5.13 Check of SABRE Steady-State Initialization and Fuel/Clad Temperature Calculations with Partial Length Fuel Model

In this test problem, a 20-second steady-state calculation is run with the base SABRE input deck for U2C10. This benchmark tests the SABRE steady-state initialization process. In addition, this benchmark problem validates the steady-state fuel heat transfer model used in SABRE. This input deck contains an ATRIUM-10 fuel model. The input deck specifies the number of fuel pins in each of the 25 axial nodes comprising the active core region. The steady-state, code-calculated fuel and clad temperatures at 2 axial locations are checked against hand calculations to verify that FORTRAN coding of the fuel model is correct.

The input deck for this benchmark problem is the same as that listed in Appendix G. This SABRE calculation corresponds to SABRE Case 13 in the Computer Case Summary. The sequence of events computed by SABRE is listed in Table 5.13-1. Table 5.13-2 shows selected SABRE fuel temperature results at t=0.0 seconds of the steady-state run. Also included in Table 5.13-2 are the results of hand calculations carried out below. The good comparison between the results verifies correct coding of the partial length fuel model. The SABRE general output edit for t=0.0 is shown in Table 5.13-3.

Figure 5.13-1 shows plots of reactor power, water level, pressure, and total core flow for the 20-second steady-state run. There are some small fluctuations in the steady-state power results, and the power is slightly above the value of 100% specified in the SABRE input deck, but these variations are small and they would have negligible effect on the results of a transient simulation. Also, the steady downcomer water level is slightly less than the value of +35" specified in the SABRE input deck, but again, the difference is very small. Based on the results plotted in Figure 5.13-1, it is concluded that the SABRE methodology produces an acceptable steady-state condition from which a transient simulation can be initiated. This case (SABRE Case 13) was run using the U2C10 kinetics file (u2c10.simtran.out) which is the output file for SIMTRAN Run#9900341.

The slightly higher steady-state power level and slightly lower steady-state water level (relative to input values) computed by SABRE are a result of the dynamic initialization process discussed in §2.4.3. This initialization process performs temporal integration of the kinetics and thermal-hydraulic equations in order to remove any initial perturbations from the solution prior to beginning the transient calculation. Generally, the dynamic initialization scheme introduces some changes in reactor operating parameters relative to those specified in the SABRE input deck. However, these differences are small, and do not have a significant effect on the predicted transient response of the reactor and containment. For instance, SABRE calculates an initial steady-state core thermal power of 3446 MW versus the value of 3441 specified in the input deck.

Hand Calculation of Fuel and Clad Temperatures

From §3.1.4, the steady-state fuel temperature is given by the simultaneous solution of the following equations:

$$\frac{2k_{f1,j}\left(T_{f1,j}-T_{f2,j}\right)}{\ln\left(\frac{r_{f1}+r_{f2}}{r_{f1}\sqrt{2}}\right)}=r_{f1}^2\,\overline{q}'''_{f1,j} \tag{5.13-1}$$

$$\frac{2k_{f1,j}\left(T_{f1,j}-T_{f2,j}\right)}{\ln\left(\frac{r_{f1}+r_{f2}}{r_{f2}\sqrt{2}}\right)}-\frac{\left(T_{f2,j}-T_{c\ell,j}\right)}{\left[\frac{\left(r_{f2}-r_{f1}\right)}{4\,r_{f2}\,k_{f2,j}}+\frac{1}{2\,r_{ci}\,H_g}+\frac{\left(r_{co}-r_{ci}\right)}{4r_{co}\,k_{c\ell,j}}\right]}=-\left(r_{f2}^2-r_{f1}^2\right)\overline{q}'''_{f2,j}, \tag{5.13-2}$$

$$\frac{\left(T_{f2,j}-T_{c\ell,j}\right)}{\left[\frac{\left(r_{f2}-r_{f1}\right)}{4\,r_{f2}\,k_{f2,j}}+\frac{1}{2\,r_{ci}\,H_g}+\frac{\left(r_{co}-r_{ci}\right)}{4\,r_{co}\,k_{c\ell,j}}\right]}-\frac{\left(T_{c\ell,surf,j}-T_{cool,j}\right)}{\left[\frac{1}{2\,r_{co}\,H_{film,j}}\right]}=0. \tag{5.13-3}$$

and

$$\frac{\left(T_{f2,j}-T_{c\ell,surf,j}\right)}{\left[\frac{\left(r_{f2}-r_{f1}\right)}{4\,r_{f2}\,k_{f2,j}}+\frac{1}{2\,r_{ci}\,H_g}+\frac{\left(r_{co}-r_{ci}\right)}{2\,r_{co}\,k_{c\ell,j}}\right]}-\frac{\left(T_{c\ell,surf,j}-T_{cool,j}\right)}{\left[\frac{1}{2\,r_{co}\,H_{film,j}}\right]}=0 \tag{5.13-4}$$

where

$$q'''_{f,j}(t)=\left[\frac{Q_{fiss}(t)\;S_j(t)}{N_c\;V_{f,j}}+\frac{Q_d(t)\;S_j(0)}{N_c\;V_{f,j}}\right](1-fq_1-fq_2),$$

$$q'''_{f1,j}(t)=C_s\;q'''_{f,j}(t),$$

$$q'''_{f1,j}(t)=(2-C_s)q'''_{f,j}(t),$$

$V_{f,j}$ = volume of fuel in axial control volume j of the active core region (ft^3),

fq_1 = fraction of total core power deposited in active core region as direct moderator heating,

fq_2 = fraction of total core power deposited in bypass region as direct moderator heating,

N_c = number of control volumes in active core region,

$Q_{fiss}(t)$ = total core fission power (Btu/sec),

$Q_d(t)$ = total decay heat generation rate (Btu/sec),

$S_j(t)$ = axial power shape function = (power in node j)/(average nodal power), and

C_s = fraction of pin power generated in inner radial fuel node.

Note that the subscript j defines the axial node (j=1,2,...,N_C). All other variables have been defined previously (see §2.3).

The following parameters are taken from the SABRE input and output files for this case:

Core power = 3446 MW = 3.2689E+06 Btu/sec
Decay Power = (0.07)(3446 MW) = 241.22 MW = 2.2882E+05 Btu/sec
Fission Power = (0.93)(3446 MW) = 3204.78 MW = 3.0401E+06 Btu/sec
fq_1 = 0.015
fq_2 = 0.020
N_C = 25
$V_{f,5} = \pi(0.1707 \text{ in})^2(0.5 \text{ ft})(91 \text{ rods})(764 \text{ bundles})/(144 \text{ in}^2/\text{ft}^2) = 22.098 \text{ ft}^3$
$V_{f,20} = \pi(0.1707 \text{ in})^2(0.5 \text{ ft})(83 \text{ rods})(764 \text{ bundles})/(144 \text{ in}^2/\text{ft}^2) = 20.156 \text{ ft}^3$
r_{f1} = radius of inner radial fuel node = 0.1207 inches = 0.01006 ft
r_{f2} = radius of outer radial fuel node = 0.1707 inches = 0.01423 ft
r_{ci} = radius at inside of cladding = 0.1740 inches = 0.01450 ft
r_{co} = radius at outside of cladding 0.1979 inches = 0.01649 ft
H_g = gap conductance = 1090 BTU/ft²-hr-°F = 0.3028 Btu/ft²-sec-°F
C_s = fuel-pin radial peaking factor due to self-shielding effects = 0.9

The thermal conductivities of UO_2 and Zircaloy-2 are given by the following correlations:†

$$k(UO_2) = \frac{3978.1}{(692.61+T)} + (6.02366x10^{-12})(T+460)^3, \quad \frac{Btu}{hr-ft-{}^oF}$$

and

† Lahey, R.T. and Moody, F.J., *The Thermal-Hydraulics of a Boiling Water Nuclear Reactor*, p. 252, ANS, 1977.

$$k(\text{Zr-2}) = 7.151 + (2.472x10^{-2})T + (1.674x10^{-6})T^2 - (3.334x10^{-10})T^3, \qquad \frac{Btu}{hr - ft - {}^oF}$$

where T is in °F. Using these correlations, the following fuel and clad thermal conductivities are computed and used in the hand calculation.

T (°F)	k(UO$_2$) (Btu/ft-sec-°F)	k(Zr-2) (Btu/ft-sec-°F)
1076.63	6.306E-04	
1197.65	5.922E-04	
847.31	7.213E-04	
908.77	6.943E-04	
573.957		2.516E-03
579.877		2.523E-03

The following constants are defined:

$$a_j = \frac{2k_{f1,j}}{\ln\left(\dfrac{r_{f1}+r_{f2}}{r_{f1}\sqrt{2}}\right)},$$

$$b_j = r_{f1}^2\, \bar{q}'''_{f1,j},$$

$$c_j = \frac{1}{\left[\dfrac{(r_{f2}-r_{f1})}{4\, r_{f2}\, k_{f2,j}} + \dfrac{1}{2\, r_{ci}\, H_g} + \dfrac{(r_{co}-r_{ci})}{4 r_{co}\, k_{c\ell,j}}\right]},$$

$$d_j = \left(r_{f2}^2 - r_{f1}^2\right)\bar{q}'''_{f2,j},$$

$$e_j = \frac{1}{\left[\dfrac{1}{2\, r_{co}\, H_{film,j}}\right]},$$

and

$$f_j = \frac{1}{\left[\dfrac{(r_{f2}-r_{f1})}{4\, r_{f2}\, k_{f2,j}} + \dfrac{1}{2\, r_{ci}\, H_g} + \dfrac{(r_{co}-r_{ci})}{2 r_{co}\, k_{c\ell,j}}\right]}.$$

The constants a_j, b_j, c_j, d_j, e_j, and f_j for nodes 5 and 20 are listed in the table below.

Node	a	b	c	d	e	f
5	2.358E-03	5.416E-01	4.396E-03	6.625E-01	1.041E-01	4.176E-03
20	2.214E-03	6.396E-01	4.322E-03	7.824E-01	1.153E-01	4.109E-03

Solving (5-7) – (5-10) for the clad and fuel temperatures results in

$$T_{cl,surf,j} = T_{cool,j} + \frac{(d_j + b_j)}{e_j},$$

$$T_{cl,j} = T_{cl,surf,j} + (d_j + b_j)\left(\frac{1}{f_j} - \frac{1}{c_j}\right),$$

$$T_{f2,j} = T_{Cl,j} + \frac{d_j + b_j}{c_j},$$

and

$$T_{f1,j} = T_{f2,j} + \frac{b_j}{a_j}.$$

Table 5.13-1
Sequence of Events Calculated by SABRE

```
*** Kinetics file is /d00/appl/sabre3v0/data/u2c10.simtran.out

*** SABRE data file is /home/eamac/sabre_31/input/ec-atws-0505/c13.dat

*** This is not a restart case

1   S A B R E  -  Version 3.1
    (13) Base Case Input Deck (ATRIUM Core) -- 20 sec SS run

 t(sec)=        .000  Low-Pres Condensate Injection Inop.
```

Table 5.13-2
Comparison of SABRE-Calculated Fuel Temperatures Against Hand Calculations

	Core Axial Node 5	Core Axial Node 20
No. of fuel pins	91	83
SABRE Axial Power Factor	1.0413	1.1431
SABRE film coefficient (BTU/sec-ft^2-°F)	3.1558	3.497
SABRE coolant temperature (°F)	547.986	550.535
SABRE fuel temp. for inner radial node (°F)	1076.63	1197.65
Hand-calculated fuel temp. for inner radial node (°F)	1077.56	1197.75
SABRE fuel temp. for outer radial node (°F)	847.31	908.77
Hand-calculated fuel temp. for outer radial node (°F)	847.87	908.89
SABRE clad temp. (°F)	573.957	579.877
Hand-calculated clad temp. (°F)	573.99	579.87
SABRE clad surface temp. (°F)	559.534	562.861
Hand-calculated clad surface temp. (°F)	559.55	562.86

Table 5.13-3
SABRE General Output Edit for t=0

```
1  S A B R E  -  Version 3.1
0   (13) Base Case Input Deck (ATRIUM Core) -- 20 sec SS run

 ** problem time and solver parameters
```

time (sec)	no. of steps	step size (sec)
.00	8000	.0050

0*** 1-D Kinetics Results

Volume No.	Axial Power profile (fiss)	Axial Power profile (decay)	Fast Flux	Therm Flux	AbsXS_Thrm Liq_Boron (cm**-1)
25	.1328	.1344	.126874E+01	.4658443E+00	.00000E+00
24	.3416	.3456	.330460E+01	.9003212E+00	.00000E+00
23	.7643	.7730	.570546E+01	.9586140E+00	.00000E+00
22	.9305	.9407	.730322E+01	.1192712E+01	.00000E+00
21	1.0515	1.0623	.826894E+01	.1347351E+01	.00000E+00
20	1.1217	1.1322	.882119E+01	.1473281E+01	.00000E+00
19	1.1678	1.1773	.911617E+01	.1565077E+01	.00000E+00
18	1.1991	1.2072	.925690E+01	.1632249E+01	.00000E+00
17	1.2165	1.2228	.932422E+01	.1674188E+01	.00000E+00
16	1.2678	1.2722	.940065E+01	.1586635E+01	.00000E+00
15	1.2634	1.2655	.925781E+01	.1600912E+01	.00000E+00
14	1.2498	1.2496	.897398E+01	.1612164E+01	.00000E+00
13	1.2266	1.2243	.861164E+01	.1612762E+01	.00000E+00
12	1.1990	1.1947	.820261E+01	.1606402E+01	.00000E+00
11	1.1669	1.1611	.777185E+01	.1596388E+01	.00000E+00
10	1.1366	1.1298	.733957E+01	.1587441E+01	.00000E+00
9	1.1077	1.1003	.692392E+01	.1579538E+01	.00000E+00
8	1.0826	1.0752	.653663E+01	.1574683E+01	.00000E+00
7	1.0621	1.0549	.618848E+01	.1575442E+01	.00000E+00
6	1.0478	1.0411	.589352E+01	.1583941E+01	.00000E+00
5	1.0413	1.0335	.565621E+01	.1599193E+01	.00000E+00
4	1.0361	1.0289	.544810E+01	.1592021E+01	.00000E+00
3	1.0072	1.0009	.509629E+01	.1500402E+01	.00000E+00
2	.8744	.8693	.408356E+01	.1229887E+01	.00000E+00
1	.3049	.3032	.200493E+01	.9597727E+00	.00000E+00

1*** fuel/clad conditions

volume no.	avg fuel temp (degf)	clad temp (degf)	clad surface temp	heat flux (btu/ft2-sec)	film coefficient (btu/hr-ft2-f)	tcrit (deg f)	t(rewet) (deg f)
25	604.291	556.812	554.776	5.104	4332.0	572.95	643.71
24	688.936	562.561	557.338	13.131	6948.2	572.98	643.71
23	875.730	572.345	560.710	29.376	10392.7	573.07	643.71
22	955.875	575.904	561.762	35.764	11467.0	573.28	643.71
21	1016.839	578.432	562.470	40.414	12189.7	573.53	643.71
20	1053.202	579.877	562.861	43.107	12589.3	573.82	643.71
19	1077.489	580.817	563.111	44.874	12844.8	574.14	643.71
18	1094.123	581.450	563.278	46.071	13014.9	574.48	643.71
17	1103.436	581.801	563.370	46.735	13108.4	574.83	643.71
16	1071.176	580.574	563.047	44.418	12779.3	575.20	643.71
15	1068.952	580.488	563.024	44.256	12756.0	575.59	643.71
14	1062.321	580.232	562.956	43.774	12686.4	575.99	643.71
13	1051.130	579.796	562.840	42.956	12567.2	576.40	643.71
12	1037.888	579.274	562.699	41.981	12423.8	576.81	643.71
11	1022.680	578.668	562.534	40.851	12255.5	577.22	643.71
10	1008.457	578.093	562.377	39.786	12094.6	577.63	643.71
9	995.024	577.544	562.225	38.771	11939.4	578.03	643.71
8	983.456	577.066	562.091	37.891	11803.1	578.44	643.71
7	974.047	576.673	561.981	37.170	11690.3	578.85	643.71
6	967.546	576.400	561.904	36.670	11611.3	579.26	643.71
5	961.964	573.957	559.534	36.445	11360.7	579.42	643.71
4	955.251	570.034	555.656	36.266	11010.0	579.42	643.71
3	938.233	565.946	551.943	35.256	10274.1	579.42	643.71
2	880.306	563.670	551.501	30.609	6868.5	579.42	643.71
1	660.752	549.369	544.686	11.703	3279.7	579.42	643.71

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1volume no.	fuel temp1 (degf)	fuel temp2 (degf)	heat gen (btu/ft3-sec)	heat gen1 (btu/ft3-sec)	heat gen2 (btu/ft3-sec)
25	616.26	592.32	832.02	748.82	915.22
24	722.18	655.70	2140.37	1926.33	2354.41
23	962.42	789.05	4788.56	4309.70	5267.42
22	1067.88	843.88	5829.77	5246.79	6412.74
21	1148.96	884.73	6587.74	5928.96	7246.51
20	1197.65	908.77	7026.83	6324.15	7729.51
19	1230.30	924.69	7314.97	6583.47	8046.47
18	1252.72	935.54	7510.05	6759.05	8261.06
17	1265.29	941.60	7618.55	6856.69	8380.40
16	1221.80	920.57	7240.85	6516.76	7964.93
15	1218.81	919.11	7214.73	6493.25	7936.20
14	1209.89	914.77	7136.31	6422.68	7849.94
13	1194.86	907.41	7003.14	6302.83	7703.45
12	1177.10	898.69	6844.41	6159.97	7528.85
11	1156.75	888.62	6660.56	5994.50	7326.62
10	1137.76	879.17	6487.15	5838.44	7135.87
9	1119.85	870.21	6322.02	5689.82	6954.22
8	1104.46	862.47	6178.78	5560.91	6796.66
7	1091.96	856.15	6061.57	5455.41	6667.72
6	1083.33	851.78	5980.18	5382.16	6578.20
5	1076.63	847.31	5942.64	5348.38	6536.90
4	1068.87	841.64	5913.37	5322.03	6504.71
3	1047.40	829.08	5748.81	5173.93	6323.69
2	971.07	789.55	4990.94	4491.85	5490.03
1	689.71	631.80	1907.91	1717.12	2098.70

1*** steam dome fluid conditions

vol no.	density (lb/ft3)	void fract	temp (deg f)	enthalpy (btu/lb)	w(bubl rise) (lb/sec)	w(stm line) (lb/sec)	w(cond) (lb/sec)	cond eff (%)	w-break (lbm/s)
1	2.351	1.000	550.535	1191.048	.000	3999.253	.000	.000	.00

0*** separator fluid conditions

vol no.	density (lb/ft3)	void fract	temp (deg f)	enthalpy (btu/lb)	boron conc (ppm)	gamma heat (btu/sec)	w-liquid (lb/sec)	w-gas (lb/sec)
1	16.038	.687	550.535	614.689	.000	.000	23786.600	3999.194
							23786.549	3999.201

0*** riser fluid conditions

vol no.	density (lb/ft3)	void fract	temp (deg f)	enthalpy (btu/lb)	boron conc (ppm)	gamma heat (btu/sec)	w-liquid (lb/sec)	w-gas (lb/sec)
1	15.976	.688	550.535	615.072	.000	.000	23786.549	3999.201
							23786.516	3999.208

0*** upper plenum fluid conditions

vol no.	density (lb/ft3)	void fract	temp (deg f)	enthalpy (btu/lb)	boron conc (ppm)	gamma heat (btu/sec)	w-liquid (lb/sec)	w-gas (lb/sec)
3	16.091	.686	550.535	614.362	.000	.000	23786.516	3999.208
2	17.892	.645	550.535	604.433	.000	.000	23786.485	3999.213
1	17.892	.645	550.535	604.433	.000	.000	23786.435	3999.220
							23770.967	4017.730

1*** by-pass fluid conditions

vol no.	density (lb/ft3)	void fract	temp (deg f)	enthalpy (btu/lb)	boron conc (ppm)	gamma heat (btu/sec)	w-liquid (lb/sec)	w-gas (lb/sec)
5	46.308	.000	547.520	546.234	.000	5823.896	3059.043	.000
4	46.417	.000	546.032	544.313	.000	17025.472	3059.109	.000
3	46.732	.000	541.669	538.724	.000	18043.419	3059.195	.000
2	47.060	.000	536.998	532.803	.000	16122.407	3059.281	.000
1	47.346	.000	532.781	527.511	.000	8364.368	3059.360	.000
							3050.581	.000

0*** core fluid conditions

vol no.	density (lb/ft3)	void fract	temp (deg f)	enthalpy (btu/lb)	boron conc (ppm)	gamma heat (btu/sec)	w-liquid (lb/sec)	w-gas (lb/sec)
27	16.136	.685	550.535	614.087	.000	.000	20711.924	4017.730
26	15.349	.703	550.535	619.136	.000	260.673	20711.977	4017.728
25	15.417	.701	550.535	618.677	.000	670.585	20738.540	3991.158
24	15.596	.697	550.535	617.497	.000	1500.270	20806.878	3922.803
23	16.010	.688	550.535	614.863	.000	1826.483	20959.772	3769.876
22	16.543	.675	550.535	611.669	.000	2063.958	21145.907	3583.696
21	17.186	.661	550.535	608.076	.000	2201.527	21356.239	3373.312
20	17.927	.644	550.535	604.259	.000	2291.802	21580.583	3148.906
19	18.765	.625	550.535	600.303	.000	2352.922	21814.118	2915.301
18	19.707	.603	550.535	596.257	.000	2386.915	22053.870	2675.469
17	20.762	.579	550.535	592.165	.000	2487.238	22297.072	2432.176
16	21.985	.551	550.535	587.910	.000	2478.265	22550.478	2178.663
15	23.354	.520	550.535	583.677	.000	2451.328	22802.949	1926.071
14	24.887	.485	550.535	579.488	.000	2405.585	23052.651	1676.232
13	26.574	.446	550.535	575.439	.000	2351.061	23297.666	1431.064
12	28.468	.403	550.535	571.462	.000	2287.908	23537.096	1191.462
11	30.630	.353	550.535	567.527	.000	2228.343	23770.055	958.308
10	33.082	.297	550.535	563.684	.000	2171.620	23996.903	731.236
9	35.932	.232	550.535	559.878	.000	2122.418	24217.922	509.958
8	39.263	.156	550.535	556.129	.000	2082.153	24433.861	293.708
7	43.276	.064	550.535	552.379	.000	2054.198	24645.614	81.576
6	46.273	.000	547.986	546.835	.000	2041.302	24726.688	.000
5	46.580	.000	543.798	541.444	.000	2031.248	24726.666	.000
4	46.879	.000	539.589	536.080	.000	1974.720	24726.645	.000
3	47.165	.000	535.458	530.865	.000	1714.393	24726.627	.000
2	47.409	.000	531.841	526.337	.000	597.755	24726.613	.000
1	47.493	.000	530.573	524.758	.000	.000	24726.613	.000
							27777.214	.000

1*** lower plenum fluid conditions

vol no.	density (lb/ft3)	void fract	temp (deg f)	enthalpy (btu/lb)	boron conc (ppm)	gamma heat (btu/sec)	w-liquid (lb/sec)	w-gas (lb/sec)
2	47.493	.000	530.572	524.757	.000	.000	27777.214	.000
1	47.490	.000	530.627	524.825	.000	.000	27777.461	.000
							27777.662	.000

0*** jet pump fluid conditions

vol no.	density (lb/ft3)	void fract	temp (deg f)	enthalpy (btu/lb)	boron conc (ppm)	gamma heat (btu/sec)	w-liquid (lb/sec)	w-gas (lb/sec)
0	47.486	.000	530.683	524.895	.000	.000	27777.696	.000
							27777.662	.000

0*** downcomer fluid conditions

vol no.	density (lb/ft3)	void fract	temp (deg f)	enthalpy (btu/lb)	w(inject) (lb/sec)	h(inject) (btu/lb)	subcool (btu/lb)	mixture lvl (inches)	w-break (lbm/s)	boron (ppm)
1	47.486	.000	530.682	524.894	3993.740	374.333	25.251	34.963	.00	.00

0*** pressure drop results

	jet pump	lower plenum	core	by-pass	upper plenum	riser	separator
			.80	10.07	.00	1.73	4.27
inlet (psi)	11.01	.00	.32	.00	.00	.00	.00
outlet (psi)	1.17	5.35	3.00	4.83	.60	1.13	.69
elevation (psi)	-5.44	2.29	6.41	.00	.01	1.92	.40
wall frict (psi)	1.67	.02	3.43				
spac frict (psi)			1.00	.00	.06	.04	-.01
spacial acc (psi)	.00	.00					

1*** misc. reactor parameters

downcomer subcooling (btu/lbm)	=	25.251
downcomer collapsed level (inch)	=	34.963
steam dome pressure (psia)	=	1049.997
steam dome fluid volume (ft3)	=	8622.250
downcomer fluid volume (ft3)	=	5711.750
pressure regulator setpoint (psia)	=	966.623
downcomer bubble rise vel (ft/sec)	=	1.147
steam flow exiting vessel (lbm/sec)	=	3999.253
number of srvs open	=	0
steam condensation rate (lbm/sec)	=	.000
condensation efficiency	=	.000
core power (mw)	=	3446.07
core power (% of rated)	=	100.15
core inlet flow (mlb/hr)	=	89.02
by-pass inlet flow (mlb/hr)	=	10.98
total vessel fluid mass (lbm)	=	515884.77
crd outlet enthalpy (btu/lbm)	=	525.02

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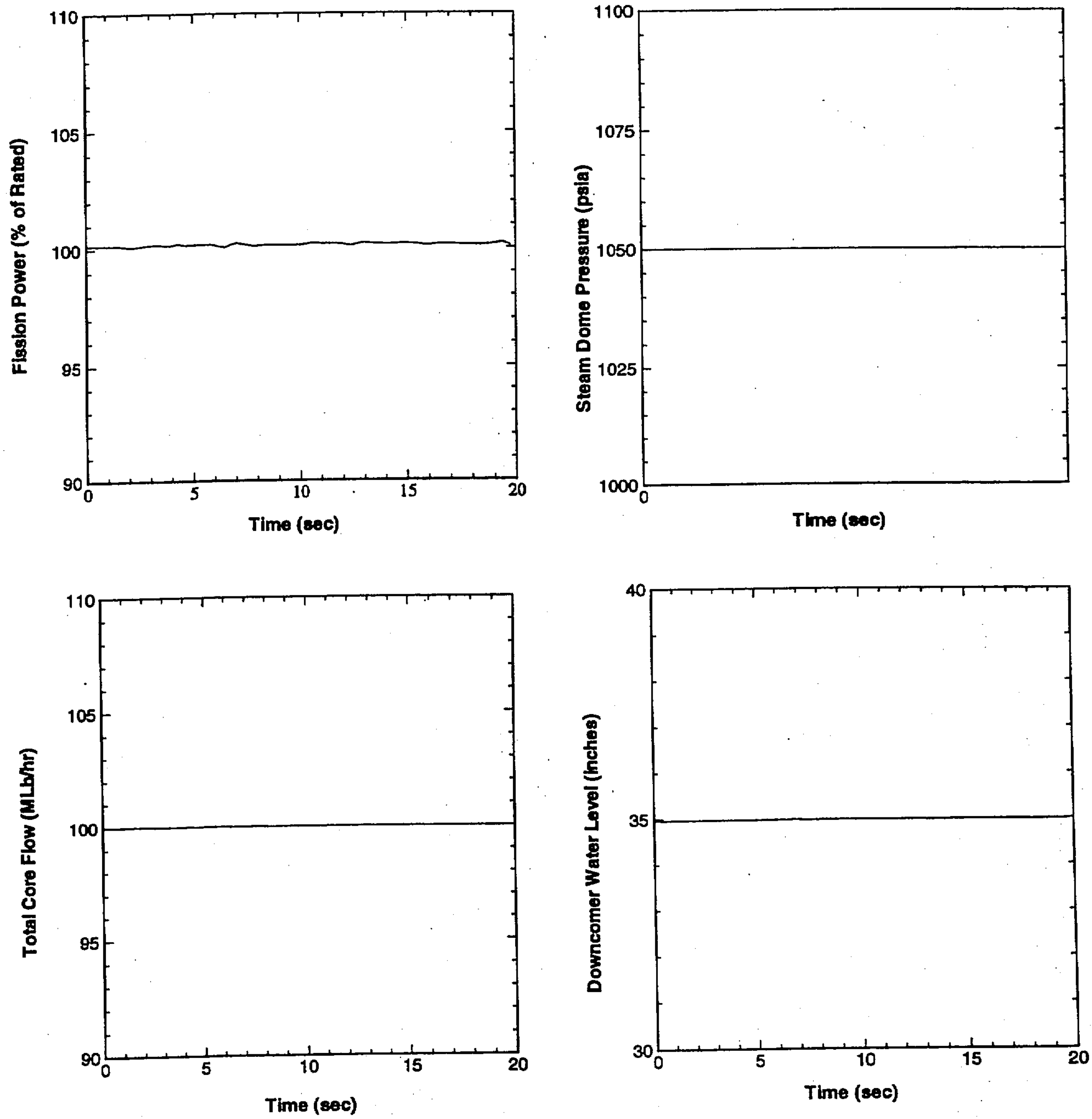

Figure 5.13-1 SABRE results for 20-second steady-state run.
(SABRE Case 13)

5.14 MSIV-Closure ATWS with SLCS Failure—Shutdown with MRI

An MSIV closure ATWS is initiated from nominal operating conditions (3441 MWt, 100 MLb/hr, and 1050 psia). The operating cycle is U2C10. In this event, the SLCS is assumed to fail, and reactor shutdown is achieved by manual rod insertion (MRI). MSIV closure is initiated at t=0, and it is assumed that the operator initiates MRI at 5 min (300 sec) into the event. The control rod insertion rate is specified at 90 sec/rod. Calculation results for SABRE Version 3.1, which uses a one-dimensional kinetics model with multiple cross-section sets to model the decay of fission power as control rods are inserted, are compared against results from SABRE Version 2.4 which employs a point kinetics model and inserts negative reactivity at a constant rate to simulate control rod insertion.

