MFTF-B Refrigerator Analysis

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February 10, 1995

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MFTF-B REFRIGERATOR ANALYSIS

LLNL SUBCONTRACT B304356

PHPK TECHNOLOGIES INC.

1.0 Introduction

The purpose of this analysis was to determine the applicability of the MFTF-B helium refrigerator to the requirements of the TPX Tokomak at Princeton. The TPX requires a high pressure stream of supercritical gas to all loads rather than the liquid helium loads that the refrigerator was originally designed to support.

2.0 Load Comparison

This study is based on the MFTF-B state point table, which is table 2.6.1.3-I of the LLNL Systems Design Description for the conceptual design review of March 29, 1993. It is assumed to be the original design table for the refrigerator, but is not based on operating data.

This table indicates a design load of 8800 watts and a delivery of 33.32 g/s of liquid helium at 4.35 K.

In contrast to this, the TPX will require a stream of supercritical gas at temperatures between 4.2 and 5 K and at pressures between 4 and 10 atmospheres. 24 g/s of this stream flows to the power leads and is returned to the system at room temperature. The remainder absorbs the magnet heat load and returns at temperatures between 6 and 9 K. The magnet loads are as follows:

- Initial load - 5750 watts
- Second year - 7480 watts
- Final maximum load - 8350 watts

3.0 Cycle Duplication

The first step in this analysis was to duplicate as closely as possible the original state point table for the refrigerator. The duplication state point table is shown in the appendix, together with the schematic diagram. The high pressure compressor flow in the duplication is 1002 g/s, compared to 993 g/s in the original table, an error of 0.9%. Our present programs use a direct computer code to calculate helium properties based on the HEPAK program developed by Cryodata, which is in turn based on revised versions of NIST Technical Note 1334 (1991). Part of the discrepancy could therefore be due to our use of more recent data.

The duplication provides the design UA values for the heat exchangers and the flow coefficients for the expanders, which permit the calculation of off-design operation. These values are also shown in the appendix.

The heat exchanger table shows total load in watts and btu, the log mean temperature difference in degrees K and the UA value in watts/K.

4.0 Cycle Simulation

4.1 Simulation method

The principle changes which occur when these cycles are operated off-design involve the heat exchangers and expanders. The pressure drops through the system change only slightly, and for purposes of this study have been ignored. The UA values for the heat exchangers are assumed to vary as the .8 power of the flow rate, using the flow values of the original cycle as a basis.

The expander calculation is somewhat more complex. For expanders #1 and #2 where expansion ratio is greater than four, it is assumed that the expander operates as a sonic orifice, and real gas orifice equations are used to calculate the flow, based on the input temperature and pressure, and the flow constants referred to above. For turbine #3 the flow is subsonic and the downstream pressure affects the flow. An excellent correlation was obtained from Air Liquide for this computation which represents the best information available at present for these very low temperatures.

The efficiency of the expanders can also be expected to vary with flow rate, and prediction of this effect is very difficult. Some loss of efficiency can be expected as the flow varies in either direction from the design point. With no actual data available for this, the following relationship was included in the programs:

$$\% \text{actual eff} = \% \text{design eff} - 10 \times \text{ABS}(1 - \text{actual flow}/\text{design flow})$$

This gives a degradation in efficiency of about 3 percentage points for a 25% change in flow rate.

For this study, with no actual data on the compressors, they are not included in the simulation. For each case, however, the compressor loading is calculated based on intake volume only. This is calculated as a percent of maximum capacity, assuming that the compressors are designed to be fully loaded at the MFTF-B design point.

4.2 Modified MFTF-B Cycle

The modified cycle schematic is shown in the appendix. Only the lower section below heat exchanger #8 is changed. Using the techniques described above, a simulation program was written, using the heat exchangers and the two warm turbines of the original cycle. Since the principle change is at the cold end, it was assumed that the #3 expander would have to be replaced, and its characteristics were chosen to match the new load requirements. The design point was for the maximum load that the system would support with 10 atmospheres load pressure and compressor flows as close as possible to the MFTF-B flows. This turned out to be a load of 7850 watts and 24 g/s lead flow, with compressor flows of 98.9% and 101.4% of the first and second stage MFTF-B flows. We received performance specifications for the #3 turbine from Air Liquide and from Lotepro, indicating efficiencies of 75% and 71% respectively. We chose to use 74% in the simulation. The simulation state point table is shown in the appendix.

