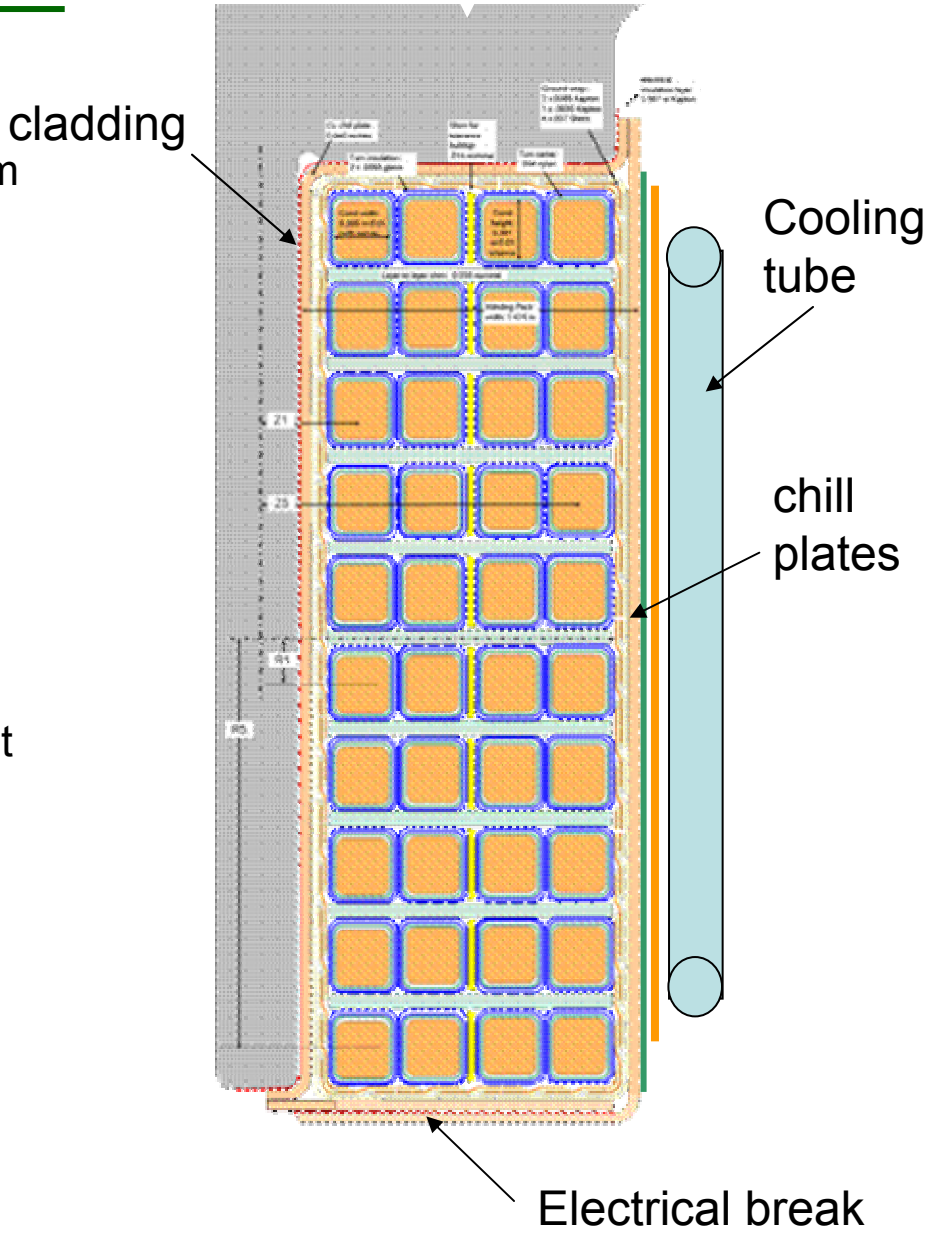
Baseline cooling concept

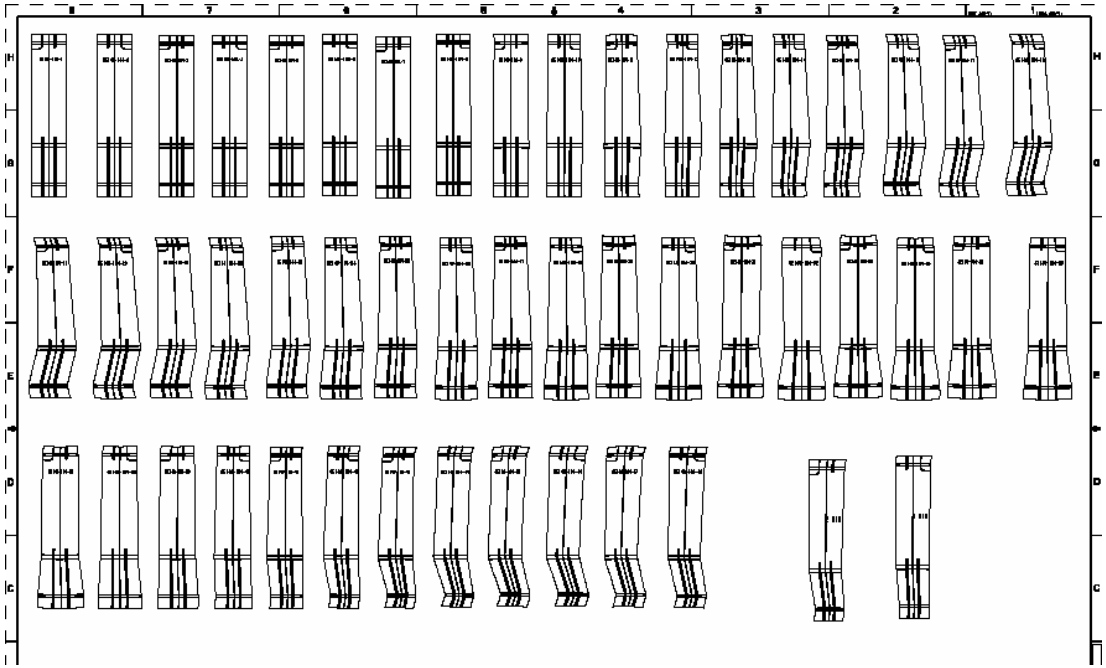
- **Requirements / constraints:**
  - 15 minute cooldown
  - copper is electrically isolated from tee
  - No electrical continuity (loops) in copper parts in any direction
  - No copper parts larger than 2 inches
  - No electrical continuity through cooling tubing
