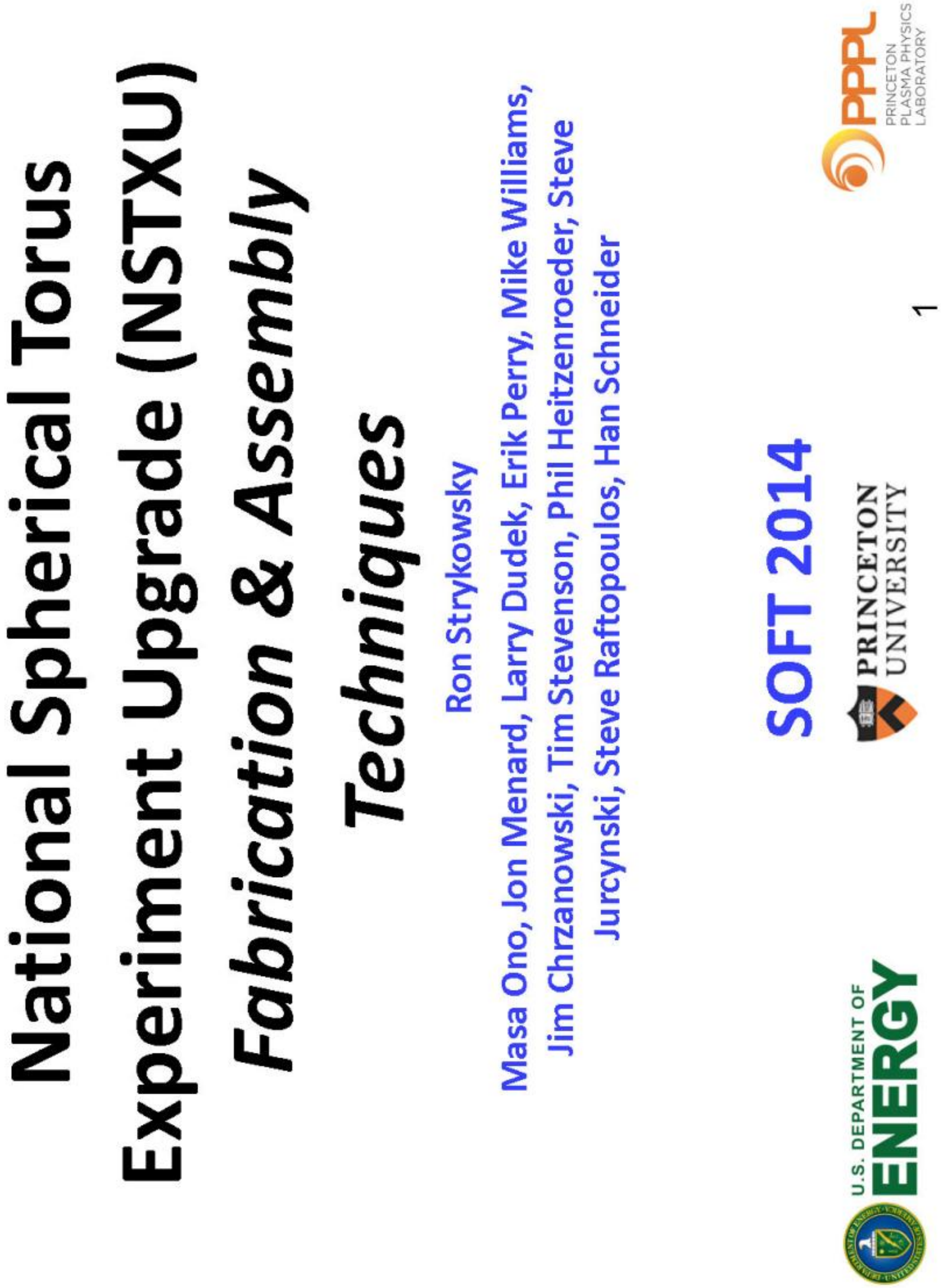
Appendix K

NSTXU Fabrication and Assembly Techniques



Appendix K

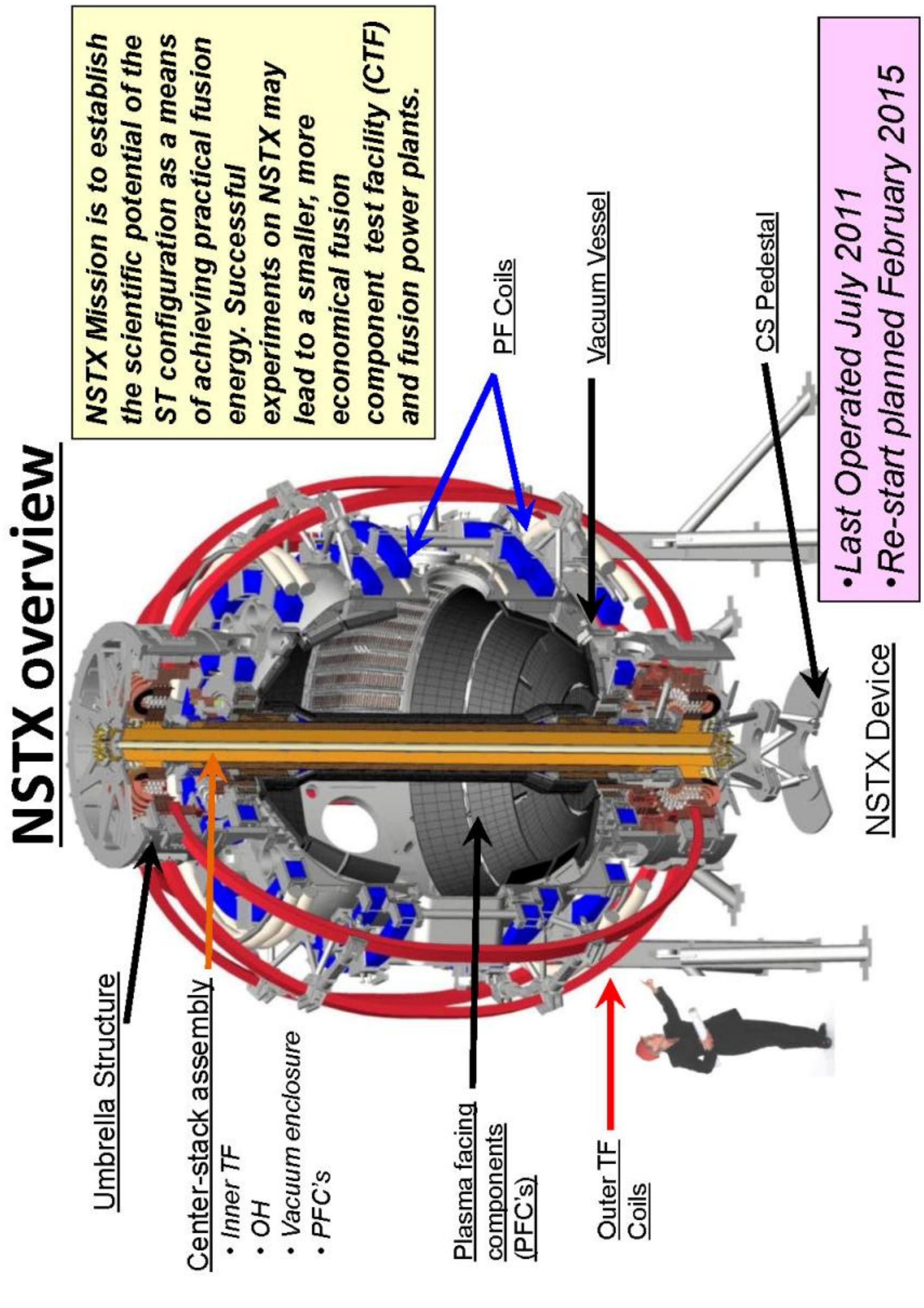
NSTXU Fabrication and Assembly Techniques (continued)

