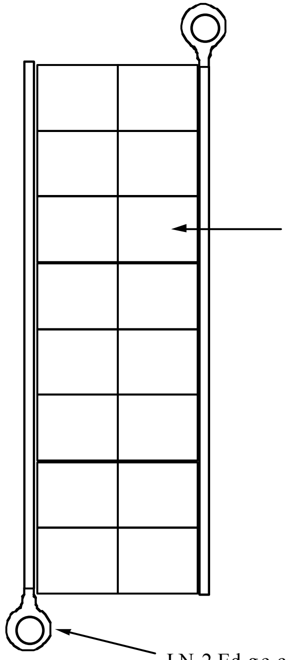
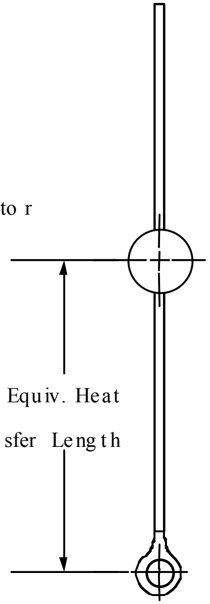
NCSX MODULAR COIL COOLING

NCSX ENGINEERING MEETING
3 APRIL 2002
FRED DAHLGREN

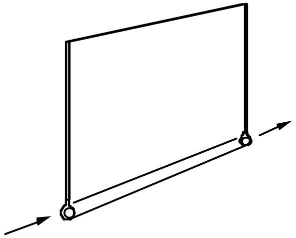
NCSX LN2 Coil Cooling Analysis:

- Transient finite-difference code FCOOL 2.2.
- Use a “lumped Mass” to represent Mod. coil conductor.
- Use an equivalent heat transfer septum length for Mod.Coils.
- Use a 1/4” O.D. tube, 0.04” wall thickness for Mod. Coils.
- Use a 0.040” thick septum for Modular Coils..
- Use 77 deg.K LN2 inlet temp.
- Use 2 -4 psi pressure drop.
- Use NIST webbook parameters for LN2 coolant @250psia.
- Varied ∂P & HTL

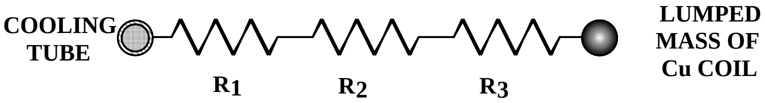




PARAMETERS:
PRESSURE DROP: 10.00 PSI
VELOCITY: 13.39 FT./SEC.
FLOW RATE: 0.94 GPM
MDOT: 0.11 LBS/SEC
PATH LENGTH: 21.50 FT.
REYNOLDS NO.: 83246.51
h- film: 1.55 btu/ft -sec.-deg. F
CUR. DENSITY: 85034.02 amp/sq.in
TIME INCR.: 0.03211 SEC
ESW: 1.20 SEC.
REP. RATE: 900.00 SEC.
INLET TEMP.: 138.00 deg. R
CMASS: 3.75 LBS
HTL: 0.42000 FT.
NODE INTERVAL: 0.43000 FT.



Thermal Analog - thermal resistance



$$\left.\begin{aligned} R1 &= \frac{L_{\text{HEAT-SINK}}}{K_{\text{HEAT-SINK}} \bullet A_{\text{HEAT-SINK}}} \\ R2 &= \frac{L_{\text{INSULATION}}}{K_{\text{INSULATION}} \bullet A_{\text{INSULATION}}} \\ R3 &= \frac{L_{\text{Cu COND.}}}{K_{\text{Cu COND.}} \bullet A_{\text{Cu COND.}}} \end{aligned}\right\}$$

$$\frac{HTL}{K_{Cu} \cdot A_{\text{COND.}}} = \sum R_i$$

$$A_{\text{COND.}} = A_{\text{Cu COND.}} \bullet DL \div HTL$$

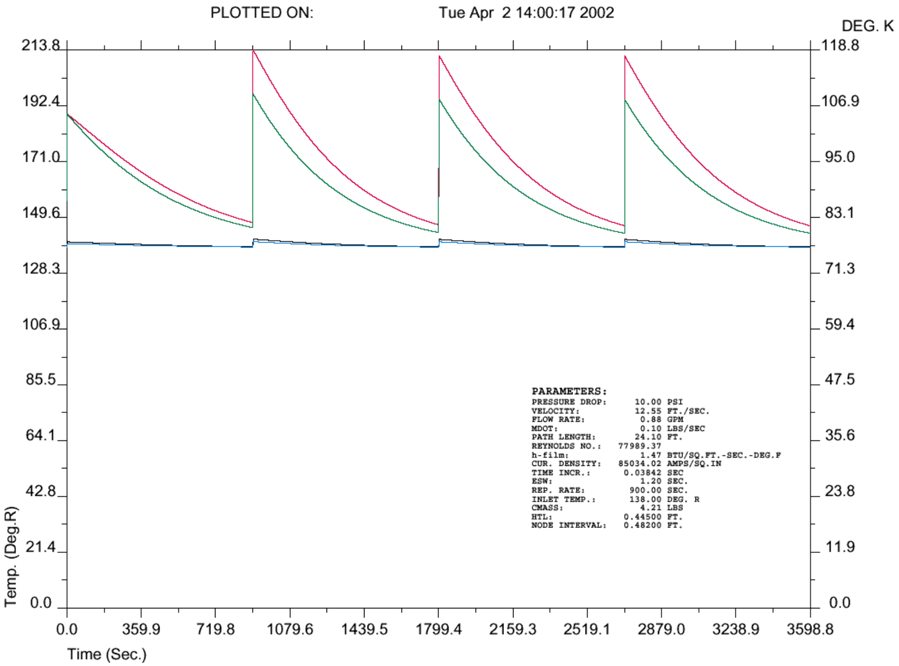
$$HTL = \left(K_{Cu} \cdot A_{\text{Cu COND.}} \bullet DL \sum \mathbf{R_i} \right)$$