4.3 Modified Cycle Simulation

Using the flow characteristics of turbine #3, and the Air Liquide equations, a complete simulation program was written to enable the calculation of other operating points. With this program it is possible to change any of the cycle parameters, including loads, pressures, throttling of the turbines, etc., to predict as closely as possible the operating conditions. The program creates a complete state point table for each case. Since the available choices are very large, only selected cases were run for this study. It was also considered undesirable to throttle any of the turbines due to the resulting efficiency loss, so all cases were run with the turbines at full flow.

5.0 Selected Operating Points

Seven off-design cases were run to determine the capacity of the machine and illustrate the effect of changes in load pressure, both at high loading and at the initial expected load of 5750 watts. The conductor load was 24 g/s in all cases. Results are shown in the following table and in the accompanying graphs. Complete state point tables for all cases are in the Appendix.

OFF-DESIGN PERFORMANCE

Case	Load	Load Press	Cycle Press	1st Comp%	2nd Comp %
Design	7850	10	19.85	98.90	101.42
#1	8850	8	20	107.66	105.75
#2	9650	6	20	114.57	108.85
#3	10500	4	20	121.74	112.24
#4	5750	10	17.82	80.65	86.67
#5	6450	8	17.82	89.22	90.45
#6	7240	6	17.82	97.31	94.11
#7	8025	4	17.82	105.25	97.88

High Load Series

Low Load Series

6.0 Conclusion

The results indicate that with a properly chosen turbine the system will operate well under the desired conditions. Additional compressor capacity may be necessary for the higher loads expected in future years, but a single turbine should cover the load changes. This study is, of course, based on the original state point table, which was a design point, and not a measured operating point. To be certain of the results, actual operating data will be necessary to confirm the condition of the present system.

APPENDIX

MFTF-B SCHEMATIC

```

1->COMP>-1->COMP->1
1      1      1      1
1>1    2>1    3>1    6>1
[XXXXXXX][XXXXXXX][XXXXXXX][XXXXXXX]HX1
4>1    5>1    9>1    7>1
1      1      1      1
1      1      [XXXXXXX][XXXXXXX]HX2

1      1      10>1    8>1
1      1      PURIFIER 1
1      1      36>1    1--<-LN2
1      1      1
[XXXXXXX][XXXXXXX][XXXXXXX]HX3
15>1    14>1    12>1
1      1      1----->---1
1      1      13>1    11>1
[XXXXXXX][XXXXXXX][XXXXXXX]HX4 EXP#1
20>1    17>1    19 1    16>1
1      1-----<-----<---1
1      18>1    1
[XXXXXXX][XXXXXXX][XXXXXXX]HX5
25>1    24>1    22>1
1      1      1----->---1
1      1      23>1    21>1
[XXXXXXX][XXXXXXX][XXXXXXX]HX6 EXP#2
28>1    1      27>1    26>1
1      1-----<-----<---1
1      1
1      1-----<---1
[XXXXXXX][XXXXXXX]HX7
1      29>1
1      X
32>1    30>1
1      EXP#3
1      31>1
[XXXXXXX][XXXXXXX]HX8
34>1    33>1
1      X
1      1
[-----VAPOR-----]
[-----LIQUID-----]
1
35>1
1