Acknowledgement

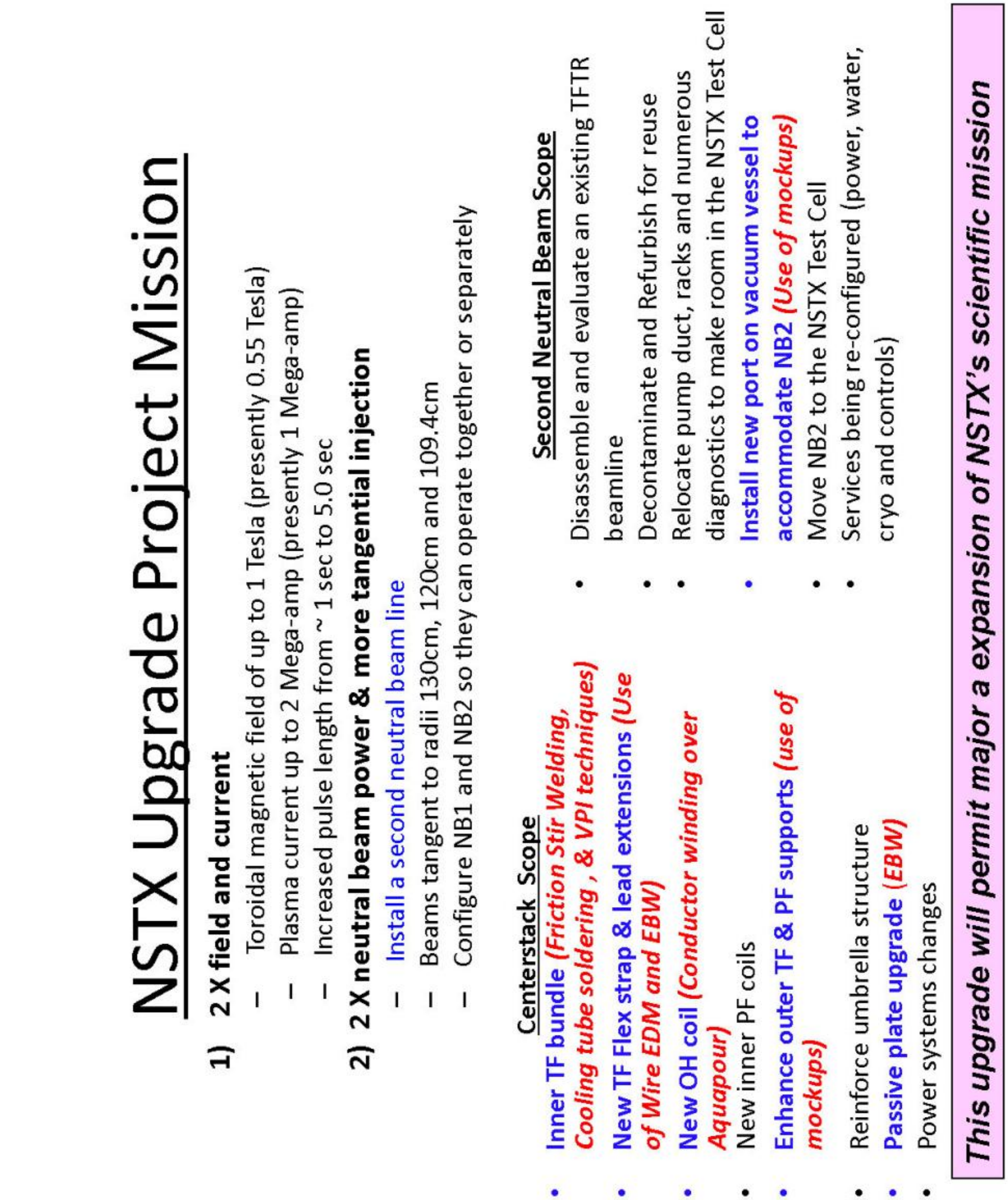
- Our thanks to the many PPPL physicists, engineers, designers, technicians, machinists and support staff and subcontractors whose combined expertise and efforts made this upgrade possible.

Appendix K

NSTXU Fabrication and Assembly Techniques (continued)



Appendix K
NSTXU Fabrication and Assembly Techniques (continued)



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NSTXU Fabrication and Assembly Techniques (continued)