$$\sum R_i = 0.224 + 0.152 + 0.000257$$

$$= 0.376$$

$$HTL = (558 \bullet 0.00196 \bullet 0.486 \bullet 0.376)^{1/2}$$

$= 0.445$ ft. (for 0.080" thk septum = 0.345ft.)



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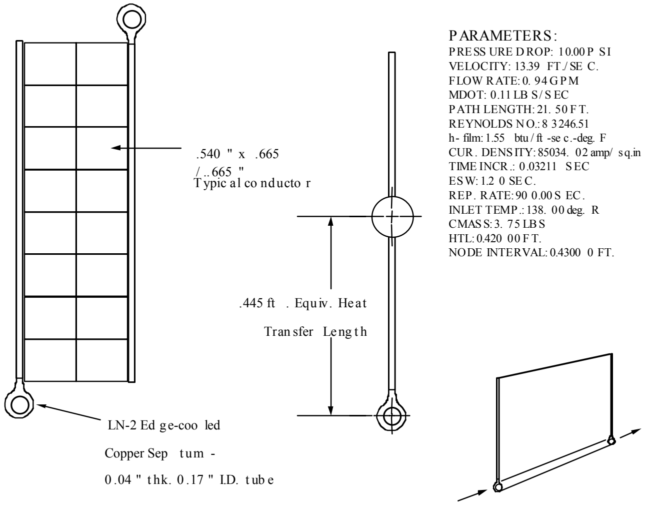
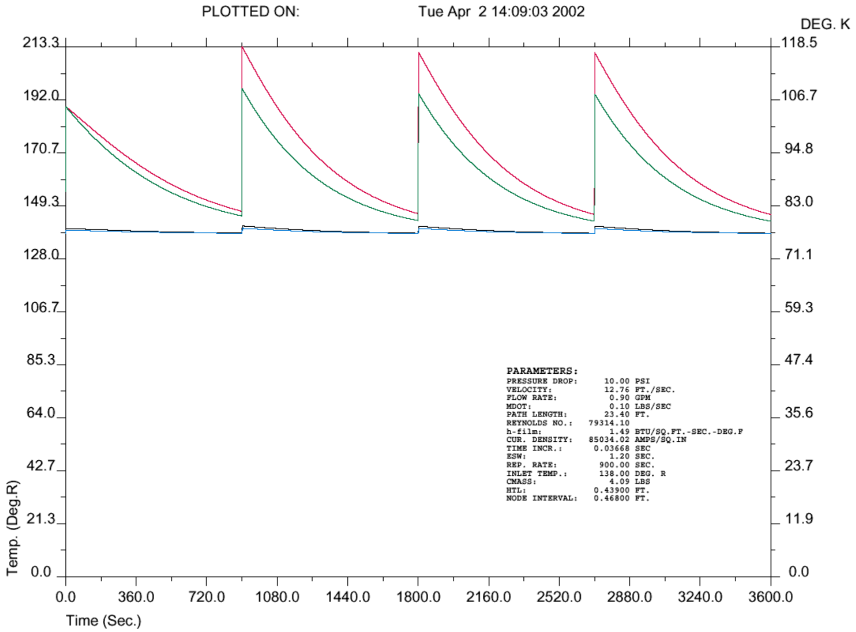
PARAMETERS:
PRESSURE DROP:       10.00 PSI
VELOCITY:            12.55 FT./SEC.
FLOW RATE:            0.88 GPM
MDOT:                 0.10 LBS/SEC
PATH LENGTH:         24.10 FT.
REYNOLDS NO.:     77989.37
h-film:               1.47 BTU/SQ.FT.-SEC.-DEG.F
CUR. DENSITY:     85034.02 AMPS/SQ.IN
TIME INCR.:        0.03842 SEC
ESW:                  1.20 SEC.
REP. RATE:          900.00 SEC.
INLET TEMP.:        138.00 DEG. R
CMASS:                4.21 LBS
HTL:               0.44500 FT.
NODE INTERVAL:     0.48200 FT.
```

NCSX - M1-COIL 1/4dia. Cooled Both Sides -04/02/02

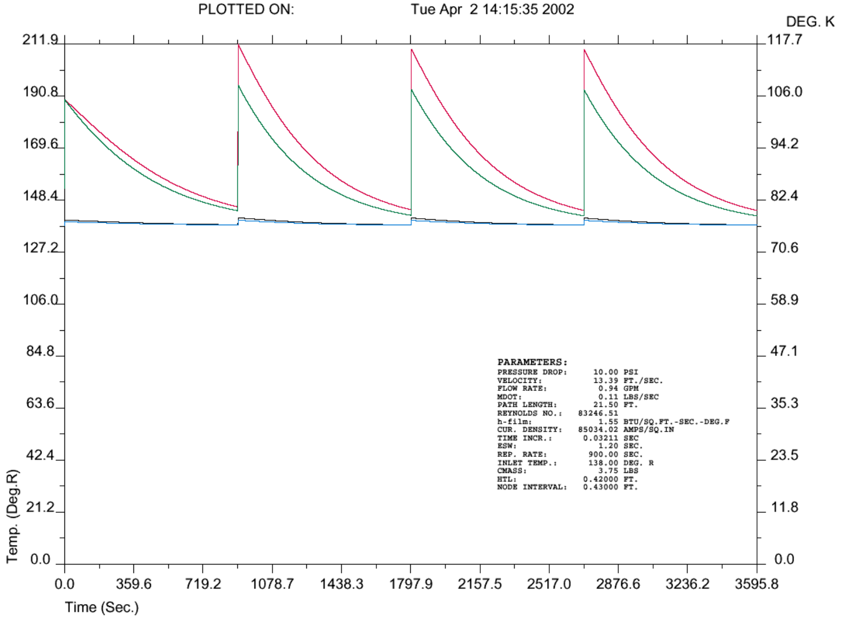


PARAMETERS:
PRESSURE DROP: 10.00 PSI
VELOCITY: 13.39 FT./SEC.