Changes made to the base 10x10 SABRE reactor model documented in Appendix G of this calculation package are shown in Table 5.14-1. The sequence of events calculated by SABRE (Version 3.1) are listed in Table 5.14-2. The SABRE 3.1 calculation corresponds to SABRE Case 14 in the Computer Case Summary, and the SABRE 2.4 calculation corresponds to SABRE Case 14a in the Computer Case Summary.

Figures 5.14-1 and 5.14-2 show that the 1-D kinetics model predicts a slower shutdown of the reactor compared to the points kinetics model. SABRE 3.1, with 1-D kinetics, predicts that the reactor becomes subcritical when ~45 control rods are inserted. With the point-kinetics version of SABRE (Version 2.4) the reactor becomes subcritical with the insertion of about 35 control rods. Plots of suppression pool temperature, drywell pressure, and drywell temperature show that the ATWS event predicted with the 1-D kinetics model is considerably more severe than that predicted by the point kinetics version of the code.

In scenarios involving MRI, the 1-D kinetics model in SABRE simulates reactor shutdown by interpolating between cross-section sets of differing control rod density as control rods are inserted. For U2C10, these cross-section sets consist of (see §2.4.8):

1. all rods out,
2. 4 rods inserted,
3. 8 rods inserted,
4. 16 rods inserted,
5. 32 rods inserted,
6. 64 rods inserted, and
7. all rods in.

In the point-kinetics version of SABRE, control rod insertion was modeled by using a constant negative reactivity insertion rate. The reactivity insertion rate in SABRE 2.4 was determined from the difference in k_{eff} between an all rods out core configuration and a core with a black and white rod pattern. Evidently, the simplistic approach used in SABRE 2.4 overpredicts the rate of reactor shutdown due to manual rod insertion.

In order to check the accuracy of the SABRE MRI model which uses multiple cross section sets to simulate control rod insertion, a SIMULATE run was made with 16 rods inserted (SIMULATE Run #0002019 in Computer Case Summary). The 16 control rods were inserted in the same pattern as in cross section set #4 mentioned above. The core channel flow and reactor pressure that were specified in the SIMULATE calculation were taken from the SABRE output at the time that the 16 rods were inserted (1740 seconds). The core inlet subcooling was specified as zero since downcomer water level is well below the feedwater spargers at this time (see Figure 5.14-2). From the output of SABRE Case 14, the reactor pressure and core channel flow at t~1740 are ~1080 psia and 14.4 MLb/hr. In the SIMULATE input file which is shown in Table 15.4-3, the total core flow rate is specified as 10.96 MLb/hr (2.74x4). In the SIMULATE output, the core channel flow is 14.4 MLb/hr which matches with the SABRE value of 14.4 MLb/hr. The target k_{eff} for U2C10 at the exposure point of interest is 1.00547 (see output for first stacked case of Run #9904113). The value of k_{eff} in the output for Run #0002019 is 1.00544 which is acceptably close to the target value. At the specified conditions, SIMULATE predicts a critical core power of 495.2 MW_{th} which corresponds to 14.4% power. This SIMULATE core power is plotted in Figure 5.14-3 which shows the details of the SABRE-calculated core thermal power response. It can be seen that the SIMULATE result agrees well with the SABRE 1-D power calculation and is considerably higher than the point kinetics result. The 'mem' file for the SIMULATE MRI case is given in Table 15.4-4.

Table 5.14-1
Changes Made to Base SABRE 10x10 Input Deck in Appendix G

Parameter	New Value
Problem end time (F.2.1)	7200 seconds
Time step data (F.3)	Max = 5 msec Min = 5. msec(t<30) Max = 30 msec Min = 30 msec (30<t)
Status of scram system (F.19.1)	-1 (scram and ARI are failed)
Minimum HPCI flow (F.20.10)	250 gpm (lowered from 500 to 250 gpm so level will stay in control band for longer period of time as reactor shuts down)
Time at which operator takes control of HPCI injection (F.20.14)	500 sec
HPCI target level table (F.20.15)	Target water level = -85 inches (middle of EOP target band)
Time at which operator takes control of RCIC injection (F.21.12)	500 sec
RCIC target level table (F.21.13)	Target water level = -85 inches (middle of EOP target band)
MSIV closure on specified time (F.25.1)	0.0 seconds
Time at which MRI is initiated (F.28.1)	300 seconds
Time at which Loop 1 of SPC becomes effective (F.50)	1000 seconds (Table A.2.1 of Ref.2
Time at which Loop 2 of SPC becomes effective (F.51)	1000 seconds (Table A.2.1 of Ref.2)

[2] GENE-637-024-0893, "Evaluation of Susquehanna ATWS Performance for Power Uprate Conditions," 9/93.

Table 5.14-2
Sequence of Events Calculated by SABRE

```
*** Kinetics file is /d00/appl/sabre3v0/data/u2c10.simtran.out

*** SABRE data file is /home/eamac/sabre_31/input/ec-atws-0505/c14.dat

*** This is not a restart case

1   S A B R E  -  Version 3.1
    (14) U2C10 -- MSIVC ATWS - No SLCS - SD w MRI


 t(sec)=       .000  Scram is Failed

 t(sec)=       .000  Low-Pres Condensate Injection Inop.

 t(sec)=       .000  ARI is Failed

 t(sec)=       .000  MSIV closure on specified time

 t(sec)=      4.005  MSIVs are closed

 t(sec)=      4.345  Recirc pump-A trip on hi Rx press.
                     Setpoint for trip =      1135.00 psig
                     Trip delay =     .230E+00 sec.

 t(sec)=      4.345  Recirc pump-B trip on hi Rx press.
                     Setpoint for trip =      1135.00 psig
                     Trip delay =     .230E+00 sec.

 t(sec)=    110.953  Feedwater Trip on low Stm Line Press
                     Flow stops when press <       175.00 psia

 t(sec)=    114.133  HPCI Suction Trans to SP on high SP level
                     SP water level =    23.83 ft

 t(sec)=    126.313  Level Setpoint Setdown
                     Setdown occurs when level drops to        13.00 in.
                     Delay for setpoint setdown =      .11E+02 sec

 t(sec)=    160.723  HPCI initiation on Low water level
                     Setpoint for initiation =       -38.00 in.

 t(sec)=    160.723  RCIC initiation on low water level
                     Setpoint for initiation =       -38.00 in.

 t(sec)=    300.013  Manual Rod Insertion initiated
                     Insertion Rate =       90.000 sec/rod

 t(sec)=    500.023  Operator takes control of HPCI inj.

 t(sec)=    500.023  Operator takes control of RCIC inj.

 t(sec)=   1000.003  Loop 1 of Supp Pool Cool Effective
                     Service Water Temperature =        88.00 F

 t(sec)=   1000.003  Loop 2 of Supp Pool Cool Effective
                     Service Water Temperature =        88.00 F

 t(sec)=   1000.033  DW Cooler Trip on Hi DW Press
                     Trip Setpoint     =         1.720 psig
```

Table 5.14-3
SIMULATE Input File for Run #0002019 – Check of SABRE MRI Model

```
15 15 25  5  0  0  0  0  0 15 16216 43172 24200100 10 80  0  0  0  0  0mcas2920
 2  0  2  0  0  2  2  2  2  2  2  2  2  2  2
ddisk MRI-CHECK (U2C10) ATWS (16  Rods In)
                    BEGEXP ENDEXP DELEXP POWER   WT   SUB   PRES
       1            15.200 15.200 00.000 123.8  2.74  0.0   1080

                     (1)  Execute INPUT & NUCLER
       2                  0

                     (2)  1=Initialize Hailing to present distrib & reset to 2
                     (7)  0=input value of subcool used to calc density
      20            S1    1
      20            S4    0

                     (3)  0=Use restart Xe  2=Use equil Xe
      21            S2    0

                     (5)  Search Option  0=No Search  2=Pwr Search  7=use file power distr
      21            S1    0

                     (9)  0=No DP Calc   3=Detl FIBWR   4=Apprx FIBWR
      21            S3    3

                     (27) 0=Control blade depletion has no effect
      21            S17   0

      30   8  S7  -- -- -- -- -- -- -- --
      30   9  S7  -- 00 -- 00 -- -- -- --
      30  10  S7  -- -- -- -- -- -- -- --
      30  11  S7  -- 00 -- 00 -- -- -- --
      30  12  S7  -- -- -- -- -- -- --
      30  13  S7  -- -- -- -- -- --
      30  14  S7  -- -- -- -- --
      30  15  S7  -- -- -- --
      99
ILAST
```

Table 15.4-4
Mem File for SIMULATE Run #0002019 – Check of SABRE MRI Model

```
1 /users/chaiko/SIMULATE/mri.simulate.out
2 *none*
3 *none*
4 *none*
5 *none*
6 3
7 MRI-CHECK (U2C10) SIMULATE EC-ATWS-0505 Rev 7
8 M A Chaiko  A6-3  Box 31
9 *none*
11
1 medium
2 *now*
3 *none*
4 *all*
5
1 *none*
2 /users/chaiko/SIMULATE
3 /users/chaiko/SIMULATE/mri.simulate.in
4 /users/chaiko/SIMULATE/r9808566.0001
5 *none*
6 *none*
7 /users/chaiko/SIMULATE/mri.simulate.restart
8 *none*
```

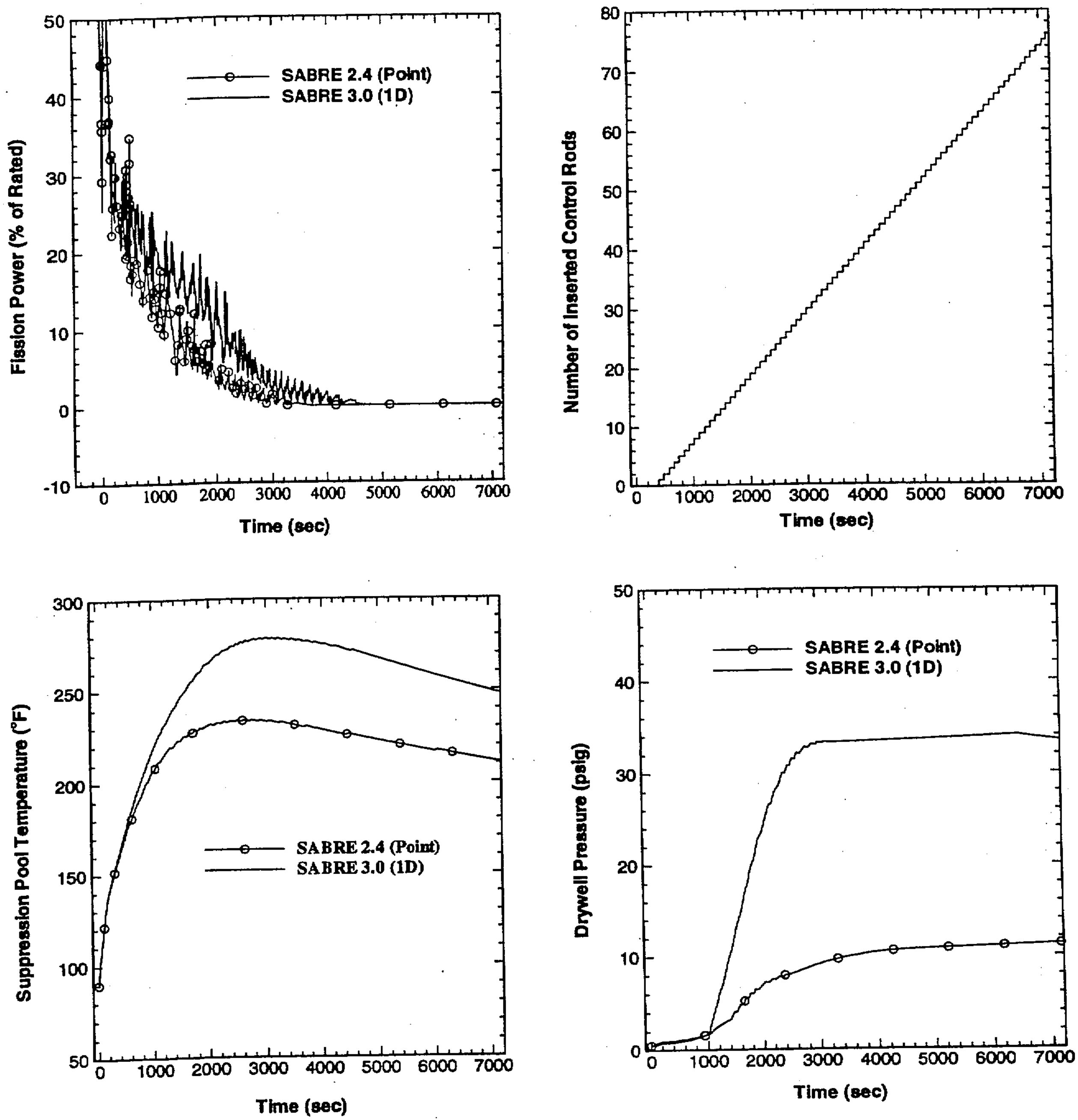

Figure 5.14-1 Comparison of SABRE 3.0 (1D kinetics) and SABRE 2.4 (point kinetics) for U2C10 MSIV closure ATWS with SLC system failure. Shutdown by manual rod insertion (MRI). (SABRE Cases 14 and 14a)

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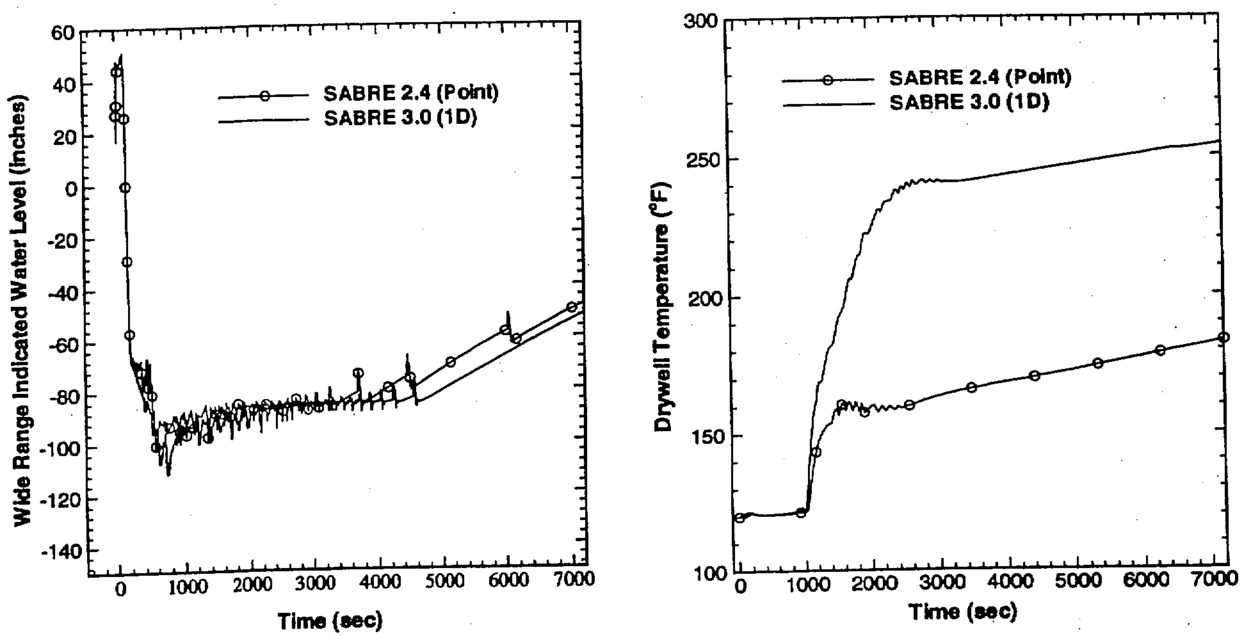

Figure 5.14-2 Comparison of SABRE 3.0 (1D kinetics) and SABRE 2.4 (point kinetics) for U2C10 MSIV closure ATWS with SLC system failure. Shutdown by manual rod insertion (MRI). (SABRE Cases 14 and 14a)

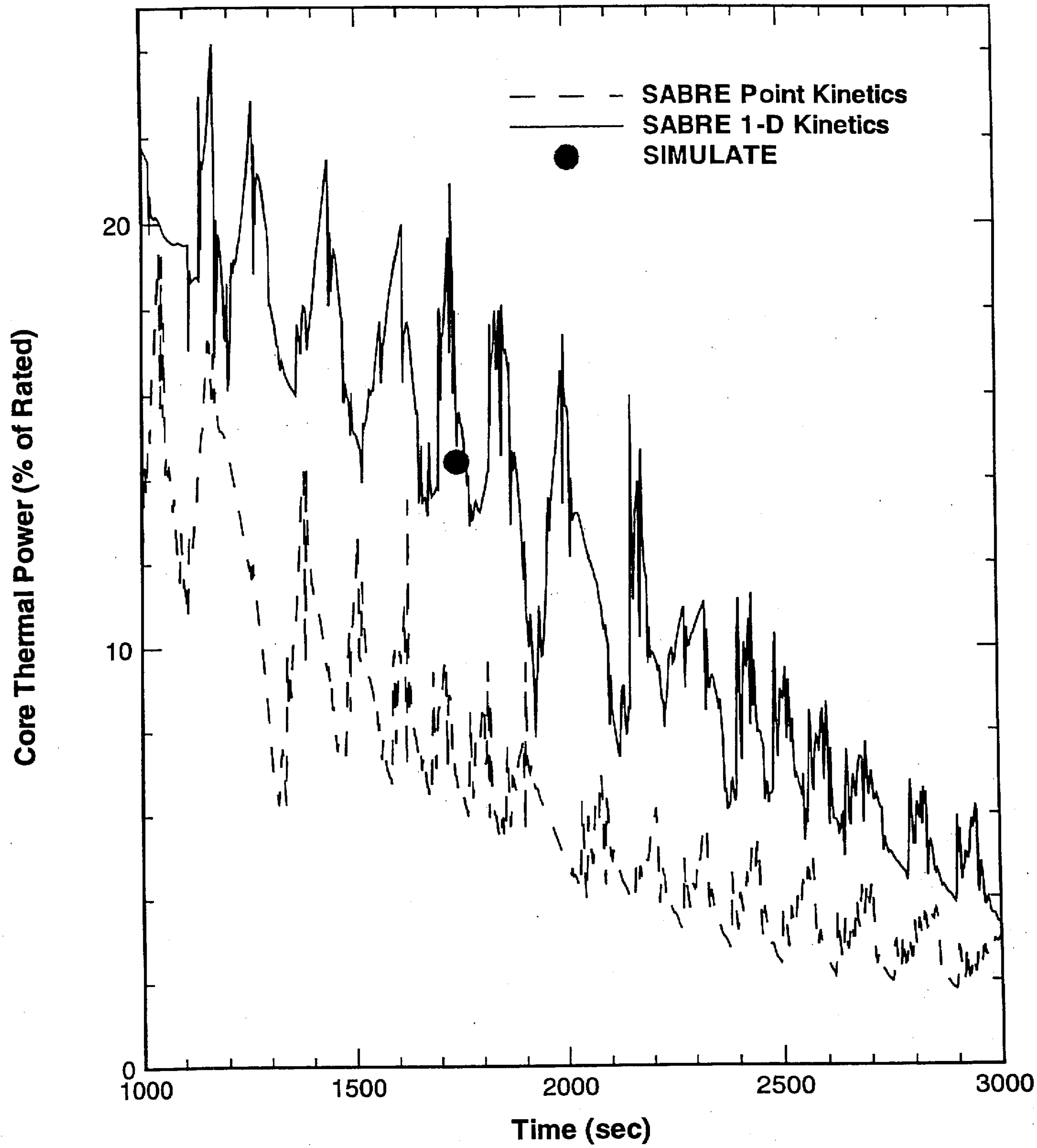

Figure 5.14-3 Comparision of SIMULATE power calculation against SABRE for case of 16 inserted rods.

5.15 Drywell Temperature Response for Small Steam Break

A small steam break is initiated at t=0. The break flow is specified as 212 Lbm/sec and the enthalpy of the steam is specified as 1190 Btu/Lbm. The event is initiated from nominal operating conditions (3441 MWt, 100 MLb/hr, and 1050 psia). The operating cycle is U2C10. In this event, the reactor vessel heat load and the drywell cooling load are both set to zero. The heat transfer to drywell steel structures is neglected by setting the heat transfer areas to very small numbers. Changes made to the base 10x10 SABRE reactor model documented in Appendix G of this calculation package are shown in Table 5.15-1. The SABRE calculation corresponds to SABRE Case 15 in the Computer Case Summary.

For this scenario, the drywell temperature response is governed by the following mass and energy balance equations:

$$\frac{dM_S}{dt} = W_{break} - x_S W_{DC} \tag{5.15-1}$$

$$\frac{dM_N}{dt} = -(1 - x_S) W_{DC} \tag{5.15-2}$$

$$\frac{d\left[M_S h_S(P_S, T_{DW}) - M_S P_S \upsilon_S + M_N C_{VN} T_{DW}\right]}{dt} = W_{break} h_{break} - x_S W_{DC} h_S \tag{5.15-3}$$

where

t =time (sec),
M_S =mass of steam in the drywell (Lbm),
M_N =mass of nitrogen in the drywell (Lbm),
W_{break} =break flow (Lbm/sec),
h_{break} =break enthalpy (Btu/Lbm),
W_{DC} =mass flow rate through downcomer vents (Lbm/sec),
y_S =mass fraction of steam in the drywell,
h_S =enthalpy of steam in the drywell (Btu/Lbm),
P_S =partial pressure of steam in the drywell (psia),
T_{DW} =drywell temperature (°F),
υ_S =specific volume of steam in the drywell (ft³/Lbm),
C_{VN} =constant-volume specific heat of nitrogen at drywell temperature (Btu/Lbm-°F),

From the input and initial conditions for the SABRE calculation, the following data is obtained for the solution of (5.15-1) and (5-15.2):

$T_{DW}(0) = 120$ °F,

$M_S(0) = 563.34$ Lbm,
$M_N(0) = 15517.03$ Lbm
V_{DW} = drywell free volume = 239,600 ft^3,
$P_{DW}(0) = 15.2$ psia

For the first 8 seconds of the transient, there is no flow through the downcomer vents. Since the break flow and enthalpy are constant, the drywell temperature can be determined by integrating (5.15-1) and (5.15-3). The drywell temperature at each time step of the integration is computed using the Ideal Gas Law for steam partial pressure and the ASME steam table routine hss for superheated enthalpy. The FORTRAN program used to compute the drywell temperature for the first 8 seconds of the transient is listed in Table 5.15-3. After about 15 minutes the drywell temperature approaches a steady-state value. At this time, nearly all of the N_2 in the drywell has been transferred to the suppression chamber, so $x_S \approx 1$ in (5.15-3). Also, at this time $W_{break} \approx W_{DC}$, therefore the energy balance becomes

$$h_{break} - h_S(P_S, T_{DW}) = 0 \tag{5.15-4}$$

As a further check on the SABRE calculation, the drywell temperature at t=15 min is obtained by solving (5.15-4). In solving (5.15-4), the SABRE-calculated drywell pressure at t=15 min is used to obtain P_S.. Solution of (5.15-4) is also performed with the FORTRAN code listed in Table 5.15-3. SABRE result for drywell temperature are compared against the solutions to (5.15-1), (5.15-3), and (5.15-4) in Figure 5.15-1. As can be seen from the Figure there is good agreement between the SABRE results and the solutions to the mass/energy balance equations presented above.

Table 5.15-1
Changes Made to Base SABRE 10x10 Input Deck in Appendix G

Parameter	New Value
Problem end time (F.2.1)	900 seconds
LOCA data (F.18)	Steam break specified via break flow and enthalpy versus time table. Break flow is 212. Lbm/sec and break enthalpy is 1190. Lbm/sec.
Initial heat load from RPV to drywell (F.55)	1.E-12 Btu/sec
Initial drywell cooling load (F.56)	1.E-12 Btu/sec
Surface area of drywell steel structures (F.67)	17870.E-12 ft^2 1039.E-12 ft^2 6082E-12 ft^2 66000.E-12 ft^2
Surface area of wetwell steel structures (F.69)	8156.E-12 ft^2 30048.E-12 ft^2

Table 5.15-2
Sequence of Events Calculated by SABRE

```
*** Kinetics file is /d00/appl/sabre3v0/data/u2c10.simtran.out

*** SABRE data file is /home/eamac/sabre_31/input/ec-atws-0505/c15.dat

*** This is not a restart case

1   S A B R E  -  Version 3.1
    (15) Small steam break

 t(sec)=        .000  Low-Pres Condensate Injection Inop.

 t(sec)=        .000  LOCA Table used for break data
                      LOCA Table ends at      =     .100E+10 sec

 t(sec)=       2.213  Scram on high drywell pressure
                      Setpoint(psig) =      .17E+01
                      Scram time (sec) =         2.80

 t(sec)=       2.213  HPCI initiation on Hi Drywell Press.
                      Setpoint for initiation =      .17E+01 psig

 t(sec)=       2.213  DW Cooler Trip on Hi DW Press
                      Trip Setpoint      =        1.720 psig

 t(sec)=       5.033  All Control Rods Inserted

 t(sec)=       6.653  Level Setpoint Setdown
                      Setdown occurs when level drops to        13.00 in.
                      Delay for setpoint setdown =      .11E+02 sec

 t(sec)=       6.653  Recirc pump-A runback on low Rx lvl
                      Setpoint for Runback =        13.00 in.
                      Trip delay =     .300E+01 sec

 t(sec)=       6.653  Recirc pump-B runback on low Rx lvl
                      Setpoint for Runback =        13.00 in.
                      Trip delay =     .300E+01 sec

 t(sec)=      28.463  MSIV closure on low reactor pressure
                      Setpoint(psia) =       875.700

 t(sec)=      32.483  MSIVs are closed

 t(sec)=      36.383  Main Turb Trip on high water level
                      Setpoint(inches) =        54.000

 t(sec)=      36.383  HPCI Trip on hi water level
                      Trip Setpoint =       .54E+02 in.

 t(sec)=      42.563  Feedwater Trip on high level
                      Trip Setpoint =       .54E+02 in.

 t(sec)=     515.453  HPCI initiation on Low water level
                      Setpoint for initiation =       -38.00 in.

 t(sec)=     515.453  RCIC initiation on low water level
                      Setpoint for initiation =       -38.00 in.

 t(sec)=     515.453  Recirc pump-A Trip on low Rx level
                      Setpoint for Trip =        -38.00 in.
                      Trip delay =     .900E+01 sec.

 t(sec)=     515.453  Recirc pump-B Trip on low Rx level
                      Setpoint for Trip =        -38.00 in.
                      Trip delay =     .900E+01 sec.
```

t(sec)=	661.959	Initiation of Core Spray Flow Reactor Press = 319.49 psig Supp Chamber Press = 30.49 psig
t(sec)=	682.037	RCIC Trip on hi water level Trip Setpoint = .54E+02 in.
t(sec)=	682.037	HPCI Trip on hi water level Trip Setpoint = .54E+02 in.