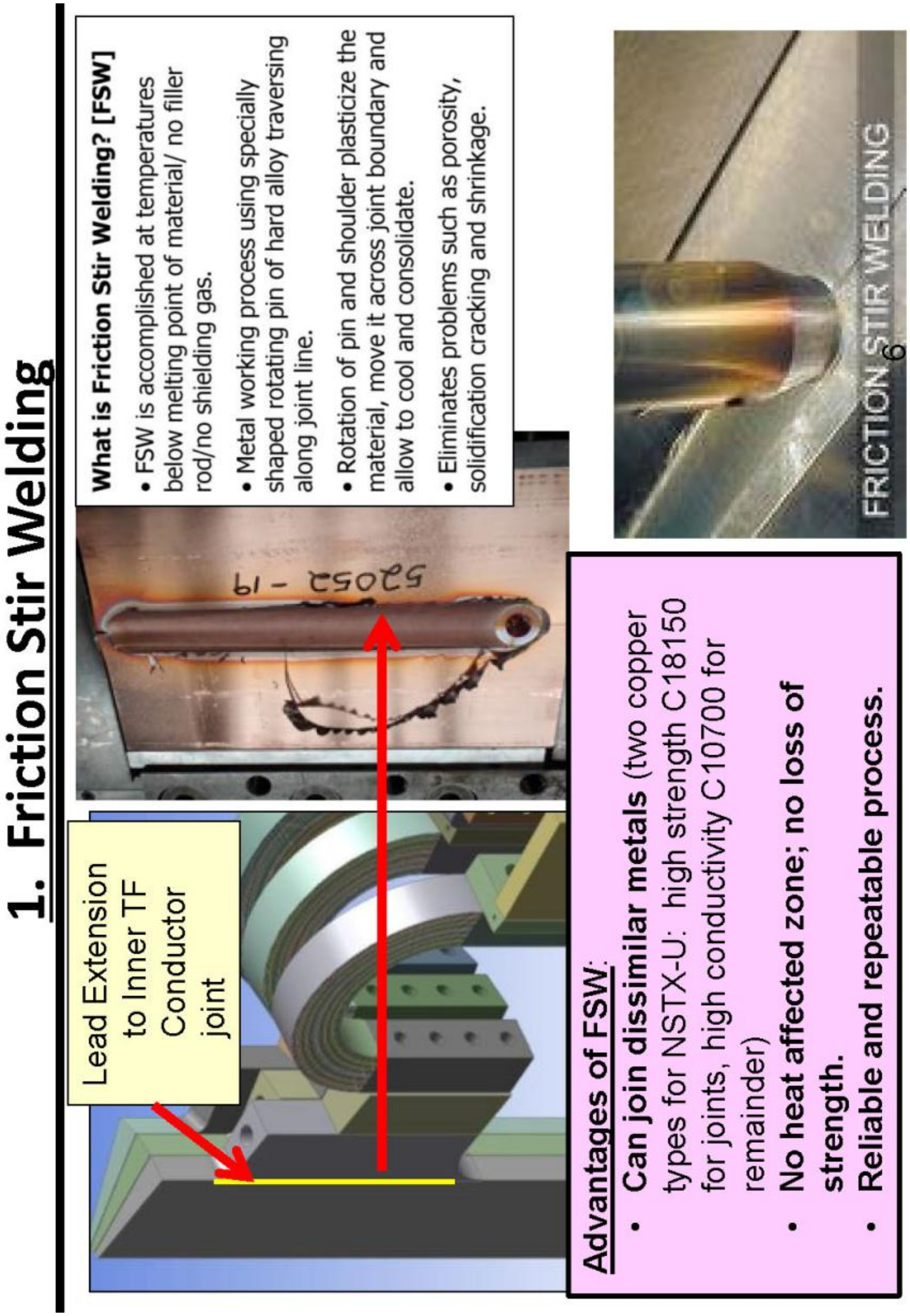
NSTX-U Fabrication & Assembly Techniques

Manufacturing techniques and processes were carefully chosen (or developed):

1. **Friction stir welding of copper** was used to join high strength to high conductivity copper grades in the TF center bundle conductors.
2. A new **non-ionic soldering process** was developed.
3. **Wire Electric Discharge Machining (EDM)** was used in the manufacture of the critical TF High-Current Connector.
4. A carefully planned **Vacuum Pressure Impregnation (VPI)** process with hard metal molds were used to assure the strength and electrical integrity of the center stack.
5. **Cyanate Ester / Epoxy Resin** was chosen because of its maintenance of strength at elevated temperature.
6. **Electron Beam Welding** was used to manufacture the TF Lead Extensions and Passive Plate expansion connectors.
7. A **water-soluble casting material** was used to maintain a thermal expansion gap between the center stack TF and OH winding. Difficulties in its implementation will be discussed.
8. **CAD solid models and mock-ups** assisted in design and assembly planning.

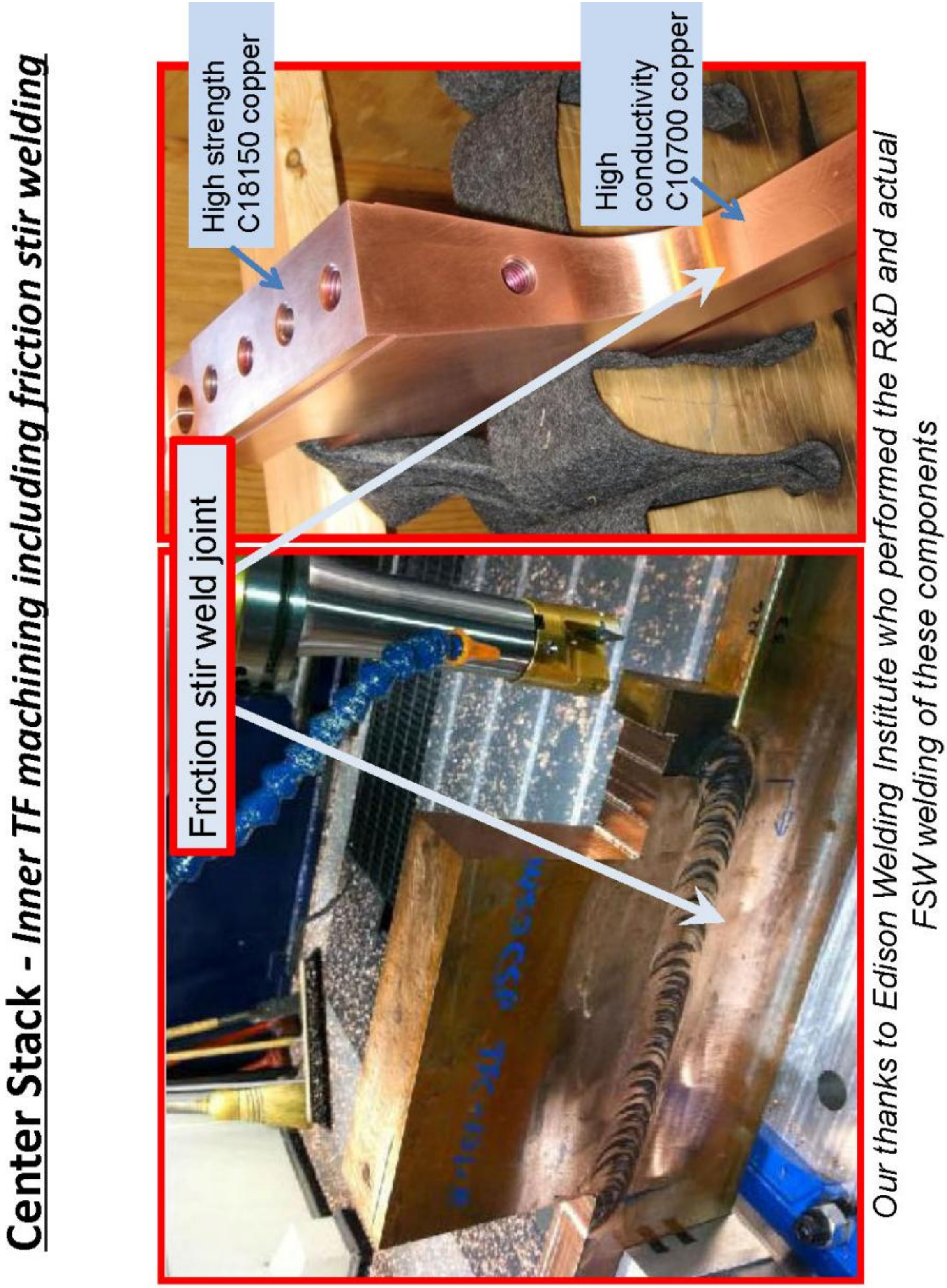
Appendix K

NSTXU Fabrication and Assembly Techniques (continued)



Appendix K

NSTXU Fabrication and Assembly Techniques (continued)

