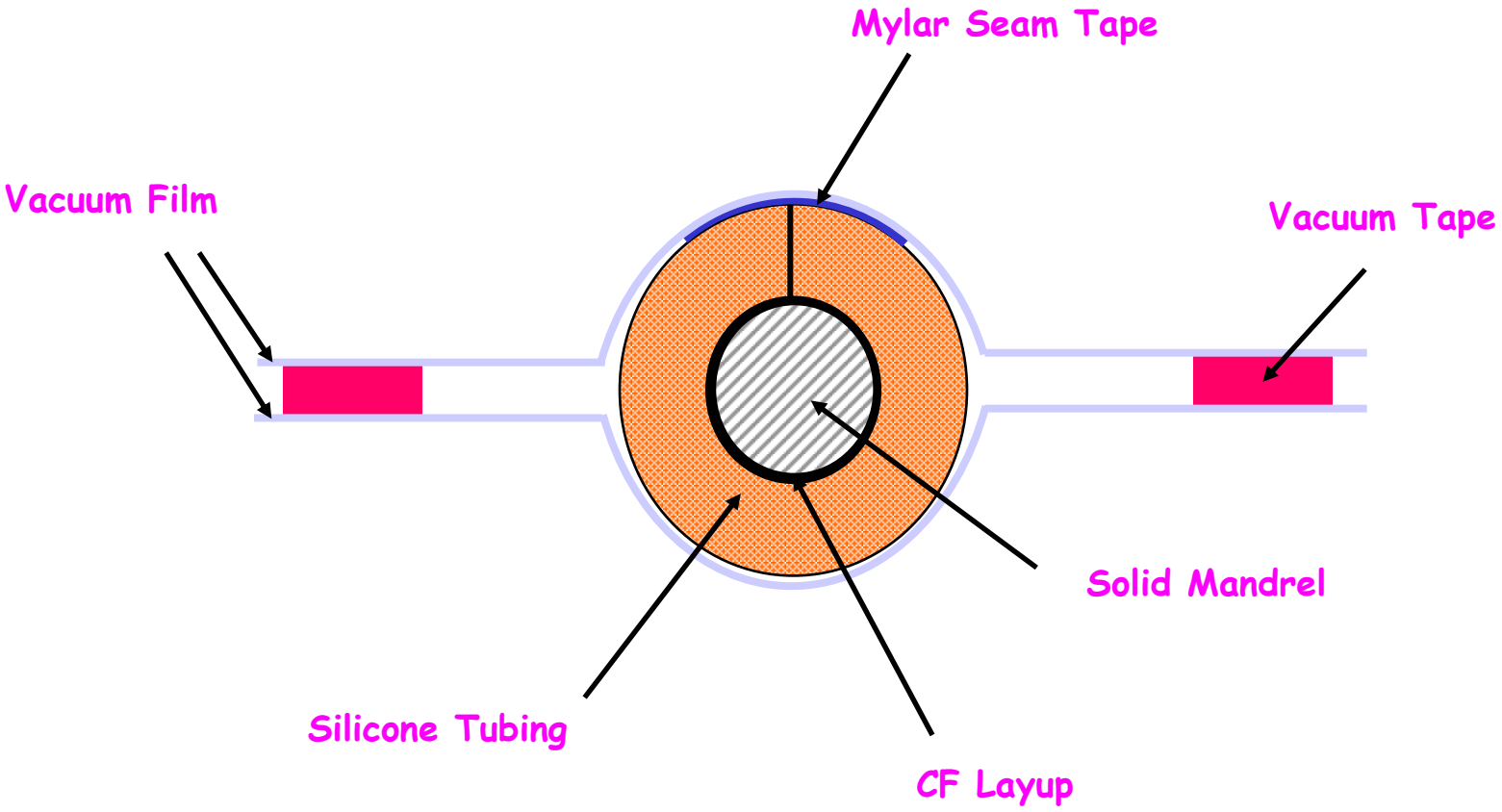
Carbon Fiber Cooling Tube Fabrication

- Technique developed by Bill Kuykendall
- Carbon fiber is wrapped around a solid steel mandrel which is held in tension during cure.
- Silicone tubing is used as an outer mold.
- Parts are cured using vacuum bag/autoclave technique.
- No bleeder cloth used, maximum resin retention.
- After curing, the tube and mandrel are heated to facilitate tube removal (CTE differentials).

Cooling Tube Layup



Lay-up Parameters

- Material: K139/Epoxy
  - Old K139/Epoxy (Hexcel) used for prototypes.
  - New K139/Cyanate Ester material to be ordered from YLA.
- 4 Ply stacking sequence $[20°/-20°]_s$
- Cured at 275°F for 2 hours, 5°/min ramp rate.
  - Vacuum applied until temperature reaches 120°F, then apply 30 psig and shut off vacuum.
  - Increase to 50 psig at 160°F.
  - Increase to 80 psig at 200°F and hold through cure and cool-down.

Leak Testing

- After initial bubble testing in water, tube is pressurized with helium to 15 psig.
- Tube surface is sniffed for leaks using Alcatel Helium Leak Detector.
  - 4 passes made along the Z axis at 90°rotations.
  - Tube is under pressure for 15-20 minutes.

Helium Leak Test Results

Tube	Leak Rate [Atm-cc/Sec]	Comments
1	$<1\times10^{-9}$	
2	6×10^{-8}	1 Localized leak. Remainder of tube $<1\times10^{-9}$
3	$<1\times10^{-9}$	
4	$<1\times10^{-9}$	

Closer Inspection of Tube #2

- Leak was detected only when the sniffer probe was within the circled region shown at right.
- Presence of the seam-line from the silicone tubing suggests effort should be taken to minimize it.

Magnification 50x

Discussion

- Once the described fabrication procedure was established, all 4 prototype tubes made have been of good quality. Fresh material should improve overall quality.
- Further efforts underway to improve straightness (better control of mandrel tension during cure).
- The prototype tubes made thus far are sized for the L0 hybrid cooling system (3.0mm ID). The L0 sensor cooling system will also use round tubes of 3.175 mm diameter. Mandrels are made from off-the-shelf precision ground rod.
- A precision ground rectangular mandrel for the L1 cooling system has been ordered.