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Table 5.15-3
FORTRAN Code Used to Solve
Mass/Energy Balance Equations (5.15-1), (5.15-3), and (5.15-4)

```
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 Ms1,Ms2,Mn1
      COMMON /data1/ R,R1,omegas,T1,Ms1,
     &               Ms2,vs1,vs2,hs1,ps1,Cvn1,
     &               Mn1,dt,hb,Wb,whb2,Pfin
      OPEN (UNIT=7, FILE='check.out',STATUS='UNKNOWN',
     &      ACCESS='APPEND' )
C**** Inputs
      R=10.731
      R1=1.9872
      omegas=18.
      T1=120.
      Cvn1 = an2cp(T1)-R1/28.D0
      Ms1=563.34
      Mn1=15517.03
      Xs1=0.053455
      P1=15.2
      ps1=Xs1*P1
      hs1=HSS(ps1,T1,dum1,vs1)
      Cvn=0.1774
      Wb=212.
      hb=1190.
      Vdw=239600.
      Pfin=49.80
C**** Compute DW Temp as function of t (sec)
      t=0.D0
      dt =1.0
      Ms2 = Ms1
      vs2 = Vdw/Ms2
      whb2 = 0.D0
   50 CONTINUE
      KOUNT=0
C**** trap zero
      Ta=100.
      Tb=500.
      fa=fun(Ta)
      fb=fun(Tb)
      IF ( fa*fb .GT. 0.D0 ) THEN
         PAUSE 'Zero not trapped'
         STOP
      END IF
  100 CONTINUE
      KOUNT=KOUNT+1
      Tc=(Ta+Tb)*0.5
      fc=fun(Tc)
C**** Check for divergence
      IF (KOUNT .GT. 100 ) THEN
         PAUSE 'Solution would not converge'
      END IF
C**** Check for convergence
      IF ( DABS(fc) .LT. 1.D-05 ) GOTO 150
      IF ( fa*fc .LT. 0.D0 ) THEN
         fb=fc
         Tb=Tc
         GOTO 100
      ELSE
         fa=fc
         Ta=Tc
         GOTO 100
      END IF
  150 CONTINUE
C**** Print the temperature
      WRITE(*,101) t,Tc
      WRITE(7,101) t,Tc
  101 FORMAT( 2F15.5 )
```

```
C**** Do another time step
      t=t+dt
      Ms2 = Ms2 + Wb*dt
      vs2 = Vdw/Ms2
      whb2 = whb2 + dt*Wb*hb
      IF ( t .GT. 8.01 ) GOTO 900
      GOTO 50
C**** Transient Problem finished
C**** Compute final temp
  900 CONTINUE
      KOUNT=0
      Ta=100.
      Tb=500.
      fa=fun1(Ta)
      fb=fun1(Tb)
C**** Check if zero is trapped
      IF ( fa*fb .GT. 0.D0 ) THEN
         PAUSE 'Zero not trapped in calc of Tfin'
         STOP
      END IF
  910 CONTINUE
      KOUNT=KOUNT+1
      IF ( KOUNT .GT. 100 ) THEN
         PAUSE 'Could not converge to Tfin'
         STOP
      END IF
      Tc=0.5*(Ta+Tb)
      fc=fun1(Tc)
C**** Check for convergence
      IF ( DABS(fc) .LT. 1.D-05 ) GOTO 950
      IF (fa*fc .LT. 0.D0 ) THEN
         fb=fc
         Tb=Tc
         GOTO 910
      ELSE
         fa=fc
         Ta=Tc
         GOTO 910
      END IF
  950 CONTINUE
      WRITE(*,101) 900.,Tc
      WRITE(7,101) 900.,Tc
      STOP
      END

      FUNCTION fun(T2)
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 Ms1,Ms2,Mn1
      COMMON /data1/ R,R1,omegas,T1,Ms1,
     &               Ms2,vs1,vs2,hs1,ps1,Cvn1,
     &               Mn1,dt,hb,Wb,whb2,Pfin
      Cvn2 = an2cp(T2)-R1/28.D0
      a=144.*9.486E-04/0.7376
      Ps2=R*(T2+459.67) / (vs2*omegas)
      hs2=HSS( ps2, T2, dum1, dum2 )
      fun= Mn1*( Cvn2*T2 - Cvn1*T1 )
      fun= fun + Ms2*( hs2 - ps2*vs2*a )
      fun= fun - Ms1*( hs1 - ps1*vs1*a )
      fun= fun - whb2
      RETURN
      END

      FUNCTION fun1(T)
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 Ms1,Ms2,Mn1
      COMMON /data1/ R,R1,omegas,T1,Ms1,
     &               Ms2,vs1,vs2,hs1,ps1,Cvn1,
     &               Mn1,dt,hb,Wb,whb2,Pfin
      fun1 = HSS( Pfin, T, dum1, dum2 )
     &     - hb
      RETURN
```