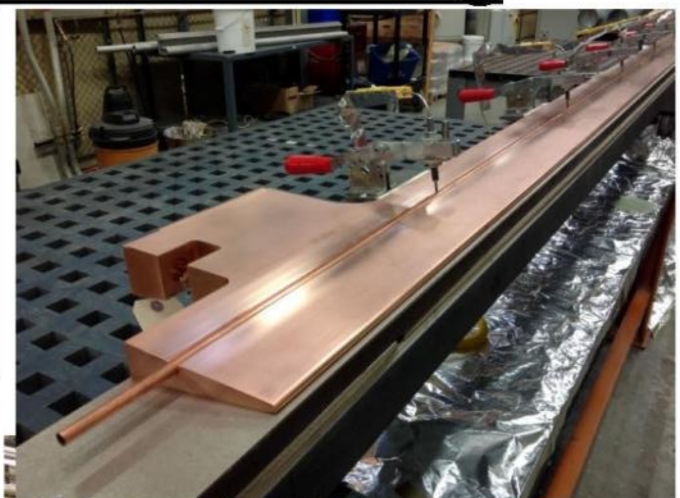


Appendix K

NSTXU Fabrication and Assembly Techniques (continued)

2. TF Cooling tube soldering

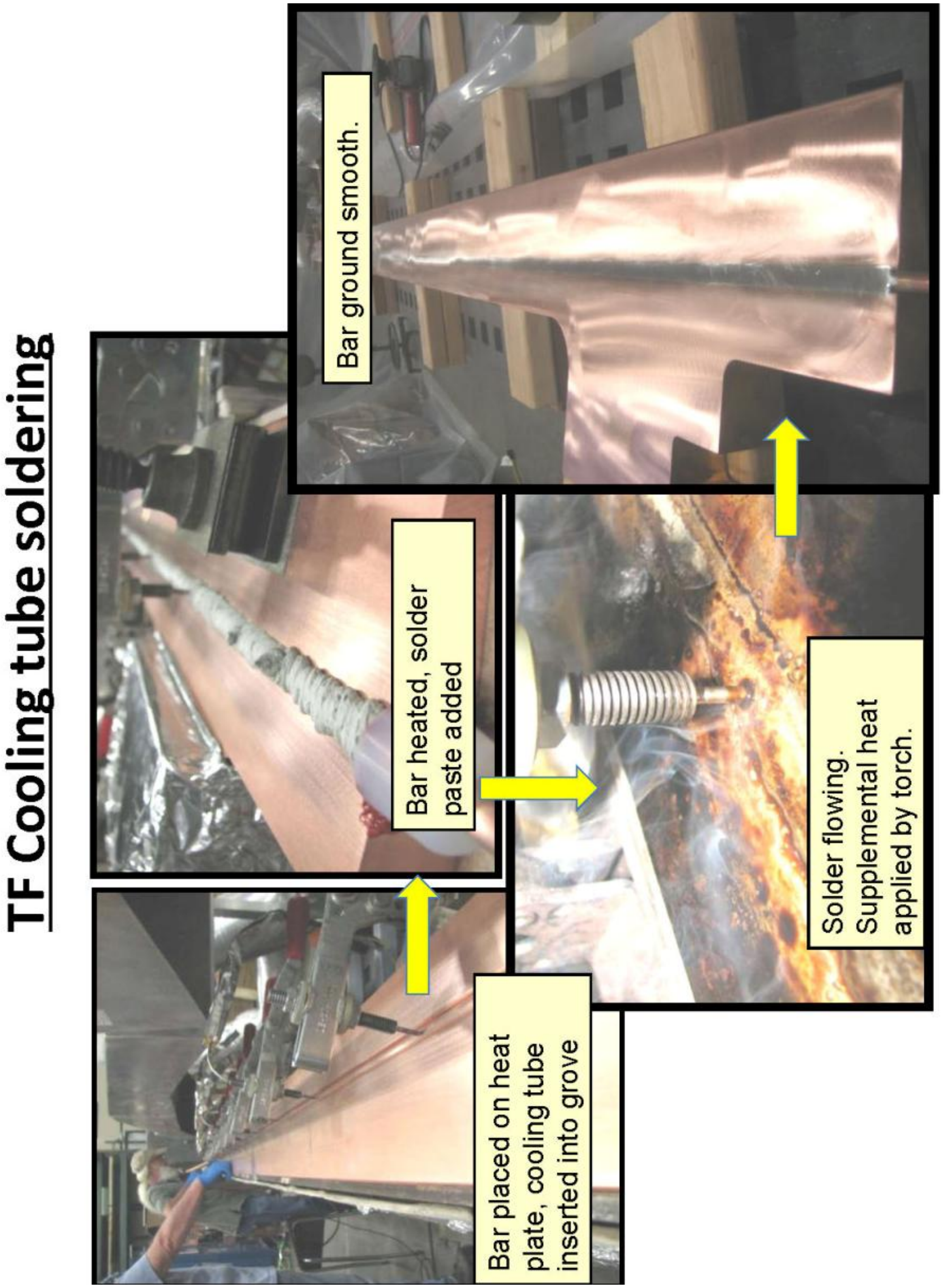
Engineering requirements;
- **Use of non ionic flux to eliminate possible carbon tracking between TF conductors.**
- **Application of uniform heating of solder paste.**
- **Complete "wetting" of tube to conductor**



- **Solder Trials:**
  - Trials have been performed with the assistance of Solder Consultant to verify materials and heating processes
  - Successful heat runs w/actual TF bar
- **Materials:**
  - Solder paste- 96.5 Sn /3.5 Ag w/ GMS based "R" flux [Glyceryl Mono-stearate, Terigitol (a detergent) and Cyclohexlamine Hydro-bromide] *(Thanks to Chemicals & Metals Technology Inc. !)*
- **Heating Method:**
  - Power supply w/heating plate
  - Torch heat to complete process

Appendix K

NSTXU Fabrication and Assembly Techniques (continued)