```

STATE POINT TABLE FOR MFTF-B CYCLE

POINT NO.	TEMP K	PRESS atm	ENTHALPY j/g	ENTROPY j/gK	FLOW g/s
1	295.000	0.840	1547.501	31.859	502.002
2	295.000	2.300	1547.980	29.767	466.706
3	303.000	20.000	1595.313	25.416	1002.028
4	77.800	0.922	419.521	24.744	502.002
5	77.800	2.360	419.876	22.790	466.706
6	295.000	1.000	456.940	4.404	170.049
7	78.000	1.077	228.727	2.974	170.049
8	79.000	2.721	49.801	0.662	170.049
9	85.797	19.750	466.054	18.878	1002.028
10	80.000	19.700	435.690	18.517	1002.028
11	47.600	19.480	264.558	15.797	216.465
12	47.600	19.480	264.558	15.797	1002.028
13	47.600	19.480	264.558	15.797	785.563
14	43.770	2.410	242.720	19.752	466.706
15	43.770	0.983	242.632	21.621	502.002
16	28.076	2.460	160.549	17.383	216.465
17	28.076	2.460	160.549	17.383	466.706
18	28.076	2.460	160.549	17.383	250.241
19	29.076	19.250	163.474	13.127	785.563
20	28.076	1.064	160.843	19.140	502.002
21	22.300	19.190	124.478	11.606	250.241
22	22.300	19.190	124.478	11.606	785.563
23	22.300	19.190	124.478	11.606	535.322
24	20.327	2.480	119.539	15.656	250.241
25	20.327	1.085	120.259	17.409	502.002
26	12.990	2.490	79.823	13.221	250.241
27	13.590	19.140	69.503	8.466	535.322
28	12.990	1.105	81.437	15.000	502.002
29	6.470	19.100	26.132	4.095	535.322
30	6.480	19.000	26.132	4.106	535.322
31	5.235	2.600	17.225	4.788	535.322
32	4.885	1.115	35.186	9.287	502.002
33	4.744	2.580	12.990	3.949	535.322
34	4.350	1.125	30.670	8.291	502.002
35	4.350	1.125	10.731	3.717	33.320
36	80.000	19.700	435.690	18.517	1002.028

HEAT EXCHANGER DATA FOR MFTF-B CYCLE

HX#	WATTS	BTU	LMTD	UA- w/K
1	1131549	3861977	8.00	141466.5
2	30426	103844	3.31	9193.0
3	171478	585256	2.94	58323.0
4	79408	271018	2.11	37678.7
5	30634	104555	1.43	21392.6
6	29429	100441	1.15	25511.2
7	23218	79243	1.01	22896.1
8	2267	7739	0.37	6099.3

EXPANDER DATA FOR MFTF-B CYCLE

EXPANDER NO. 1	22.51 KW	K =	487.27	EFF'Y = 73.0%
EXPANDER NO. 2	11.17 KW	K =	376.93	EFF'Y = 71.0%
EXPANDER NO. 3	4.77 KW	K =	446.47	EFF'Y = 72.0%

SCHEMATIC FOR MFTF-B MODIFIED FOR THE TPX

```

1----->----->-----1
1                                     1
1<42    1->COMP>-1->COMP->1
1      1>1      2>1      3>1      6>1.
1  [XXXXXXXX][XXXXXXXX][XXXXXXXX][XXXXXXXX]HX1
      4>1      5>1      9>1      7>1
          1          1          1          1
          1          1      [XXXXXXXX][XXXXXXXX]HX2
          1          1      10>1      8>1
          1          1      PURIFIER      1
          1          1      36>1      1-<-LN2
          1          1          1
[XXXXXXXX][XXXXXXXX][XXXXXXXX]HX3
15>1      14>1      12>1
      1          1          1----->----1
      1          1      13>1      11>1
[XXXXXXXX][XXXXXXXX][XXXXXXXX]HX4 EXP#1
20>1      17>1      19 1      16>1
44>1      1-----<-----<----1
      1      18>1      1
[XXXXXXXX][XXXXXXXX][XXXXXXXX]HX5
25>1      24>1      22>1
      1          1          1----->----1
      1          1      23>1      21>1
[XXXXXXXX][XXXXXXXX][XXXXXXXX]HX6 EXP#2
28>1      1          27>1      26>1
43>1      45>1-----<-----<----1
      1          1
      1          1-----<----1
[XXXXXXXX][XXXXXXXX]HX7
      1      29>1
      1          X
32>1      30>1
      1          EXP#3
      1      31>1
[XXXXXXXX][XXXXXXXX]HX8
34>1      33>1
      1          1      40>1-----<----1
1      1          X          X          1
1<41    1      35>1      1          1
1  [-----VAPOR--1-----] LOAD
1  [-----LIQUID-1--38-----] 1
1      37>1      39>1
1-----<-TO LEADS--1----->----->----1