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```
      END

      FUNCTION an2cp(temp)
c calculates n2 cp (btu/lbm-f) from temperature (degf)
c equation for cp is from table-d of chemical process principles
c by hougen, watson, and ragatz, wiley, 1959.
      implicit real*8(a-h,o-z)
      data   a,b,c,d / 6.903d0, -.03753d-2, 0.1930d-5, -0.6861d-9 /
      tk=5.d0*( temp-32.d0 )/9.d0 +273.15d0
      cp=a+b*tk+c*tk**2+d*tk**3
      an2cp=cp/28.0d0
      return
      end
```

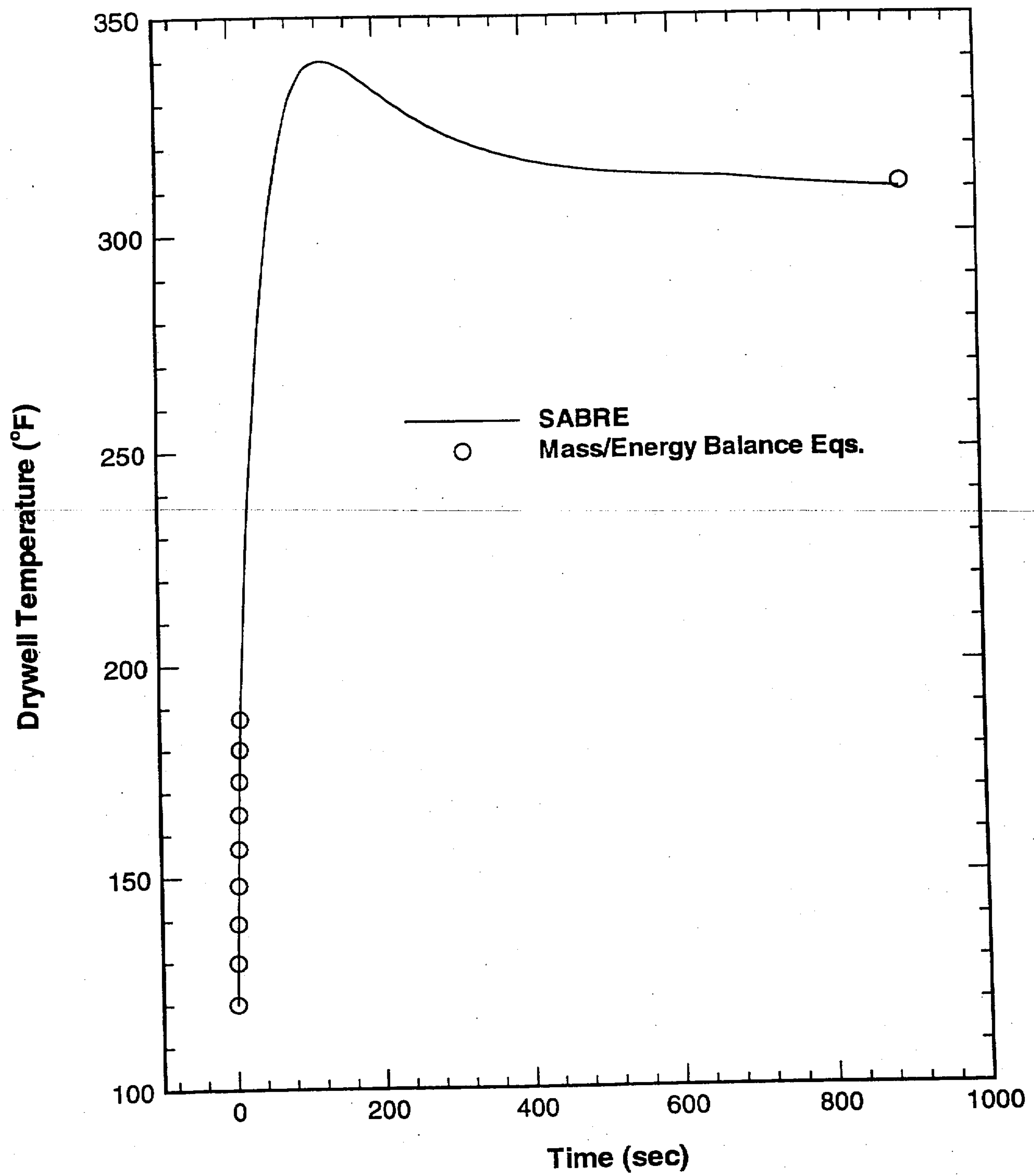

Figure 5.15-1 Comparison of SABRE-calculated drywell temperature against solution to energy balance equations (Eqs. 5.15-1, 5.15-3, and 5.15-4) for small steam break accident.

APPENDIX-A

Derivation of Downcomer and Steam Dome Mass and Energy Balances

A.1 Downcomer Region

For the downcomer region, the fluid mass balance is given by

$$\frac{dM_{DC}}{dt} = W_{inj} + W_{cond} + W_{\ell S}(L_S, t) - W_J(0,t) - W_{vs} - W_{break} \quad \text{(A-1)}$$

where $M_{DC}(t)$ is the downcomer fluid mass, W_{inj} is the injection flow rate, W_{cond} is the rate of steam condensation occurring on the cold make-up flow [see Eq. (2.2-5)], $W_{\ell S}(L_S, t)$ is the liquid flow rate at the separator exit, $W_J(0,t)$ is the flow rate at the jet pump inlet, W_{VS} is the vapor separation rate from the downcomer due to bouancy effects, and W_{break} is the break flow used in modeling a Loss-of-Coolant Accident (LOCA).

The equation of state for the downcomer region can be expressed as

$$\rho_{DC} = \rho_{DC}\left(P^*, \bar{h}_{DC}\right) \quad \text{(A-2)}$$

where P* is the system pressure, and $\bar{h}_{DC}$ is the volume-weighted enthalpy.

Using (A-2), the term dM_{DC}/dt in (A-1) can be expressed as

$$\frac{dM_{DC}}{dt} = \frac{d(V_{DC}\,\rho_{DC})}{dt} = \rho_{DC}\frac{dV_{DC}}{dt} + V_{DC}\frac{\partial \rho_{DC}}{\partial \bar{h}_{DC}}\frac{d\bar{h}_{DC}}{dt} + V_{DC}\frac{\partial \rho_{DC}}{\partial P^*}\frac{dP^*}{dt}. \quad \text{(A-3)}$$

Substitution of (A-3) into (A-1) leads to

$$\rho_{DC}\frac{dV_{DC}}{dt} + V_{DC}\frac{\partial \rho_{DC}}{\partial \bar{h}_{DC}}\frac{d\bar{h}_{DC}}{dt} + \left(V_{DC}\frac{\partial \rho_{DC}}{\partial P^*}\right)\frac{dP^*}{dt} = W_{inj} + W_{Cond} + W_{\ell S}(L_S, t) - W_J(0,t) - W_{vs} - W_{break} \quad \text{(A-4)}$$

Although the downcomer and steam dome volumes vary with time, the sum of the two volumes is constant and is denoted by V_O. V_{DC} is therefore give by

$$V_{DC} = V_0 - V_{SD} \quad \text{(A-5)}$$

where V_{SD} refers to the steam dome fluid volume. Substitution of (A-5) into (A-4) yields the downcomer mass balance equation (2.2-1).

Neglecting potential and kinetic energy effects, the energy balance for the downcomer region can be written as

$$\frac{dU_{DC}}{dt} = W_{inj}h_{inj} + W_{Cond}h_{g\,SD} + W_{\ell S}(L_S,t)\,h_{\ell\,S}(L_S,t) - W_{\ell J}(0,t)\,h_{\ell J}(0,t) - W_{gJ}(0,t)\,h_{gJ}(0,t) - W_{vs}\;h_{g\,DC} - W_{break}\;\bar{h}_D - \frac{P^*}{J}\frac{dV_{DC}}{dt} \qquad \text{(A-6)}$$

where h_{inj} is the injection-flow enthalpy, $h_{g\,SD}$ is the steam-dome gas-phase enthalpy, $h_{\ell J}(0,t)$ refers to the liquid phase enthalpy on the inlet boundary of the jet pump region, $h_{gJ}(0,t)$ is the gas-phase enthalpy on the inlet boundary of the jet pump region, $h_{\ell S}(L_S,t)$ denotes the liquid-phase enthalpy at the separator exit, $h_{g\,DC}$ is the gas phase enthalpy in the downcomer, and $\bar{h}_{DC}$ is the volume-weighted enthalpy in the downcomer region. Also, the last term on the right-hand side of (A-6) represents the work done on the downcomer fluid because of volume change. The total internal energy U_{DC} of the fluid in the downcomer region can be expressed as

$$U_{DC} = V_{DC}\;\rho_{DC}\left(P^*,\bar{h}_{DC}\right)\left[\bar{h}_{DC} - \frac{P^*}{J\,\rho\left(P^*,\bar{h}_{DC}\right)}\right]. \qquad \text{(A-7)}$$

Taking the time derivative of (A-7) leads to

$$\frac{dU_{DC}}{dt} = \left(\rho_{DC}\,\bar{h}_{DC} - \frac{P^*}{J}\right)\frac{dV_{DC}}{dt} + V_{DC}\left(\rho_{DC} + \bar{h}_{DC}\frac{\partial\rho_{DC}}{\partial\bar{h}_{DC}}\right)\frac{d\bar{h}_{DC}}{dt} + V_{DC}\left(\bar{h}_{DC}\frac{\partial\rho_{DC}}{\partial P^*} - \frac{1}{J}\right)\frac{dP^*}{dt}. \qquad \text{(A-8)}$$

Substitution of (A-8) into (A-6) yields

$$\rho_{DC}\;\bar{h}_{DC}\frac{dV_{DC}}{dt} + V_{DC}\left(\rho_{DC} + \bar{h}_{DC}\frac{\partial\rho_{DC}}{\partial\bar{h}_{DC}}\right)\frac{d\bar{h}_{DC}}{dt} + V_{DC}\left(\bar{h}_{DC}\frac{\partial\rho_{DC}}{\partial P^*} - \frac{1}{J}\right)\frac{dP^*}{dt}$$
$$= W_{inj}\,h_{inj} + W_{Cond}\;h_{g\,SD} + W_{\ell S}(L_S,t)\,h_{\ell S}(L_S,t) - W_{\ell J}(0,t)\,h_{\ell J}(0,t) - W_{gJ}(0,t)\,h_{gJ}(0,t) \qquad \text{(A-9)}$$
$$- W_{vs}\;h_{g\,DC} - W_{break}\;\bar{h}_{DC} - \frac{P^*}{J}\frac{dV_{DC}}{dt}.$$

Inclusion of (A-5) into (A-9) results in the energy balance (2.2-2).

A.2 Steam Dome Region

For the steam dome region, the fluid mass balance is

$$\frac{dM_{SD}}{dt} = W_{gS}(L_S, t) + W_{vs} - W_{stm} - W_{Cond} - W_{break} \tag{A-10}$$

where W_{stm} is flow rate of steam exiting the vessel. The steam dome fluid mass can be expressed as

$$M_{SD} = V_{SD}\, \rho_{SD}\left(P^*, \bar{h}_{SD}\right) \tag{A-11}$$

where $\bar{h}_{SD}$ is the volume-weighted enthalpy of the steam dome fluid. Evaluation of dM_{SD}/dt using (A-11) leads to

$$\frac{dM_{SD}}{dt} = \rho_{SD}\frac{dV_{SD}}{dt} + V_{SD}\frac{\partial \rho_{SD}}{\partial \bar{h}_{SD}}\frac{d\bar{h}_{SD}}{dt} + V_{SD}\frac{\partial \rho_{SD}}{\partial P^*}\frac{dP^*}{dt}. \tag{A-12}$$

Substitution of (A-12) into (A-10) leads directly to the mass balance Eq. (2.2-3).

With the assumptions used in obtaining the downcomer energy balance, the steam dome energy balance becomes

$$\frac{dU_{SD}}{dt} = W_{gS}^{g}(L_S, t)\; h_S^g(L_S, t) + W_{vs}\; h_{gD} - \left(W_{stm} + W_{break}\right)\bar{h}_{SD} - W_{Cond}\; h_{gSD} - \frac{P^*}{J}\frac{dV_{SD}}{dt} \tag{A-13}$$

where U_{SD} is the total internal energy of the fluid in the steam dome region. Using a relation analogous to (A-7), the total internal energy time derivative can be expressed as

$$\frac{dU_{SD}}{dt} = \left(\rho_{SD}\bar{h}_{SD} - \frac{P^*}{J}\right)\frac{dV_{SD}}{dt} + V_{SD}\left(\rho_{SD} + \bar{h}_{SD}\frac{\partial \rho_{SD}}{\partial \bar{h}_{SD}}\right)\frac{d\bar{h}_{SD}}{dt} + V_{SD}\left(\bar{h}_{SD}\frac{\partial \rho_{SD}}{\partial P^*} - \frac{1}{J}\right)\frac{dP^*}{dt}. \tag{A-14}$$

Substitution of (A-14) into (A-13) yields Equation (2.2-4).

APPENDIX B
Derivation of Fuel and Cladding Heat Balance Equations

Neglecting axial conduction, the heat conduction equation governing the temperature distribution in an average-power fuel rod is given by

$$\rho_f C_{p,f} r \frac{\partial T_f}{\partial t} = -\frac{\partial (r q_r'')}{\partial r} + r q''' \tag{B-1}$$

where

ρ_f	=	fuel density (lbm/ft³),
$C_{p,f}$	=	fuel specific heat (Btu/lbm °F),
$T_f(r,z,t)$	=	fuel temperature (°F),
r	=	radial coordinate (ft),
z	=	axial coordinate (ft),
$q_r''(r,z,t)$	=	radial heat flux (Btu/ft²-sec),
S(z,t)	=	normalized axial power shape function, and
$q'''(r,t)$	=	axial-average volumetric heat generation rate (Btu/ft³-sec).

In SABRE, a two-radial-node model is used to simulate fuel heat transfer. The governing equation for the inner node is derived by integrating Eq. (B-1) over the nodal cross-sectional area, i.e., from $r=0$ to $r=r_a$ and from $\theta=0$ to $\theta=2\pi$. Carrying out the spatial integration on each of the terms in Eq. (B-1), and introducing area-averaged variables, yields

$$\int_0^{2\pi} d\theta \int_0^{r_a} dr\, r\, \rho_f C_{p,f} \frac{\partial T_f(r,z,t)}{\partial t} = \rho_{f,a} C_{p,fa} \pi r_a^2 \frac{\partial T_{fa}(z,t)}{\partial t}, \tag{B-2}$$

$$-\int_0^{2\pi} d\theta \int_0^{r_a} dr \frac{\partial [r q_r''(r,z,t)]}{\partial r} = -2\pi r_a q_r''(r_a,z,t), \tag{B-3}$$

$$\int_0^{2\pi} d\theta \int_0^{r_a} dr\, r\, q'''(r,z,t) = \pi r_a^2 \bar{q}_{fa}'''(z,t), \tag{B-4}$$

where

$T_{fa}(z,t)$ = the radial-average temperature for the inner fuel node (°F),

r_a = radius of inner fuel node (ft),

$\rho_{fa}, C_{p,fa}$ = density (lbm/ft^3) and specific heat (Btu/lbm-°F) of the fuel within the inner node,

$\bar{q}'''_{fa}(z,t)$ = radially-averaged volumetric heat generation rate within the inner node (Btu/ft^3-sec).

With Equations. (B-2) - (B-4), Eq. (B-1) becomes

$$\rho_{fa}\, C_{p,fa}\, r_a^2 \frac{\partial T_{fa}(z,t)}{\partial t} = -2\, r_a\, q''_r(r_a,z,t) + r_a^2\, \bar{q}'''_{fa}(z,t) \qquad \textbf{(B-5)}$$

Similarly, integrating each term in (B-1) over the cross-sectional area of the outer node ($r_a<r<r_b$ and $0<\theta<2\pi$) leads to

$$\int_0^{2\pi} d\theta \int_{r_a}^{r_b} dr\, r\, \rho_f\, C_{p,f} \frac{\partial T_f(r,z,t)}{\partial t} = \rho_{fb}\, C_{p,fb}\, \pi \left(r_b^2 - r_a^2\right) \frac{\partial T_{fb}(z,t)}{\partial t}, \qquad \textbf{(B-6)}$$

$$-\int_0^{2\pi} d\theta \int_{r_a}^{r_b} dr \frac{\partial \left[r\, q''_r(r,z,t)\right]}{\partial r} = -2\pi \left[r_b\, q''_r(r_b,z,t) - r_a\, q''_r(r_a,z,t)\right], \qquad \textbf{(B-7)}$$

and

$$\int_0^{2\pi} d\theta \int_{r_a}^{r_b} dr\, r\, \bar{q}'''(r,z,t) = \pi \left(r_b^2 - r_a^2\right) \bar{q}'''_{fb}(z,t). \qquad \textbf{(B-8)}$$

With Eqs. (B-6) through (B-8), the heat balance equation for the outer fuel node becomes

$$\rho_{fb}\, C_{p,fb} \left(r_b^2 - r_a^2\right) \frac{\partial T_{fb}(z,t)}{\partial t} = -2 r_b\, q''_r(r_b,z,t) + \left(r_b^2 - r_b^2\right) \bar{q}'''_{fb}(z,t) \qquad \textbf{(B-9)}$$

$\rho_{fb}, C_{p,fb}$ = density (lbm/ft^3) and specific heat (Btu/lbm °F) of fuel in outer fuel node,

$T_{fb}(z,t)$ = radial-average fuel temperature in outer node (°F),

r_{fb} = radius of fuel pellet (ft), and

$\overline{q}'''_{fb}(z,t)$ = volumetric heat generation rate within outer fuel node (Btu/ft^3-sec).

In the SABRE code, the fuel nodes are chosen to be of equal volume so that $r_a = r_b/\sqrt{2}$. The rate of heat flow from the inner to outer fuel node is approximated by the steady-state conduction relation

$$2\pi\, r_a\, q''_r(r_a,z,t) \approx \overline{P}_L \frac{T_{fa}(z,t)-T_{fb}(z,t)}{(r_2-r_1)/k_{fa}} \tag{B-10}$$

r_1, r_2 = the radial locations coincident with the radially-averaged temperatures T_{fa} and T_{fb}, respectively (°F),

$\overline{P}_L$ = logarithmic mean perimeter for heat transfer from inner fuel node to outer fuel node (ft),

= $\dfrac{(r_2-r_1)}{\ln(r_2/r_1)}$

In Equation (B-10), the conductivity k_{fa} is used because the inner node has a thickness greater than that of the outer node. Since the outer node is relatively thin, the parameter r_2 is taken as the radial midpoint of the outer node, i.e.,

$$r_2 = \frac{1}{2}(r_a + r_b) \tag{B-11}$$

For the transient calculation, the location r_1 is assumed to correspond with the radial location coincident with T_{fa} under steady-state conditions. Thus, r_1 is obtained from the following steady-state solution of the heat conduction problem for a solid cylinder with a radially-uniform heat generation rate:

$$T_{fa,S}(r,z) = \frac{\overline{q}'''_{fa,S}(z)}{4k_{fa}}\left[r_a^2 - r^2\right] + T_{fa,S}(r_a,z) \tag{B-12}$$

where the subscript S denotes steady-state conditions. Given $T_{fa,s}(r_a,z)$, Eq. (B-12) holds for $0<r<r_a$. The radial average steady-state temperature is defined by

$$T_{fa,S}(z) \equiv \frac{1}{\pi r_a^2}\int_0^{2\pi} d\theta \int_0^{r_a} dr\; r\; T_{fa,S}(r,z) \tag{B-13}$$

Substitution of (B-12) into (B-13) yields

$$T_{fa,s}(z) = T_{fa,S}(r_a,\ z) + \frac{1}{8k_{fa}}\,\overline{q}'''_{fa,s}(z)\ r_a^2. \tag{B-14}$$

Equating the right-hand sides of Eqs. (B-13) and (B-14) and replacing r with r_1 leads to the following relation for the location of the radial average temperature in the inner node:

$$r_1 = \frac{r_a}{\sqrt{2}} \tag{B-15}$$

Combining Eqs. (B-10), (B-11), and (B-15) gives the rate of heat transfer per unit area from the inner to outer node as

$$q_r''(r_a, z, t) = \frac{k_{fa}\left[T_{fa}(z,t) - T_{fb}(z,t)\right]}{r_a \ln\left(\dfrac{r_a + r_b}{r_a\sqrt{2}}\right)}. \tag{B-16}$$

The radially-averaged heat balance equation for the cladding is derived in a manner analogous to that used for obtaining (B-9). The resulting heat balance is

$$\rho_{cl}\, C_{p,cl}\, \left(r_{co}^2 - r_{ci}^2\right) \frac{\partial T_{cl}(z,t)}{\partial t} = 2\, r_b\, q_r''(r_b, z, t) - 2\, r_{co}\, q_r''(r_{co}, z, t) \tag{B-17}$$

where

ρ_{cl} = cladding density (lbm/ft^3),

$C_{p,cl}$ = cladding specific heat (lbm/ft^3),

T_{cl} = radial average cladding temperature (°F),

r_{ci} = inside clad radius (ft), and

r_{co} = outside clad radius (ft).

In order to complete the fuel heat transfer description, the heat fluxes $q_r''(r_b, z, t)$ *and* $q_r''(r_{co}, z, t)$ must be expressed in terms of the various temperatures. Using a lumped resistance model, these quantities can be approximated by relations analogous to (B-10):

$$2\pi\, r_b\, q''(r_b, z, t) = \frac{\left[T_{fb}(z,t) - T_{cl}(z,t)\right]}{\dfrac{(r_b - r_2)}{2\pi\, r_b\, k_{f2}} + \dfrac{1}{2\pi r_{ci} H_g} + \dfrac{(r_{co} - r_{ci})}{4\pi r_{co} k_{cl}}} \tag{B-18}$$

and

$$2\pi\, r_{co}\, q''(r_{co}, z, t) = \frac{\left[T_{cl,surf}(z,t) - T_{cool}(z,t)\right]}{\dfrac{1}{2\pi\, r_{co}\, H_{film}}}. \tag{B-19}$$

where $T_{cl,surf}$ is the cladding surface temperature. Combining (B-11), (B-16), (B-18), and (B-19) with (B-5), (B-9), and (B-17) gives the radially-averaged fuel and cladding heat transfer equations:

$$\rho_{fa}\, C_{p,fa}\, r_a^2 \frac{\partial T_{fa}(z,t)}{\partial t} = -\frac{2k_{fa}\left(T_{fa}-T_{fb}\right)}{\ln\left(\dfrac{r_a+r_b}{r_a\sqrt{2}}\right)} + r_a^2\, \bar{q}'''_{fa}(z,t), \tag{B-20}$$

$$\rho_{fb}\, C_{p,fb}\left(r_b^2-r_a^2\right)\frac{\partial T_{fb}(z,t)}{\partial t} = \frac{2\,k_{fa}\left(T_{fa}-T_{fb}\right)}{\ln\left(\dfrac{r_a+r_b}{r_a\sqrt{2}}\right)} - \frac{\left(T_{fb}-T_{cl}\right)}{\left[\dfrac{\left(r_b-r_a\right)}{4\,r_b\,k_{fb}}+\dfrac{1}{2\,r_{ci}\,H_g}+\dfrac{\left(r_{co}-r_{ci}\right)}{4\,r_{co}\,k_{cl}}\right]} + \left(r_b^2-r_a^2\right)\bar{q}'''_{fb}(z,t), \tag{B-21}$$

and

$$\rho_{cl}\, C_{p,cl}\left(r_{co}^2-r_{ci}^2\right)\frac{\partial T_{cl}(z,t)}{\partial t} = \frac{\left(T_{fb}-T_{cl}\right)}{\left[\dfrac{\left(r_b-r_a\right)}{4r_b k_{fb}}+\dfrac{1}{2r_{ci}H_g}+\dfrac{\left(r_{co}-r_{ci}\right)}{4r_{co}k_{cl}}\right]} - \frac{\left(T_{cl,surf}-T_{cool}\right)}{\left[\dfrac{1}{2r_{co}H_{film}}\right]}. \tag{B-22}$$

APPENDIX C
Derivation of Error Term in Equation (3.1.2-1)

In this Appendix, the magnitude of the error term in Equation (3.1.2-1) is derived.

By the mean-value theorem, we have the following result

$$\int_{z_j}^{z_j+\Delta z} dz\ \rho(z,t)\,\bar{h}(z,t) = \rho(\xi,t)\int_{z_j}^{z_j+\Delta z} dz\ \bar{h}(z,t) = \Delta z\ \rho(\xi,t)\,\bar{h}_j(t), \tag{C-1}$$

where $\xi \in (z_j, z_j + \Delta z)$.

Also by the mean-value theorem, we have the following relation for the control-volume-average fluid density

$$\rho_j(t) \equiv \frac{1}{\Delta z}\int_{z_j}^{z_j+\Delta z} dz\rho(z,t) = \rho(\zeta,t), \tag{C-2}$$

where $\zeta \in (z_j, z_j + \Delta z)$ Note that in general $\xi \neq \zeta$.

$\rho(\xi,t)$ can be expressed in terms of $\rho(\zeta,t)$ through the following Taylor Series expansion:

$$\rho(\xi,t) = \rho(\zeta,t) + \left[\frac{\partial\rho(\zeta,t)}{\partial\zeta}\right](\xi - \zeta) + \ldots. \tag{C-3}$$

Since ξ *and* ζ are both contained within the interval $(z_j, z_j + \Delta z)$, we have the following result

$$\xi - \zeta = O(\Delta z). \tag{C-4}$$

Combining (C-2), (C-3), and (C-4) gives

$$\rho(\xi,t) = \rho_j(t) + O(\Delta z) \tag{C-5}$$

Finally, substitution of (C-5) into (C-1) leads to the desired result:

$$\int_{z_j}^{z_j+\Delta z} dz\rho(z,t)\bar{h}(z,t) = \Delta z\ \rho_j(t)\,\bar{h}_j(t) + O(\Delta z^2) \tag{C-6}$$

APPENDIX D
AUXILIARY CALCULATIONS

D.1 Geometric and Hydraulic Parameters for Code Input

D.1.1 Jet Pump Region

This region consists of all twenty jet pumps.

Fluid volume = $(2)(125.06\ \text{ft}^3) = 250.12\ \text{ft}^3$
($125.06\ \text{ft}^3$ is the volume of 10 jet pumps.)[1]

Height of region = 16.495 ft.[1]

Flow path length = height = 16.495 ft.

Flow area = volume/height = $250.12\ \text{ft}^3/16.495\ \text{ft} = 15.16\ \text{ft}^2$

Hydraulic diameter = hydraulic diameter of a single jet pump $\approx \sqrt{\dfrac{4V_1}{\pi h}}$

where

V_1 = fluid volume for a single jet pump = $(250.12\ \text{ft}^3)/20 = 12.51\ \text{ft}^3$, and
h = jet pump height = 16.495 ft.

Therefore,

Hydraulic diameter = $\sqrt{\dfrac{(4)(12.51\ \text{ft}^3)}{\pi(16.495\ \text{ft})}} = 0.98\ \text{ft}.$

Friction factor = 0.013 [2]

---

[1] Dodge, C.E., Geosits, J.J., and Lehmann, C.R., "Qualification of Transient Analysis Methods for BWR Design and Analysis", PL-NF-89-005, Rev. 0, p. 18, Pennsylvania Power & Light Company, Allentown, PA, December, 1989.

[2] "Flow of Fluids through Valves, Fittings, and Pipe", Technical Paper No. 410, p. A-25, Crane Company, 300 Park Avenue, New York, NY, 1980.

Fluid Inertia

The fluid inertia for the jet pump region is calculated as[3]

$$\text{Fluid inertia} = \frac{1}{\sum_{i=1}^{20}(A_i/L_i)}$$

where

A_i = average flow area for one jet pump (ft^2), and

L_i = flow path length for a jet pump (ft).

$\therefore$ Fluid inertia = $(1/20)(L_1/A_1) = (1/20)[16.495/(15.16/20)] = 16.495/15.16 = 1.1\ ft^{-1}$

Jet pump inlet pressure loss coefficient

Diameter of jet pump throat = 8.15 inches[4]

Flow area per jet pump = {throat area} - {area occupied by nozzle}

$$\text{Flow area per jet pump} = \frac{\pi}{4}\left[(8.15\ in)^2 - (3.14\ in)^2\right] = 44.43\ in^2.$$

It is assumed that the jet pump nozzle does not affect the inlet loss coefficient except for the fact that it causes a decrease in the effective flow area.

$$\text{Throat diameter based on effective flow area} = \sqrt{\frac{(44.43 in^2)(4)}{\pi}} = 7.52 in.$$

Radius of curvature of jet pump throat = 0.56 in. [see Ref. 4]

Radius of curvature/diameter = 0.56/7.52 = 0.074

The loss coefficient for this value of radius/diameter is 0.24.[5] The flow area associated with the loss coefficient is 44.43 in^2 (0.309 ft^2), i.e., the effective flow area at the throat of a single jet pump. In SABRE, all twenty jet pumps are lumped into a single control volume. Therefore, the appropriate inlet flow area is (20)(0.309 ft^2)=6.18 ft^2.

Inlet loss coefficient = 0.24, Inlet Flow Area = 6.18 ft^2.

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[3] Harrison, J.F., et al., "RETRAN-02 — A Program for Transient Thermal-Hydraulic Analysis of Complex Fluid Flow Systems", Volume 5: Modelling Guidelines, p. II-16, NP-1850-CCM, Electric Power Research Institute, Palo Alto, CA, April, 1986.

[4] PLE-4610, File 244-03, "Jet Pump Details", March 5, 1984.

[5] Idel'Chik, I.E., *Handbook of Hydraulic Resistance Coefficients of Local Resistance and of Friction*, AEC-TR-6630, p. 93, 1966.

Jet pump outlet pressure loss coefficient

The jet pump outlet pressure loss coefficient is estimated by combining the loss coefficients for a 90° bend and a sudden expansion:

$$K = K_{bend} + K_{exp}$$

where

K_{bend} = 30f,[6] and

K_{exp} = $(1-\beta^2)^2$ (Ref. 6).

Here,

f = friction factor for 19" pipe (inside diameter of diffuser at exit is 19") = 0.012 (Ref. 6), and

β = (flow area at jet pump exist)/(flow area of lower plenum/20).

The flow area at the exit of a jet pump is 1.97 ft^2, and the total flow area of the lower plenum is 93.87 ft^2.[7] Therefore, β is 0.42, and the expansion loss coefficient is 0.678. The loss coefficient for the jet pump exit, based on the jet pump exit flow area, is (30)(0.012) + 0.678 = 1.04.

Since all twenty jet pumps are lumped into a single control volume, the flow area used in SABRE for the jet pump exit is (20)(1.97 ft^2) = 39.40 ft^2. Therefore, the jet pump exit loss coefficient and associated flow area are given by

$\therefore$ K = 1.04, Outlet Flow Area = 39.40 ft^2.

D.1.2 Lower Plenum Region

Fluid Volume = 2286.69 ft^3 [Ref. 7]

Height of region = elevation difference between bottom of jet pump region and bottom of lower reflector region

Height of region = 16.876 ft - 9.937 ft = 6.94 ft. [Ref. 7, pp. 17-18]

Flow path length = 17.28 ft [Ref. 7]

Flow area = volume/flow length = 2286.99 ft^3/17.28 ft = 132.33 ft^2

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[6] "Flow of Fluids through Valves, Fittings, and Pipe", Technical Paper No. 410, Crane Company, 300 Park Avenue, New York, NY, 1980.

[7] Dodge, C.E., Geosits, J.J., and Lehmann, C.R., "Qualification of Transient Analysis Methods for BWR Design and Analysis", PL-NF-89-005, Rev. 0, p. 18, Pennsylvania Power & Light Company, Allentown, PA, December, 1989.

Hydraulic diameter = 1.014 ft [Ref. 7]

Friction factor = 0.013 [Ref. 6]

Fluid inertia = (flow path length)/(flow area) = 17.28 ft/132.33 ft^2 = 0.13 ft^{-1}

D.1.3 Core Region

The present model includes the active core region and the upper and lower reflector regions. The core is assumed to be loaded with ANF 9x9 fuel.

Lower Reflector Region

The height of the lower reflector region is 1.15 ft [Ref. 7, p. 17]. The SABRE code assumes that the flow area of the lower reflector region is equal to the flow area of the active core. Also, fluid friction is neglected within this region.

Active Core

Channel internal cross-sectional area[8] = $(5.278\ in)^2$ = 27.86 in^2

Cladding outside diameter (fuel rods) = 0.424 in [Ref. 8]

Cladding outside diameter (water rods) = 0.425 in [Ref. 8]

Cross-sectional area of fuel rods = $\frac{\pi}{4}(0.424\ in)^2 = 0.141\ in^2$

Cross-sectional area of water rods = $\frac{\pi}{4}(0.425\ in)^2 = 0.142\ in^2$

Total cross-sectional area occupied by fuel and water rods = $(79)(0.141\ in^2) + (2)(0.142\ in^2) = 11.42\ in^2$

Flow area per channel = 27.86 in^2 - 11.42 in^2 = 16.44 in^2

Total active core flow area = (764)(16.44 in^2)(ft^2/144 in^2) = 87.2 ft^2

Flow path length = length of active fuel = 150 in = 12.5 ft [Ref. 8]

Active Core fluid volume = (12.5 ft)(87.2 ft^2) = 1090 ft^3

Height of region = flow path length = 12.5 ft

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[8] "Susquehanna Unit 2 Cycle 4 Fuel Cycle Design Report", ANF-89-063(P), Advanced Nuclear Fuels Corporation, Rev. 1, April, 1989.

Hydraulic diameter = [(4)(fluid volume)]/[wetted surface area]
Surface area per channel= (12.5 ft)[2π(0.425 in) + 79π(0.424 in) + 4(5.278 in)][ft/12 in]
= 134.39 ft^2

Fluid volume per channel = 1090 ft^3/764 = 1.427 ft^3

Core region hydraulic diameter = [(4)(1.427 ft^3)]/(134.39 ft^2) = 0.0425 ft.

Friction Factor
The friction factor for the core is calculated from the following correlation:[9]

$$f_C = 0.175\, \mathrm{Re}_C^{-0.187}$$

where
f_C = core friction factor
Re_C = Reynolds number for core region.

The Reynolds number Re_C is given by

$$\mathrm{Re}_C = \frac{G_C D_{hC}}{\mu_\ell}$$

where
G_C = core mass flux (Lb/ft^2/sec)
D_{hC} = core hydraulic diameter (ft)
μ_ℓ = liquid phase viscosity (Lb/ft sec).

f_C is calculated by SABRE at the initial reactor conditions and is then held constant throughout the transient.

Spacer Friction
The loss coefficient, based on the channel flow area, for a single fuel spacer is given by the following correlation:[10]

$$K_{sp} = 6.983\, \mathrm{Re}_C^{-0.171}.$$

In the SABRE calculation, the fluid friction due to the spacers is distributed over the length of the active fuel by defining a spacer friction factor,

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[9] "Principal Fuel Management Parameters Susquehanna Unit 2, Cycle 4", ANF-88-158(P), Advanced Nuclear Fuels Corporation, October, 1988.
[10] "Susquehanna 2 ANF-3 Design Report Mechanical, Thermal, and Neutronics Design for ANF 9x9 Fuel Assemblies," ANF-88-210(P), Rev. 0, February, 1989.

$$f_{sp} \equiv \frac{N_{sp} K_{sp} D_h}{L_C},$$

where

N_{sp} = number of fuel spacers = 7, and

L_C = length of active core region (ft).

Fluid Inertia

The fluid inertia for the core region is given by[11]

$$I_C = \frac{1}{\sum_{i=1}^{764}(A_i/L_i)}$$

where

I_C = core region inertia (ft^{-1}),

A_i = flow area of a single core channel (ft^2), and

L_i = flow path length of a core channel (ft).

Flow area per channel = 16.44 in^2 = 0.1142 ft^2.

In the calculation of I_C, the flow path length L_i includes the upper and lower reflector regions in addition to the active core region.

L_i = active core length + lower reflector length + upper reflector length
= 12.5 ft + 1.15 ft + 1.218 ft [Ref. 7, p. 17]
= 14.868 ft. (i = 1, 2, 3, ..., 764)

$$I_C = \frac{L_1}{(764)A_1} = \frac{14.868 ft}{(764)(0.1142 ft^2)} = 0.17 ft^{-1}.$$

Orifice and Lower Tie Plate Loss Coefficients

The lower tie plate loss coefficient used in the RETRAN model of SSES is 1.37 [Ref. 7, p. 20]. This value (1.37) is based on the flow area through the lower tie plate which is 49.8 ft^2 [Ref. 7, p. 20]. The lower tie plate loss coefficient K_{ltp} for SABRE is

$K_{ltp} = 1.37$, Flow Area through Lower Tie Plate = 49.8 ft^2.

[11] Harrison, J.F., et al., "RETRAN-02 — A Program for Transient Thermal-Hydraulic Analysis of Complex Fluid Flow Systems", Volume 5: Modelling Guidelines, NP-1850-CCM, Electric Power Research Institute, p. II-16, Palo Alto, CA, April, 1986.

The reactor core contains three types of orifices: central, side-entry peripheral, and bottom-entry peripheral.[12] In this analysis, the core region is modeled with a central region orifice. The loss coefficient for the orifice is calculated below:

Orifice pressure drop at design conditions[13] = 5.09 psi

Flow rate through orifice = {rated total core flow} - {leakage flow through core support plate}.

Rated total core flow = 100×10^6 Lb/hr = 27,778 Lb/sec.

Leakage flow through core support plate ≈ (1/3){leakage flow through lower tie plate holes}[14]

Since the total bypass flow rate is ~10 MLb/hr, the following relation holds:

Leakage flow through lower tie plate holes ≈ 10 MLb/hr - {Leakage flow through core support plate}

∴ Leakage flow through core support plate ≈ (1/4)(10 MLb/hr) = 2.5 MLb/hr.

The flow rate through the orifice is then

Flow rate through orifice = 100 MLb/hr - 2.5 MLb/hr = 97.5 MLb/hr.

The loss coefficient for the orifice K_{or} can then be calculated from

$$5.09 psi = \frac{K_{or} G_{or}^2}{2 g_c (144) \rho_{or}}$$

where

G_{or} = mass flux through orifice (based on orifice flow area) (Lb/ft^2 sec)

A_{or} = combined orifice flow area for all fuel bundles = 22.67 ft^2 [Ref. 1, p. 22]

ρ_{or} = liquid density at 1053 psia and 528 °F [Ref. 13, Figure 5.1-1] = 47.3 Lb/ft^3.

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12 "Principal Fuel Management Parameters Susquehanna Unit 2, Cycle 4", ANF-88-158(P), Advanced Nuclear Fuels Corporation, October, 1988.

13 "Susquehanna Steam Electric Station Units 1 and 2 Final Safety Analysis Report", Table 4.4-1, Pennsylvania Power & Light Company, Allentown, PA.

14 "Susquehanna 2 ANF-3 Design Report Mechanical, Thermal and Neutronics Design for ANF 9x9 Fuel Assemblies", ANF-88-210(P), Advanced Nuclear Fuels Corporation, February, 1989.

$$G_{or} = \left(\frac{97.5\,x10^6\,Lb}{hr}\right)\left(\frac{hr}{3600\,sec}\right)\left(\frac{1}{22.67\,ft^2}\right) = 1194.68\frac{Lb}{ft^2\,sec}$$

∴ K_{or}	= (5.09)(2)(32.2)(144)(47.3)/(1194.68)^2	= 1.57,	A_{or} = 22.67 ft^2

Upper Reflector Region

The height of the upper reflector is 1.218 ft [Ref. 7, p. 17]. The SABRE code assumes that the flow area of the upper reflector is equal to the flow area of the active core region. Wall friction is neglected within the upper reflector.

The local pressure loss at the outlet of the upper reflector region is computed using the loss coefficient from the PP&L RETRAN model,

K_{UR} = 3.64 [Ref. 7, p. 20]

The corresponding flow area at the exit of the upper reflector is 139.8 ft^2 [Ref. 7, p. 20].

D.1.4 Bypass Region

Bypass flow area	= 67.87 ft^2	[Ref. 7, p. 17]	

Hydraulic diameter	= 0.196 ft	[Ref. 7, p. 17]

Height of region	= 14.87 ft

The height of the bypass region is equal to the height of the active core region plus the height of the upper and lower reflector regions.

Friction factor	= f_B = 0.0185	[Ref. 5, p.A-25]

Fluid Inertia

The fluid inertia for the bypass region is given by

$$I_B = \frac{L_B}{A_B}$$

where

L_B = flow path length (ft)

A_B = flow area (ft^2)

I_B	= 14.87 ft/67.87 ft^2 = 0.22 ft^{-1}.

Loss Coefficient for Bypass Inlet

The loss coefficient for the bypass inlet was determined by requiring a bypass inlet flow of ~10MLb/hr upon initialization of the SABRE code with total core flow (active core flow plus bypass flow) specified at 100 MLb/hr. A loss coefficient of 0.5065 [based on the leakage area (0.976 ft^2, Ref. 7, p. 22) from the lower reflector to the bypass channel] was found to give the correct flow split between the active and bypass regions. Leakage from the lower plenum directly into the bypass channel is neglected in the SABRE model.

Loss Coefficient for Bypass Outlet
The flow area at the exit of the bypass channel is 48.98 ft^2 (Ref. 7, p. 21). The pressure loss associated with the bypass outlet has been neglected because it is small in comparison to the inlet pressure loss.

D.1.5 Upper Plenum Region

Fluid volume = 955.35 ft^3 [Ref. 7, p. 18]

Region height = 4.98 ft [Ref. 7, p. 18]

Flow area = 955.35 ft^3/4.98 ft = 191.84 ft^2.

Using the flow area and flow path length from p. 18 of Ref. 7, the fluid inertia for the upper plenum region is

I_U = (3.77 ft)/(249.78 ft^2) = 0.015 ft^{-1}.

Hydraulic diameter = 3.97 ft [Ref. 7, p. 18]

Friction factor based on the hydraulic diameter given above = 0.01
[Ref. 6, p. A-25]

In the upper plenum, three control volumes are used to describe the spatial variation in fluid conditions. The flow area on the outlet boundary of the upper plenum is equal to the flow area of the riser pipes which is 39.66 ft^2 (see Section D.1.6).

The lower boundary of the first node in the upper plenum is in contact with the upper reflector and bypass regions. Thus, two junction areas, equal to the exit area of the upper reflector (139.8 ft^2) and the bypass exit flow area (49.98 ft^2), are used in calculating the flow of mass and energy across the inlet boundary of the first node in the upper plenum region.

D.1.6 Riser Region

Fluid Volume = 402.78 ft^3 [Ref. 7, p. 18, Control Volume 90]

Region height = 10.156 ft [Ref. 7, p. 18, Control Volume 90]

Control-Volume Flow area = 402.78 ft^3/10.156 ft = 39.66

Flow area at inlet of riser = 45.10 ft^2 [Ref. 7, p. 21, Junction 80]

Flow area at outlet of riser = 35.67 ft^2 [Ref. 7, p. 21, Junction 90]

Hydraulic diameter = 0.505 ft [Ref. 7, p. 18, Control Volume 90]

Friction factor based on hydraulic diameter = 0.015 [Ref. 6, p. A-25]

Fluid Inertia

Based upon a typical flow regime map, the flow regime within the riser region should be annular under the conditions of interest.[15] This is demonstrated through the following calculations:

Rated flow through risers = 100×10^6 Lb/hr

Riser flow area = 39.66 ft^2

Mass flux through riser = (100×10^6 Lb/hr)/(39.66 ft^2) = 2.52×10^6 Lb/hr ft^2

The flow regime map indicates that the flow regime in the riser (which typically has a void fraction of ~0.7 or greater) will be annular as long as the mass flux is greater than ~0.25×10^6 Lb/hr. Since this mass flux corresponds to ~10% core flow, it is reasonable to assume that annular flow exists for the majority of conditions of interest in this work. In computing the fluid inertia for this region, it is assumed that the inertia of the vapor core is negligible. The area occupied by the liquid annulus (assuming a riser void fraction of 0.7 which is typical for natural circulation conditions) is

Cross-sectional area of liquid = 0.3(39.66 ft^2) = 11.90 ft^2.

Thus the fluid inertia is

$$I_R = (10.156 \text{ ft})/(11.90 \text{ ft}^2) = 0.85 \text{ ft}^{-1}.$$

Inlet Loss Coefficient for Riser Region

The value for this loss coefficient is taken from the Susquehanna RETRAN model (Ref. 7, p. 21)

Inlet loss coefficient = 0.41 (based on inlet flow area of 45.10 ft^2)

D.1.7 Separator Region

Fluid volume = 438.24 ft^3 [Ref. 7, p. 18, Control Volume 100]

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[15] McFadden, J.H., et. al., "RETRAN-02 — A Program for Transient Thermal-Hydraulic Analysis of Complex Fluid Flow Systems", Volume 1: Theory and Numerics (Revision 2), NP-1850-CCMA, p. III-31, Electric Power Research Institute, Palo Alto, CA, November, 1984.

Region height = 6.167 ft [Ref. 7, p. 18, Control Volume 100]

Control-volume flow area = volume/height = $(438.24\ ft^3)/(6.167\ ft)$ = $71.06\ ft^2$.

Flow area at separator inlet = $35.67\ ft^2$ [Ref. 7, p. 21, Junction 90]

Flow area at separator outlet = $40.73\ ft^2$ [Ref. 7, p. 21, Junction 100]

Hydraulic diameter = 0.514 ft [Ref. 7, p. 18, Volume 100]

Friction factor = 0.015 [Ref. 6, p. A-25]

Fluid Inertia

For a separator inlet quality of 0.20, which is typical for natural circulation operation at normal water level, the separator inertia is[16] $\sim 190\ ft^{-1}$. Since there are 225 separators, the region inertia is $90/225 = 0.84\ ft^{-1}$.

$\therefore \quad I_S = 0.84\ ft^{-1}$.

Loss Coefficient for Separator Inlet

The initial pressure drop across the separator is estimated from the following vendor pressure drop equation:

$$\Delta P_{friction} = 0.0112\ W_S^2 \upsilon_H\ (psi)$$ [17]

where

W_S = flow rate at separator inlet (MLb/hr)

$\upsilon_{H,S}$ = homogeneous specific volume at separator inlet

= $x\upsilon^g + (1-x)\upsilon^f \quad (ft^3/Lb)$

x = flow quality.

It is assumed that all of the local frictional resistance is concentrated at the separator inlet because of the higher fluid density compared with that at the separator outlet. The separator inlet loss coefficient K_{S1} is calculated by equating the above pressure drop relation to the local and distributed pressure drop contributions:

$$0.0112 W_S^2 \upsilon_{H,S} = \frac{K_{S,1}\ G_S^2\ \Phi_H}{2\ g_c \rho_f (144)} + \frac{f_S\ G_S^2\ L_S\ \varphi}{2\ g_c \rho_f (144) D_{h,S}} \qquad \text{(D.1.7-1)}$$

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16 "Qualification of the One Dimensional Core Transient Model for Boiling Water Reactors", NEDO-24154, Figure 4.3, October, 1978.

17 "Final Report: Startup Test Program Browns Ferry Nuclear Plant Unit 1", NEDO-20747, January, 1975.

where

W_S = mass flow rate at separator inlet (MLb/hr),
$\upsilon_{H,S}$ = homogeneous specific volume at separator inlet (ft^3/Lb),
$K_{S,1}$ = separator inlet loss coefficient,
G_S = separator inlet mass flux (Lb/ft^2 sec),
Φ_H = homogeneous two-phase multiplier,
ρ_f = liquid phase density (Lb/ft^3),
φ = Martinelli-Nelson two phase multiplier,
$D_{h,S}$ = separator region hydraulic diameter (ft),
f_S = friction factor for separator region, and
L_S = flow length for separator region (ft).

The value of $K_{S,1}$ is calculated by SABRE through solution of Equation D.1.7-1 during the initialization process. The value of this loss coefficient is then held constant during the transient simulation.

D.1.8 Steam Dome Region

Steam Dome Volume

In the SABRE model, the steam dome volume is calculated by subtracting the downcomer fluid volume from the combined steam dome/downcomer volume which is denoted as V_0. The combined volume, which includes the steam line volume up to the inboard MSIV, is obtained from the PP&L RETRAN model for Susquehanna (Ref. 7, pp. 18, 26, and 27) as follows:

$$V_0 = V_{120} + V_{130} + V_{135} + V_{148} + V_{310} + V_{320}$$
$$V_0 = 6502.74 + 2788.98 + 2182.60 + 1641.96 + 900.13 + 317.32 = 14,334 \text{ ft}^3 \quad \text{(D.1.8-1)}$$

The steam dome volume is then computed as

$$V_{SD} = V_0 - V_D \quad \text{where} \quad \text{(D.1.8-2)}$$

V_D = Downcomer fluid volume (ft^3).

D.1.9 Downcomer Region

In order to account for the non-uniform flow area of the downcomer region, water level as a function of downcomer fluid volume is obtained from the following table.[18, 19] A plot of this data is shown in Figure D.1.9-1.

Table D.1.9-1
Downcomer Level Versus Fluid Volume

Fluid Volume (ft^3)	Downcomer Level (in. above instrument zero)
0.0	-406.00
58.72	-400.50
743.37	-336.38
982.48	-311.19
1641.96	-211.00
2507.76	-161.50
2858.99	-113.55
2903.69	-108.88
2978.47	-102.88
3073.37	-96.88
3189.01	-90.88
3326.01	-84.88
5084.56	-13.50
5197.85	-6.50
5902.70	50.37
6143.75	60.13
6613.54	80.00
14420.99	348.50

A downcomer level of 80" corresponds to the top of the steam separators. If the liquid level or two-phase mixture level, within the downcomer region, exceeds 80", then the free area of the downcomer occupies the total free area of the reactor vessel. Note that in SABRE, the downcomer region is a variable-volume region, and by definition it occupies all of the volume external to the shroud except the steam region.

An area-versus-level table is also used in SABRE to calculate the vapor separation rate from the downcomer under conditions where the downcomer consists of a two-phase mixture (see Equation 2.2-6). The area-versus-level table (Table D.1.9-2) is obtained by differencing the data in Table D.1.9-1. A plot of free area versus level is given in Figure D.1.9-2.

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[18] PP&L Report NPE-89-001, "The PP&L Approach to Risk Management and Risk Assessment", Rev. 2, p. 362, January 1989.

[19] PP&L Calculation No. NFE-B-01-002, Rev. 3, "Base RETRAN Model".

Table D.1.9-2
Downcomer Free Area Versus Downcomer Level

Downcomer Free Area (ft^2)	Downcomer Level (in. above instrument zero)
128.11	-406.00
128.11	-400.50
128.13	-336.38
113.91	-311.19
114.62	-211.00
138.09	-161.50
87.90	-113.55
114.86	-108.88
149.56	-102.88
189.80	-96.88
231.28	-90.88
274.00	-84.88
295.64	-13.50
194.21	-6.50
148.73	50.37
296.37	60.13
283.72	80.00
348.94	348.50

Figure D.1.9-1
Downcomer Water Level versus Downcomer Fluid Volume.

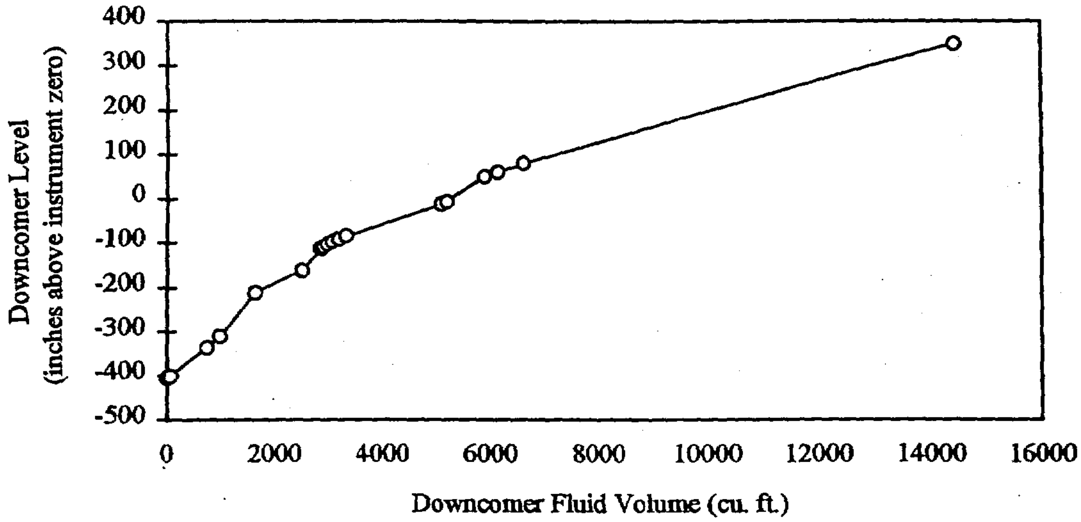
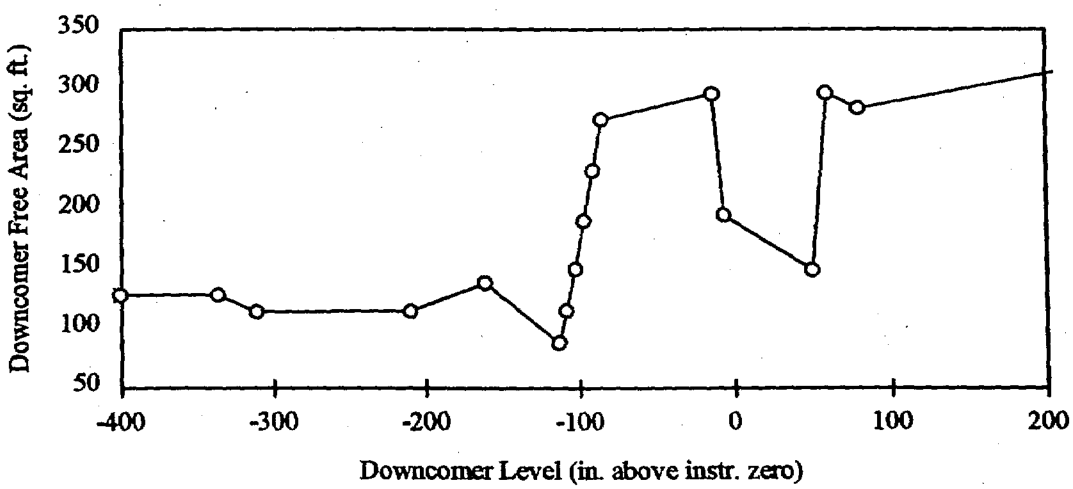


Figure D.1.9-2
Downcomer Free Area Versus Downcomer Level



D.2 Data for Reactor Heat Structures

Two reactor heat structures, in addition to the fuel rods, are included in the SABRE reactor model: the reactor vessel and the internal steel structures. Numerical values for the model parameters are given below.

Mass and Surface Area of Reactor Vessel
The radius of curvature of the top and bottom head of the reactor is 127 inches.[20] The inside surface area of the hemisphere is $(2\pi\,(127\text{ in})^2/144) = 704\text{ ft}^2$. The inside surface area of the cylindrical part of the vessel is $[\pi\,(251)/12]\,[876-(2)(127)]/12 = 3406\text{ ft}^2$. Total inside surface area A_{Rx} of the reactor vessel is $(2)(704) + 3406 = 4814\text{ ft}^2$.

The total mass of the reactor vessel is approximately given by

$$\text{Vessel Mass} = M_{Rx} = (4814\text{ ft}^2)(6.19/12\text{ ft})\,\rho_{steel}$$
$$= (2483\text{ ft}^3)\,\rho_{steel} \quad \text{(Table 1.3-1 of FSAR, Rev. 48, 12/94)}$$

$$\rho_{steel} = 489\text{ lbm/ft}^3.$$[21]

$$M_{Rx} = (2483\text{ ft}^3)\,(489\text{ lbm/ft}^3) = 1.21 \times 10^6\text{ lbm}$$

Mass and Surface Area of Vessel Internals
The total solid volume, excluding the fuel, is

$(2263.91 - 871.39)\text{ ft}^3 = 1393\text{ ft}^3$.[22]

A characteristic thickness of 1" is assumed for the internal structures. The surface area A_{VI} of the vessel internals is then estimated as

$$\text{Surface area} = A_{VI} = \text{(Volume)(2)/(characteristic thickness)}$$
$$= (1393\text{ ft}^3)(2)/(1/12\text{ ft}) = 33{,}432\text{ ft}^2.$$

$$\text{Mass of vessel internals} = M_{VI} = (1393\text{ ft}^3)\,(489\text{ lbm/ft}^3) = 6.81 \times 10^5\text{ lbm}$$

Heat Transfer Coefficient
For the submerged part of the structures, single-phase, forced-convection heat transfer is assumed. A value of 200 Btu/hr-ft^2-°F is assumed for the heat transfer coefficient. This value is estimated from the data given on p. 10-41 of Ref. 21. For the region where the metal is in contact with steam, a value of 10 Btu/hr-ft^2-°F is assumed for the forced-

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[20] PP&L Drawing FF110760 Sheet 0101, Rev. 1, "Reactor Primary System Weights & Volumes".
[21] "Chemical Engineers' Handbook", 5th Edition, p. 3-90, McGraw-Hill Book Company, New York, 1973.
[22] PP&L Drawing FF110760 Sheet 0101, Rev. 1, "Reactor Primary System Weights & Volumes".

convection heat transfer coefficient. These heat transfer coefficients are supplied as part of the input data so values other than these can be specified.

The heat transfer coefficient for the metal is a fuction of the reactor water level. The water-level-dependnt heat transfer coefficient is approximated by

$$h = \left[\frac{L}{L_t}\right](200/3600) + \left[\frac{L_t - L}{L_t}\right](10/3600) \qquad \text{(Btu/sec-ft}^2\text{-°F)} \qquad \textbf{(D.2-1)}$$

where

L = RPV water level measured from bottom of vessel (inches), and
L_t = Total height of vessel = 876 inches.(Ref. 22)

Parameter values for the reactor vessel and internals heat structure models are summarized in Table D.2-1.

Table D.2-1
Reactor Heat Structure Model Parameters

Parameter	Description	Value
M_{Rx}	Vessel mass (lbm)	1.21×10^6
M_{VI}	Mass of vessel internals (lbm)	6.81×10^5
A_{Rx}	Area for heat transfer between reactor vessel and coolant (ft²)	4814
A_{VI}	Area for heat transfer between vessel internals and coolant (ft²)	33,432
h_{Rx1}	Coefficient for heat transfer between coolant and reactor vessel (Btu/sec-ft²-°F)	From Eq. D.2-1
h_{VI}	Coefficient for heat transfer between coolant and vessel internals (Btu/sec-ft²-°F)	From Eq. D.2-1
C_{ps}	Specific heat of steel (Btu/lbm-°F)	~0.14[23]

[23] Kern, D.Q., Process Heat Transfer, p. 799, McGraw-Hill, 1950.

D.3 Partial Derivatives of Fluid Density

The nodal continuity and energy equations (3-6) and (3-14) contain terms which involve the density partial derivatives $\partial\rho/\partial P^*$ *and* $\partial\rho/\partial\bar{h}$ where $\bar{h}$ is the volume-weighted enthalpy [see Equation (2.1-5)] and P* is the system pressure which is taken to be equivalent to the steam dome pressure. This section discusses the computation of these derivatives for the three fluid states: subcooled liquid, equilibrium two-phase mixture, and super-heated vapor.

D.3.1 Subcooled Liquid

For this thermodynamic state, SABRE computes $\partial\rho/\partial P^*$ *and* $\partial\rho/\partial\bar{h}$ in subroutine DERLIQ. This subroutine was developed by analytically differentiating the curve-fit polynomials in FORTRAN function VPHL(P,H) which gives subcooled or saturated liquid specific volume as a function of pressure P and enthalpy H. Function VPHL is taken from the RETRAN code.[24] Thus $\partial\rho/\partial P^*$ *and* $\partial\rho/\partial\bar{h}$ are obtained from

$$\frac{\partial\rho}{\partial P^*}=\frac{\partial\left[\upsilon_\ell(P^*,h_\ell)\right]^{-1}}{\partial P^*}=-\left[\upsilon_\ell(P^*,h_\ell)\right]^{-2}\frac{\partial\upsilon_\ell(P^*,h_\ell)}{\partial P^*} \quad \text{(D.3-1)}$$

and

$$\frac{\partial\rho}{\partial\bar{h}}=\frac{\partial\left[\upsilon_\ell(P^*,h_\ell)\right]^{-1}}{\partial h_\ell}=-\left[\upsilon_\ell(P^*,h_\ell)\right]^{-2}\frac{\partial\upsilon_\ell(P^*,h_\ell)}{\partial h_\ell} \quad \text{(D.3-2)}$$

Note that in this thermodynamic region $\bar{h}=h_\ell$. Also, in the above relations, $\upsilon_\ell(P^*,h_\ell)\equiv VPHL(P^*,h_\ell)$.

D.3.2 Two-Phase Mixture

In the two-phase region, the fluid density and volume-weighted enthalpy are given by

$$\rho=(1-\alpha)\rho_\ell+\alpha\rho_g \quad \text{(D.3-3)}$$

and

$$\bar{h}=\left[\rho_\ell(1-\alpha)h_\ell+\rho_g\alpha h_g\right]/\rho. \quad \text{(D.3-4)}$$

Since the two-phase mixture is assumed to be at thermodynamic equilibrium, ρ_ℓ *and* ρ_g depend only on the system pressure P*. Equations (D.3-3) and (D.3-4) can be used to solve for α in terms of $\rho_\ell, \rho_g, h_\ell, h_g,$ *and* $\bar{h}$. The resulting relation is

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24 McFadden, J.H., et. al., "RETRAN-02 — A Program for Transient Thermal-Hydraulic Analysis of Complex Fluid Flow Systems", Volume 1: Theory and Numerics (Revision 2), NP-1850-CCMA, Electric Power Research Institute, Palo Alto, CA, November, 1984.

$$\alpha = \frac{\rho_\ell(\bar{h} - h_\ell)}{[\rho_\ell(\bar{h} - h_\ell) + \rho_g(h_g - \bar{h})]}. \quad \textbf{(D.3-5)}$$

Substitution of (D.3-5) into (D.3-3) yields the equation of state for the two-phase mixture:

$$\rho(P^*, \bar{h}) = \rho_\ell(P^*) - \frac{\rho_\ell(P^*)[\rho_\ell(P^*) - \rho_g(P^*)][\bar{h} - h_\ell(P^*)]}{\{\rho_\ell(P^*)[\bar{h} - h_\ell(P^*)] + \rho_g(P^*)[h_g(P^*) - \bar{h}]\}}. \quad \textbf{(D.3-6)}$$

The partial derivatives $\partial\rho/\partial P^*$ and $\partial\rho/\partial\bar{h}$ are then computed by application of the chain rule to (D.3-6):

$$\frac{\partial\rho}{\partial P^*} = \frac{\partial\rho}{\partial\rho_\ell}\frac{d\rho_\ell}{dP^*} + \frac{\partial\rho}{\partial\rho_g}\frac{d\rho_g}{dP^*} + \frac{\partial\rho}{\partial h_\ell}\frac{dh_\ell}{dP^*} + \frac{\partial\rho}{\partial h_g}\frac{dh_g}{dP^*} \quad \textbf{(D.3-7)}$$

and

$$\frac{\partial\rho}{\partial\bar{h}} = \frac{-\rho_\ell\rho_g(h_g - h_\ell)(\rho_\ell - \rho_g)}{[\rho_\ell(\bar{h} - h_\ell) + \rho_g(h_g - \bar{h})]^2} \quad \textbf{(D.3-8)}$$

where

$$\frac{\partial\rho}{\partial\rho_\ell} = 1 + \left\{\frac{(\bar{h} - h_\ell)[\rho_g(\rho_g - 2\rho_\ell)(h_g - \bar{h}) - \rho_\ell\rho_\ell(\bar{h} - h_\ell)]}{[\rho_\ell(\bar{h} - h_\ell) + \rho_g(h_g - \bar{h})]^2}\right\}, \quad \textbf{(D.3-9)}$$

$$\frac{\partial\rho}{\partial\rho_g} = \frac{\rho_\ell\rho_\ell(\bar{h} - h_\ell)(h_g - h_\ell)}{[\rho_\ell(\bar{h} - h_\ell) + \rho_g(h_g - \bar{h})]^2}, \quad \textbf{(D.3-10)}$$

$$\frac{\partial\rho}{\partial h_\ell} = \frac{\rho_\ell\rho_g(\rho_\ell - \rho_g)(h_g - \bar{h})}{[\rho_\ell(\bar{h} - h_\ell) + \rho_g(h_g - \bar{h})]^2}, \quad \textbf{(D.3-11)}$$

and

$$\frac{\partial\rho}{\partial h_g} = \frac{\rho_\ell\rho_g(\rho_\ell - \rho_g)(\bar{h} - h_\ell)}{[\rho_\ell(\bar{h} - h_\ell) + \rho_g(h_g - \bar{h})]^2}. \quad \textbf{(D.3-12)}$$

In SABRE, the density of saturated vapor and liquid are computed from the FORTRAN function routines VPHV and VPHL as

$$\rho_g(P^*) = \{VPHV[P^*, HGP(P^*)]\}^{-1} \quad \textbf{(D.3-13)}$$

and

$$\rho_\ell(P^*) = \{VPHL[P^*, HFP(P^*)]\}^{-1} \quad \textbf{(D.3-14)}$$

where the FORTRAN functions HGP(P*) and HFP(P*) give, respectively, the saturated vapor and liquid specific enthalpies as a function of pressure. The FORTRAN functions VPHV, VPHL, HGP, and HFP are all taken from the RETRAN code. (Ref. 24)

$\frac{d\rho_g}{dP^*}$ *and* $\frac{d\rho_\ell}{dP^*}$ are computed from

$$\frac{d\rho_g}{dP^*} = -\frac{\left(\frac{\partial \upsilon_g}{\partial P^*} + \frac{\partial \upsilon_g}{\partial h_g}\frac{dh_g}{dP^*}\right)}{\left[\upsilon_g(P^*, h_g)\right]^2} \quad \textbf{(D.3-15)}$$

and

$$\frac{d\rho_\ell}{dP^*} = -\frac{\left(\frac{\partial \upsilon_\ell}{\partial P^*} + \frac{\partial \upsilon_\ell}{\partial h_\ell}\frac{dh_\ell}{dP^*}\right)}{\left[\upsilon_\ell(P^*, h_\ell)\right]^2} \quad \textbf{(D.3-16)}$$

where $\upsilon_g(P^*, h_g) \equiv VPHV\left[P^*, HGP(P^*)\right]$ *and* $\upsilon_g(P^*, h_g) \equiv VPHV\left[P^*, HGP(P^*)\right]$ The derivatives $\partial\upsilon_g/\partial P^*$, $\partial\upsilon_g/\partial h_g$, $\partial\upsilon_\ell/\partial P^*$, $\partial\upsilon_\ell/\partial h_\ell$, dh_g/dP^*, *and* dh_ℓ/dP^* are computed in subroutines formulated by analytically differentiating the curve-fit polynomials in the RETRAN functions VPHL, VPHL, HGP, and HFP.

D.3.3 Super-Heated Vapor Region

In the super-heated vapor region, the volume-weighted enthalpy $\bar{h}$ is equivalent to the specific enthalpy of the vapor h_g. In this thermodynamic region, $\partial\rho/\partial P^*$ *and* $\partial\rho/\partial\bar{h}$ are computed from

$$\frac{\partial\rho}{\partial P^*} = \frac{\partial\left[\upsilon_g(P^*, h_g)\right]^{-1}}{\partial P^*} = -\left[\upsilon_g(P^*, h_g)\right]^{-2}\frac{\partial\upsilon_g(P^*, h_g)}{\partial P^*} \quad \textbf{(D.3-17)}$$

and

$$\frac{\partial\rho}{\partial\bar{h}} = \frac{\partial\left[\upsilon_g(P^*, h_g)\right]^{-1}}{\partial h_g} = -\left[\upsilon_g(P^*, h_g)\right]^{-2}\frac{\partial\upsilon_g(P^*, h_g)}{\partial h_g} \quad \textbf{(D.3-18)}$$

where $\upsilon_g(P^*, h_g) \equiv VPHV(P^*, h_g)$

D.4 Steam Condensation Rate

SABRE models condensation of steam on cold make-up flow under conditions where downcomer water level is below the elevation of the feedwater spargers. The elevation of the feedwater spargers is calculated in Section D.5.

The steam condensation rate on the cold make-up flow is governed by the following energy balance:

$$W_{inj}\left(h'_{inj} - h_{inj}\right) = W_{cond}\left(h_{g\,SD} - h'_{inj}\right) \qquad \textbf{(D.4-1)}$$

where

W_{inj} = injection flow rate (Lb/sec),
W_{cond} = steam condensation rate (Lb/sec),
h_{inj} = enthalpy of injection flow (Btu/Lb),
$h_{g\,SD}$ = enthalpy of steam in steam dome region (Btu/Lb), and
h'_{inj} = enthalpy of injection flow after condensation has occurred (Btu/Lb).

Note that $h'_{inj} \le h_f(P^*)$ *where* $h_f(P^*)$ is the specific enthalpy of saturated liquid at pressure P*. Equation (D.4-1) assumes that the liquid formed as a result of steam condensation comes to thermal equilibrium with the injection flow, i.e., the condensate may transfer heat to the make-up flow and consequently cool below the saturation temperature corresponding to P*. The condensation efficiency η is defined as

$$\eta \equiv \frac{h'_{inj} - h_{inj}}{h_f(P^*) - h_{inj}}. \qquad \textbf{(D.4-2)}$$

Using Equation (D.4-2) to eliminate h'_{inj} in Equation (D.4-1) leads to the following expression for the steam condensation rate W_{cond}:

$$W_{cond} = \frac{\eta W_{inj}\left[h_f(P^*) - h_{inj}\right]}{\left(h_{g\,SD} - h_{inj}\right) - \eta\left[h_f(P^*) - h_{inj}\right]}. \qquad \textbf{(D.4-3)}$$

A General Electric experimental study indicates that steam condensation efficiency for HPCI flow is in the 95 to 100 percent range.[25] GE test results show that the condensation efficiency is insensitive to the following operating parameters:

- Injection water flow rate,
- RPV water level, and
- Reactor pressure.

Based on these findings, a condensation efficiency of 95% is used in SABRE calculations. The condensation efficiency is assumed to increase linearly from zero with water level at or above the feedwater nozzles to 95% with water level 1 meter or more below the nozzles.

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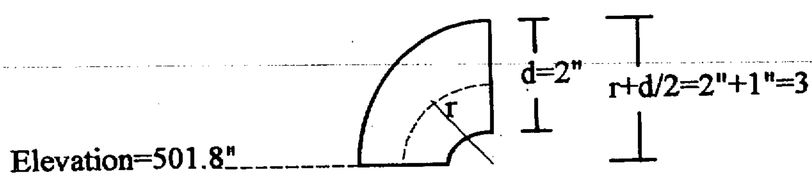
25 APED-5447, "Depressurization Performance of the General Electric Boiling Water Reactor High Pressure Coolant Injection System", May, 1969.

A recent calculational estimate of condensation efficiency[26], with the feedwater spargers uncovered , indicates that a lower bound on η is about 50%. Thus any sensitive studies with respect to the condensation efficiency should consider values of η in the range $0.50 \leq \eta \leq 0.95$.

D.5 Elevation of Feedwater Spargers

The center-line of the feedwater spargers is located at 498.5" above the bottom of the reactor vessel (Ref. 22). Each sparger is constructed of 6" schedule 40 pipe (Ref. 22) which has an outside diameter of 6.625" (p. B-16 of Ref. 6). Thus the elevation at the top of the sparger is 498.5" + 6.625"/2 = 501.8". The nozzles on the spargers are 2" schedule 40 elbows.[27] It is assumed that the nozzles are short radius elbows so that the dimensions of an elbow are as shown below (see p. A-29 of Ref. 1):



The elevation at the center line of the nozzles is therefore 501.8" + 3" - 1" = 503.8" above the bottom of the reactor vessel. This elevation with respect to instrument zero is 503.8" - 527.5" = -23.7".

D.6 SRV Flow Area and Critical Mass Flux Correction

The flow rate per SRV is given in Table 5.2-2 of the Susquehanna FSAR. The data is repeated here in Table D.6-1. In SABRE, the critical mass flux through the SRVs is computed from the homogeneous critical flow model (Section 2.6). The flow area per SRV is 0.11192 ft^2 (ref. 7, p. 22).

Comparison of the flow rates obtained from the critical flow model with the data in Table D.6-1 indicates that the model over-predicts the steam flow rate through the SRVs. In order to have SABRE compute SRV flow rates consistent with the values in Table D.6-1, the mass flux obtained from the critical flow model is multiplied by a correction factor of 0.884.

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26 Jensen, P., and Healzer, J., "Water Level Reduction to Suppress Instability During a BWR ATWS", NSAC-163, Appendix C, Electric Power Research Institute, Palo Alto, CA, March 1992.
27 SSES FSAR Figure 121.7-3b, Rev. 46, 06/93.

Table D.6-1
(Data is From Table 5.2-2 of SSES FSAR)

No. of Valves in SRV Group	Spring Set Pressure (psig)	ASME Rated Capacity at 103% Spring Set Pressure (Lb/hr each)	103% of Spring Set Pressure (psia)
2	1146	862,400	1195.08
4	1175	883,950	1224.95
4	1185	891,380	1235.25
3	1195	898,800	1245.55
3	1205	906,250	1255.85

D.7 Time Constants for Coastdown of Recirculation Pump Flow and Feedwater Enthalpy

Recirculation Pump Flow

The time constant governing the coastdown of the recirculation pump drive flow, following a pump trip, should be in the range of 3 to 4.5 seconds.[28] A value of 4 seconds is used in the SABRE model.

Feedwater Enthalpy

A time constant of 60 seconds is used to simulate the thermal capacitance of the feedwater heaters.[29]

D.8 Delayed Group Fractions and Decay Constants

SABRE uses 6 delayed neutron groups in the kinetics model (see Section 2.4). Values for the delayed group fractions (β_i/β) and associated decay constants λ_i are given in the following table:[30]

28 "Selected Transient Predictions for Susquehanna Steam Electric Station Unit 2 Startup Test Program", Section 3.4.3.1, PP&L Report NPE-85-001.

29 NEDO-32047, "ATWS Rule Issues Relative to Core Thermal-Hydraulic Stability", January, 1992.

30 PLI-73515, "Power Uprate Project -- ATWS Nuclear Fuel Characteristics Data Transmittal", February 10, 1993, File P88-1.

Table D.8-1
Delayed Group Fraction and Decay Constants

Delayed Group	Group Fraction (β_i/β)	Decay Constant λ_i (sec^{-1})
1	0.032	0.0128
2	0.205	0.0316
3	0.185	0.122
4	0.395	0.324
5	0.147	1.40
6	0.036	3.87

D.9 Valve Data for Turbine-Trip and MSIV-Closure Transients

The following valve parameters are required as input data for SABRE calculations:

Turbine Stop Valve Stroke Time
The closure time of the Stop valve is 0.1 seconds.[31]

Time Constant for Turbine Bypass Valve Operation
The time constant for valve operation is approximated by 1/3 of the valve stroke time (plus any delay). In the case of a turbine trip, the bypass valves reach 80% open in about 0.4 seconds (0.1 sec delay plus 0.3 sec stroke time).[32] The time to reach full open is estimated to be 0.1 sec + 0.3/0.8 sec = 0.475 sec. Therefore, the bypass valve time constant is

$$\tau_{BP} = 0.475/3 = 0.16 \text{ seconds.} \quad \text{(D.9-1)}$$

Time constant for turbine control valve operation
The valve time constant is approximated by 1/3 of the valve stroke time.

$$\tau_{CV} = 0.15/3 = 0.05 \text{ seconds.}$$[33]

MSIV Stroke Time
MSIV closure time must be less than 5.0 seconds and greater than 3.0 seconds.[34] A value of 4 seconds is typically used in SABRE calculations.

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31 GEZ-7127, "Susquehanna Steam Electric Station Unit Numbers 1 and 2 Transient Safety Analysis Design Report," p. 2-51, September, 1981.
32 NPE-85-001, "Selected Transient Predictions for Susquehanna Steam Electric Station Unit 2 Startup Test Program," p. 18.
33 EC-FUEL-0969, Section B.7.
34 "Selected Transient Predictions for Susquehanna Steam Electric Station Unit 2 Startup Test Program", Section 3.8.3.1, PP&L Report NPE-85-001.

Safety/Relief Valve Stroke Time

This value is used for the opening and closing time of an SRV. Since the SABRE code does not allow for a delay on SRV actuation, the appropriate delay is included in the stroke time. The SRV opening delay is 0.4 sec, and the closure delay is 0.3 seconds.[35] The valve opening time is 0.15 seconds (Ref. 42). The valve closure time is assumed equal to the opening time. Using an average delay of 0.35 seconds with an opening/closure time of 0.15 seconds gives an effective stroke time of <u>0.5 seconds</u>.

D.10 Safety/Relief Valve Set Points

The nominal SRV set points used in SABRE are[36]

Table D.10-1
SRV Relief and Reset Pressures

SRV	SRV Group	Relief Pressure (psia)	Reset Pressure (psia)
B	1	1113	987
E	1	1116	990
A	2	1126	999
C	2	1127	1000
D	2	1129	1002
H	2	1135	1007
F	3	1137	1009
P	3	1138	1010
R	3	1145	1016
S	3	1146	1017
J	4	1148	1018
L	4	1151	1021
N	4	1156	1026
G	5	1161	1030
K	5	1164	1033
M	5	1174	1042

D.11 Control Rod Insertion Time

The "best-estimate" control rod insertion time is taken from the Susquehanna RETRAN model.[37] The time interval required for control rod insertion is 2.8 seconds.

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35 GENE-637-024-0893, "Evaluation of Susquehanna ATWS Performance for Power Uprate Conditions," Table 2.2, October 1993.

36 GENE-637-024-0893, "Supplement 1 to the Evaluation of Susquehanna ATWS Performance for Power Uprate Conditions", October 1993.

37 Calc. EC-FUEL-0520.

D.12 Setpoint for ATWS Recirculation Pump Trip

The setpoint for the ATWS recirculation pump trip on high steam dome pressure is 1135 psig (SSES Unit 1 TRM, Table 2.2-1, 04/02/1999).

D.13 Time Delay for Recirculation Pump Trip on Main Turbine Trip

The time delay from closure of the turbine stop valve to initiation of the recirculation pump trip is 0.175 seconds.[38]

D.14 Pressure Regulator Gain

G_{PR} = (3.3% Steam Flow)/psi.[39]

D.15 Feedwater Controller Gain and Time Constant

In order to maintain RPV water level near the normal operating range (between 30 and 39 inches), SABRE uses a proportional control model to adjust the feedwater flow rate under transient conditions (see Section 2.7). This is a highly simplified description of the actual controller. The Susquehanna feedwater controller is a proportional-integral, three-element (the three elements are level, feedwater flow, and steam flow) system.[40]

In SABRE, the feedwater controller response is approximated by the following first-order model:

$$\tau_{FC}\frac{dW_F}{dt} = \left(W_F' - W_F\right)$$

where

$$W_F' = G_{FC,1}\left(L_{set} - L_{NR}\right) + G_{FC,2}\left(W_{steam} - W_{FW}\right),$$

and

W_F = feedwater flow (lbm/sec),
τ_{FC}= feedwater system time constant (sec),
$G_{FC,1}$ = controller gain (lbm/sec-inch),
$G_{FC,2}$ = controller gain (dimensionless),
L_{set} = level setpoint (inches), and
L_{NR} = narrow range water level (inches).

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38 PP&L Calculation No. NFE-B-01-002, Rev. 3, "Base RETRAN Model".

39 Calc. EC-FUEL-0969, Section D.4.

40 GEZ-6899, "Susquehanna Nuclear Power Station Control Systems Design Report", Section 7, March, 1982.

The constants $G_{FC,1}$, $G_{FC,2}$, and τ_{FC} were determined by trial and error. The three constants were varied until the SABRE calculated water level and feedwater flow showed good agreement with the plant data presented in Section 5.1. Optimal values of $G_{FC,1}$,$G_{FC,2}$, and τ_{FC} were found to be 200, 1, and 1, respectively.

D.16 Boron Transport Time

Two-Pump Operation

For two-pump operation, the time required for boron solution to travel from the SLCS pumps to the reactor is 30 seconds.[41] It is also assumed that the boron does not have a negative reactivity effect until it travels once around the natural circulation loop and re-enters the core. The loop transit time is estimated from SABRE calculations to be ~45 seconds.

One-Pump Operation

For one-pump operation, the transport time from the pump to the vessel should double from 30 seconds to 60 seconds. The loop transit time remains at 45 seconds.

D.17 Model Parameters for Boron Injection System

Boron Injection Rate

The nominal injection rate of elemental boron is 0.28 Lbm/sec for two-pump operation.[42]

Cold Shutdown Boron Weight

The normal temperature of the sodium pentaborate solution is 110 °F.[43] At this temperature the density of the solution is 9.1 Lb/gal.[43] Also, the mass of B per mass of sodium pentaborate is 0.183. With this information, the concentration of B in the SLC tank is calculated to be 23,000 ppm.[43]

If it cannot be assured that the reactor will be subcritical under all conditions without boron, Susquehanna EOPs require boron injection until the Cold Shutdown Boron weight is injected. The Cold Shutdown Boron Weight corresponds to 4191 gallons of solution.[44] In terms of mass of elemental boron, the Cold Shutdown Boron Weight corresponds to

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41 NEDE-24222, "Assessment of BWR Mitigation of ATWS, Volume II (NUREG 0460 Alternate No. 3)",Table 3.1.1-1 (p. 3-43), December, 1979.

42 GENE-637-024-0893, "Evaluation of Susquehanna ATWS Performance for Power Uprate Conditions," p. 7, September, 1993.

43 Refling, J.G., "Calculation of Plant Specific Parameters for Rev. 4 of the Emergency Procedure Guidelines," PP&L Calculation SE-B-NA-121.

44 EO-100-113, Rev. 4, "Level/Power Control", p. 13 of 67.

$$\begin{Bmatrix} Cold\ Shutdown \\ Boron\ Weight \end{Bmatrix} = (4191 gal\ of\ Soln)\left(\frac{9.1\ Lb\ \text{Soln}}{gal\ of\ \text{Soln}}\right)\left(\frac{23{,}000\ Lb\ of\ B}{10^6 Lb\ of\ Soln}\right) = 877\ Lb\ of\ B.$$

D.18 Data for Containment Model

D.18.1 Initial Pool Temperature

The maximum average suppression temperature allowed by Technical Specifications is 90 °F (Tech Spec 3.6.2.1, Amendment 178). This is the maximum value that should be used for the initial suppression pool temperature.

D.18.2 Cross-Sectional Area of Suppression Pool

Because of the presense of the downcomer pipes within the suppression chamber (the bottom of the downcomers correspond to 12 feet above the bottom of the pool), the free surface area of the pool is dependent on pool level. That is, the free surface area changes at 12 feet above the bottom of the pool. The free surface area of the SP is 5277 ft^2 at normal pool level.[45] Therefore, this is the free area for level > 12 feet. The volume of water in the SP at 24 feet is 133,540 ft^3 (Tech. Spec. Bases Section 3.6.2.2, Rev. 0). Therefore the pool free area for level less than 12 feet is calculated from

$133{,}540\ ft^3 = (12\ ft)A + (24-12)(5277\ ft^2)$ or,

$A = [133{,}540 - 12(5277)]/12 = 5851.3\ ft^2$.

The following data table accounts for the area change with SP level:

Elevation above Bottom of SP (ft)	Free Area (ft^2)
00.00	5851.3
12.00	5851.3
12.01	5277.0
52.50	5277.0

D.18.3 Initial Suppression Pool Water Level

The normal suppression pool water level is between 22 and 24 feet (Tech. Spec. 3.6.2.2, Amendment 178).

D.18.4 Initial Suppression Chamber Air Space Temperature

It is generally assumed that the initial suppression chamber air temperature is equal to the pool temperature.

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[45] SSES FSAR, Table 6.2-23.

D.18.5 Heat Load From Reactor Vessel

The initial heat loss from the reactor vessel to the drywell is approximated by the system heat loss listed in the reactor heat balance.[46] This value is 1.1 MW (1043 Btu/sec). Based on this value of the reactor heat load, the parameter $(hA)_{Rx2}$ in Equation (2-64) is given by

$$(hA)_{Rx2} = (1043 \text{ Btu/sec}) / [T_{Rx}(0) - T_{DW}(0)]$$

where

$T_{Rx}(0)$ = reactor vessel metal temperature at t=0. This is set equal to the coolant saturation temperature at t=0.

$T_{DW}(0)$ = drywell atmosphere temperature at t=0 (°F).

D.18.6 Drywell Cooling Load

As discussed in Section 2.10, the initial drywell cooling load $Q_{cool}(0)$ is set equal to the initial reactor heat load $Q_{Rx2}(0)$. [See Equations (2.10-21) and (2.10-22)]. Therefore, the constant $(UA)_{cool}$ in Equation (2-65) can be determined from

$$(UA)_{cool} = \frac{Q_{Rx2}(0)}{[T_{DW}(0) - T_{cool}(0)]}$$

where

$T_{cool}(0)$ = initial cooling water temperature (°F).

The cooling water temperature T_{cool} is the average of the inlet and outlet temperatures, $T_{cool,1}$ and $T_{cool,2}$ respectively:

$$T_{cool}(t) \equiv [T_{cool,1} + T_{cool,2}(t)] / 2.$$

The inlet cooling water temperature $T_{cool,1}$ is set to 50°F,[47] and the outlet temperature is calculated from an energy balance on the cooling water

$$Q_{cool}(t) = W_{cool}\, C_{pw} [T_{cool,2}(t) - T_{cool,1}] = (UA)_{cool}\, \{T_{DW} - [T_{cool,1} + T_{cool,2}(t)]\} / 2$$

where

W_{cool} = cooling water flow rate = 51.6 lbm/sec (Ref. 47), and

C_{pw} = specific heat of water = 1.0 Btu/lbm°F.

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46 NEDC-32161P, "Power Uprate Engineering Report for Susquehanna Steam Electric Station Units 1 and 2," December 1993.

47 PP&L Calculation EC-THYD-1001, "CONTAIN Model for Primary Containment".

D.18.7 Drywell Free Volume

The drywell free volume is 239,600 ft^3 (SSES FSAR, Table 6.2-1, Rev. 48, 12/94).

D.18.8 Initial Drywell Temperature

The initial drywell temperature is specified as 120°F (Ref. 47).

D.18.9 Initial Relative Humidity in Drywell

The initial relative humidity in the drywell is 48% (Ref. 47).

D.18.10 Initial Relative Humidity in Wetwell

It is assumed that the wetwell air space is saturated. Therefore, initial relative humidity is 100%.

D.18.11 Initial Drywell Pressure

Initial drywell pressure = 0.5 psig (Ref. 47).

D.18.12 Initial Wetwell Pressure

Initial wetwell pressure = 0.5 psig (Ref. 47)

D.18.13 Heat Transfer from SRV Tailpipe

The SABRE containment model considers heat transfer from the SRV tailpipes to the wetwell atmosphere. The rate of heat transfer to the air space is calculated from

$$Q_{TP} = N_{SRV} D_{TP} L_{TP} h_{TP} (T_{TP} - T_{SC}) \qquad \text{(D.18.13-1)}$$

where

N_{SRV} = number of open SRVs,
D_{TP} = diameter of the SRV tailpipe
= 12 inches[48]
L_{TP} = length of tailpipe within wetwell air space (ft),
h_{TP} = heat transfer coefficient at outer surface of tailpipe (Btu/sec-ft^2-°F)
T_{TP} = temperature of tailpipe (°F), and
T_{SC} = suppression chamber atmosphere temperature (°F).

The average length of an SRV tailpipe, inside the wetwell is 68 ft (Ref. 48). The bottom of the tailpipe is approximately 3'-6" from the suppression pool basemat (Ref. 48). Therefore, the length of the tailpipe exposed to the suppression chamber atmosphere is

$$L_{TP} = 68 - (L_{SP} - 3.5) = 71.5 \text{ ft} - L_{SP} \qquad \text{(D.18.13-2)}$$

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48 "Susquehanna Steam Electric Station Individual Plant Evaluation," NPE-91-001, p. C-91, December 1991.

where

L_{SP} is the suppression pool water level measured in feet.

The heat transfer coefficient at the outer surface of the tailpipe is computed by summing the contributions from natural convection and radiation.

$$h_{TP} = h_{TP,n} + h_{TP,r}. \tag{D.18.13-3}$$

The natural convection coefficient $h_{TP,n}$ (Btu/sec. ft^2 °F) is determined from the following correlation for heat transfer from a vertical cylinder.[49]

$$h_{TP,n} = 5.3 \times 10^{-5} (T_{TP} - T_{SC})^{1/3}, \tag{D.18.13-4}$$

and the radiation coefficient $h_{TP,r}$ (Btu/sec ft^2 °F) is calculated from[50]

$$h_{TP,r} = \frac{\varepsilon_{TP}\ \sigma\ \left[(T_{TP} + 459.67)^4 - (T_{SC} + 459.67)^4\right]}{(T_{TP} - T_{SC})} \tag{D.18.13-5}$$

where

ε_{TP} = emissivity of pipe = 0.85, and
σ = Stefan-Boltzmann constant
= 4.761×10^{-13} Btu/sec ft^2 °F^4.

In calculating the rate of heat transfer from the SRV tailpipes, it is assumed that the pipe temperature is equal to the saturation temperature at the pressure inside the tailpipe. The internal pressure of the tailpipe P_{TP} (psia) is calculated from

$$P_{TP} = P_{SC} + \rho_{SP} \frac{g}{gc} \frac{(L_{SP} - 3.5')}{144} + \frac{K_{quen} (W_{SRV} / N_{SRV})^2}{2 g_c \rho_g (P_{TP}) A_{TP}^2 (144)} \tag{D.18.13-6}$$

where

P_{SC} = suppression chamber atmosphere pressure (psia),
ρ_{SP} = density of water in suppression pool (lbm/ft^3),
g = 32.2 ft/sec^2,
g_c = 32.2 ft·lbm/lb$_f$·sec^2,
L_{SP} = suppression pool level (ft),

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49 Holman, J.P., *Heat Transfer*, 3rd Edition, McGraw-Hill, p. 219, New York, 1972.
50 Incropera, F.P., & DeWitt, D.P., *Fundamentals of Heat Transfer*,, , pp. 448-449, Wiley, New York, 1981.

K_{quen} = loss coefficient for quencher, based on area of tailpipe,
W_{SRV} = steam flow rate through SRVs (lbm/sec),
N_{SRV} = number of open SRVs,
$\rho^g(P_{TP})$ = density of saturated steam at pressure P_{TP} (lbm/ft^3), and
A_{TP} = flow area of SRV tailpipe (ft^2).

A value of 1.0 (loss due to expansion from pipe; see Ref. 6, p. A-29) is used to approximate K_{quen}. Equation (D.18.13-6) is solved by iteration because the steam density is a function of the pipe pressure.

D.18.14 Surface Area of Drywell Heat Structures

The SABRE model accounts for the thermal capacitance of the steel structures within the containment. Within the drywell these structures are divided into four categories: wall, roof, floor, and internal structures (see Section 2.10). The wall, roof, and floor structures account for the thermal capacitance of the drywell liner, and drywell structural steel (grating, support steel, pipe hangers, and equipment) is modeled as the internal heat structure. Surface areas for these heat structures are given below:

<u>**Surface Area of Drywell Wall**</u>

The drywell geometry is approximated by a frustrum of a right circular cone. A diagram of the idealized geometry is shown below. Dimensions are from Drawing C-331 (E-105332).

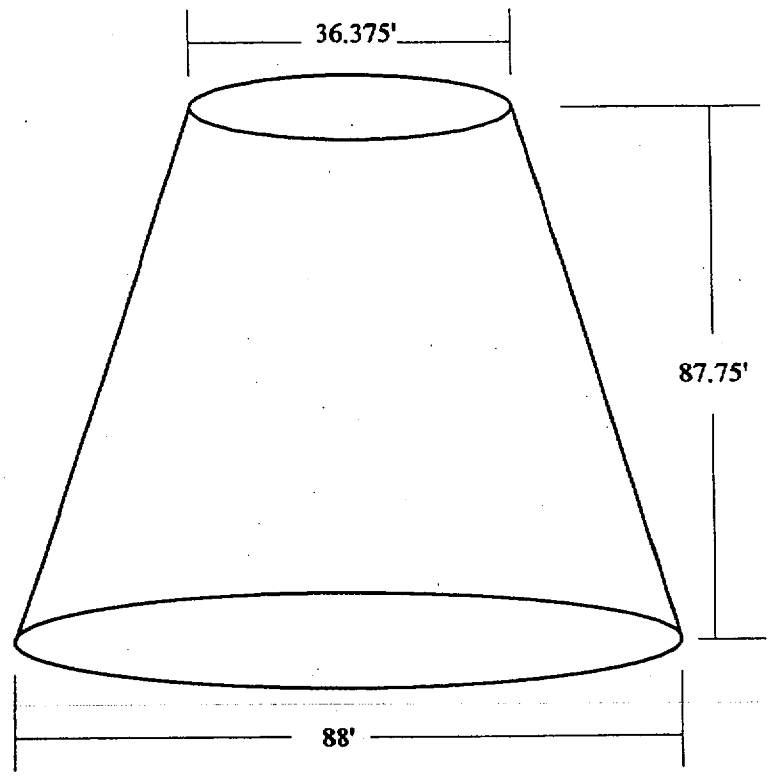

Figure D.18.14-1 Idealized geometry of drywell for purposes of calculating heat transfer dimensions.

Surface area of drywell wall $= \pi\left(\frac{88}{2}+\frac{36.375}{2}\right)\sqrt{\left(\frac{88}{2}-\frac{36.375}{2}\right)^2+(87.75)^2}$

$= 17{,}870\ ft^2$.

<u>**Surface Area of Drywell Roof**</u>

Surface area of drywell roof $= \pi\,(18.188\ ft)^2 = 1039\ ft^2$

<u>**Surface Area of Drywell Floor**</u>

Surface area of drywell floor $= \pi(44)^2 = 6082\ ft^2$

<u>**Surface Area of Drywell Internals**</u>

The total mass of steel in the drywell, including the liner plate,

$= 4(153{,}902+192{,}727+53{,}080)\ Lb_m$[51] $= 1{,}598{,}836\ Lb_m$

Total mass of liner plate $= (0.25/12)(17{,}870+1039+6082)\rho_{steel}$

$= (0.0208)(24{,}991)(489) = 254{,}188\ Lb_m$.

Total mass of internals $= 1{,}598{,}836 - 254{,}188 = 1{,}344{,}648\ Lb_m$

---

[51] PP&L Calc. SE-B-NA-108, Rev. 0, p. 97

Volume of internals = $(1,344,648\ Lb_m)/(489 Lb_m/ft^3) = 2,750\ ft^3$

A characteristic thickness of 1" is assumed for the drywell internal structural steel. The heat transfer area of the internal structures is then $2(2,750)/(1/12) = 66,000\ ft^2$

D.18.15 Volume of Drywell Steel Structures

The volume of the steel structures is used in calculating the thermal capacitance. Volumes of the four drywell heat structures are:

Volume of drywell wall = (surface area) x (thickness)
= $(17,870\ ft^2)(0.25/12\ ft) = 372\ ft^3$

Volume of drywell floor = (surface area) x (thickness)
= $(6082\ ft^2)(0.25/12\ ft) = 127\ ft^3$

Volume of drywell roof = (surface area) x (thickness)
= $(1039\ ft^2)(0.25/12\ ft) = 22\ ft^3$

Volume of Internal Structural Steel = $= 2750\ ft^3$.

D.18.16 Surface Area of Wetwell Heat Structures

There are two wetwell heat structures modeled in SABRE: the drywell liner which is attached to the wall of the wetwell and the structural steel. Only the steel within the suppression chamber air space is included. The thermal capacitance of the submerged steel is neglected because it is small compared to that of the water (normal water level is assumed).

Surface area of Wetwell Wall = $2\pi\ (44\ ft)\ (52.5 - 23)\ ft = 8156\ ft^2$
[Drawing C-331 (E-105332)]

Mass of liner plate in air space = $(8156\ ft^2)(0.25\ ft/12)\rho$,
$(8156)(0.02083)(489) = 83,076\ Lb_m$.

Mass of Structural Steel in air space = $(4)\ (153,028\ Lb_m) = 612,112\ Lb_m$
(PP&L Calculation SE-B-NA-108, Rev. 0, p. 97))

Volume of internals (structural steel) = $(612,112\ Lb_m)/(489 Lb_m/ft^3) = 1,252\ ft^3$

A characteristic thickness of 1" is assumed for the internals in the wetwell. Based on this assumption, the heat transfer area associated with the internals = $(2)(1,252)/(1/12) = 30,048\ ft^2$

D.18.17 Volume of Wetwell Steel Structures

The liner plate is 1/4" thick; therefore, the volume of the plate is
Volume of Wetwell Wall = $(8156\ ft^2)(0.0208\ ft) = 170\ ft^3$

Volume of Internal Structural Steel = 1252 ft^3

D.18.18 Characteristic Length of Containment Heat structures

Characteristic lengths area used by the code in computing the heat transfer coefficients. The heat transfer correlations used in SABRE are the same as those used in the COTTAP code.[52]

Characteristic Length of Drywell Wall = height = 87.75 ft

Characteristic Length of Drywell Roof = Area/perimeter = $\frac{(1039\ ft^2)}{\pi(36.375\ ft)} = 9.1\ ft$

Characteristic Length of Drywell Floor = Area/perimeter = $\frac{(6082\ ft^2)}{\pi(88\ ft)} = 22\ ft$

A characteristic length (height) of 10 ft is assumed for modeling the structural steel in the drywell and wetwell.

Characteristic Length of Wetwell Wall = height = (52.5 - 23) ft = 29.5 ft.

D.19 Model for Wide Range Level Indication

The Wide Range Level model is based on the instrument information provided in PP&L Calculation No. ICC-LT-24201B. The Wide Range indicated level is a function of the pressure differential across the differential pressure transmitter. The level indicator reads -150" when the differential pressure is -212.98 inches of water and +60" when the differential pressure is -66.16 inches of water. Thus, the Wide Range Water Level (in inches) is given by

$$L_{WR} = -150 + 1.4303(\Delta P + 212.98)$$

where

ΔP = differential pressure (inches of water) across pressure transmitter.

ΔP is the difference between the variable leg and reference leg pressures at the transmitter (see figure in Calculation No. ICC-LT-24201B). This pressure differential is calculated as follows:

$$\Delta P = 27.73(P_V - P_R)$$

where

P_V = Variable leg pressure (psia)

P_R = Reference leg pressure (psia)

The constant 27.73 is the conversion factor from psia to inches of water at standard conditions (0 °C). The pressures P_V and P_R are calculated up to the point defined by elevation (d) within the Reactor Building (see Figure in ICC-LT-24201B). Beyond this point, the elevation heads will cancel. The pressure P_V is given by

$$P_V = \frac{[z_1\rho_g + z_2\rho_f + z_3\rho_{DC} + z_4\rho_{DW}]}{(12)(144)} - \frac{\rho_{DC}V_{DC}^2}{(2)(144)g_c}$$

where

52 "COTTAP-2, Rev. 1, Theory and Input Description Manual," SE-B-NA-046, Rev. 1, November 1990.

z_1 = a - L_{Rx},
z_2 = Max(L_{Rx} + 10.66, 0.0)
z_3 = Min(150.84, L_{Rx} + 161.5)
z_4 = c - d
a = 12(782.21308 - e)
b = 12(775.50000 - e)
c = 366.00000
d = 12(756.97000 - e)
e = 732.33333
g_c = 32.2 ft-Lb_m/Lb_f-sec^2
V_{DC} = fluid velocity (ft/sec) in downcomer = $(W_{Jet} + W_{break})/[(88ft^2)\rho_{DC}]$
W_{jet} = Mass flow rate from downcomer to jet pumps (Lb_m/sec),
W_{break} = Break flow (if liquid break in downcomer region) (Lb_m/sec),
ρ_{DC} = fluid density in downcomer region (Lb_m/ft^3), and
ρ_{DW} = density of water at Drywell temperature (Lb_m/ft^3).

The pressure P_R (psia) is calculated as

$$P_R = \frac{\rho_{DW}(a-b)+\rho_{RB}(b-d)}{(12)(144)}$$ where

ρ_{RB} = density of water at Reactor Building temperature (Lb_m/ft^3).

The elevations a, b, c, d, and e are taken from Calc. ICC-LT-24201B.

D.20 Core Spray Flow

Core Spray injection rate, for 1 division, is taken from Figure 6.3-79 of the Susquehanna FSAR (Rev. 50, 07/96). Core Spray flow is expressed as a function of the pressure difference between the reactor vessel and the containment. In the SABRE code, the suppression chamber atmosphere pressure is used as the containment pressure in determining the Core Spray flow rate. Table D.20-1 gives the Core Spray flow as a function of pressure differential.

Table D.20-1
Core Spray Injection Rate as a Function of Reactor/Containment Pressure Differentail

[Reactor Pressure] - [Containment Pressure] (psi)	Core Spray Injection Rate (1 Division) (gpm)
0	7790
56	7000
122	6000
172	5000
214	4000
245	3000
266	2000
277	1000
289	0.
1500	0.

APPENDIX E
FORTRAN Program Used to Compute Heated Channel Response in Section 5.9