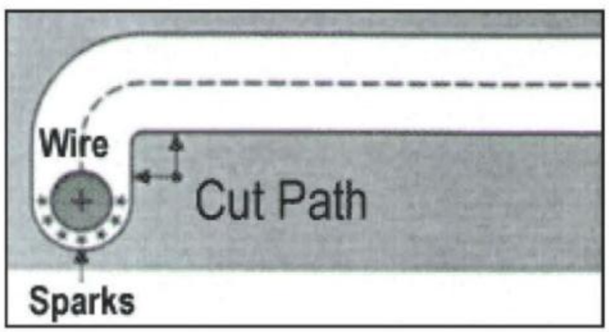


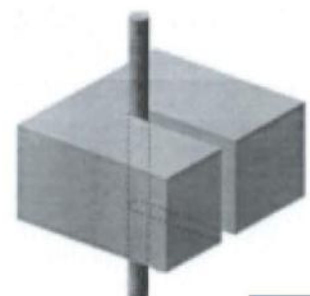
3. Wire EDM – What it is

From Wikipedia, the free encyclopedia

An electrical discharge machine

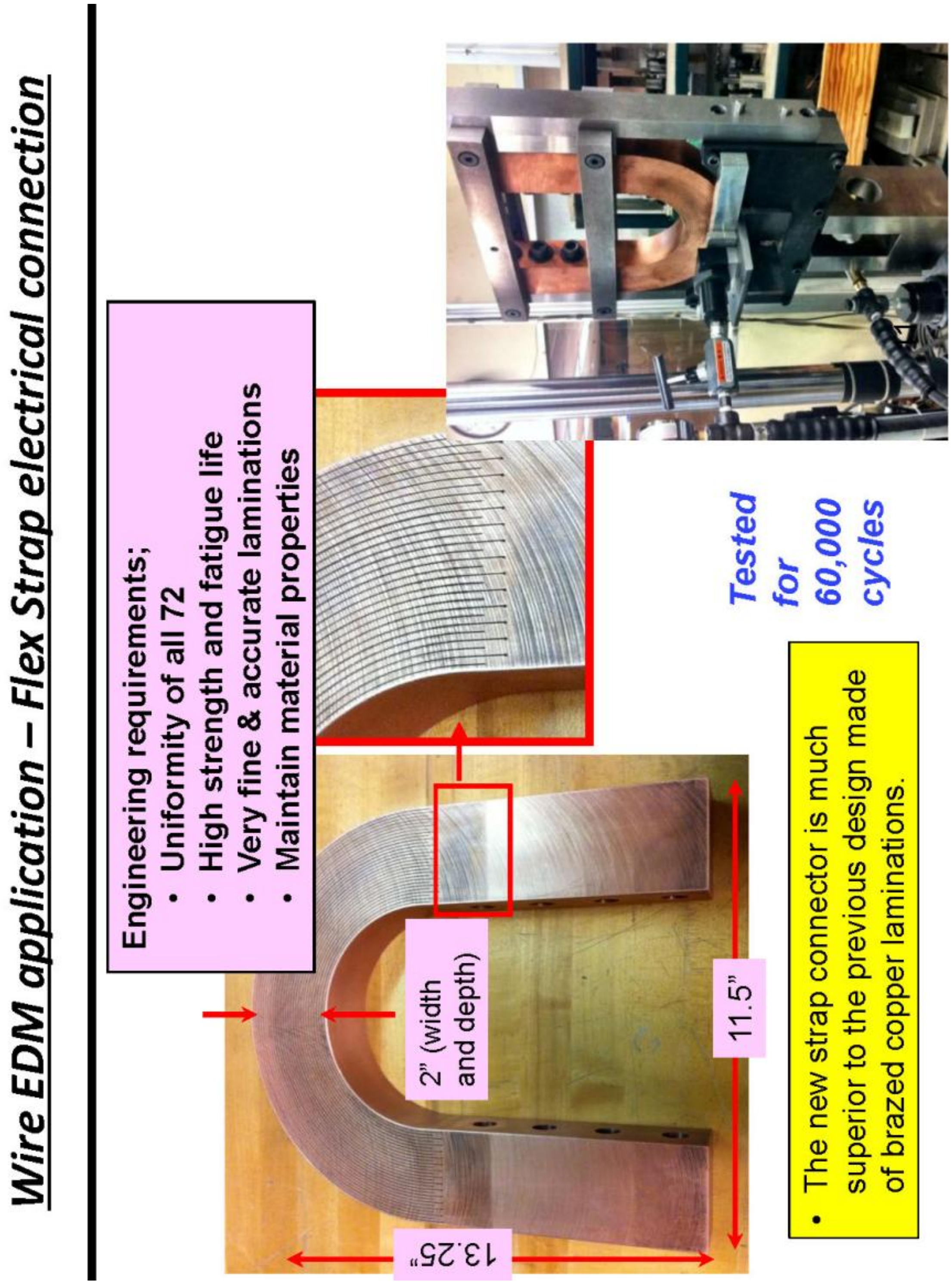
Electric discharge machining (EDM), sometimes colloquially also referred to as spark machining, spark eroding, burning, die sinking, wire burning or wire erosion, is a manufacturing process whereby a desired shape is obtained using electrical discharges (sparks).[1] Material is removed from the workpiece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. One of the electrodes is called the tool-electrode, or simply the 'tool' or 'electrode', while the other is called the workpiece-electrode, or 'workpiece'.





Appendix K

NSTXU Fabrication and Assembly Techniques (continued)



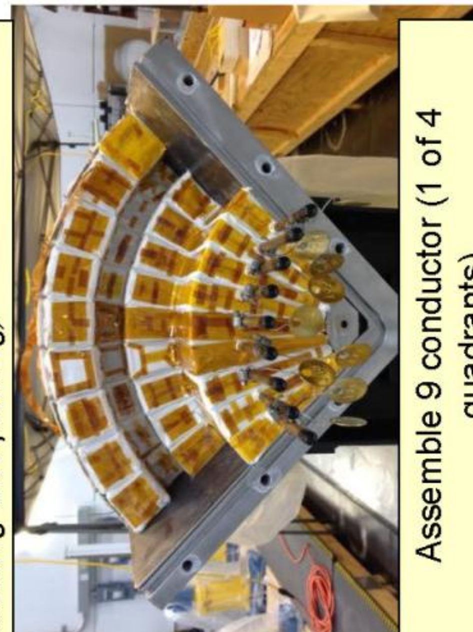
Appendix K

NSTXU Fabrication and Assembly Techniques (continued)

4. Fabrication of Inner TF Bundle – Preparing for VPI

Engineering requirements;
- Complete epoxy wetting of all surfaces (fiberglass, Kapton, conductor) was critical to meet design strength
- Maintenance of strength at 100 C peak coil temperature.
- The required mold ensured uniform final dimensions

Apply turn insulation (dry) by hand *(after gritblasting and priming)*



Assemble 9 conductor (1 of 4 quadrants)