  - Fits in .08 inches laterally (not tube)

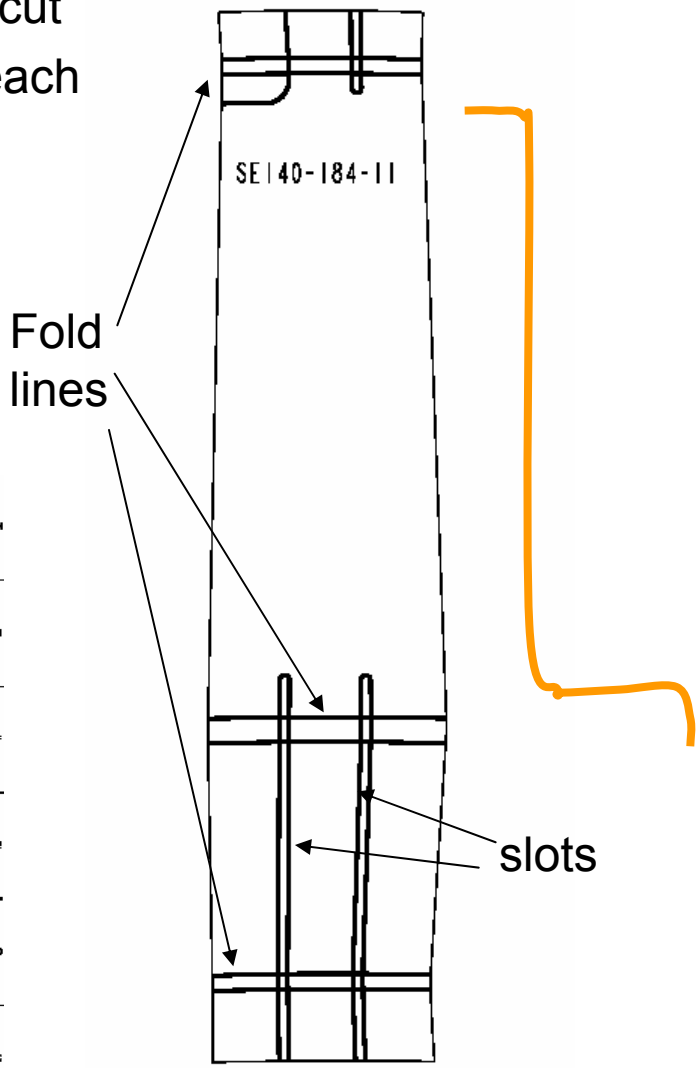
- **Design**
  - Copper cladding, formed from flat developments, next to tee
  - Copper chill plates on outside of winding pack connected to cladding
  - Chill plates have electrical break
  - Tubing brazed to copper strips
  - Strips attached to chill plates