FLOW RATE: 0.94 GPM
MDOT: 0.11 LBS/SEC
PATH LENGTH: 21.50 FT.
REYNOLDS NO.: 83246.51
h-film: 1.55 btu/ft-sec.-deg. F
CUR. DENSITY: 85034.02 amp/sq.in
TIME INCR.: 0.03211 SEC
ESW: 1.20 SEC.
REP. RATE: 900.00 SEC.
INLET TEMP.: 138.00 deg. R
CMASS: 3.75 LBS
HTL: 0.42000 FT.
NODE INTERVAL: 0.43000 FT.



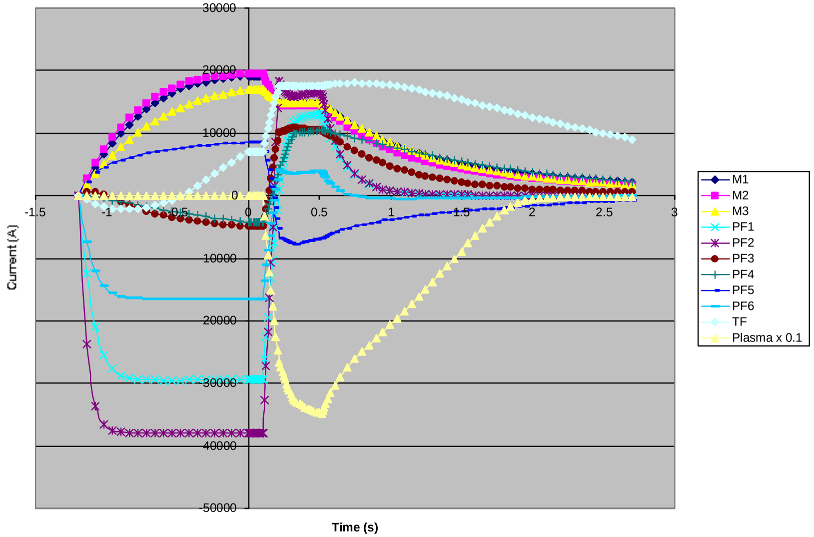
```
PARAMETERS:
PRESSURE DROP:       10.00 PSI
VELOCITY:            12.76 FT./SEC.
FLOW RATE:            0.90 GPM
MDOT:                 0.10 LBS/SEC
PATH LENGTH:         23.40 FT.
REYNOLDS NO.:     79314.10
h-film:               1.49 BTU/SQ.FT.-SEC.-DEG.F
CUR. DENSITY:     85034.02 AMPS/SQ.IN
TIME INCR.:        0.03668 SEC
ESW:                  1.20 SEC.
REP. RATE:          900.00 SEC.
INLET TEMP.:        138.00 DEG. R
CMASS:                4.09 LBS
HTL:               0.43900 FT.
NODE INTERVAL:     0.46800 FT.
```

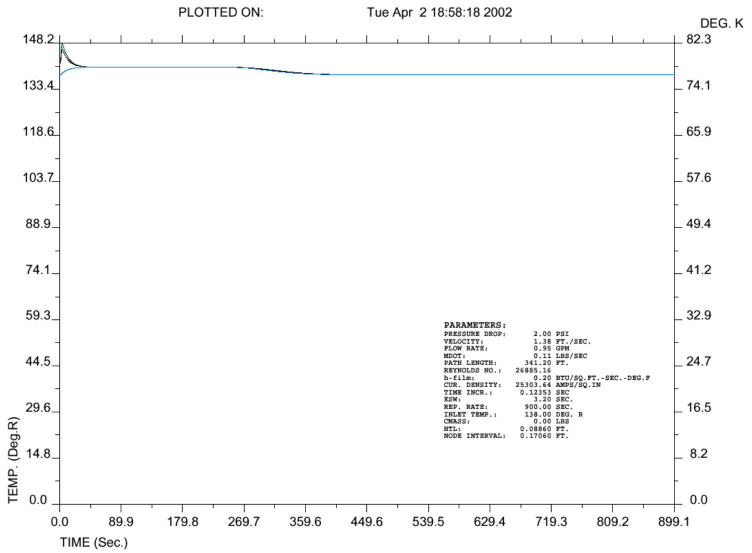
NCSX - M2-COIL 1/4 dia. Cooled Both Sides -04/02/02