Assemble individual conductors into Quadrant mold

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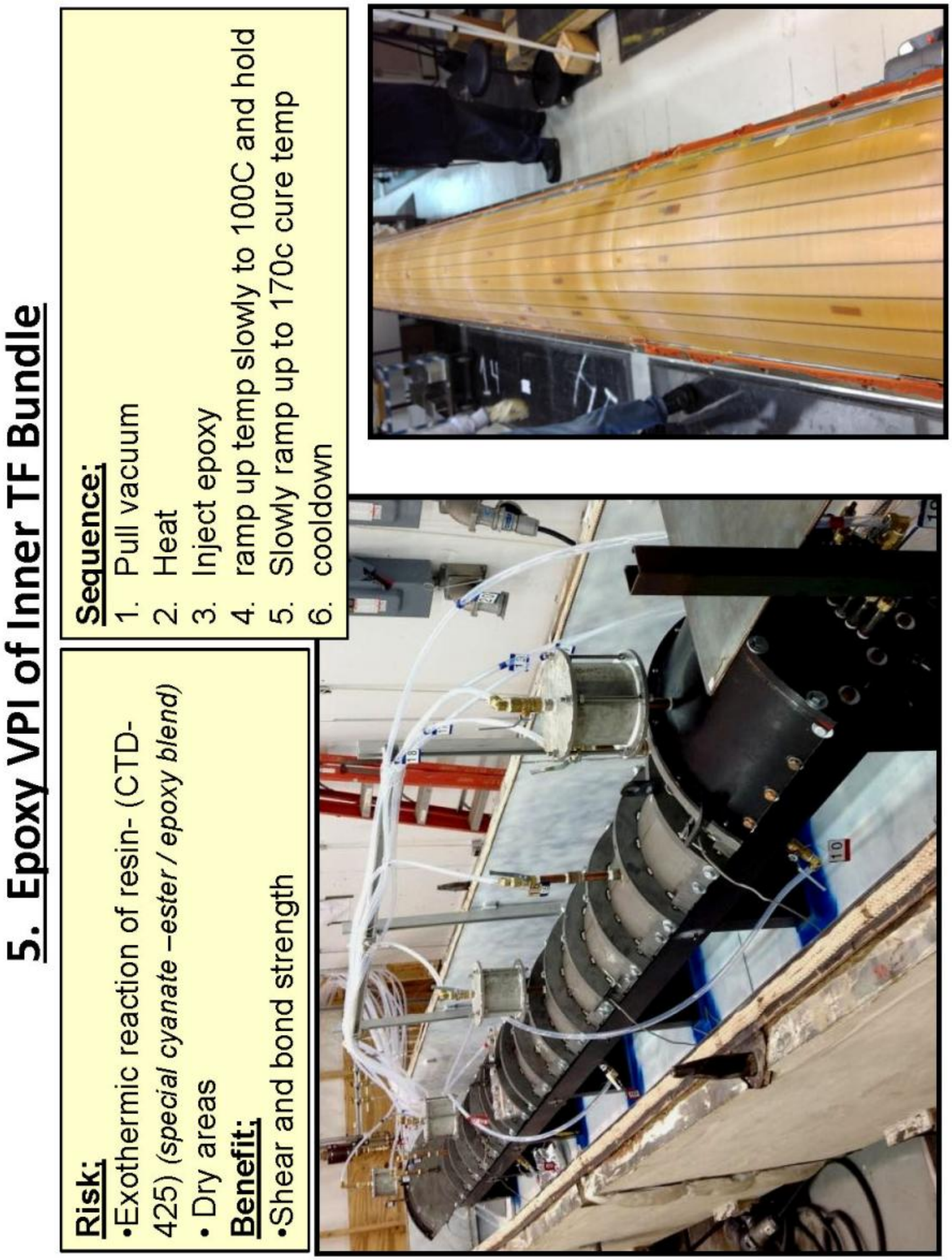
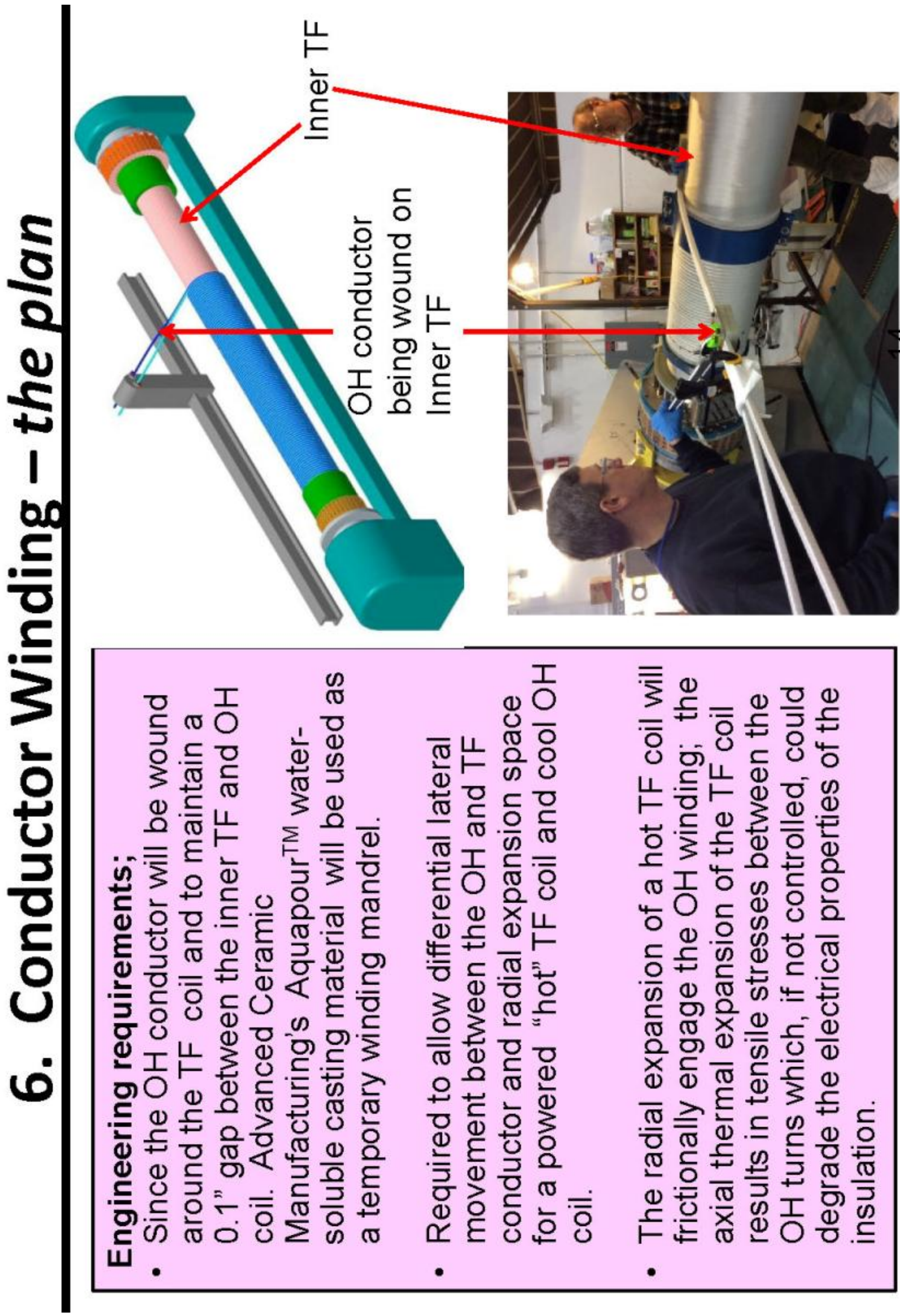
NSTXU Fabrication and Assembly Techniques (continued)