Baseline cooling concept , cladding fabrication

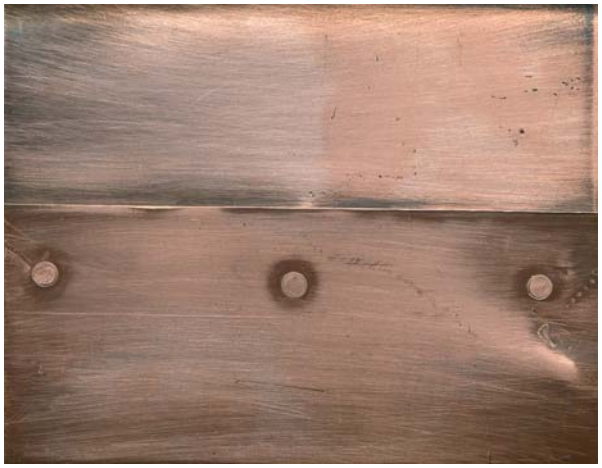
- Parts designed as flat developments, water jet cut
- Fold lines and part numbers also etched onto each part via water jet
- Parts bent at 90 deg on fold lines
- Parts annealed
- Parts “worked” into place on tee
- Parts insulated with Kapton on back side

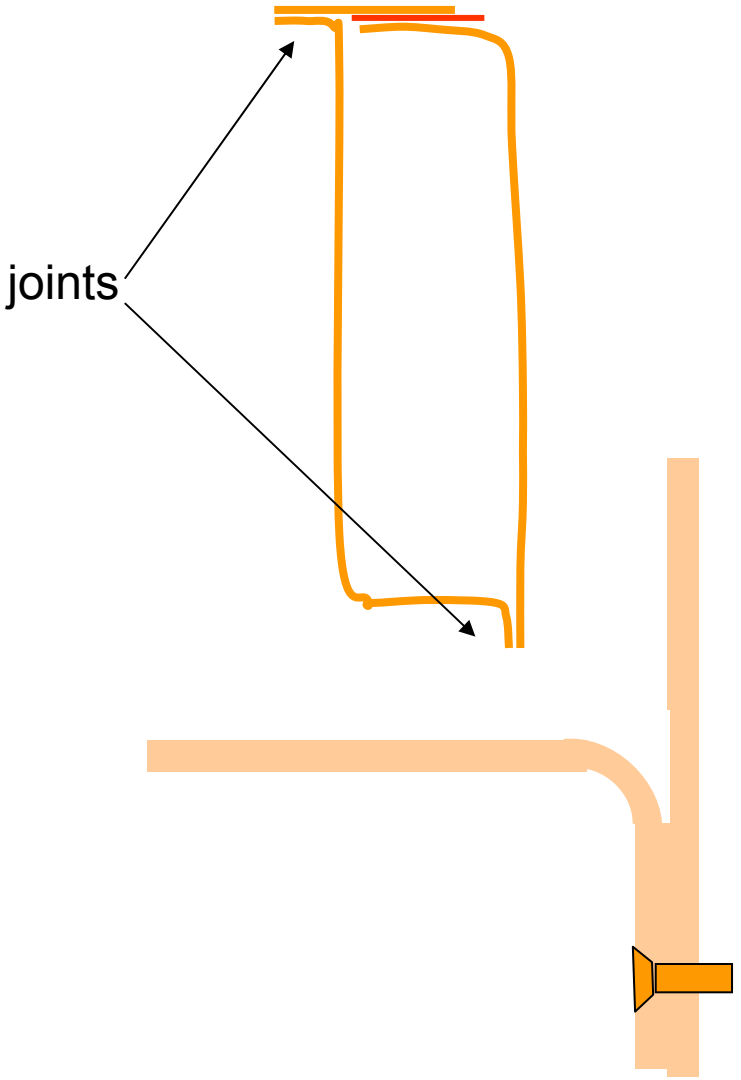




Baseline cooling concept , cladding to chill plate joint

- Several options for connecting cladding to chill plates
  - Brazing
  - Tig welding
  - Riveting
- Riveting looks pretty good