```
PARAMETERS:
PRESSURE DROP:       10.00 PSI
VELOCITY:            13.39 FT./SEC.
FLOW RATE:            0.94 GPM
MDOT:                 0.11 LBS/SEC
PATH LENGTH:         21.50 FT.
REYNOLDS NO.:     83246.51
h-film:               1.55 BTU/SQ.FT.-SEC.-DEG.F
CUR. DENSITY:     85034.02 AMPS/SQ.IN
TIME INCR.:        0.03211 SEC
ESW:                  1.20 SEC.
REP. RATE:          900.00 SEC.
INLET TEMP.:        138.00 DEG. R
CMASS:                3.75 LBS
HTL:               0.42000 FT.
NODE INTERVAL:     0.43000 FT.
```

NCSX - M3-COIL 1/4 dia. Cooled Both Sides -04/02/02





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PARAMETERS:
PRESSURE DROP:       2.00 PSI
VELOCITY:            1.38 FT./SEC.
FLOW RATE:           0.95 GPM
MDOT:                0.11 LBS/SEC
PATH LENGTH:       341.20 FT.
REYNOLDS NO.:    26885.16
h-film:              0.20 BTU/SQ.FT.-SEC.-DEG.F
CUR. DENSITY:    25303.64 AMPS/SQ.IN
TIME INCR.:       0.12353 SEC
ESW:                 3.20 SEC.
REP. RATE:         900.00 SEC.
INLET TEMP.:       138.00 DEG. R
CMASS:               0.00 LBS
HTL:              0.08860 FT.
NODE INTERVAL:    0.17060 FT.
```
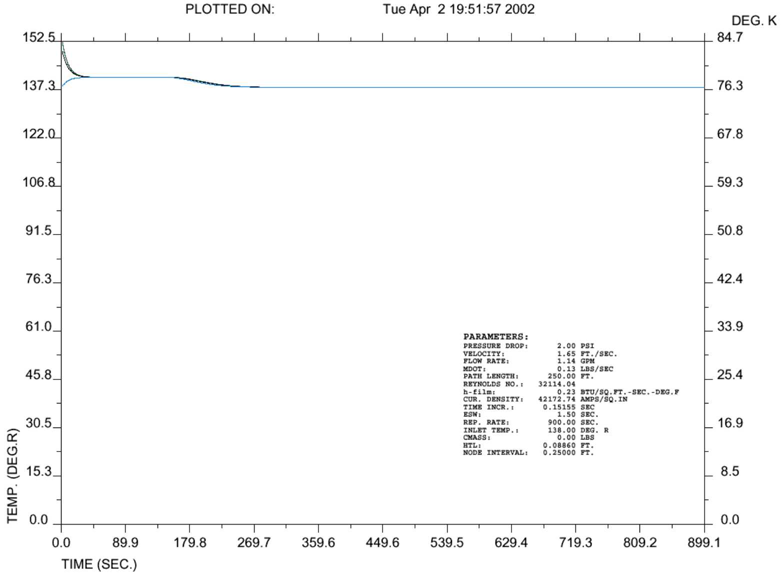
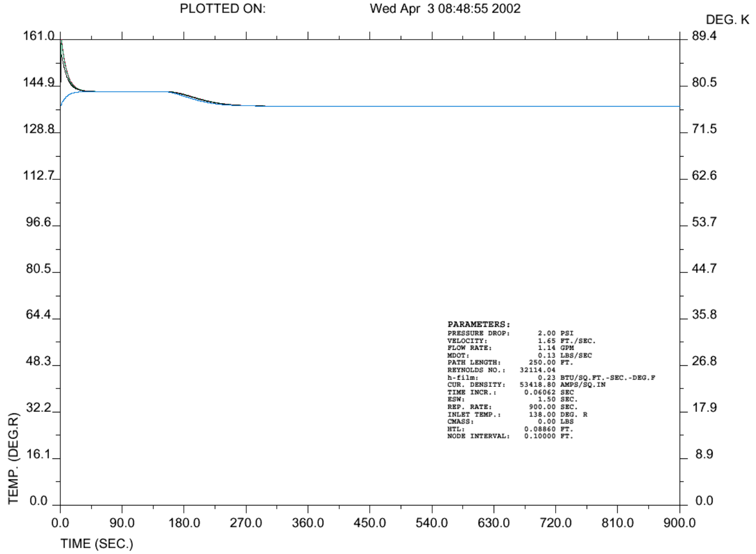

NCSX - TF COIL - 3.2 sec. ESW - 18kA - 340 ft.