```
C**************************************************************************
C
C   C O U N T E R - C U R R E N T   F L O W   S I M U L A T I O N
C                  I N   F U E L   B U N D L E
C**************************************************************************
C**** NOMENCLATURE
C
C
C     VARIABLES:
C     AHT  = Heat transfer area (ft2)
C     ALPH = Nodal void fraction
C     CO   = Bubble concentration parameter
C     HBAR = Volume-weighted enthalpy (Btu/Lbm)
C     DHDT= temporal derivative of vol-weighted enthalpy (Btu/Lbm-sec)
C     HG   = Gas-phase enthalpy (Btu/Lbm)
C     HL   = Liquid-phase enthalpy (Btu/Lbm)
C     POWER= Power in channel node (Btu/sec)
C     PRPH = Partial derivative of density w/r to vol-weighted enthalpy
C            (Lbm-Lbm/ft3-BTU)
C     PRPP = Partial derivative of density w/r to pressure (Lbm/ft-Lbf)
C     Pt   = Temporal derivative of fluid pressure (LBf/ft2-sec)
C     Q    = Control-volume heat source (BTU/sec)
C     QPP  = Heat flux to coolant (BTU/ft2-sec)
C     RO   = Control volume density (Lbm/ft3)
C     ROt  = Temporal derivative of fluid density (Lbm/ft3-sec)
C     ROG  = Control volume gas phase density (Lbm/ft3)
C     ROL  = Control volume liq-phase density (Lbm/ft3)
C     SM   = Mass source (Lbm/sec)
C     SH   = Enthalpy associated with mass source (BTU/Lbm)
C     Vgj  = Drift velocity (ft/sec)
C     SUFFIX C => CHANNEL
C**************************************************************************