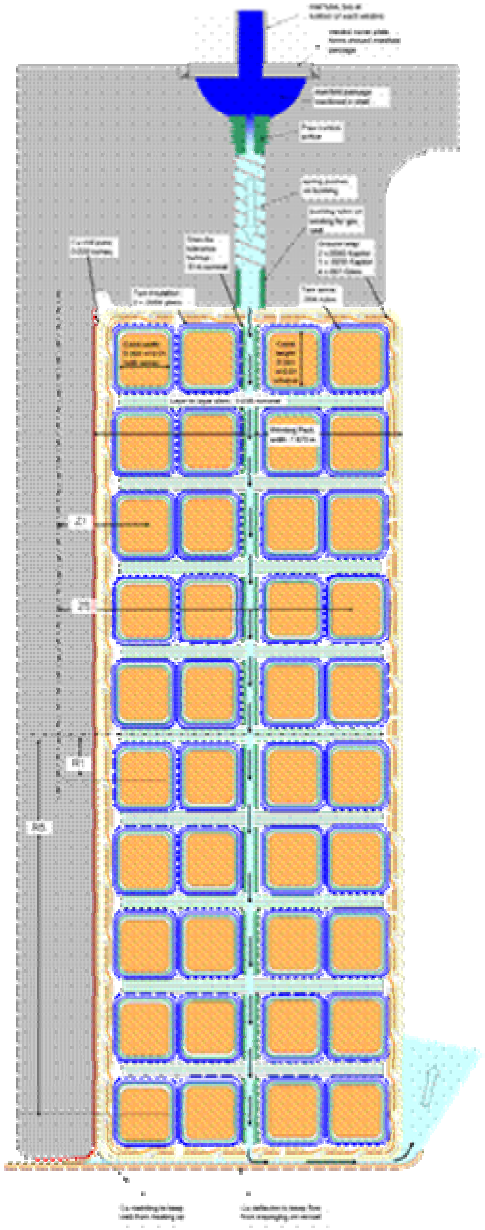


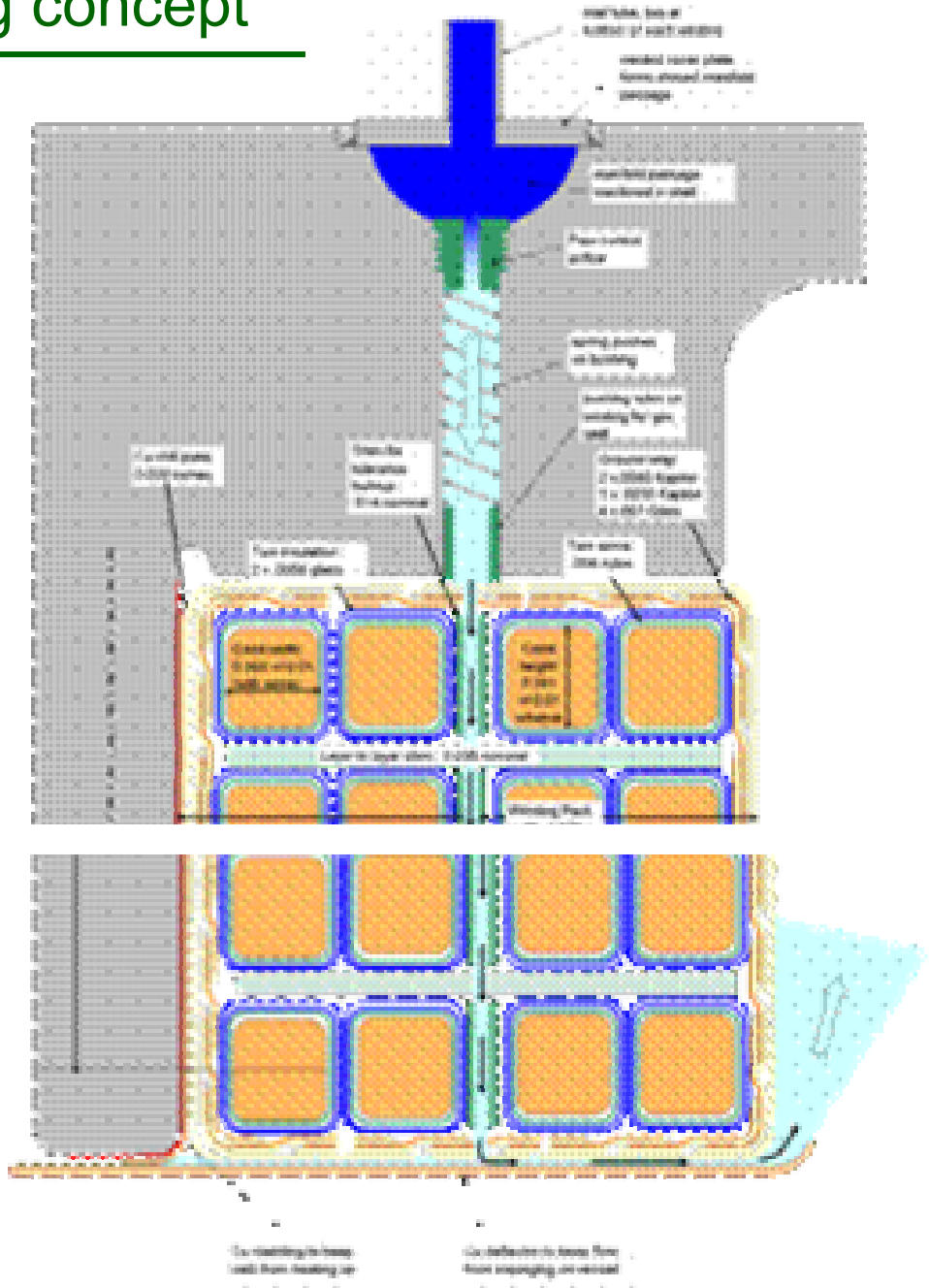
Baseline cooling concept issues

- Difficult to make cladding
- Difficult to make chill plates
- Difficult to connect cladding to chill plates
- Difficult to connect tubing to chill plates