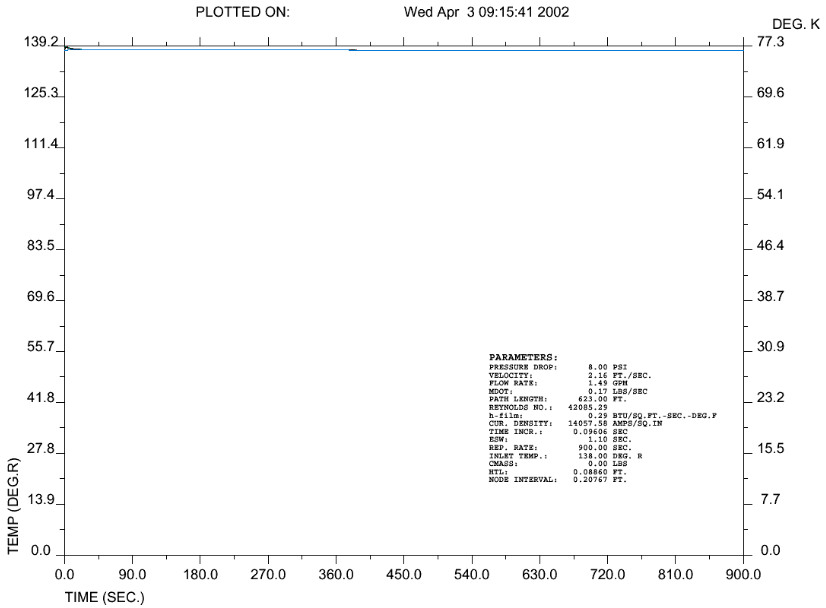
```
PARAMETERS:
PRESSURE DROP:       2.00 PSI
VELOCITY:            1.65 FT./SEC.
FLOW RATE:           1.14 GPM
MDOT:                0.13 LBS/SEC
PATH LENGTH:       250.00 FT.
REYNOLDS NO.:    32114.04
h-film:              0.23 BTU/SQ.FT.-SEC.-DEG.F
CUR. DENSITY:    42172.74 AMPS/SQ.IN
TIME INCR.:       0.15155 SEC
ESW:                 1.50 SEC.
REP. RATE:         900.00 SEC.
INLET TEMP.:       138.00 DEG. R
CMASS:               0.00 LBS
HTL:              0.08860 FT.
NODE INTERVAL:    0.25000 FT.
```

NCSX - PF-1 - 1.5sec. ESW - 30kA - 250ft.



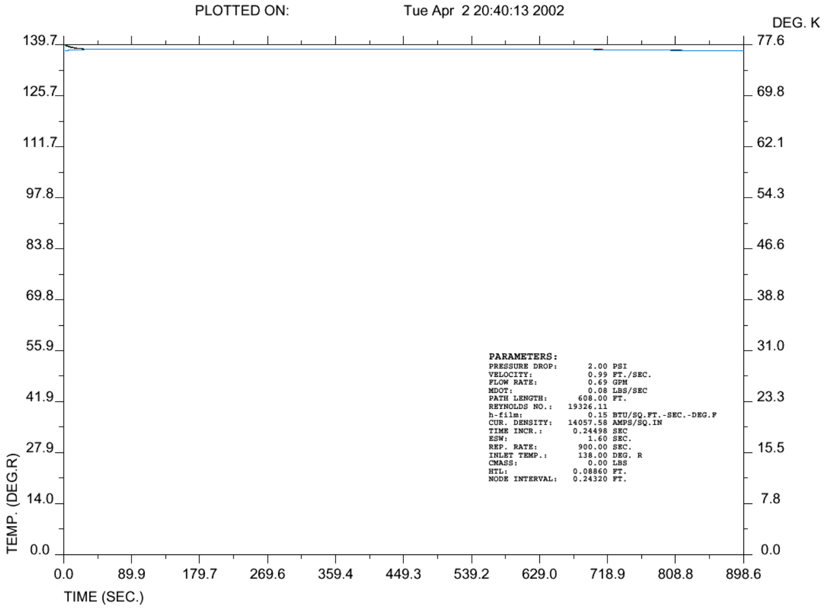
```
PARAMETERS:
PRESSURE DROP:       2.00 PSI
VELOCITY:            1.65 FT./SEC.
FLOW RATE:           1.14 GPM
MDOT:                0.13 LBS/SEC
PATH LENGTH:       250.00 FT.
REYNOLDS NO.:    32114.04
h-film:              0.23 BTU/SQ.FT.-SEC.-DEG.F
CUR. DENSITY:    53418.80 AMPS/SQ.IN
TIME INCR.:       0.06062 SEC
ESW:                 1.50 SEC.
REP. RATE:         900.00 SEC.
INLET TEMP.:       138.00 DEG. R
CMASS:               0.00 LBS
HTL:              0.08860 FT.
NODE INTERVAL:    0.10000 FT.
```

NCSX - PF-2 - 1.5sec. ESW - 38kA - 250ft.