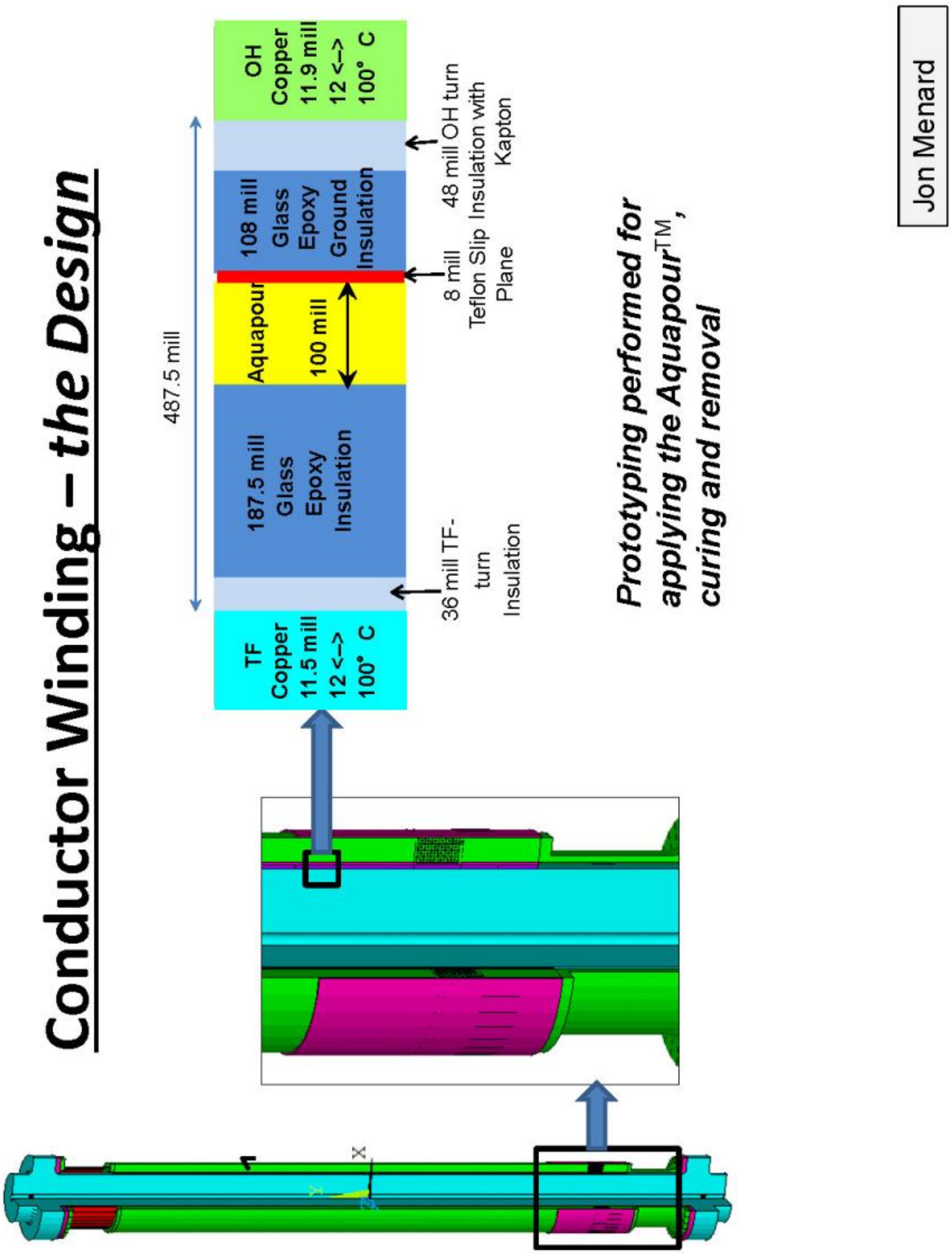
Appendix K

NSTXU Fabrication and Assembly Techniques (continued)



Appendix K

NSTXU Fabrication and Assembly Techniques (continued)



Appendix K

NSTXU Fabrication and Assembly Techniques (continued)

Conductor Winding – *the execution*

- ✓ Aquapour Mandrel formed
- ✓ OH Winding completed
- ✓ VPI process completed as planned
- ✓ Visual inspection of VPI = no dry spots
- ✓ Hydro and flow test cooling passages (200 psi operating pressure)
- ✓ Megger to = 13kv (operating voltage 6kv)
- ✓ Major risk retired !
- ✓ Sanding complete to remove excess resin
- Aqua pour removal – UNSUCCESSFUL
  - Sealing failed and epoxy resin infiltrated the Aquapour™
  - Could not flush out with water
  - Used mechanical chisels on ends in an attempt to break through end-plug to no avail
- ✓ Attempted heating/cooling the OH/TF respectively to open gap and demonstrate the OH moved independent of the TF
- ✓ Decision to live with the "Aquament"

Conductor Winding – *epilog*

1. Anticipated thermal radial expansion must now be accommodated by employing engineering and administrative controls during operations.
2. Performance parameters can still be met.
3. Lessons learned! The VPI process is very, very effective. Next time:
   - If possible re-think the design solution (i.e., Teflon spacers, etc.)
   - When the Aquapour solution is best, take extreme care in designing the seals between the Aquapour™ and resin.

7. E-Beam Welding

From Wikipedia, the free encyclopedia

Electron beam welding (EBW) is a fusion welding process in which a beam of high-velocity electrons is applied to two materials to be joined. The work pieces melt and flow together as the kinetic energy of the electrons is transformed into heat upon impact. EBW is often performed under vacuum conditions to prevent dissipation of the electron beam. It was developed by the German physicist Karl-Heinz Steigerwald, who was at the time working on various electron beam applications. Steigerwald conceived and developed the first practical electron beam welding machine, which began operation in 1958.[1] American inventor James T. Russell has also been credited with designing and building the first electron-beam welder.[2][3][4]

Engineering requirements;

- Deep penetration of weld
- Low weld distortion
- Narrow application of heat thus the hardness of joined pieces not adversely effected by heat