- Difficult to maintain electrical isolation to tee and avoid electrical around winding pack

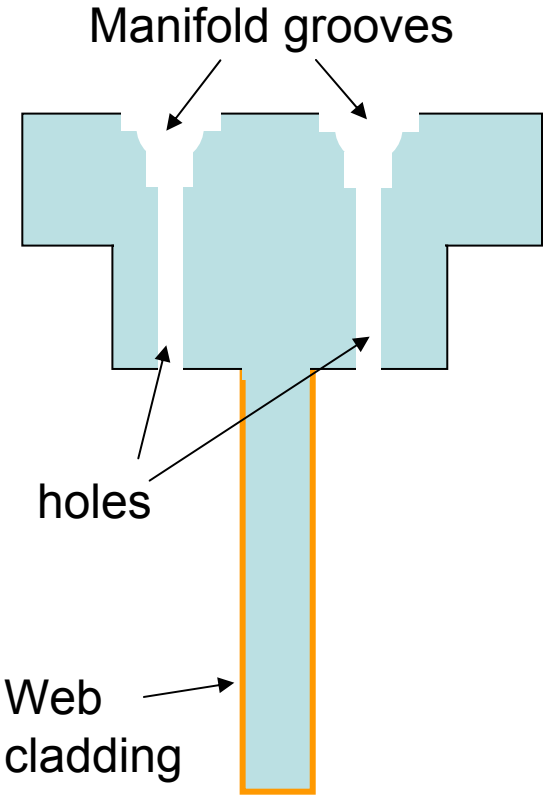
- The above is expected to take three weeks longer per coil and cost a significant amount of money (>$500k above estimate?)

