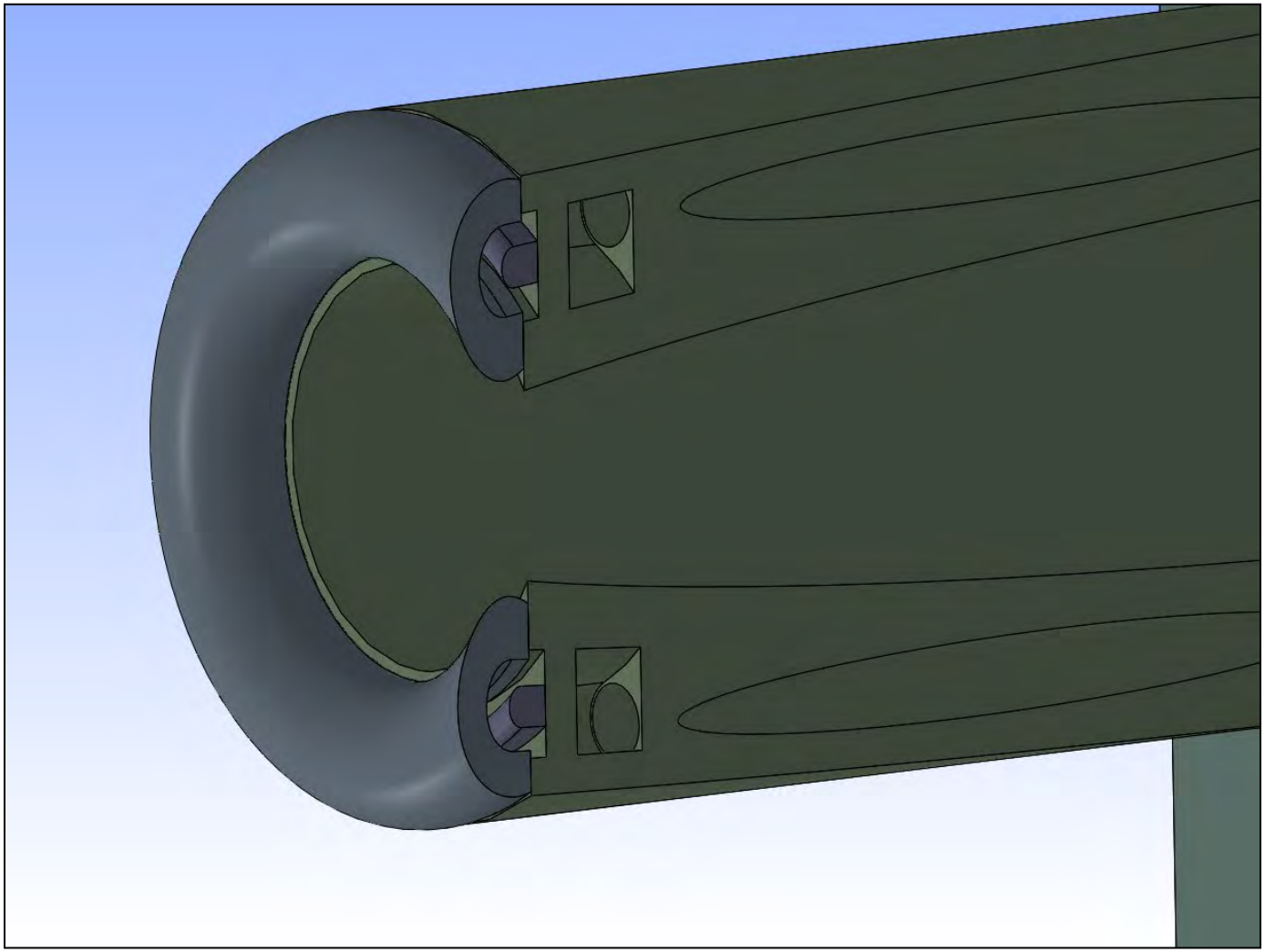
SolidWorks: Simplified End Cap and Spacer Ring ASM:



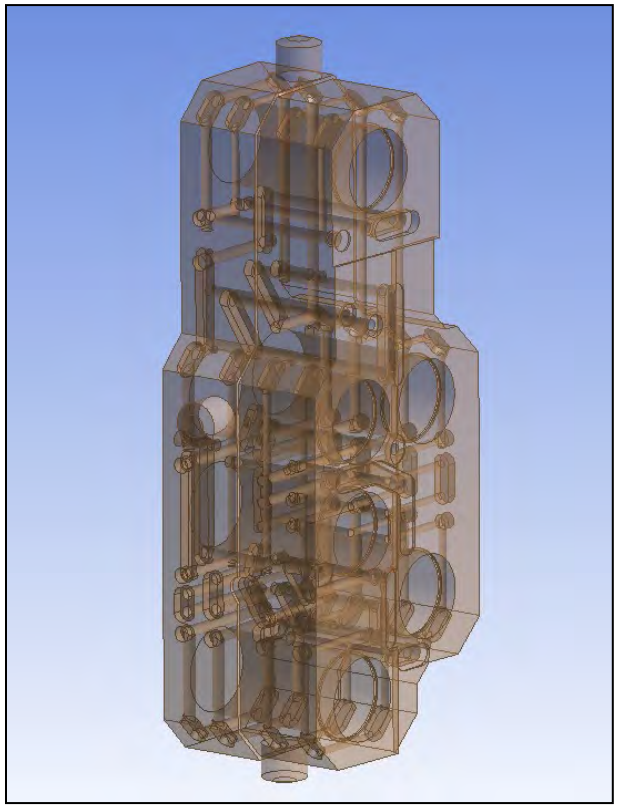
SolidWorks: High-Fidelity Feed Horn, End Cap, and Spacer Ring ASM

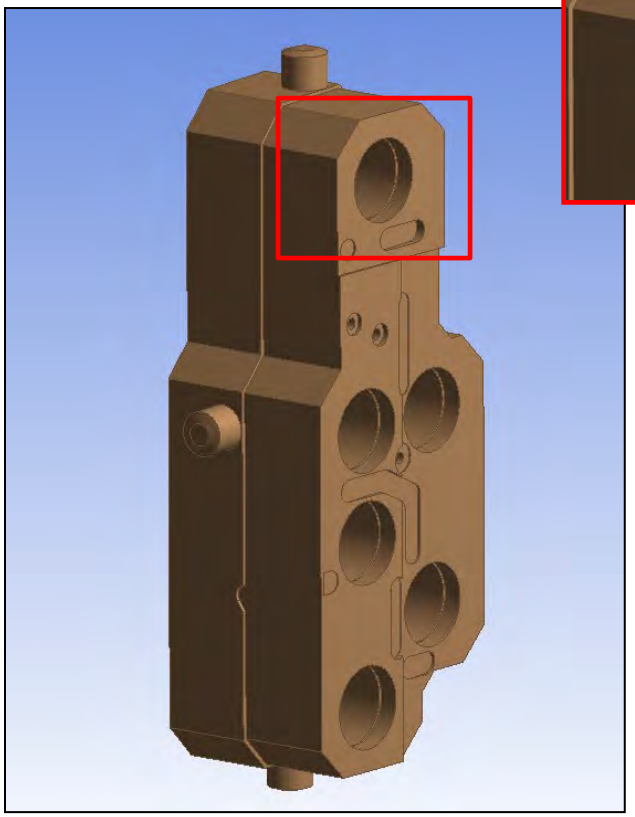


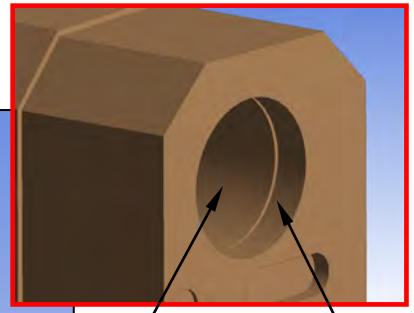
SolidWorks: Simplified Feed Horn, End Cap, and Spacer Ring ASM