```

DESIGN POINT TABLE - MFTF-B MODIFIED FOR THE TPX

POINT NO.	TEMP K	PRESS atm	ENTHALPY j/g	ENTROPY j/gK	FLOW g/s
1	294.440	0.840	1544.595	31.849	508.226
2	294.440	2.300	1545.073	29.757	474.912
3	303.000	19.850	1595.264	25.431	1007.138
4	77.912	0.922	420.102	24.752	508.226
5	77.912	2.360	420.458	22.798	474.912
6	294.440	1.000	456.358	4.402	148.339
7	78.000	1.077	228.727	2.974	148.339
8	87.000	2.721	49.801	0.662	148.339
9	85.409	19.600	463.982	18.870	1007.138
10	80.377	19.550	437.628	18.558	1007.138
11	46.124	19.330	256.637	15.645	218.294
12	46.124	19.330	256.637	15.645	1007.138
13	46.124	19.330	256.637	15.645	788.844
14	42.271	2.410	234.898	19.570	474.912
15	42.271	0.983	234.833	21.439	508.226
16	27.259	2.460	156.247	17.228	218.294
17	27.010	2.460	154.935	17.179	474.912
18	26.939	2.460	154.559	17.165	256.618
19	27.968	19.100	157.239	12.926	788.844
20	27.010	1.064	155.273	18.938	508.226
21	21.166	19.040	117.760	11.313	256.618
22	21.166	19.040	117.760	11.313	788.844
23	21.166	19.040	117.760	11.313	532.226
24	19.201	2.480	113.529	15.352	256.618
25	19.201	1.085	114.341	17.110	508.226
26	12.311	2.490	76.047	12.922	256.618
27	12.793	18.990	64.091	8.071	532.226
28	12.221	1.105	77.322	14.673	508.226
29	6.363	18.950	25.644	4.035	532.226
30	6.374	18.850	25.644	4.046	532.226
31	6.050	10.150	21.067	4.327	532.226
32	5.112	1.115	36.808	9.612	508.226
33	4.601	10.100	15.205	3.236	532.226
34	4.350	1.125	30.670	8.291	508.226
35	4.601	10.100	15.205	3.236	532.226
36	80.377	19.550	437.628	18.558	1007.138
37	4.500	10.000	14.821	3.166	532.226
39	4.500	10.000	14.821	3.166	508.226
40	6.366	4.000	30.267	6.736	508.226
41	4.500	10.000	14.821	3.166	24.000
43	12.175	1.105	77.070	14.652	508.226
44	26.939	1.064	154.900	18.924	508.226
45	12.221	2.490	75.544	12.881	256.618

OFF-DESIGN CASE #1

CYCLE PRESSURE 20 ATM
24 G/S 8850 WATTS

LOAD PRESSURE 8 ATM

POINT NO.	TEMP K	PRESS atm	ENTHALPY j/g	ENTROPY j/gK	FLOW g/s
1	294.267	0.840	1543.693	31.846	555.378
2	294.267	2.300	1544.172	29.754	470.727
3	303.000	20.000	1595.313	25.416	1050.104
4	77.861	0.922	419.839	24.749	555.378
5	77.861	2.360	420.194	22.794	470.727
6	294.267	1.000	456.177	4.401	154.371
7	78.000	1.077	228.727	2.974	154.371
8	87.000	2.721	49.801	0.662	154.371
9	85.338	19.750	463.652	18.850	1050.104
10	80.317	19.700	437.349	18.538	1050.104
11	46.789	19.480	260.217	15.705	218.366
12	46.789	19.480	260.217	15.705	1050.104
13	46.789	19.480	260.217	15.705	831.739
14	43.013	2.410	238.768	19.660	470.727
15	43.013	0.983	238.691	21.530	555.378
16	27.613	2.460	158.114	17.296	218.366
17	27.587	2.460	157.973	17.290	470.727
18	27.580	2.460	157.935	17.289	252.361
19	28.602	19.250	160.802	13.035	831.739
20	27.587	1.064	158.287	19.048	555.378
21	21.999	19.190	122.695	11.525	252.361
22	21.999	19.190	122.695	11.525	831.739
23	21.999	19.190	122.695	11.525	579.378
24	20.114	2.480	118.406	15.600	252.361
25	20.114	1.085	119.143	17.354	555.378
26	12.806	2.490	78.803	13.142	252.361
27	13.515	19.140	68.994	8.429	579.378
28	12.891	1.105	80.907	14.959	555.378
29	6.800	19.100	27.492	4.300	579.378
30	6.809	19.000	27.492	4.311	579.378
31	6.204	8.150	21.558	4.669	579.378
32	5.262	1.115	37.827	9.808	555.378
33	4.725	8.100	14.698	3.426	579.378
34	4.350	1.125	30.670	8.291	555.378
35	4.725	8.100	14.698	3.426	579.378
36	80.317	19.700	437.349	18.538	1050.104
37	4.500	8.000	13.848	3.257	579.378
39	4.500	8.000	13.848	3.257	555.378
40	6.334	4.000	29.783	6.659	555.378
41	4.500	8.000	13.848	3.257	24.000
43	12.931	1.105	81.122	14.975	555.378
44	27.580	1.064	158.249	19.047	555.378
45	12.891	2.490	79.272	13.178	252.361