      Implicit Real*8(A-H,O-Z)

      common /var/ AHTC(51),ALPHC(51),ALPHB(51),COC(51),
     &           COB(51),HBARC(51),DHDTC(51),HLC(51),
     &           HLB(51),HGC(51),HGB(51),GCV(51),GC(51),
     &           PRPHC(51),PRPPC(51),QC(51),QppC(51),
     &           ROC(51),ROGC(51),ROGB(51),ROLC(51),
     &           ROLB(51),SMC(51),SHC(51),TEMPC(51),
     &           ULB(51),UGB(51),VgjC(51),VgjB(51),
     &           WLB(51),WGB(51),WOUTO(51),XC(51),APF(51),
     &           ICAL(51)

      COMMON /PROPY/ HG,HF,VF,VG,ROF,ROG,DHFDP,DHGDP,DRFDP,DRGDP,AMUF,
     &               AMUCL(51),THRMCL(51),CPCL(51),THERMF,CPCF,
     &               AMUCG(51),THRMCG(51),CPCG(51),
     &               TSAT,SIGMA,SUBDC,IVOID,IJKC

      OPEN (4, FILE='step1.out', STATUS='NEW')
      OPEN (5, FILE='step2.out', STATUS='NEW')
      G = 1.D0
      AJ = 778.D0
      NSC=0
      FREQ=0.0D0

C**** SPECIFY THE NUMBER OF NODES
      NODE = 25

C**** SPECIFY THE CHANNEL POWER (BTU/SEC)
      POWER = 455.D0

C**** Set the initial time t and the time step size, AND THE END TIME
      t=0.D0
      DELT = 0.050D0
      TEND = 80.D0


C**** SPECIFY THE DOME PRESSURE
      PRX1 = 1000.D0
      PRX  = 1000.D0*144.D0
      PRX0=PRX

C**** SPECIFY THE SATURATION FLUID PROPERTIES
         HF= HFP(PRX1)
         HG= HGP(PRX1)
         VF= VPHL(PRX1,HF)
         VG= VPHV(PRX1,HG)
         VFG = VG - VF
         ROF= 1.D0/VF
         ROG= 1.D0/VG
         TSAT= TPHL(PRX1,HF)
         SIGMA= CIGMA(TSAT)
         DHFDP= DHFP(PRX1)
         DHGDP= DHGP(PRX1)
         DRFDP= DRFP(PRX1, HF, DHFDP)
         DRGDP= DRGP(PRX1, HG, DHGDP, VG)


C**** SET CHANNEL FLOW AREA, CONTROL VOLUME LENGTH AND NODAL VOLUME.
      AC  = 87.11/764.D0
      DELZC = 12.5D0/FLOAT(NODE)
      VC = AC*DELZC
```

```
C**** Set temporal derivative of pressure, core-inlet flow, and
C**** nodal power.
C**** Total core power (at rated conditions) = 3.1D6 Btu/sec
C**** Channel power (at rated conditions) = 3.1D6/764 Btu/sec
      Pt = 0.0D0
      POWERt = 0.D0

C**** Set the initial state of the Core Channel
      DO 10 J=1,NODE,1
      APF(J)=1.D0
      WOUTO(J)=0.D0
      GCV(J)=0.D0
      GC(J) = 0.D0
      ROGC(J)  = ROG
      ROLC(J)  = ROF
      HGC(J)   = HG
      HLC(J)   = HF
      ALPHC(J)=0.0D0
      QC(J) = 0.00D0
      QPPC(J) = 0.D0
      SMC(J) = 0.D0
      SHC(J) = 200.D0
      ROC(J) = ALPHC(J)*ROGC(J) + ( 1.D0-ALPHC(J) )*ROLC(J)
      HBARC(J) = ( ALPHC(J)*HGC(J)*ROGC(J) +
     &           ( 1.D0-ALPHC(J) )*HLC(J)*ROLC(J) )/ROC(J)
      CALL DDEN( PRX1, HBARC(J), PRPPC(J), PRPHC(J) )
   10 CONTINUE
      GC(NODE+1)=0.D0
      NODE1=NODE-1


C**** Set conditions on upper boundary
C**** Put saturated liquid on upper boundary
      HBAR2 = HBARC(NODE)
      CALL STATE( 26,PRX1,HBAR2,RO2,ROL2,ALPH2,TEMP2,
     &            ROG2, HG2 )
      HL2 = DMIN1(HF,HBAR2)
      RO2 = (1.D0-ALPH2)*ROL2 + ALPH2*ROG2
      Call VOIDL( ALPH2,ROL2,ROG2,SIGMA,5,99,0.D0,
     &            CO2,VGJ2,X2 )


C**** Specify no flow on boundary 1
      WGB(1)=0.D0
      WLB(1)=0.D0
      HLB(1)=HF
      HGB(1)=HG

C**** calculate the number of time steps
      NSTEP = DINT( TEND/DELT ) + 1

      KJ=0
      DO 50 K=1,50000,1
      KJ=KJ+1
      IF ( T .GT. TEND ) STOP

      DO 59 J=1,NODE,1
      CALL DDEN( PRX1, HBARC(J), PRPPC(J), PRPHC(J) )
   59 CONTINUE

      HBAR2 = HBARC(NODE)
      CALL STATE( 26,PRX1,HBAR2,RO2,ROL2,ALPH2,TEMP2,
     &            ROG2, HG2 )
      HL2 = DMIN1(HF,HBAR2)
      RO2 = (1.D0-ALPH2)*ROL2 + ALPH2*ROG2
      Call VOIDL( ALPH2,ROL2,ROG2,SIGMA,5,99,0.D0,
     &            CO2,VGJ2,X2 )

      DO 60  J=1,NODE,1
      I = J+1
      APF(J)=1.D0
      PI=3.14159D0
      QC(J) = POWER*APF(J)/FLOAT(NODE)

C**** SPECIFY THE SATURATION FLUID PROPERTIES
         HF= HFP(PRX1)
         HG= HGP(PRX1)
         VF= VPHL(PRX1,HF)
         VG= VPHV(PRX1,HG)
         VFG = VG - VF
         ROF= 1.D0/VF
         ROG= 1.D0/VG
         TSAT= TPHL(PRX1,HF)
         SIGMA= CIGMA(TSAT)
         DHFDP= DHFP(PRX1)
         DHGDP= DHGP(PRX1)
         DRFDP= DRFP(PRX1, HF, DHFDP)
         DRGDP= DRGP(PRX1, HG, DHGDP, VG)