DesignModeler: High-Fidelity Antenna Block Solid Model



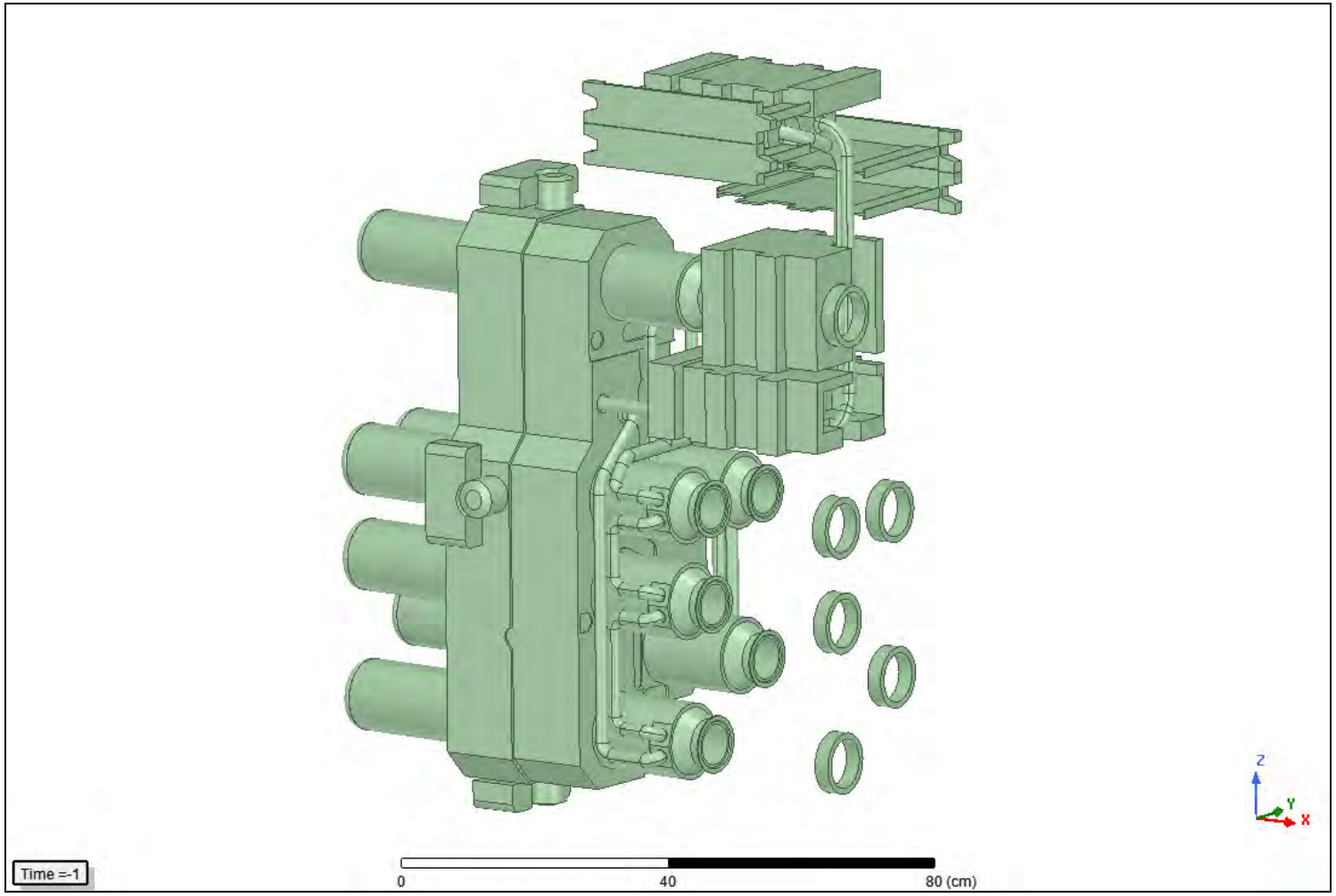




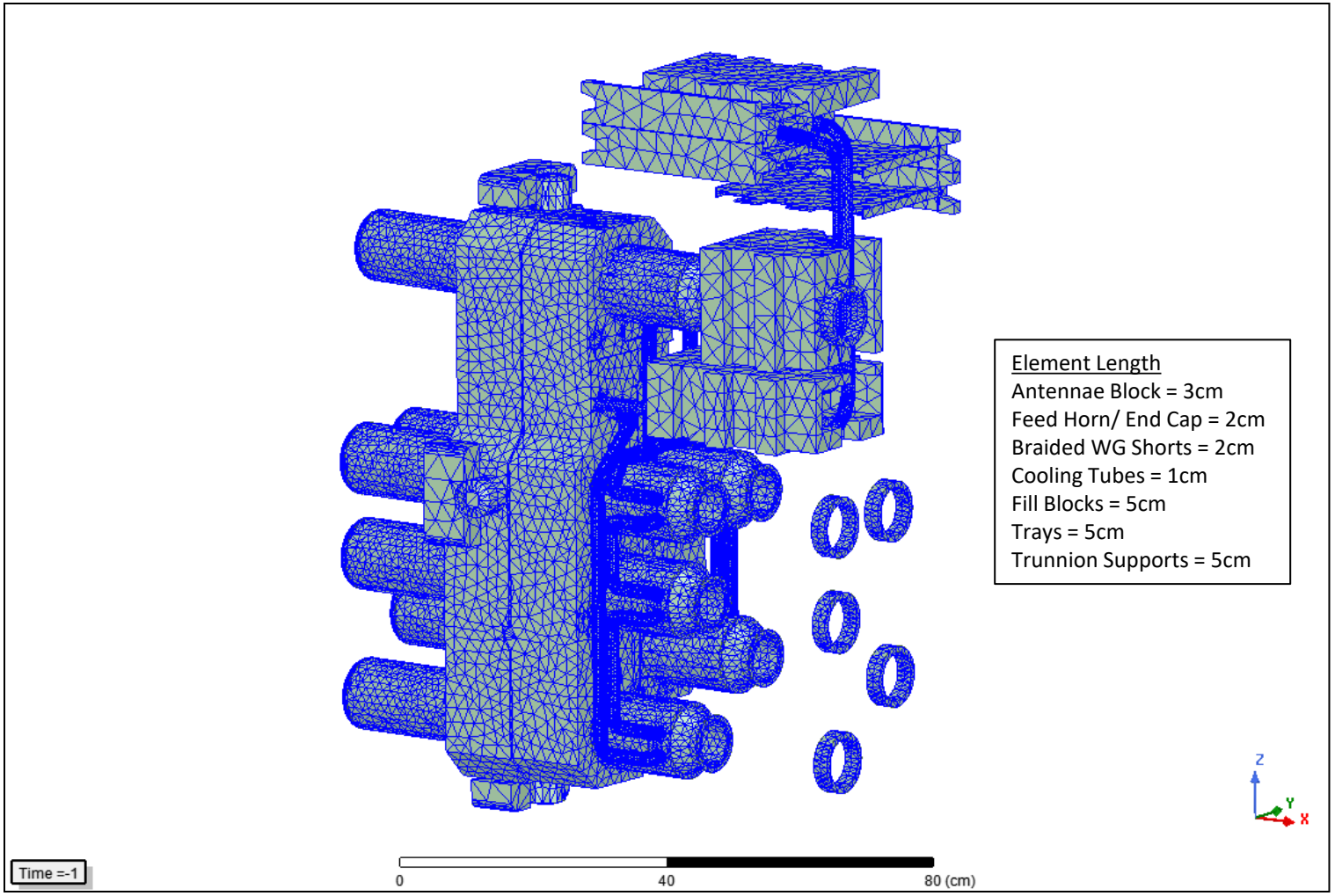
Insulated Boundary Condition; 6 PLS

Electrical Contact: 6 PLS

Maxwell: High-Fidelity Replacement Components
Solid Model



Maxwell: High-Fidelity Replacement Components
Isolated ASM Mesh Test: # Tets = 1.048E06



Failed: High-Fidelity EM Analysis:
Conclusions and Recommendations

- After more than 200 attempts - adjusting element length, surface resolution, and other mesh controls - the high-fidelity model failed to mesh. Either:
  - There is a problem with the geometry or the set-up; or
  - The model is too large/ complex, and beyond Maxwell's capabilities
- The model file has been sent to ANSYS Tech Support who:
  - May easily fix the meshing problem, run the full transient solution, and provide the results;
  - Be unable able to get the model to mesh and ask permission to simplify the model;
  - Consider the problem out-of-scope of standard tech support and require a consulting fee to work on; or
  - Try to get the model to mesh but fail, and realize the model is beyond Maxwell's capabilities; they may or may not tell us if they reach this conclusion.
- Recommendations:
  - If ANSYS fails to get the H-F model to solve, make the case for using smeared-properties results, if we are convinced they are valid; or
  - Find an alternative EM analysis software:
    - ANSYS EMAG
    - COMSOL
    - OPERA

Appendix