OFF-DESIGN CASE #2

CYCLE PRESSURE 20 ATM
24 G/S 9650 WATTS

LOAD PRESSURE 6 ATM

POINT NO.	TEMP K	PRESS atm	ENTHALPY j/g	ENTROPY j/gK	FLOW g/s
1	294.154	0.840	1543.106	31.844	592.578
2	294.154	2.300	1543.584	29.752	464.322
3	303.000	20.000	1595.313	25.416	1080.899
4	78.060	0.922	420.870	24.762	592.578
5	78.060	2.360	421.226	22.808	464.322
6	294.154	1.000	456.060	4.401	158.535
7	78.000	1.077	228.727	2.974	158.535
8	87.000	2.721	49.801	0.662	158.535
9	85.519	19.750	464.599	18.861	1080.899
10	80.509	19.700	438.356	18.550	1080.899
11	47.458	19.480	263.797	15.781	216.804
12	47.458	19.480	263.797	15.781	1080.899
13	47.458	19.480	263.797	15.781	864.095
14	43.738	2.410	242.553	19.748	464.322
15	43.738	0.983	242.465	21.617	592.578
16	27.995	2.460	160.120	17.368	216.804
17	28.122	2.460	160.791	17.392	464.322
18	28.155	2.460	160.965	17.398	247.517
19	29.179	19.250	164.052	13.147	864.095
20	28.122	1.064	161.083	19.149	592.578
21	22.693	19.190	126.802	11.709	247.517
22	22.693	19.190	126.802	11.709	864.095
23	22.693	19.190	126.802	11.709	616.578
24	20.859	2.480	122.377	15.794	247.517
25	20.859	1.085	123.057	17.545	592.578
26	13.255	2.490	81.290	13.333	247.517
27	14.122	19.140	73.113	8.727	616.578
28	13.452	1.105	83.904	15.186	592.578
29	7.073	19.100	28.681	4.472	616.578
30	7.081	19.000	28.681	4.482	616.578
31	6.134	6.150	21.496	4.942	616.578
32	5.306	1.115	38.128	9.865	592.578
33	4.844	6.100	14.328	3.653	616.578
34	4.350	1.125	30.670	8.291	592.578
35	4.844	6.100	14.328	3.653	616.578
36	80.509	19.700	438.356	18.550	1080.899
37	4.500	6.000	12.927	3.369	616.578
39	4.500	6.000	12.927	3.369	592.578
40	6.297	4.000	29.211	6.569	592.578
41	4.500	6.000	12.927	3.369	24.000
43	13.537	1.105	84.360	15.220	592.578
44	28.155	1.064	161.257	19.155	592.578
45	13.452	2.490	82.378	13.414	247.517