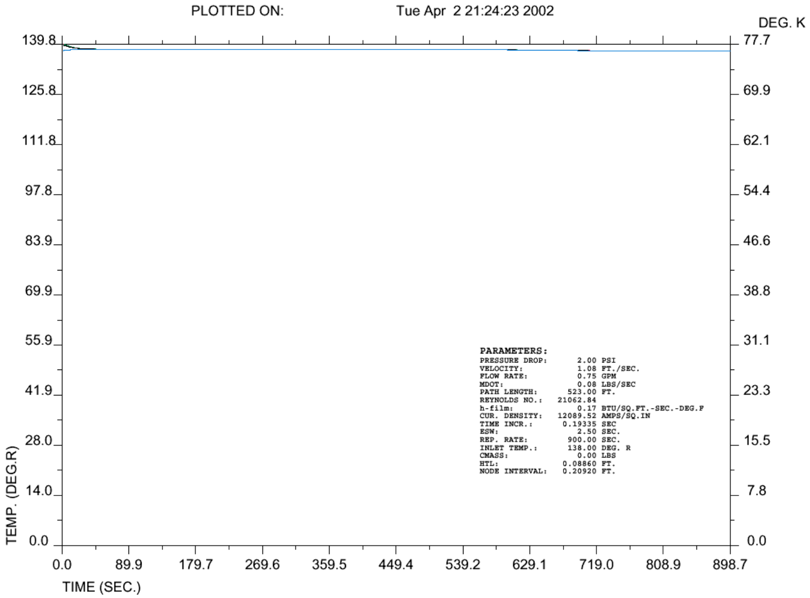
```
PARAMETERS:
PRESSURE DROP:       8.00 PSI
VELOCITY:            2.16 FT./SEC.
FLOW RATE:           1.49 GPM
MDOT:                0.17 LBS/SEC
PATH LENGTH:       623.00 FT.
REYNOLDS NO.:    42085.29
h-film:              0.29 BTU/SQ.FT.-SEC.-DEG.F
CUR. DENSITY:    14057.58 AMPS/SQ.IN
TIME INCR.:       0.09606 SEC
ESW:                 1.10 SEC.
REP. RATE:         900.00 SEC.
INLET TEMP.:       138.00 DEG. R
CMASS:               0.00 LBS
HTL:              0.08860 FT.
NODE INTERVAL:    0.20767 FT.
```

NCSX - PF-3 - 1.1sec. ESW - 10kA - 623ft.



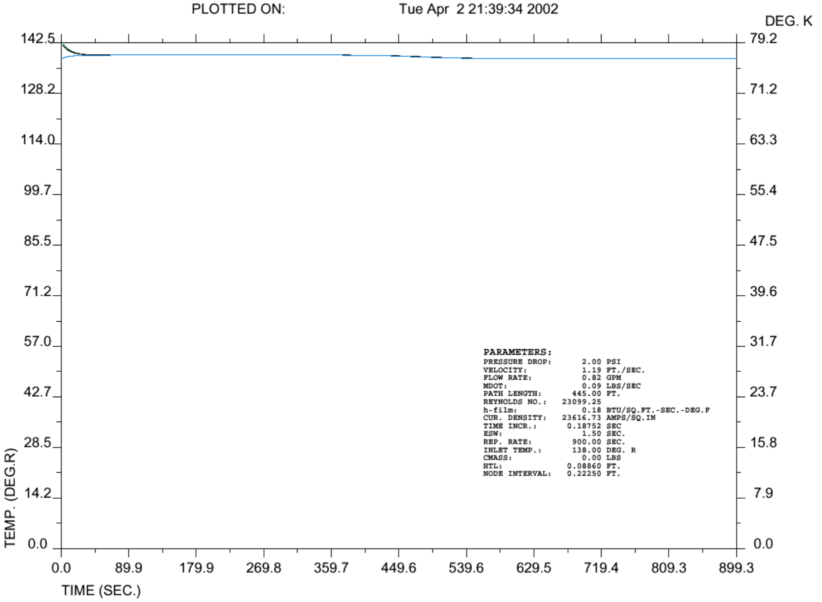
```
PARAMETERS:
PRESSURE DROP:       2.00 PSI
VELOCITY:            0.99 FT./SEC.
FLOW RATE:           0.69 GPM
MDOT:                0.08 LBS/SEC
PATH LENGTH:       608.00 FT.
REYNOLDS NO.:    19326.11
h-film:              0.15 BTU/SQ.FT.-SEC.-DEG.F
CUR. DENSITY:    14057.58 AMPS/SQ.IN
TIME INCR.:       0.24498 SEC
ESW:                 1.60 SEC.
REP. RATE:         900.00 SEC.
INLET TEMP.:       138.00 DEG. R
CMASS:               0.00 LBS
HTL:              0.08860 FT.
NODE INTERVAL:    0.24320 FT.
```

NCSX - PF-4 1.6sec. ESW - 10kA - 606ft.(2 path/coil)



```
PARAMETERS:
PRESSURE DROP:       2.00 PSI
VELOCITY:            1.08 FT./SEC.
FLOW RATE:           0.75 GPM
MDOT:                0.08 LBS/SEC
PATH LENGTH:       523.00 FT.
REYNOLDS NO.:    21062.84
h-film:              0.17 BTU/SQ.FT.-SEC.-DEG.F
CUR. DENSITY:    12089.52 AMPS/SQ.IN
TIME INCR.:       0.19335 SEC
ESW:                 2.50 SEC.
REP. RATE:         900.00 SEC.
INLET TEMP.:       138.00 DEG. R
CMASS:               0.00 LBS
HTL:              0.08860 FT.
NODE INTERVAL:    0.20920 FT.
```

NCSX - PF-5 - 2.5sec. ESW - 8.6kA - 528ft. (2 paths/coil)