      CALL STATE( J,PRX1,HBARC(J),ROC(J),ROLC(J),ALPHC(J),TEMPC(J),
     &            ROGC(J), HGC(J) )
      HLC(J) = DMIN1( HF,HBARC(J) )

      Call VOIDL( ALPHC(J),ROLC(J),ROGC(J),SIGMA,4,J,GCV(J),
     &            COC(J),VGJC(J), XC(J) )

      IF ( J .NE. NODE ) THEN
      Call Step( 0.D0, 0.D0,
     &    HBARC(J),PRPHC(J),PRPPC(J),Pt,VC,DELZC,SMC(J),SHC(J),AC,
     &    ALPHC(J), ALPHC(I), ROLC(J), ROLC(I), ROGC(J), ROGC(I),
     &    HLC(J), HLC(I), HGC(J), HGC(I), COC(J), COC(I),
```

```
     &     VGJC(J), VGJC(I), QC(J), QPPC(J), ROC(J), PhC,
     &     WGB(J), WLB(J), HGB(J), HLB(J),
     &     WLB(I), WGB(I),
     &     ALPHB(I),
     &     HLB(I), HGB(I), ROLB(I), ROGB(I), DHDTC(J),
     &     3, J, UGB2, ULB2, WOUTO(J), HBARC(I) )
      ELSE IF ( J .EQ. NODE ) THEN
      Call Step( 0.D0, 0.D0,
     &     HBARC(J),PRPHC(J),PRPPC(J),Pt,VC,DELZC,SMC(J),SHC(J),AC,
     &     ALPHC(J), ALPH2, ROLC(J), ROL2, ROGC(J), ROG2,
     &     HLC(J), HL2, HGC(J), HG2, COC(J), CO2,
     &     VGJC(J), VGJ2, QC(J), QPPC(J), ROC(J), PhC,
     &     WGB(J), WLB(J), HGB(J), HLB(J),
     &     WLB(I), WGB(I),
     &     ALPHB(I),
     &     HLB(I), HGB(I), ROLB(I), ROGB(I), DHDTC(J),
     &     3, J, UGB2, ULB2, WOUTO(J), HBARC(I) )
      END IF

      WOUTO(J) = WLB(I) + WGB(I)
      GC(I) = ( WLB(I) + WGB(I) )/AC
      GCV(J) = ( GC(J) + GC(I) )/2.D0
      ugb(1)=0.d0
      ulb(1)=0.d0
      ugb(i)=ugb2
      ulb(i)=ulb2
   60 CONTINUE


      IF (KJ .EQ. 10 ) Then
C**** Write the header
      WRITE(4,102)
  102 Format('       ')
      WRITE(4,101) t,K
  101 Format(' TIME = ', F12.3, '  NO. STEPS = ', I7 )
      WRITE(4,103)
  103 Format('   NODE',9x,'ALPH',9x,'HBAR',10x,'WLB',9x,
     &'WGB',10x,'Q',10x,'CO',9x,'VGJ',9x,'ULIQ',9x,'UGAS')

      DO 70 M=NODE,1,-1
      WRITE(4,104) M,ALPHC(M),HBARC(M),WLB(M+1),WGB(M+1),QC(M),
     &                COC(M),VGJC(M),ulb(m+1),ugb(m+1)
  104 Format(' ', I5,5x,E12.4,8F12.4,6x,I5,5x,E12.4,5x,2f14.2 )
   70 CONTINUE
      M=0
      WRITE(4,1104) M,WLB(1),WGB(1),ulb(1),ugb(1)
 1104 FORMAT(' ', I5,29X,2F12.4,30x,2f14.2 )
      KJ=0
      END IF

C**** Print the liquid and vapor flow rates at the top of the channel
      Write(*,4361) t,WLB(NODE+1),WGB(NODE+1),ALPHB(NODE+1),PRX1
      Write(5,4361) t,WLB(NODE+1),WGB(NODE+1),ALPHB(NODE+1),PRX1
 4361 FORMAT(' ', 5F12.5 )

C**** Integrate the energy balance equations for the core channel.
      NSC = 0
      DO 80 MN=1,NODE,1
      HBARC(MN) = HBARC(MN) + DELT*DHDTC(MN)
      IF ( HBARC(MN) .GT. HG ) NSC=NSC+1
   80 CONTINUE

      pt=0.d0
      PRX = PRX + DELT*PT
      PRX1=PRX/144.D0
      POWER = POWER + DELT*POWERt
      t = t + DELT

   50 CONTINUE

      STOP
      END


      SUBROUTINE VOIDL( ALPH, ROL, ROV, SIGMA, IREG, INODE,
     &                 G, CO, Vgj, X )
      IMPLICIT REAL*8(A-H,O-Z)
C**** Computes Vgj and CO using the Ohkawa-Lahey Void Model
C     Input :  ALPH = Void fraction
C              ROL  = Liquid phase density (Lbm/ft3)
C              ROV  = Vapor phase density (Lbm/ft3)
C              SIGMA= Interfacial Tension (Lbf/ft)
C              IREG = Region number
C                   = 1 => Jet Pump
C                   = 2 => Lower PLenum
C                   = 3 => Core
C                   = 4 => Bypass
C                   = 5 => Upper Plenum
C                   = 6 => Riser
C                   = 7 => Separator
C                   = 8 => Downcomer
C              INODE= Node within region IREG
C              G    = Volume-average mass flux (Lbm/ft2-sec)
C
C     Output : CO   = Radial bubble concentration parameter
C              Vgj  = Drift velocity (ft/sec)
C              X    = Flow quality
C****

      If ( alph .gt. 1.d0 .or. alph .lt. 0.d0 ) then
         WRITE(4,101)
  101    format(' Void fraction out of range in subroutine void ')
```

```
      WRITE(4,102) IREG,INODE,ALPH
102   format(' Region = ', I4, ' Node = ', I4, ' Void = ', F12.4 )
    End If

    IF ( alph .GE. 1.d0 ) Then
      C0 = 1.d0
      Vgj=0.d0
      return
    End If

    a1 = ROV/ROL

    d = 0.5881164d0 - 1.81701d0*dsqrt( a1 ) +
   &    2.00025d0*a1 - 3.34398d0*( a1 )**1.5d0

    y1 = 4.72085d0 - 17.26736d0*dsqrt( a1 ) + 56.14883d0*a1
   &     + 113.216d0*( a1 )**1.5d0 -
   &     1250.603*( a1 )**2 + 3039.767d0*( a1 )**(2.5d0)
   &     - 2431.8228*( a1 )**3

    y = dmax1( 3.136d0, y1 )

    a2 = 32.2d0*32.2d0*sigma*( ROL - ROV )/ROL**2
    a2 = a2**0.25d0

    a3 = ( alph - d )/( 1.d0 - d )
    a3 = 1.d0 - a3**2

    a4 = dsqrt( a1 )

    Vgj1 = 2.9d0*a2

    Vgj2 = y*a2*a3

    C01  = ( 1.2d0 - 0.2d0*a4 )*( 1.d0 - dexp( -18.d0*alph ) )

    C02  = 1.d0 + 0.2d0*( 1.d0 - a4 )*a3

    If ( alph .lt. d ) then
       Vgj = Vgj1
       C0  = C01
    else
       Vgj = dmin1( Vgj1, Vgj2 )
       C0  = dmin1( C01, C02 )
    End If

C**** Compute the quality for two-phase friction calc
    G1 = G
    IF ( DABS(G) .LE. 10.D0 ) Then
       X1 = ( ROV*VGJ/(-10.D0) + C0*ROV/ROL )*ALPH
       X1 = X1/( 1.D0 + ALPH*C0*ROV/ROL - C0*ALPH )
       IF ( X1 .GT. 1.D0 ) X1 = 1.D0
       IF ( X1 .LT. 0.D0 ) X1 = 0.D0
       X2 = ( ROV*VGJ/(10.D0) + C0*ROV/ROL )*ALPH
       X2 = X2/( 1.D0 + ALPH*C0*ROV/ROL - C0*ALPH )
       IF ( X2 .GT. 1.D0 ) X2 = 1.D0
       IF ( X2 .LT. 0.D0 ) X2 = 0.D0
       SLOPE = ( X2-X1 )/20.D0
       X = X1 + SLOPE*( G + 10.D0 )
    ELSE
       X = ( ROV*VGJ/G + C0*ROV/ROL )*ALPH
       X = X/( 1.D0 + ALPH*C0*ROV/ROL - C0*ALPH )
    END IF

    RETURN
    END


      FUNCTION CIGMA(TEMP)
C**** SATURATED LIQUID SURFACE TENSION (LBF/FT) AS A FUNCTION OF
C**** TEMPERATURE (DEGF) - RETRAN02 PROP FIT
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION A(5)
      DATA A / 0.D0,  1.121404688D-3,  -5.752805180D-6,  1.286274560D-8,
     &          -1.149719290-11 /
      DATA B,D / 0.83D0, 1.160936807D-1 /
      TT=TEMP
      T=((5.D0/9.D0)*(TT-32.D0))+273.D0
      TK=647.3D0 - T
      S1=(D*TK*TK)/(1.D0 + B*TK)
      S2=0.D0
      DO 10 J=2,5
      S2=S2+A(J)*TK**J
   10 CONTINUE
      CIGMA=(S1+S2)*6.852292D-5
      RETURN
      END


C***************************************************************************
C****
      SUBROUTINE DDEN(P,HO,PRPP,PRPH)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON /PROPY/ HG,HF,VF,VG,ROF,ROG,DHFDP,DHGDP,DRFDP,DRGDP,AMUF,
     &               AMUCL(51),THRMCL(51),CPCL(51),THERMF,CPCF,
     &               AMUCG(51),THRMCG(51),CPCG(51),
     &               TSAT,SIGMA,SUBDC,IVOID,IJKC
      COMMON /DDBUG/ LLL
C**** THIS ROUTINE CALCULATES THE PARTIAL DERIVITIVES OF DENSITY W/R
C**** TO PRESSURE AND ENTHALPY FOR SUBCOOLED, TWO-PHASE, AND SUPER-
C**** HEATED FLUID.
```

```
C      INPUT :  P = PRESSURE (PSIA)
C               H = ENTHALPY (BTU/LBM)
C      OUTPUT:  PRPP = PARTIAL DERIVATIVE OF DENSITY W/R TO PRESSURE
C                      (LBM/FT-LBF)
C               PRPH = PARTIAL DERIVATIVE OF DENSITY W/R TO ENTHALPY
C                      (LBM-LBM/FT3-BTU)
C**** SMOOTH DERIVATIVES IF CLOSE TO SATURATION LINE TO ELIMINATE
C**** DISCONTINUITIES.
      H = HO
      X = ( H - HF )/( HG - HF )
C     AAA = 2.D0*0.00125D0
      AAA = 2.D0*0.0100D0
      X1 = -AAA
      X2 =  AAA
      X3 =  1.D0-AAA
      X4 =  1.D0+AAA

      IF ( X .GT. X3  .AND.  X .LT. X4 ) THEN
         H3 = HF + X3*( HG - HF )
         H4 = HF + X4*( HG - HF )
         VG4 = VPHV( P, H4 )
         CALL DERVAP( P, H4, VG4, PRPP4, PRPH4 )
         H = H3
         HHF= H - HF
         HGH= HG - H
         F1 = (ROG - ROF)*ROF*HHF
         F2 = HGH*ROG + HHF*ROF
         F22M1= 1.D0/F2**2
         F5= F1*F22M1
         PRPRF = 1.D0 - ( F5 - ( ROG - 2.D0*ROF )/F2 )*HHF
         PRPRG = - F5*HGH + ROF*HHF/F2
         PRPHF = ( F5 + (ROF - ROG)/F2 )*ROF
         PRPHG = -F1*ROG*F22M1
         PRPP3 = PRPRF*DRFDP + PRPRG*DRGDP + PRPHF*DHFDP + PRPHG*DHGDP
         PRPH3 = -( F5 + ROF/F2 )*(ROF-ROG)
         PRPP = PRPP3 + (PRPP4-PRPP3)*( X - X3 )/( X4 - X3 )
         PRPH = PRPH3 + (PRPH4-PRPH3)*( X - X3 )/( X4 - X3 )
         GO TO 99
      END IF

      IF ( X .GT. X1  .AND.  X .LT. X2 ) THEN
         H1 = HF + X1*( HG - HF )
         CALL DERLIQ( P, H1, PRPP1, PRPH1 )
         H2 = HF + X2*( HG - HF )
         H = H2
         HHF= H - HF
         HGH= HG - H
         F1 = (ROG - ROF)*ROF*HHF
         F2 = HGH*ROG + HHF*ROF
         F22M1= F2**(-2)
         F5= F1*F22M1
         PRPRF = 1.D0 - ( F5 - ( ROG - 2.D0*ROF )/F2 )*HHF
         PRPRG = - F5*HGH + ROF*HHF/F2
         PRPHF = ( F5 + (ROF - ROG)/F2 )*ROF
         PRPHG = -F1*ROG*F22M1
         PRPP2 = PRPRF*DRFDP + PRPRG*DRGDP + PRPHF*DHFDP + PRPHG*DHGDP
         PRPH2 = -( F5 + ROF/F2 )*(ROF-ROG)
         PRPP = PRPP1 + (PRPP2-PRPP1)*(X-X1)/(X2-X1)
         PRPH = PRPH1 + (PRPH2-PRPH1)*(X-X1)/(X2-X1)
         GO TO 99
      END IF

      IF ( X .GT. X2 )  GO TO 10
C**** SUBCOOLED-LIQUID REGION *******************
      CALL DERLIQ( P, H, PRPP, PRPH )
      GO TO 99
   10 CONTINUE
      IF ( X .GE. X4 ) GO TO 20
C**** TWO-PHASE REGION ***************************
      HHF= H - HF
      HGH= HG - H
      F1 = (ROG - ROF)*ROF*HHF
      F2 = HGH*ROG + HHF*ROF
      F22M1= F2**(-2)
      F5= F1*F22M1
      PRPRF = 1.D0 - ( F5 - ( ROG - 2.D0*ROF )/F2 )*HHF
      PRPRG = - F5*HGH + ROF*HHF/F2
      PRPHF = ( F5 + (ROF - ROG)/F2 )*ROF
      PRPHG = -F1*ROG*F22M1
      PRPP = PRPRF*DRFDP + PRPRG*DRGDP + PRPHF*DHFDP + PRPHG*DHGDP
      PRPH = -( F5 + ROF/F2 )*(ROF-ROG)
      GO TO 99
   20 CONTINUE
C**** SUPER-HEATED VAPOR REGION
      VG=VPHV(P,H)
      CALL DERVAP( P, H, VG, PRPP, PRPH )

   99 CONTINUE
      PRPP = PRPP/144.D0

      RETURN
      END
C
C****
C
      FUNCTION DRFP(P, H, DHFDP)
      IMPLICIT REAL*8(A-H,O-Z)
C**** CALCULATES DERIVITIVE OF SATURATED LIQUID DENSITY (RF) W/R
C**** TO PRESSURE (P)
C**** P = PRESSURE (PSIA)
C**** H = ENTHALPY (BTU/LBM)
C**** DHFDP = DERIVATIVE OF SATURATED LIQUID ENTHALPY W/R TO
```

```
C****         PRESSURE (BTU/LBM-PSIA)
      DIMENSION C(5,3)
      DATA C / -.411796175D1,     -.3811294543D-3,    .4308265942D-5,
     &          -.9160120130D-8,    .8017924673D-11,  -.4816067020D-5,
     &           .7744786733D-7,  -.6988467605D-9,    .1916720525D-11,
     &          -.1760288590D-14, -.1820625039D-8,    .1440785930D-10,
     &          -.2082170753D-13, -.3603625114D-16,   .7407124321D-19  /
      FP = (((C(5,2)*H+C(4,2))*H+C(3,2))*H+C(2,2))*H+C(1,2)
      FP = FP+((((C(5,3)*H+C(4,3))*H+C(3,3))*H+C(2,3))*H+C(1,3))*2.D0*P
      F = (((C(5,1)*H+C(4,1))*H+C(3,1))*H+C(2,1))*H+C(1,1)
      F = F+((((C(5,2)*H+C(4,2))*H+C(3,2))*H+C(2,2))*H+C(1,2))*P
      F=F+((((C(5,3)*H+C(4,3))*H+C(3,3))*H+C(2,3))*H+C(1,3))*P**2
      FH =((4.D0*C(5,1)*H+3.D0*C(4,1))*H+2.D0*C(3,1))*H+C(2,1)
      FH =FH+(((4.D0*C(5,2)*H+3.D0*C(4,2))*H+2.D0*C(3,2))*H+C(2,2))*P
      FH=FH+(((4.D0*C(5,3)*H+3.D0*C(4,3))*H+2.D0*C(3,3))*H+C(2,3))*P**2
      PVLPP=FP*DEXP(F)
      VF=DEXP(F)
      PVLPH=FH*DEXP(F)
      DRFP= -(1.D0/VF**2)*(PVLPP+PVLPH*DHFDP)
      RETURN
      END

      SUBROUTINE DERLIQ(P, H, PRLPP, PRLPH )
      IMPLICIT REAL*8(A-H,O-Z)
C**** CALCULATES THE PARTIAL DERIVATIVES OF SUBCOOLED LIQUID DENSITY
C     WITH RESPECT TO PRESSURE AND ENTHALPY
C     INPUT:  P = PRESSURE (PSIA)
C             H = ENTHALPY (BTU/LBM)
C
C     OUTPUT: PRLPP = PARTIAL DERIVATIVE OF DENSITY W/R TO PRESSURE
C                     (LBM/FT3-PSIA)
C             PRLPH = PARTIAL DERIVATIVE OF DENSITY W/R TO ENTHALPY
C****                 (LBM-LBM/FT3-BTU)
      DIMENSION C(5,3)
      DATA C / -.411796175D1,     -.3811294543D-3,    .4308265942D-5,
     &          -.9160120130D-8,    .8017924673D-11,  -.4816067020D-5,
     &           .7744786733D-7,  -.6988467605D-9,    .1916720525D-11,
     &          -.1760288590D-14, -.1820625039D-8,    .1440785930D-10,
     &          -.2082170753D-13, -.3603625114D-16,   .7407124321D-19  /
      FP=(((C(5,2)*H+C(4,2))*H+C(3,2))*H+C(2,2))*H+C(1,2)
      FP=FP+((((C(5,3)*H+C(4,3))*H+C(3,3))*H+C(2,3))*H+C(1,3))*2.D0*P
      F=(((C(5,1)*H+C(4,1))*H+C(3,1))*H+C(2,1))*H+C(1,1)
      F=F+((((C(5,2)*H+C(4,2))*H+C(3,2))*H+C(2,2))*H+C(1,2))*P
      F=F+((((C(5,3)*H+C(4,3))*H+C(3,3))*H+C(2,3))*H+C(1,3))*P**2
      FH=((4.D0*C(5,1)*H+3.D0*C(4,1))*H+2.D0*C(3,1))*H+C(2,1)
      FH=FH+(((4.D0*C(5,2)*H+3.D0*C(4,2))*H+2.D0*C(3,2))*H+C(2,2))*P
      FH=FH+(((4.D0*C(5,3)*H+3.D0*C(4,3))*H+2.D0*C(3,3))*H+C(2,3))*P**2
      PVLPP=FP*DEXP(F)
      VL=DEXP(F)
      PVLPH=FH*DEXP(F)
      PRLPP= -PVLPP/(VL*VL)
      PRLPH= -PVLPH/(VL*VL)
      RETURN
      END

      FUNCTION DHFP(P)
C****     DERIVITIVE OF SATURATED LIQUID ENTHALPY WITH RESPECT
C****     TO PRESSURE
C****     P IS IN (PSIA) AND HF IS IN (BTU/LBM)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION CF1(9),CF2(9),CF3(9)
      DATA CF1 / .6970887859D2, .333752994D2, .2318240735D1,
     >.1840599513D0, -.5245502284D-2, .2878007027D-2,
     >.1753652324D-2, -.4334859629D-3, .3325699282D-4 /
      DATA CF2 / .8408618802D6, .3637413208D6, -.4634506669D6,
     >.1130306339D6, -.4350217298D3, -.3898988188D4,
     >.6697399434D3, -.4730726377D2, .1265125057D1 /
      DATA CF3 / .9060030436D3, -.1426813520D2, .1522233257D1,
     >-.6973992961D0, .1743091663D0, -.2319717696D-1,
     >.1694019149D-2, -.6454772171D-4, .1003003098D-5 /
      IF (P .GT. 900.D0) GOTO 15
      FLNP=DLOG(P)
      DHFP=CF1(2)
      DO 10 J=3,9,1
      DHFP=DHFP+CF1(J)*FLOAT(J-1)*FLNP**(J-2)
   10 CONTINUE
      DHFP=(DHFP/P)
      RETURN
   15 CONTINUE
      IF (P .GT. 2400.D0) GOTO 25
      FLNP=DLOG(P)
      DHFP=CF2(2)
      DO 20 J=3,9,1
      DHFP=DHFP+CF2(J)*FLOAT(J-1)*FLNP**(J-2)
   20 CONTINUE
      DHFP=(DHFP/P)
      RETURN
   25 CONTINUE
      PDIF=(3208.2D0 - P)**.41D0
      DPDIF=-0.41D0*(3208.2D0 - P)**(-0.59D0)
      DHFP=CF3(2)
      DO 30 J=3,9,1
      DHFP=DHFP+CF3(J)*FLOAT(J-1)*PDIF**(J-2)
   30 CONTINUE
      DHFDP=(DHFP*DPDIF)
      RETURN
      END
C ****
C ********************************************************************
C ****
      FUNCTION DHGP(P)
      IMPLICIT REAL*8(A-H,O-Z)
```

```
C *** CALCULATES THE DERIVITIVE OF SATURATED VAPOR SPECIFIC
C *** ENTHALPY (BTU/LBM) WITH RESPECT TO PRESSURE (PSIA)
      DIMENSION CG1(12),CG2(9),CG3(7)
      DATA CG1 / .1105836875D4, .1436943768D2, .8018288621D0,
     > .1617232913D-1,-.1501147505D-2, 0.D0, 0.D0, 0.D0, 0.D0,
     >-.1237675562D-4, .3004773304D-5,-.2062390734D-6  /
      DATA CG2 / -.2234264997D7, .1231247634D7,-.1978847871D6,
     > .1859988044D2, -.2765701318D1, .1036033878D4,
     >-.2143423131D3, .1690507762D2,-.4864322134D0 /
      DATA CG3 / .9059978254D3, .5561957539D1, .3434189609D1,
     >-.6406390628, .5918579484D-1, -.2725378570D-2,
     > .5006336938D-4 /
      IF (P .GT. 1200.D0) GOTO 15
      FLNP=DLOG(P)
      DHGP=CG1(2)
      DO 10 J=3,12,1
      DHGP=DHGP+CG1(J)*FLOAT(J-1)*FLNP**(J-2)
   10 CONTINUE
      DHGP=(DHGP/P)
      RETURN
   15 CONTINUE
      IF(P .GT. 2600.D0) GOTO 25
      FLNP=DLOG(P)
      DHGP=CG2(2)
      DO 20 J=3,9,1
      DHGP=DHGP+CG2(J)*FLOAT(J-1)*FLNP**(J-2)
   20 CONTINUE
      DHGP=(DHGP/P)
      RETURN
   25 CONTINUE
      PDIF=(3208.2D0 - P)**.41D0
      DPDIF=(-.41D0)*(3208.2D0 - P)**(-.59D0)
      DHGP=CG3(2)
      DO 30 J=3,7,1
      DHGP=DHGP+CG3(J)*FLOAT(J-1)*PDIF**(J-2)
   30 CONTINUE
      DHGP=(DHGP*DPDIF)
      RETURN
      END
C ****
C ******************************************************************
C ****
      SUBROUTINE DERVAP(P,H,VG,PRGPP,PRGPH)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION C(3,4)
      DATA C / -.1403086182D4, .1802594763D1, -.2097279215D-3,
     >.3817195017D0, -.5394444747D-3,
     >.1855203702D-6, -.6449501159D-4, .8437637660D-7,
     >-.2713755001D-10, .7823817858D-8, -.1053834646D-10,
     >.3629590764D-14 /
      PVGPH = (2.D0*C(3,1)*H + C(2,1))/P +
     >2.D0*C(3,2)*H + C(2,2) +
     >(2.D0*C(3,3)*H + C(2,3))*P +
     >(2.D0*C(3,4)*H + C(2,4))*P*P
      PVGPP = -((C(3,1)*H + C(2,1))*H + C(1,1))/P**2 +
     >(C(3,3)*H + C(2,3))*H + C(1,3) +
     >2.D0*(((C(3,4)*H + C(2,4))*H + C(1,4))*P)
      PRGPP = -(1.D0/VG**2)*PVGPP
      PRGPH = -(1.D0/VG**2)*PVGPH
      RETURN
      END
C ****
C ******************************************************************
C ****
      FUNCTION DRGP(P,H,DHGDP,VG)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION C(3,4)
      DATA C / -.1403086182D4, .1802594763D1, -.2097279215D-3,
     >.3817195017D0, -.5394444747D-3,
     >.1855203702D-6, -.6449501159D-4, .8437637660D-7,
     >-.2713755001D-10, .7823817858D-8, -.1053834646D-10,
     >.3629590764D-14 /
      PVGPP = (C(3,3)*H + C(2,3))*H + C(1,3) -
     >((C(3,1)*H + C(2,1))*H+C(1,1))*(1.D0/P**2) +
     >2.D0*((C(3,4)*H + C(2,4))*H + C(1,4))*P
      PVGPH = (2.D0*C(3,3)*H + C(2,3))*P + 2.D0*C(3,2)*H+C(2,2)+
     >(2.D0*C(3,1)*H + C(2,1))/P + (2.D0*C(3,4)*H+C(2,4))*P**2
      DRGP = -(1.D0/VG**2)*(PVGPP+PVGPH*DHGDP)
      RETURN
      END


CVPHV
C
      FUNCTION VPHV(P,H)
      IMPLICIT REAL*8 (A-H,O-Z)
C****    SATURATED OR SUPERHEATED SPECIFIC VOLUME (FT3/LBM)
C****    AS A FUNCTION OF PRESSURE (LBF/IN2) AND ENTHALPY
C****    (BTU/LBM) - RETRAN02 PROP FIT
      DIMENSION CN2(3,4)
      DATA CN2 / -.1403086182D4,.1802594763D1,
     1-.2097279215D-3,.3817195017D0,-.5394444747D-3,.1855203702D-6,
     2-.6449501159D-4,.8437637660D-7,-.2713755001D-10,.7823817858D-8,
     3-.1053834646D-10,.3629590764D-14/
      H1=1.D0
      H2=H1*H
      H3=H2*H
      VPHV=(CN2(1,1)*H1+CN2(2,1)*H2+CN2(3,1)*H3) / P
      VPHV=VPHV+CN2(1,2)*H1+CN2(2,2)*H2+CN2(3,2)*H3
      VPHV=VPHV+(CN2(1,3)*H1+CN2(2,3)*H2+CN2(3,3)*H3)*P
      VPHV=VPHV+(CN2(1,4)*H1+CN2(2,4)*H2+CN2(3,4)*H3)*P**2
```

```
      RETURN
      END
C


      SUBROUTINE STATE(J,P,H,RO,ROL,ALPH,TEMP, ROGAS, HGAS)
      IMPLICIT REAL*8(A-H,O-Z)
C**** CALCULATES FLUID DENSITY FROM PRESSURE (PSIA) AND VOLUME-WEIGHTED
C**** ENTHALPY (BTU/LBM)
      COMMON /PROPY/ HG,HF,VF,VG,ROF,ROG,DHFDP,DHGDP,DRFDP,DRGDP,AMUF,
     &               AMUCL(51),THRMCL(51),CPCL(51),THERMF,CPCF,
     &               AMUCG(51),THRMCG(51),CPCG(51),
     &               TSAT,SIGMA,SUBDC,IVOID,IJKC
       IF ( H .LE. HF) THEN
           RO= 1.DO/VPHL(P,H)
           ROL= RO
           ALPH=0.DO
           TEMP= TPHL(P,H)
           ROGAS = ROG
           HGAS = HG
       END IF
       IF ( H .GT. HF    .AND.    H .LT. HG ) THEN
           RO= ROF*ROG*(HG-HF)
           RO= RO/( ROG*HG-ROF*HF+(ROF-ROG)*H )
           ROL= ROF
           ALPH= ( RO - ROL )/( ROG - ROF )
C****      IF ( ALPH .LT. 1.D-6 ) ALPH=1.D-6
           TEMP=TSAT
           ROGAS = ROG
           HGAS = HG
       END IF
       IF ( H .GE. HG ) THEN
           RO= 1.DO/VPHV( P, H )
           ROL= ROF
           ALPH = 1.DO
           TEMP = TPHV( P, H )
       ROGAS = RO
       HGAS = H
       END IF
       RETURN
       END