OFF-DESIGN CASE #3

CYCLE PRESSURE 20 ATM LOAD PRESSURE 4 ATM
24 G/S 10500 WATTS

POINT NO.	TEMP K	PRESS atm	ENTHALPY j/g	ENTROPY j/gK	FLOW g/s
1	294.016	0.840	1542.391	31.842	631.170
2	294.016	2.300	1542.869	29.750	459.385
3	303.000	20.000	1595.313	25.416	1114.555
4	77.907	0.922	420.077	24.752	631.170
5	77.907	2.360	420.433	22.797	459.385
6	294.016	1.000	455.916	4.400	163.715
7	78.000	1.077	228.727	2.974	163.715
8	87.000	2.721	49.801	0.662	163.715
9	85.356	19.750	463.744	18.851	1114.555
10	80.338	19.700	437.462	18.539	1114.555
11	47.933	19.480	266.338	15.834	215.717
12	47.933	19.480	266.338	15.834	1114.555
13	47.933	19.480	266.338	15.834	898.838
14	44.282	2.410	245.393	19.812	459.385
15	44.282	0.983	245.297	21.681	631.170
16	28.285	2.460	161.650	17.422	215.717
17	28.576	2.460	163.181	17.476	459.385
18	28.649	2.460	163.561	17.489	243.669
19	29.677	19.250	166.852	13.242	898.838
20	28.576	1.064	163.456	19.233	631.170
21	23.278	19.190	130.243	11.859	243.669
22	23.278	19.190	130.243	11.859	898.838
23	23.278	19.190	130.243	11.859	655.170
24	21.481	2.480	125.686	15.950	243.669
25	21.481	1.085	126.322	17.699	631.170
26	13.649	2.490	83.463	13.494	243.669
27	14.576	19.140	76.167	8.940	655.170
28	13.855	1.105	86.054	15.344	631.170
29	7.061	19.100	28.628	4.464	655.170
30	7.069	19.000	28.628	4.474	655.170
31	5.765	4.150	20.214	5.049	655.170
32	5.163	1.115	37.158	9.680	631.170
33	4.896	4.100	13.963	3.894	655.170
34	4.350	1.125	30.670	8.291	631.170
35	4.896	4.100	13.963	3.894	655.170
36	80.338	19.700	437.462	18.539	1114.555
37	4.500	4.000	12.113	3.517	655.170
39	4.500	4.000	12.113	3.517	631.170
40	6.268	4.000	28.749	6.495	631.170
41	4.500	4.000	12.113	3.517	24.000
43	13.940	1.105	86.505	15.376	631.170
44	28.649	1.064	163.834	19.246	631.170
45	13.855	2.490	84.599	13.577	243.669

OFF-DESIGN CASE #4

CYCLE PRESSURE 17.82 ATM
24 G/S 5750 WATTS

LOAD PRESSURE 10 ATM.

POINT NO.	TEMP K	PRESS atm	ENTHALPY j/g	ENTROPY j/gK	FLOW g/s
1	295.024	0.840	1547.626	31.860	410.035
2	295.024	2.300	1548.105	29.768	426.603
3	303.000	17.820	1594.599	25.655	860.638
4	78.014	0.922	420.630	24.759	410.035
5	78.014	2.360	420.987	22.804	426.603
6	295.024	1.000	456.965	4.404	130.860
7	78.000	1.077	228.727	2.974	130.860
8	87.000	2.721	49.801	0.662	130.860
9	85.566	17.570	464.267	19.108	860.638
10	80.367	17.520	437.062	18.786	860.638
11	45.724	17.300	254.281	15.835	196.638
12	45.724	17.300	254.281	15.835	860.638
13	45.724	17.300	254.281	15.835	664.001
14	41.872	2.410	232.816	19.520	426.603
15	41.872	0.983	232.758	21.390	410.035
16	27.888	2.460	159.558	17.348	196.638
17	27.247	2.460	156.186	17.225	426.603
18	27.050	2.460	155.145	17.187	229.966
19	28.054	17.070	157.965	13.196	664.001
20	27.247	1.064	156.513	18.984	410.035
21	21.073	17.010	117.785	11.554	229.966
22	21.073	17.010	117.785	11.554	664.001
23	21.073	17.010	117.785	11.554	434.035
24	19.130	2.480	113.150	15.332	229.966
25	19.130	1.085	113.969	17.090	410.035
26	12.660	2.490	77.988	13.078	229.966
27	13.281	16.960	68.404	8.618	434.035
28	12.867	1.105	80.777	14.949	410.035
29	7.727	16.920	31.195	5.032	434.035
30	7.731	16.820	31.195	5.043	434.035
31	7.139	10.150	27.284	5.268	434.035
32	5.915	1.115	42.037	10.563	410.035
33	4.983	10.100	16.545	3.515	434.035
34	4.350	1.125	30.670	8.291	410.035
35	4.983	10.100	16.545	3.515	434.035
36	80.367	17.520	437.062	18.786	860.638
37	4.500	10.000	14.821	3.166	434.035
39	4.500	10.000	14.821	3.166	410.035
40	6.274	4.000	28.845	6.510	410.035
41	4.500	10.000	14.821	3.166	24.000
43	12.988	1.105	81.424	14.999	410.035
44	27.050	1.064	155.481	18.946	410.035
45	12.867	2.490	79.138	13.168	229.966