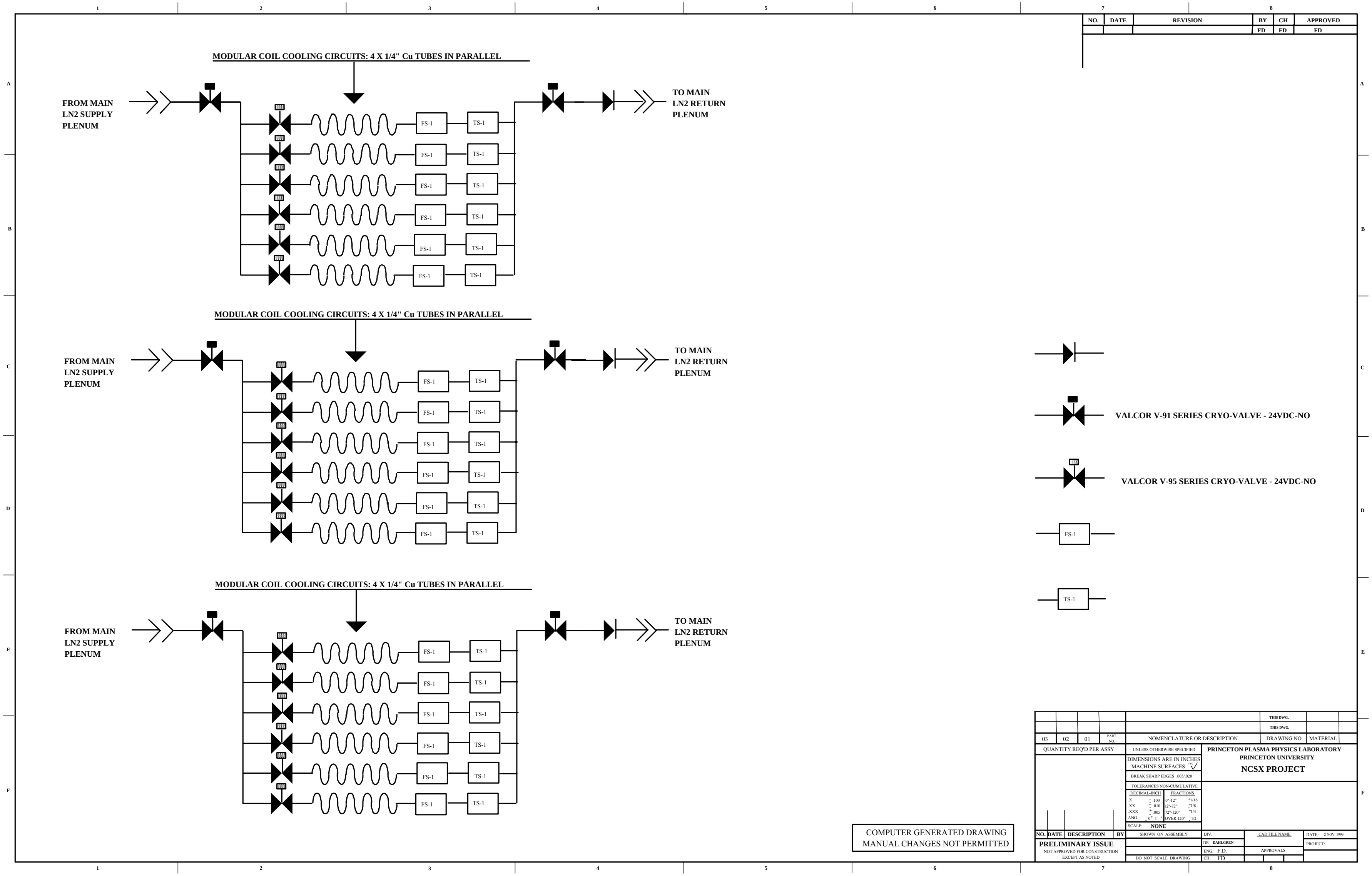


```
PARAMETERS:
PRESSURE DROP:       2.00 PSI
VELOCITY:            1.19 FT./SEC.
FLOW RATE:           0.82 GPM
MDOT:                0.09 LBS/SEC
PATH LENGTH:       445.00 FT.
REYNOLDS NO.:    23099.25
h-film:              0.18 BTU/SQ.FT.-SEC.-DEG.F
CUR. DENSITY:    23616.73 AMPS/SQ.IN
TIME INCR.:       0.18752 SEC
ESW:                 1.50 SEC.
REP. RATE:         900.00 SEC.
INLET TEMP.:       138.00 DEG. R
CMASS:               0.00 LBS
HTL:              0.08860 FT.
NODE INTERVAL:    0.22250 FT.
```