Alternate mod coil cooling concept

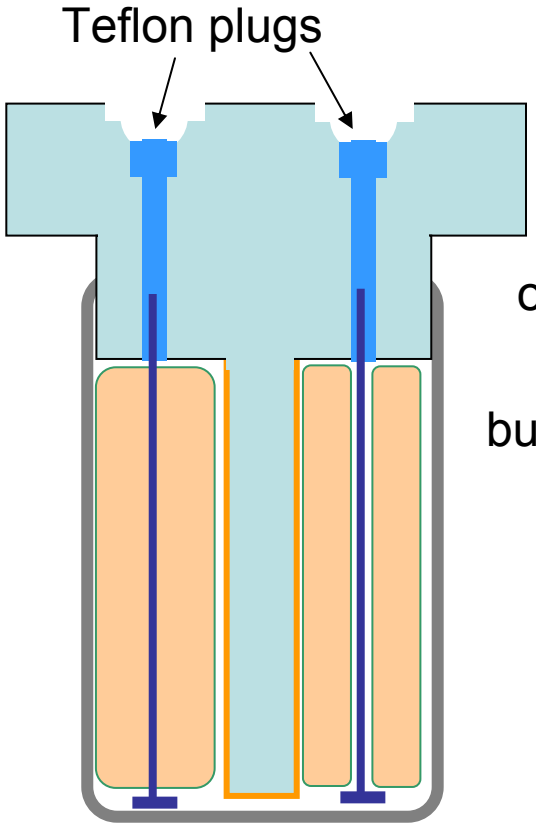




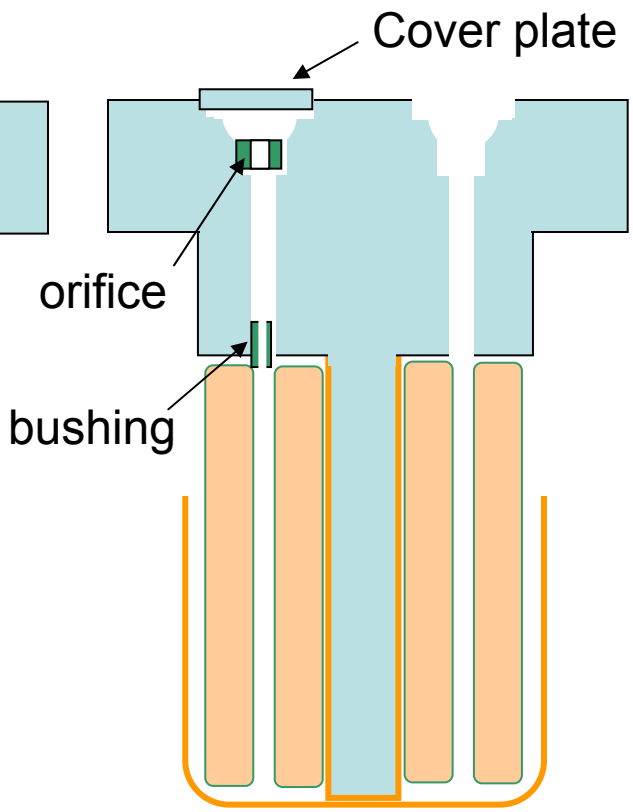
Cooling passage fabrication sequence



Machine casting, install web cladding



Plug, put in passage forming strips (.06 x .5 in) and VPI



Remove plugs and passage formers, install orifices, bushings, deflectors and weld cover plates

Potential advantages over baseline

operation		
windings will cool off faster		don't know yet
shell has more direct cooling		from manifold groove and inlet holes
fabrication		
no formed parts, only web side cladding, much easier than baseline to install		
web cladding does not have to track with coil, can be glued to web		
no tubing connections across electrical isolation		

Arithmetic for passages, flow rate, etc.

flat passages per inlet	1		
depth of passage	0.5		
width of passage	0.06		
length of passage	4.661		
cooled area	466.1	in^2	
uncooled area	2144.06		
cross sect. per passage	0.03	in^2	
total cross section / coil	3	in^2	
inlet pressure	100	psi	
exit pressure	15	psi	
inlet and exit temp	77	K	
heat of vaporization	200	J/g	
heat input per pulse	1.03E+06	J/winding pack	max, coil 2, per tech. data
LN2 boil-off per pulse	5.13E+03	g/winding pack	
	6.87E+00	l/winding pack /pulse	
cooldown time	15	min	
assumed inlet flow	0.015261	l/s	
	0.238455	gpm	
assumed exit (gas) flow	2562.5	cm^3/sec	
velocity in passages	1.32E+00	m/s	

Potential issues

operation		
tracking path turn-to-turn		~ 0.4 inches / elec. turn
ground wrap punctured at top and bottom of winding pack		
not enough area to cool down		
as soon as epoxy gets cold, LN2 will not vaporize		
pressure forces windings apart (100 psi * 233 in^2 = 10 tons of separating force)		passage area / uncooled area = 233/1070 =0 .2, stress in epoxy/glass ~ 20 psi
hard to balance flow among passages		use smaller orifice at top of passage
passages get clogged up		use larger orifice at top of passage
when winding pack squirms around on tee, the inlet holes do not match up well with the passages		use spring-loaded G10 bushing, held in by orifice?
fabrication		
additional machining may be expensive (100 - 200 more holes per winding form, 600 inches of groove to machine and weld closed		
cannot get passage-former out of potted winding pack		
weld seams distort coil		

Where do we go from here?

Note: FDR documentation due Friday