OFF-DESIGN CASE #5

CYCLE PRESSURE 17.82 ATM
24 G/S 6450 WATTS

LOAD PRESSURE 8 ATM

POINT NO.	TEMP K	PRESS atm	ENTHALPY j/g	ENTROPY j/gK	FLOW g/s
1	294.844	0.840	1546.690	31.856	456.213
2	294.844	2.300	1547.168	29.764	417.916
3	303.000	17.820	1594.599	25.655	898.129
4	78.031	0.922	420.723	24.760	456.213
5	78.031	2.360	421.079	22.806	417.916
6	294.844	1.000	456.777	4.403	135.895
7	78.000	1.077	228.727	2.974	135.895
8	87.000	2.721	49.801	0.662	135.895
9	85.545	17.570	464.159	19.107	898.129
10	80.372	17.520	437.086	18.786	898.129
11	46.605	17.300	258.993	15.937	194.744
12	46.605	17.300	258.993	15.937	898.129
13	46.605	17.300	258.993	15.937	703.386
14	42.856	2.410	237.950	19.641	417.916
15	42.856	0.983	237.875	21.511	456.213
16	28.456	2.460	162.547	17.454	194.744
17	28.003	2.460	160.162	17.369	417.916
18	27.872	2.460	159.476	17.345	223.172
19	28.875	17.070	162.563	13.357	703.386
20	28.003	1.064	160.459	19.127	456.213
21	22.098	17.010	123.840	11.835	223.172
22	22.098	17.010	123.840	11.835	703.386
23	22.098	17.010	123.840	11.835	480.213
24	20.244	2.480	119.100	15.635	223.172
25	20.244	1.085	119.827	17.388	456.213
26	13.367	2.490	81.911	13.379	223.172
27	14.142	16.960	74.273	9.046	480.213
28	13.666	1.105	85.044	15.270	456.213
29	8.036	16.920	32.865	5.244	480.213
30	8.039	16.820	32.865	5.254	480.213
31	7.040	8.150	27.412	5.551	480.213
32	5.952	1.115	42.263	10.601	456.213
33	5.160	8.100	16.397	3.770	480.213
34	4.350	1.125	30.670	8.291	456.213
35	5.160	8.100	16.397	3.770	480.213
36	80.372	17.520	437.086	18.786	898.129
37	4.500	8.000	13.848	3.257	480.213
39	4.500	8.000	13.848	3.257	456.213
40	6.221	4.000	27.986	6.373	456.213
41	4.500	8.000	13.848	3.257	24.000
43	13.817	1.105	85.850	15.329	456.213
44	27.872	1.064	159.778	19.102	456.213
45	13.666	2.490	83.556	13.501	223.172