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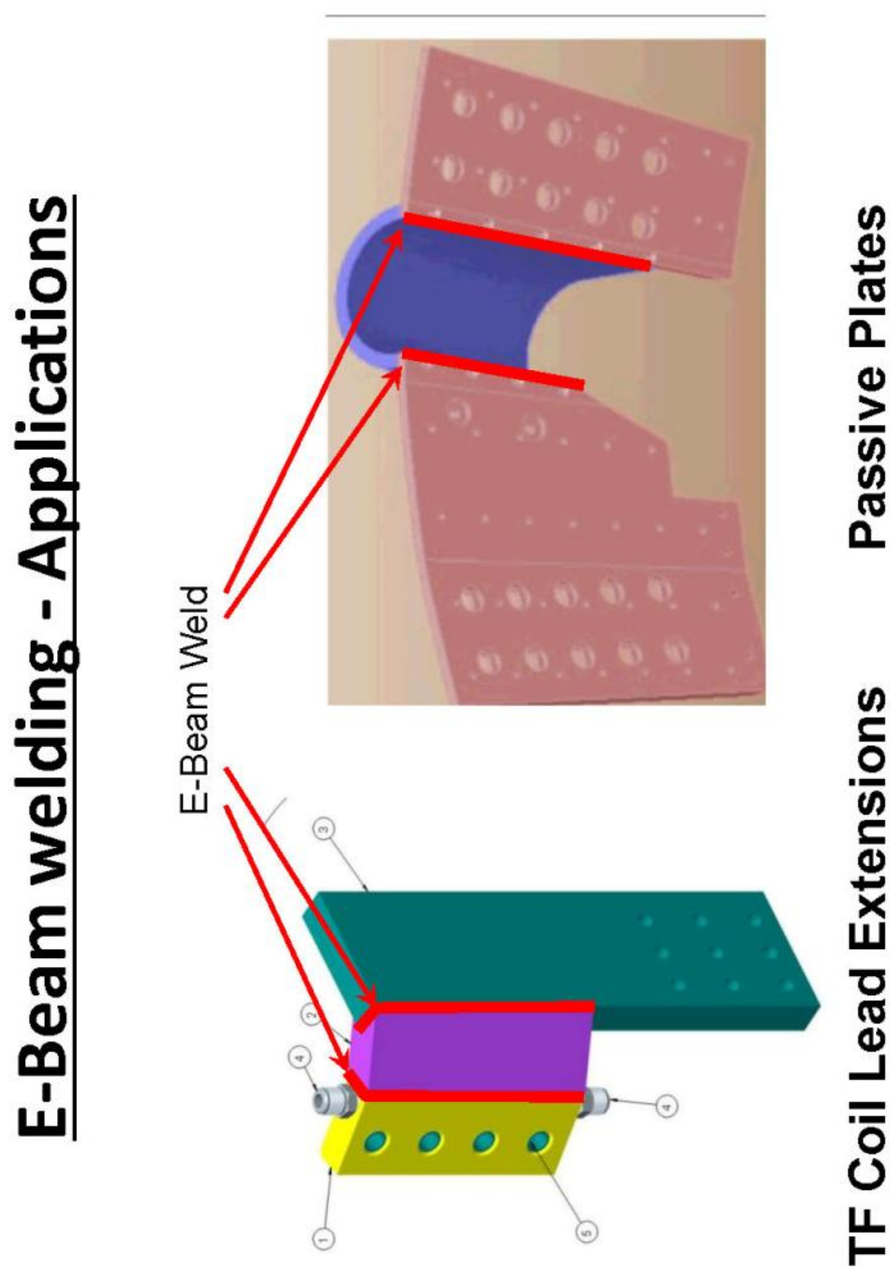
NSTXU Fabrication and Assembly Techniques (continued)



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NSTXU Fabrication and Assembly Techniques (continued)

8. Use of CAD Solid Models & Mockup Prototypes

Engineering considerations

- CAD solid models are extremely helpful in developing designs and planning assembly, but mock-up prototypes provide an even higher level of realism for critical engineering details.

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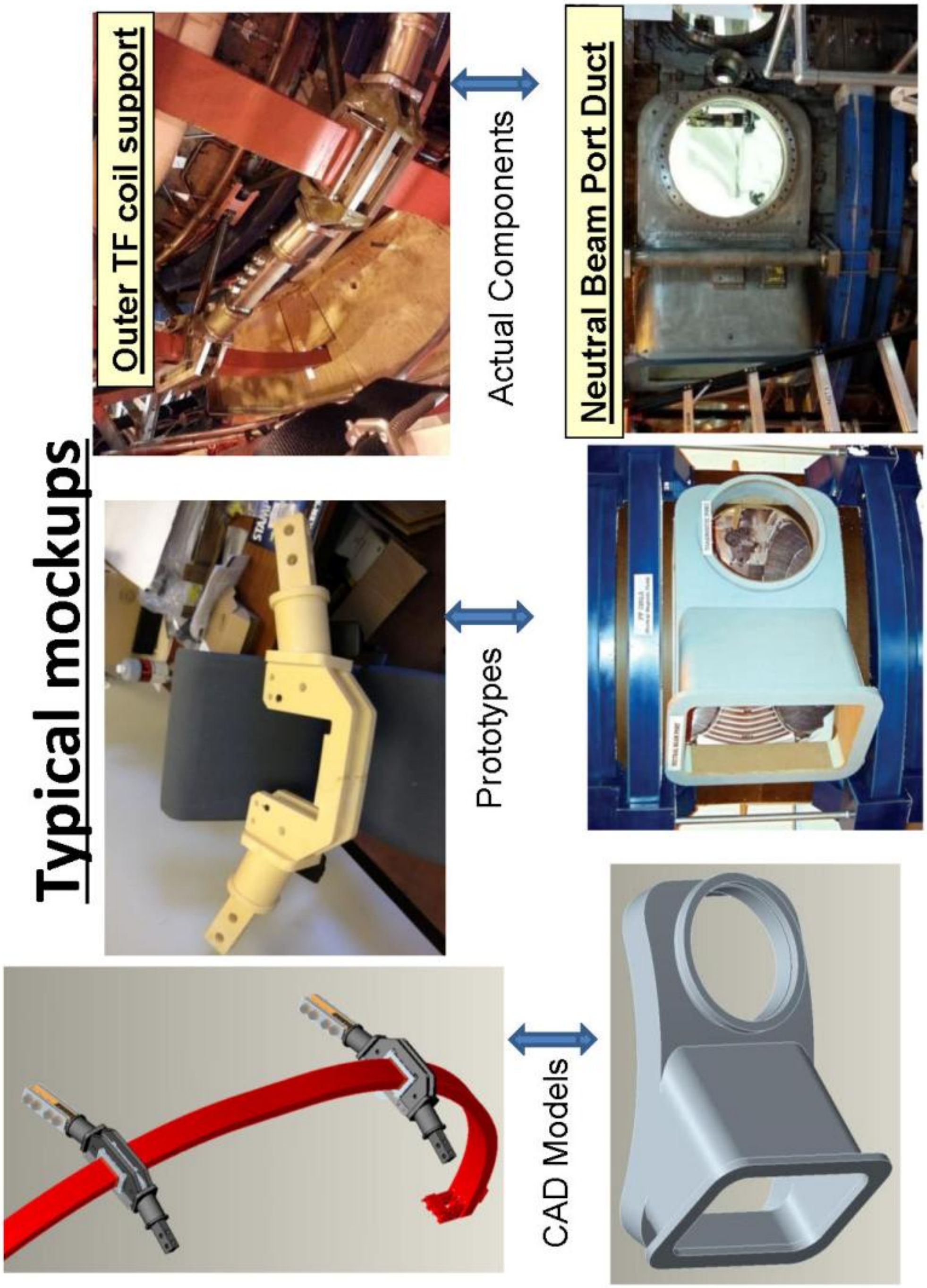
NSTXU Fabrication and Assembly Techniques (continued)



Summary

Turning an complex and difficult engineering vision (design) into reality required;

- An understanding of available industry manufacturing processes and techniques
- Value engineering - collaborative peer reviews and dialogue to benefit from the experiences from others
- Clever and pragmatic applications of those techniques and processes into a design that is constructible
- Talented physicists, engineers, designers, and technicians working together as a team