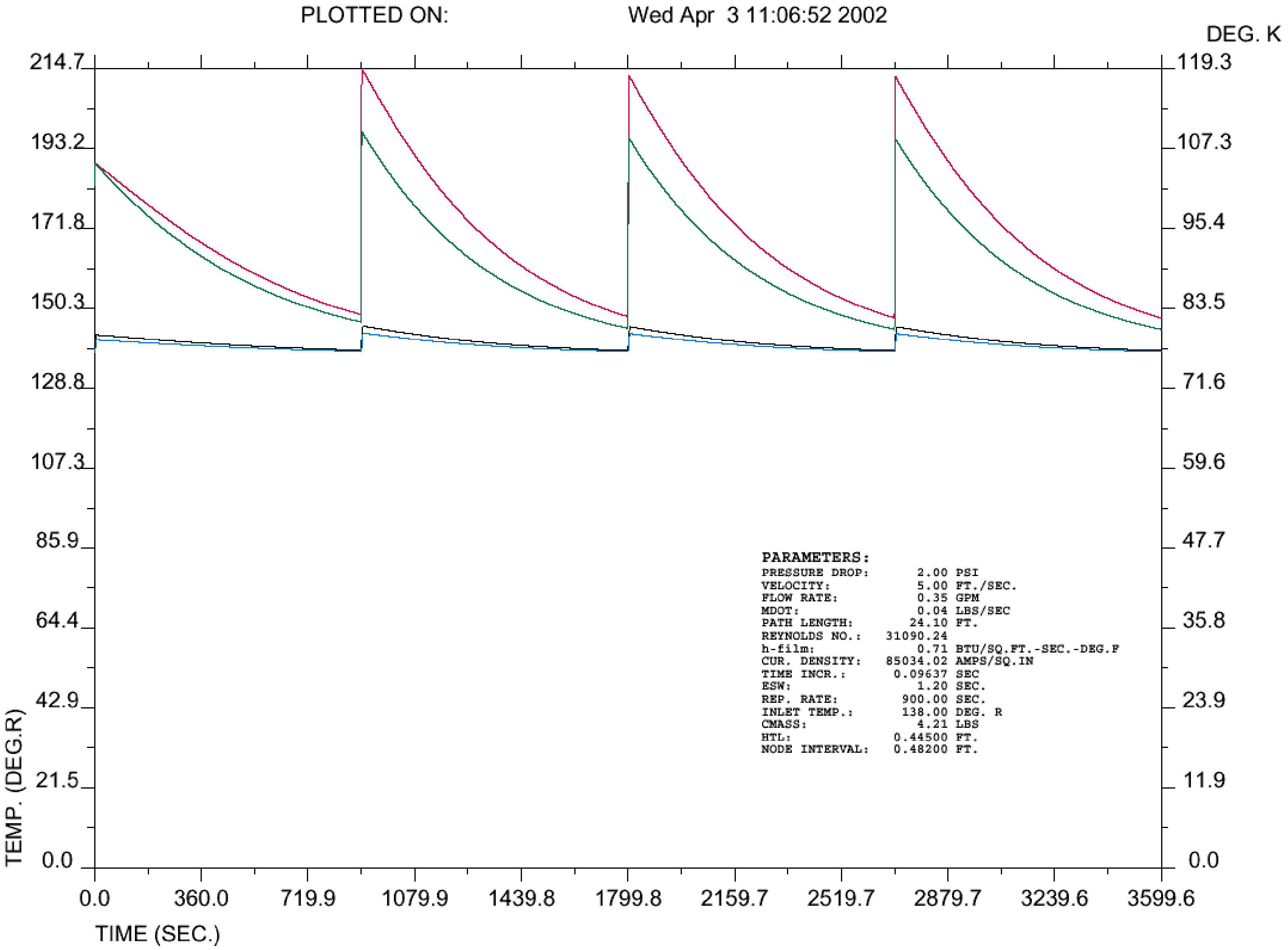
NCSX - PF-6 1.5sec. ESW - 16.8kA - 445ft.

NCSX COIL SYSTEMS - THERMO-HYDRAUILC DATA

	ESW	I (kA)	ŽT (peak-deg.K)	T max (deg.K)	ŽP(psi)	GPM/coil	GPM (total)
M1	1.2	24.0	36.1	117.4	10	0.88	5.2
M2	1.2	24.0	36.2	117.2	10	0.90	5.4
M3	1.2	24.0	36.4	116.5	10	0.94	5.6
PF1	1.5	30.0	7.9	84.9	2	0.92	1.9
PF2	1.5	38.0	12.4	89.4	2	1.14	2.3
PF3	1.1	10.0	0.3	77.3	2	0.68	1.4
PF4	1.6	10.0	0.7	77.7	2	0.68[1]	2.8
PF5	2.5	8.6	0.7	77.7	2	0.75[1]	3.0
PF6	1.5	16.8	2.2	79.2	2	0.82	1.7
TF1	3.2	18.0	5.6	82.4	2	0.95	5.7
TF2	3.2	18.0	5.6	82.4	2	0.95	5.7
TF3	3.2	18.0	5.6	82.4	2	0.95	5.7
							46.4



NCSX MODULAR COIL LN2 COOLING CIRCUIT



```
PARAMETERS:
PRESSURE DROP:       2.00 PSI
VELOCITY:            5.00 FT./SEC.
FLOW RATE:           0.35 GPM
MDOT:                0.04 LBS/SEC
PATH LENGTH:        24.10 FT.
REYNOLDS NO.:   31090.24
h-film:              0.71 BTU/SQ.FT.-SEC.-DEG.F
CUR. DENSITY:   85034.02 AMPS/SQ.IN
TIME INCR.:      0.09637 SEC
ESW:                 1.20 SEC.
REP. RATE:         900.00 SEC.
INLET TEMP.:       138.00 DEG. R
CMASS:               4.21 LBS
HTL:             0.44500 FT.
NODE INTERVAL:   0.48200 FT.
```

NCSX - M-1 COIL Re-Run with 2psi drop