OFF-DESIGN CASE #6

CYCLE PRESSURE 17.82 ATM
24 G/S 7240 WATTS

LOAD PRESSURE 6 ATM

POINT NO.	TEMP K	PRESS atm	ENTHALPY j/g	ENTROPY j/gK	FLOW g/s
1	294.686	0.840	1545.872	31.854	499.672
2	294.686	2.300	1546.350	29.762	410.854
3	303.000	17.820	1594.599	25.655	934.526
4	78.139	0.922	421.283	24.767	499.672
5	78.139	2.360	421.639	22.813	410.854
6	294.686	1.000	456.614	4.402	140.682
7	78.000	1.077	228.727	2.974	140.682
8	87.000	2.721	49.801	0.662	140.682
9	85.617	17.570	464.532	19.111	934.526
10	80.470	17.520	437.597	18.793	934.526
11	47.425	17.300	263.368	16.030	193.034
12	47.425	17.300	263.368	16.030	934.526
13	47.425	17.300	263.368	16.030	741.492
14	43.760	2.410	242.671	19.750	410.854
15	43.760	0.983	242.582	21.620	499.672
16	28.984	2.460	165.323	17.550	193.034
17	28.698	2.460	163.823	17.498	410.854
18	28.621	2.460	163.418	17.484	217.820
19	29.631	17.070	166.788	13.502	741.492
20	28.698	1.064	164.094	19.255	499.672
21	22.984	17.010	129.021	12.065	217.820
22	22.984	17.010	129.021	12.065	741.492
23	22.984	17.010	129.021	12.065	523.672
24	21.187	2.480	124.121	15.877	217.820
25	21.187	1.085	124.778	17.627	499.672
26	13.977	2.490	85.271	13.625	217.820
27	14.846	16.960	78.978	9.371	523.672
28	14.310	1.105	88.475	15.516	499.672
29	8.070	16.920	33.053	5.268	523.672
30	8.072	16.820	33.053	5.278	523.672
31	6.637	6.150	26.032	5.652	523.672
32	5.774	1.115	41.151	10.412	499.672
33	5.225	6.100	16.031	3.991	523.672
34	4.350	1.125	30.670	8.291	499.672
35	5.225	6.100	16.031	3.991	523.672
36	80.470	17.520	437.597	18.793	934.526
37	4.500	6.000	12.927	3.369	523.672
39	4.500	6.000	12.927	3.369	499.672
40	6.187	4.000	27.416	6.281	499.672
41	4.500	6.000	12.927	3.369	24.000
43	14.462	1.105	89.282	15.572	499.672
44	28.621	1.064	163.691	19.241	499.672
45	14.310	2.490	87.096	13.754	217.820

OFF-DESIGN CASE #7

CYCLE PRESSURE 17.82 ATM
24 G/S 8025 WATTS

LOAD PRESSURE 4 ATM

POINT NO.	TEMP K	PRESS atm	ENTHALPY j/g	ENTROPY j/gK	FLOW g/s
1	294.512	0.840	1544.965	31.851	542.411
2	294.512	2.300	1545.443	29.758	405.535
3	303.000	17.820	1594.599	25.655	971.945
4	77.976	0.922	420.438	24.756	542.411
5	77.976	2.360	420.793	22.802	405.535
6	294.512	1.000	456.432	4.402	146.139
7	78.000	1.077	228.727	2.974	146.139
8	87.000	2.721	49.801	0.662	146.139
9	85.429	17.570	463.551	19.100	971.945
10	80.288	17.520	436.649	18.781	971.945
11	48.059	17.300	266.749	16.101	191.745
12	48.059	17.300	266.749	16.101	971.945
13	48.059	17.300	266.749	16.101	780.201
14	44.484	2.410	246.445	19.836	405.535
15	44.484	0.983	246.346	21.705	542.411
16	29.392	2.460	167.471	17.624	191.745
17	29.257	2.460	166.759	17.600	405.535
18	29.222	2.460	166.578	17.593	213.790
19	30.239	17.070	170.173	13.615	780.201
20	29.257	1.064	167.009	19.355	542.411
21	23.701	17.010	133.188	12.243	213.790
22	23.701	17.010	133.188	12.243	780.201
23	23.701	17.010	133.188	12.243	566.411
24	21.948	2.480	128.166	16.065	213.790
25	21.948	1.085	128.771	17.812	542.411
26	14.471	2.490	87.975	13.815	213.790
27	15.383	16.960	82.511	9.604	566.411
28	14.788	1.105	91.012	15.690	542.411
29	7.884	16.920	32.035	5.140	566.411
30	7.888	16.820	32.035	5.150	566.411
31	6.016	4.150	23.689	5.638	566.411
32	5.438	1.115	38.996	10.027	542.411
33	5.211	4.100	15.715	4.241	566.411
34	4.350	1.125	30.670	8.291	542.411
35	5.211	4.100	15.715	4.241	566.411
36	80.288	17.520	436.649	18.781	971.945
37	4.500	4.000	12.113	3.517	566.411
39	4.500	4.000	12.113	3.517	542.411
40	6.158	4.000	26.908	6.199	542.411
41	4.500	4.000	12.113	3.517	24.000
43	14.918	1.105	91.705	15.737	542.411
44	29.222	1.064	166.829	19.349	542.411
45	14.788	2.490	89.707	13.933	213.790

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