       FUNCTION VPHL(P,H)
       IMPLICIT REAL*8 (A-H,O-Z)
C****     SATURATED OR SUBCOOLED SPECIFIC VOLUME (FT3/LBM) AS
C****     A FUNCTION OF PRESSURE (LBF/IN2) AND ENTHALPY
C****     (BTU/LBM) - RETRANO2 PROP FIT
       DIMENSION CN1(5,3)
      DATA CN1 / -.411796175D1,-.3811294543D-3,
     1.4308265942D-5,-.916012013D-8,.8017924673D-11,-.481606702D-5,
     2.7744786733D-7,-.6988467605D-9,.1916720525D-11,-.1760288590D-14,
     3-.1820625039D-8,.144078593D-10,-.2082170753D-13,-.3603625114D-16,
     4.7407124321D-19/
       H1=1.DO
       H2=H1*H
       H3=H2*H
       H4=H3*H
       H5=H4*H
       VPHL=CN1(1,1)*H1+CN1(2,1)*H2+CN1(3,1)*H3+CN1(4,1)*H4+CN1(5,1)*H5
       VPHL=VPHL+(CN1(1,2)*H1+CN1(2,2)*H2+CN1(3,2)*H3+CN1(4,2)*H4+CN1
     1(5,2)*H5)*P
       VPHL=VPHL+(CN1(1,3)*H1+CN1(2,3)*H2+CN1(3,3)*H3+CN1(4,3)*H4+CN1
     1(5,3)*H5)*P**2
       VPHL=DEXP(VPHL)
       RETURN
       END
C


       FUNCTION TPHL(P,H)
C**** SATURATED OR SUBCOOLED LIQUID TEMPERATURE (DEGF) AS A
C**** FUNCTION OF PRESSURE (PSIA) AND ENTHALPY (BTU/LBM)
       IMPLICIT REAL*8(A-H,O-Z)
       DIMENSION CT1(4,2),CT2(5,5)
       DATA CT1 / .3276275552D2, .9763617, .1857226027D-3,
     &-.468267433D-6, .3360880214D-2, -.5595281760D-4,
     &.1618595991D-6, -.1180204381D-9 /
       DATA CT2 / .6390801208D3, -.3055217235D1, .8713231868D-2,
     &-.6269403683D-5, -.98447D-17, -.4302857237, .2673303422D-2,
     &-.5198380474D-5, .3037825558D-8, .3309704045D-12,
     &.1174524584D-3, -.6839200986D-6, .1168011772D-8,
     &-.4260074181D-12, -.2732087163D-15, -.147397729D-7,
     &.8018858166D-10, -.1164901355D-12, .4559400289D-17,
     &.5825511142D-19, .7104327342D-12, -.3649500626D-14,
     &.4457387575D-17, .1678398723D-20, -.3756804091D-23 /
       IF (P .GT. 3208.2 ) GO TO 10
       TPHL = ((CT1(4,1)*H+CT1(3,1))*H+CT1(2,1))*H+CT1(1,1)
       TPHL=TPHL+(((CT1(4,2)*H+CT1(3,2))*H+CT1(2,2))*H+CT1(1,2))*P
       RETURN
   10 CONTINUE
       TPHL=(((CT2(5,1)*H+CT2(4,1))*H+CT2(3,1))*H+CT2(2,1))*H+CT2(1,1)
       TPHL=TPHL+((((CT2(5,2)*H+CT2(4,2))*H+CT2(3,2))*H+CT2(2,2))*H+
     &CT2(1,2))*P
       DO 20 J=3,5
       TPHL=TPHL+((((CT2(5,J)*H+CT2(4,J))*H+CT2(3,J))*H+CT2(2,J))*H+
     &CT2(1,J))*P**(J-1)
   20 CONTINUE
       RETURN
```

```
      END
C******************** END OF FUNCTION TPHL *******************************


      FUNCTION TPHV(P,H)
C****    SATURATED OR SUPERHEATED VAPOR TEMPERATURE (DEGF) AS A
C****    FUNCTION OF PRESSURE (PSIA) AND ENTHALPY (BTU/LBM)
C****    - RETRANO2 PROP FIT
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION CT3(5,5),CT4(5,5)
      DATA CT3 /  -.1179100862D5,       .2829274345D2,
     &            -.2678181564D-1,      .1218742752D-4,
     &            -.2092033147D-8,      .1256160907D3,
     &            -.3333448495D0,       .3326901268D-3,
     &            -.1477890326D-6,      .2463258371D-10,
     &            -.1083713369D0,       .292817773D-3,
     &            -.2972436458D-6,      .1342639113D-9,
     &            -.2275585718D-13,     .3278071846D-4,
     &            -.8970959364D-7,      .9246248312D-10,
     &            -.4249155515D-13,     .7338316751D-17,
     &            -.3425564927D-8,      .9527692453D-11,
     &            -.1001409043D-13,     .4703914404D-17,
     &            -.8315044742D-21 /
      DATA CT4 /  .3795256853D4,       -.6347031007D1,
     &            .2867228326D-2,       .5953599813D-8,
     &            .4798207438D-10,     -.3910086240D1,
     &            .1222747819D-1,      -.1404664699D-4,
     &            .7505679464D-8,      -.1608693653D-11,
     &            .3410500159D-4,       .7010900113D-9,
     &           -.1030201866D-9,       .5731099333D-14,
     &            .3720795449D-16,      .1527377542D-6,
     &           -.5356866315D-9,       .6823225984D-12,
     &           -.3668096142D-15,      .6946004624D-19,
     &           -.1437179752D-10,      .5006731336D-13,
     &           -.6365519546D-16,      .3473711350D-19,
     &           -.6842306083D-23 /
       IF ( P .GT. 3208.2D0 ) GO TO 15
       TPHV=(((CT3(5,1)*H+CT3(4,1))*H+CT3(3,1))*H+CT3(2,1))*H+CT3(1,1)
       TPHV=TPHV+((((CT3(5,2)*H+CT3(4,2))*H+CT3(3,2))*H+CT3(2,2))*H+
     &    CT3(1,2))*P
       DO 10 J=3,5,1
       TPHV=TPHV+((((CT3(5,J)*H+CT3(4,J))*H+CT3(3,J))*H+CT3(2,J))*H+
     &    CT3(1,J))*P**(J-1)
   10 CONTINUE
       RETURN
   15 CONTINUE
       TPHV=(((CT4(5,1)*H+CT4(4,1))*H+CT4(3,1))*H+CT4(2,1))*H+CT4(1,1)
       TPHV=TPHV+((((CT4(5,2)*H+CT4(4,2))*H+CT4(3,2))*H+CT4(2,2))*H+
     &    CT4(1,2) )*P
       DO 20 J=3,5,1
       TPHV=TPHV+((((CT4(5,J)*H+CT4(4,J))*H+CT4(3,J))*H+CT4(2,J))*H+
     &    CT4(1,J))*P**(J-1)
   20 CONTINUE
       RETURN
       END

C
      FUNCTION HGP(P)
      IMPLICIT REAL*8 (A-H,O-Z)
C****      SATURATED VAPOR ENTHALPY (BTU/LBM) AS A FUNCTION OF
C****      PRESSURE (LBF/IN2) - RETRANO2 PROP FIT
      DIMENSION CG1(12),CG2(9),CG3(7)
      DATA CG1 / .1105836875D4,.1436943768D2,.8018288621D0,
     1.1617232913D-1,-.1501147505D-2,4*0.0D0,-.1237675562D-4,
     2.3004773304D-5,-.2062390734D-6/
      DATA CG2 / -.2234264997D7,.1231247634D7,-.1978847871D6,
     1.1859988044D2,-.2765701318D1,.1036033878D4,-.2143423131D3,
     2.1690507762D2,-.4864322134D0/
      DATA CG3 / .9059978254D3,.5561957539D1,.3434189609D1,
     1-.6406390628D0,.5918579484D-1,-.2725378570D-2,.5006336938D-4/
      IF(P.GT.1200.D0)GO TO 15
      FLNP=DLOG(P)
      HGP=CG1(1)+CG1(2)*FLNP
      DO 10 J=3,12
      HGP=HGP+CG1(J)*FLNP**(J-1)
   10 CONTINUE
      RETURN
   15 CONTINUE
      IF(P.GT.2600.D0)GO TO 25
      FLNP=DLOG(P)
      HGP=CG2(1)+CG2(2)*FLNP
      DO 20 J=3,9
      HGP=HGP+CG2(J)*FLNP**(J-1)
   20 CONTINUE
      RETURN
   25 CONTINUE
      PDIF=(3208.2D0-P)**.41D0
      HGP=CG3(1)+CG3(2)*PDIF
      DO 30 J=3,7
      HGP=HGP+CG3(J)*PDIF**(J-1)
   30 CONTINUE
      RETURN
      END
C
C*************************************************************************


C
      FUNCTION HFP(P)
      IMPLICIT REAL*8 (A-H,O-Z)
```

```
C****      SATURATED LIQUID ENTHALPY (BTU/LBM) AS A FUNCTION OF
C****      PRESSURE (LBF/IN2) - RETRAN02 PROP FIT
      DIMENSION CF1(9),CF2(9),CF3(9)
      DATA CF1 / .6970887859D2,.3337529994D2,.2318240735D1,
     1.1840599513D0,-.5245502284D-2,
     2.2878007027D-2,.1753652324D-2,-.4334859629D-3,.3325699282D-4/
      DATA CF2 / .8408618802D6,.3637413208D6,-.4634506669D6,
     1.1130306339D6,-.4350217298D3,-.3898988188D4,.6697399434D3,
     2-.4730726377D2,.1265125057D1/
      DATA CF3 / .9060030436D3,-.1426813520D2,.1522233257D1,
     1-.6973992961D0,.1743091663D0,-.2319717696D-1,.1694019149D-2,
     2-.6454772171D-4,.1003003098D-5/
      IF( P .GT. 900.D0 )GO TO 15
      FLNP=DLOG(P)
      HFP=CF1(1)+CF1(2)*FLNP
      DO 10 J=3,9
      HFP=HFP+CF1(J)*FLNP**(J-1)
   10 CONTINUE
      RETURN
   15 CONTINUE
      IF(P.GT.2400.D0)GO TO 25
      FLNP=DLOG(P)
      HFP=CF2(1)+CF2(2)*FLNP
      DO 20 J=3,9
      HFP=HFP+CF2(J)*FLNP**(J-1)
   20 CONTINUE
      RETURN
   25 CONTINUE
      PDIF=(3208.2D0-P)**.41D0
      HFP=CF3(1)+CF3(2)*PDIF
      DO 30 J=3,9
      HFP=HFP+CF3(J)*PDIF**(J-1)
   30 CONTINUE
      RETURN
      END
C
CHGP


      Subroutine Step( ExMass, ExEner,
     &                 HBAR, PRPH, PRPP, Pt, V, DELZ, S, HS, A,
     &                 ALPH1, ALPH2, ROL1, ROL2, ROG1, ROG2,
     &                 HL1, HL2, HG1, HG2, C01, C02,
     &                 VGJ1, VGJ2, Q, QPP, RO, Ph,
     &                 WGB1, WLB1, HGB1, HLB1,
     &                 WLB2, WGB2, ALPHB2,
     &                 HLB2, HGB2, ROLB2, ROGB2,  DHDT,
     &                 IREG, NODE, UGB2, ULB2, WOUTO, HBAR2 )
     &
C**** NOMENCLATURE
C                            **INPUT**
C
C        PRPH1 = Partial deriv of density w/r to enthalpy for volume 1
C                (Lbm-Lbm/ft3-Btu)
C        PRPP1 = Partial deriv of density w/r to press for vol 1
C                (Lbm/ft-Lbf)
C        Pt    = Temporal deriv of system pressure (Lbf/ft2-sec)
C        DELZ  = Control volume length (ft)
C        S1    = Mass source in volume 1 (Lbm/sec)
C        HS1   = Enthalpy associated w mass source in vol 1 (Btu/Lbm)
C        A     = Flow area (ft2)
C        ALPH1 = Void fraction in volume 1
C        ALPH2 = Void fraction in volume 2
C        ROL1  = Liquid density in vol 1 (Lbm/ft3)
C        ROL2  = Liquid density in vol 2 (Lbm/ft3)
C        ROG1  = Gas density in vol 1 (Lbm/ft3)
C        ROG2  = Gas density in vol 2 (Lbm/ft3)
C        HBAR1 = Volume-weighted enthalpy in vol 1 (Btu/Lbm)
C        HL1   = Liquid enthalpy in vol 1 (Btu/Lbm)
C        HL2   = Liquid enthalpy in vol 2 (Btu/Lbm)
C        HG1   = Gas enthalpy in vol 1 (Btu/Lbm)
C        HG2   = Gas enthalpy in vol 2 (Btu/Lbm)
C        C01   = Bubble concentration parameter in vol 1
C        C02   = Bubble concentration parameter in vol 2
C        HBAR2 = Volume-weighted enthalpy in Vol 1 (Btu/Lbm)
C        VGJ1  = Drift velocity in vol 1 (ft/sec)
C        VGJ2  = Drift velocity in vol 2 (ft/sec)
C        Q1    = Internal heat gen rate in vol 1 (Btu/sec)
C        QPP1  = Heat flux at walls of vol 1 (Btu/ft2-sec)
C        RO1   = Mixture density in vol 1 (Lbm/ft3)
C        Ph    = Heated perimeter (ft)
C        ULB1  = Liquid velocity on boundary 1 (ft/sec)
C        UGB1  = Gas velocity on boundary 1 (ft/sec)
C        ALPHB1= Void fraction on boundary 1
C        ROLB1 = Liquid density on boundary 1 (Lbm/ft2)
C        ROGB1 = Gas density on boundary 1 (Lbm/ft2)
C        HLB1  = Liquid enthalpy on boundary 1 (Btu/Lbm)
C        HGB1  = Gas enthalpy on boundary 1 (Btu/Lbm)
C                            **OUTPUT**
C        COB2  = Bubble concentration param on boundary 2
C        VGJB2 = Drift velocity on boundary 2 (ft/sec)
C        ALPHB2= Void fraction on boundary 2
C        ULB2  = Liquid velocity on boundary 2 (ft/sec)
C        UGB2  = Gas velocity on boundary 2 (ft/sec)
C        HLB2  = Liquid enthalpy on boundary 2 (Btu/Lbm)
C        HGB2  = Gas enthalpy on boundary 2 (Btu/Lbm)
C        ROLB2 = Liquid density on boundary 2 (Lbm/ft3)
C        ROGB2 = Gas density on boundary 2 (Lbm/ft3)
C        DHDT1 = Temporal derivative of vol-weighted enthalpy in
C                volume 1 (Btu/Lbm-sec)
C

      IMPLICIT Real*8(A-H,O-Z)
```

```
      COMMON /PROPY/ HG,HF,VF,VG,ROF,ROG,DHFDP,DHGDP,DRFDP,DRGDP,AMUF,
     &               AMUCL(51),THRMCL(51),CPCL(51),THERMF,CPCF,
     &               AMUCG(51),THRMCG(51),CPCG(51),
     &               TSAT,SIGMA,SUBDC,IVOID,IJKC

      AJ = 778.D0
      KOUNT=0
      FUNP=0.D0
c     WRITE(4,5551)
c5551 FORMAT(' Entering NE Step ')
c5552 FORMAT(' Leaving NE Step ')


C**** Make a guess for the outlet flow rate.  Use inlet flow as
C**** initial guess.
      W0 = WOUT0
C**** REVERSE SIGN OF FLOW FOR JET PUMP
   10 Continue
      IF ( IREG .EQ. 1 ) THEN
         WOUT1=-W0
      ELSE
         WOUT1=W0
      END IF
      IF ( KOUNT .GT. 25 ) GO TO 800
      Call Jun1( WOUT1, A, C01, C02, Vgj1, Vgj2, alph1, alph2,
     &           rog1, rog2, rol1, rol2, hg1, hg2,
     &           hl1, hl2, sigma, sigma,
     &           UGB2, ULB2, ALPHB2, ROGB2, ROLB2, HGB2, HLB2,
     &           WGB2, WLB2, IREG, NODE )
C**** CHECK FOR CONSISTANCY OF CALC
      IF ( DABS( WOUT1 - WGB2 - WLB2 ) .GT. 1.D-6 ) THEN
         WRITE(*,103) WOUT1,WGB2,WLB2,IREG
  103    FORMAT(' WOUT1,WG,WL,IREG= ', 3F12.3, I5 )
         STOP
      END IF
C**** IF JET PUMP REGION, REVERSE SIGNS OF FLOW FOR MASS/ENERGY EQNS
      IF ( IREG .EQ. 1 ) THEN
         WGB2=-WGB2
         WLB2=-WLB2
         ULB2=-ULB2
         UGB2=-UGB2
      END IF
      WIN = WGB1 + WLB1
      EIN = WGB1*HGB1 + WLB1*HLB1
      WOUT1 = WGB2 + WLB2
      EOUT1 = WGB2*HGB2 + WLB2*HLB2
      CALL EQNME( WIN, EIN, WOUT1, EOUT1, S, HS, PRPP, PRPH,
     &           Pt, HBAR, Q, QPP, Ph, DELZ, V, RO,
     &           dhdt, FUN1, IREG, ExMass, ExEner )

C**** Compute the derivative of FUN w/r to W
      W2 = W0 + 20.D0
      IF ( IREG .EQ. 1 ) THEN
         WOUT2= -W2
      ELSE
         WOUT2=W2
      END IF
      Call Jun1( WOUT2, A, C01, C02, Vgj1, Vgj2, alph1, alph2,
     &           rog1, rog2, rol1, rol2, hg1, hg2,
     &           hl1, hl2, sigma, sigma,
     &           UGB2, ULB2, ALPHB2, ROGB2, ROLB2, HGB2, HLB2,
     &           WGB2, WLB2, IREG, NODE )
C**** CHECK FOR CONSISTANCY OF CALC
      IF ( DABS( WOUT2 - WGB2 - WLB2 ) .GT. 1.D-6 ) THEN
         WRITE(*,104) WOUT2,WGB2,WLB2,IREG
  104    FORMAT(' WOUT2,WG,WL,IREG= ', 3F12.3, I5 )
         STOP
      END IF
C**** IF JET PUMP REGION, REVERSE SIGNS OF FLOW FOR MASS/ENERGY EQNS
      IF ( IREG .EQ. 1 ) THEN
         WGB2=-WGB2
         WLB2=-WLB2
         ULB2=-ULB2
         UGB2=-UGB2
      END IF
      WOUT2 = WGB2 + WLB2
      EOUT2 = WGB2*HGB2 + WLB2*HLB2
      CALL EQNME( WIN, EIN, WOUT2, EOUT2, S, HS, PRPP, PRPH,
     &           Pt, HBAR, Q, QPP, Ph, DELZ, V, RO,
     &           dhdt, FUN2, IREG, ExMass, ExEner )

      DFDW = (FUN2-FUN1)/(WOUT2-WOUT1)

C**** CHECK SIZE OF DERIVATIVE FOR POSSIBLE DIVERGENCE
C     IF ( DABS(DFDW) .LT. 1.D-5 ) THEN
C        WRITE(*,101) IREG,INODE,DFDW
C 101    FORMAT(' IREG,INODE,DFDW= ', 2I5,1P,E14.5)
C     END IF

C**** Use Newton's Method to find W
      IF (KOUNT .LT. 4 ) Then
        ep=1.D0
      ELSE
        ep=0.1D0
      END IF
      WOUTN = WOUT1 - ep*FUN1/DFDW


C**** Check for divergence of iteration
      IF ( DABS(WOUTN) .GT. 5.D5 ) Then
      WRITE(4,102)
```

```
  102 Format(' Flow divergence in NE STEP - Try bisection ')
      GO TO 800
      END IF

C**** Check for convergence
      IF ( DABS(WOUT1) .LT. 1.D0 ) Then
         ERROR = DABS(WOUTN-WOUT1)
      ELSE
         ERROR = DABS( (WOUTN-WOUT1)/WOUT1 )
      END IF
      IF ( ERROR .GT. 1.D-4 ) Then
         KOUNT=KOUNT+1
         WO=WOUTN
         GO TO 10
      END IF
      IF ( IREG .EQ. 1 ) THEN
         WOUTN=-WOUTN
      ELSE
         WOUTN=WOUTN
      END IF
      Call Jun1( WOUTN, A, C01, C02, Vgj1, Vgj2, alph1, alph2,
     &           rog1, rog2, rol1, rol2, hg1, hg2,
     &           hl1, hl2, sigma, sigma,
     &           UGB2, ULB2, ALPHB2, ROGB2, ROLB2, HGB2, HLB2,
     &           WGB2, WLB2, IREG, NODE )
      IF ( IREG .EQ. 1 ) THEN
         WGB2=-WGB2
         WLB2=-WLB2
         UGB2=-UGB2
         ULB2=-ULB2
      END IF
      WOUT = WGB2 + WLB2
      EOUT = WGB2*HGB2 + WLB2*HLB2
      CALL EQNME( WIN, EIN, WOUT, EOUT, S, HS, PRPP, PRPH,
     &            Pt, HBAR, Q, QPP, Ph, DELZ, V, RO,
     &            dhdt, FUN, IREG, ExMass, ExEner )
      RETURN


  800 Continue
      kk=0
      WO=WOUTO
C**** Try bisection method
C**** First try to trap zero
      DELWO = 0.10D0
      DELW=DELWO
  810 Continue
      W1 = WO - DELW
      W2 = WO + DELW
      IF ( IREG .EQ. 1 ) THEN
         WOUT1 = -W1
         WOUT2 = -W2
      ELSE
         WOUT1 = W1
         WOUT2 = W2
      END IF
      Call Jun1( WOUT1, A, C01, C02, Vgj1, Vgj2, alph1, alph2,
     &           rog1, rog2, rol1, rol2, hg1, hg2,
     &           hl1, hl2, sigma, sigma,
     &           UGB2, ULB2, ALPHB2, ROGB2, ROLB2, HGB2, HLB2,
     &           WGB2, WLB2, IREG, NODE )
      IF ( IREG .EQ. 1 ) THEN
         WGB2=-WGB2
         WLB2=-WLB2
         UGB2=-UGB2
         ULB2=-ULB2
      END IF
      WTEMP1=WGB2
      WTEMP2=WLB2
      WOUT1 = WGB2 + WLB2
      EOUT1 = WGB2*HGB2 + WLB2*HLB2
      CALL EQNME( WIN, EIN, WOUT1, EOUT1, S, HS, PRPP, PRPH,
     &            Pt, HBAR, Q, QPP, Ph, DELZ, V, RO,
     &            dhdt, FUN1, IREG, ExMass, ExEner )

      Call Jun1( WOUT2, A, C01, C02, Vgj1, Vgj2, alph1, alph2,
     &           rog1, rog2, rol1, rol2, hg1, hg2,
     &           hl1, hl2, sigma, sigma,
     &           UGB2, ULB2, ALPHB2, ROGB2, ROLB2, HGB2, HLB2,
     &           WGB2, WLB2, IREG, NODE )
      IF ( IREG .EQ. 1 ) THEN
         WGB2=-WGB2
         WLB2=-WLB2
         ULB2=-ULB2
         UGB2=-UGB2
      END IF
      WOUT2 = WGB2 + WLB2
      EOUT2 = WGB2*HGB2 + WLB2*HLB2
      CALL EQNME( WIN, EIN, WOUT2, EOUT2, S, HS, PRPP, PRPH,
     &            Pt, HBAR, Q, QPP, Ph, DELZ, V, RO,
     &            dhdt, FUN2, IREG, ExMass, ExEner )

      IF ( kk .eq. 18 .AND. HBAR .GT. HF .AND. HBAR2 .LT. HF ) Then
      Call Jun1( 0.0D0, A, C01, C02, Vgj1, Vgj2, alph1, alph2,
     &           rog1, rog2, rol1, rol2, hg1, hg2,
     &           hl1, hl2, sigma, sigma,
     &           UGB2, ULB2, ALPHB2, ROGB2, ROLB2, HGB2, HLB2,
     &           WGB2, WLB2, IREG, NODE )
      CALL EQNME( WIN, EIN, 0.D0, 0.D0, S, HS, PRPP, PRPH,
     &            Pt, HBAR, Q, QPP, Ph, DELZ, V, RO,
     &            dhdt, FUNP, IREG, ExMass, ExEner )
      UGB2=0.D0
```

```
      ULB2=0.D0
      WGB2=0.D0
      WLB2=0.D0
      WRITE(*,7612) TIMEX,FUNP/144.D0
 7612 FORMAT(' T,FUN= ', 2F14.5 )
      RETURN
      ELSE IF (KK .EQ. 18 ) THEN
      Write(*,320)
      Write(10,320)
  320 Format(' Cant trap zero in NE Step ')
      Write(*,321) IREG,NODE,KK,TIMEX
      Write(10,321) IREG,NODE,KK,TIMEX
  321 Format(' Reg,Node,KOUNT,TIMEX = ', 3I5,F12.3 )
      STOP
      END IF

C     WRITE(10,6538)
C     Write(10,321) IREG,NODE,KK,TIMEX
C     Write(10,6531) WOUT1,WOUT2
C     Write(10,6539) FUN1,WTEMP1,WTEMP2
C     Write(10,6540) FUN2,WGB2,WLB2
C     write(10,6541) G1,G2,G,ALPHZ
C6531 FORMAT(' W1,W2= ', 6F14.4 )
C6538 FORMAT('      ')
C6539 FORMAT(' FUN1,WG1,WL1= ', 3F14.4 )
C6540 FORMAT(' FUN2,WG2,WL2= ', 3F14.4 )
C6541 FORMAT(' G1,G2,G,ALPH= ', 4F14.4 )


       IF ( FUN1*FUN2 .GT. 0.D0 ) Then
         kk=kk+1
         DELW = 2.D0*DELW
         GO TO 810
       ELSE
         CONTINUE
       END IF

C**** Zero trapped - Initiate bisection
       KKB=0
  820 Continue
       IF ( KKB .GT. 50 ) GO TO 900
       IF ( W2 .LT. 1.D0 ) Then
          ERROR = DABS( W1 - W2 )
       ELSE
          ERROR = DABS( (W1-W2)/W2 )
       END IF
       IF ( ERROR .LT. 1.D-4 ) GO TO 850
       W3 = 0.5D0*( W1 + W2 )
       IF ( IREG .EQ. 1 ) THEN
           WOUT3=-W3
       ELSE
           WOUT3=W3
       END IF
       Call Jun1( WOUT3, A, C01, C02, Vgj1, Vgj2, alph1, alph2,
     &           rog1, rog2, rol1, rol2, hg1, hg2,
     &           hl1, hl2, sigma, sigma,
     &           UGB2, ULB2, ALPHB2, ROGB2, ROLB2, HGB2, HLB2,
     &           WGB2, WLB2, IREG, NODE )
        IF ( IREG .EQ. 1 .AND. NODE .EQ. 1 ) THEN
           WGB2=-WGB2
           WLB2=-WLB2
           UGB2=-UGB2
           ULB2=-ULB2
        END IF
        WOUT = WGB2 + WLB2
        EOUT = WGB2*HGB2 + WLB2*HLB2
        CALL EQNME( WIN, EIN, WOUT, EOUT, S, HS, PRPP, PRPH,
     &             Pt, HBAR, Q, QPP, Ph, DELZ, V, RO,
     &             dhdt, FUN3, IREG, ExMass, ExEner )
        IF ( FUN1*FUN3 .LT. 0.D0 ) Then
           W2 = W3
           FUN2 = FUN3
           KKB=KKB+1
           GO TO 820
        ELSE
           W1 = W3
           FUN1 = FUN3
           KKB=KKB+1
           GO TO 820
        END IF
  850 Continue
c       WRITE(4,5552)
        RETURN

  900 Continue
        WRITE(4,109) W0,W
  109 Format(' No Converg in STEP, W0,W = ', 2F12.4 )
        STOP

        END


        SUBROUTINE EQNME(WIN, EIN, WOUT, EOUT, S, HS, PRPP, PRPH,
     &                  Pt, HBAR, Q, QPP, Ph, DELZ, V, RO,
     &                  dhdt, FUN, IREG, ExMass, ExEner )
        IMPLICIT REAL*8 (A-H, O-Z)

        AJ = 778.D0
        FACTP=1.D0
C**** COntinuity eqn
C       V*PRPH*dHdt + V*PRPP*Pt = WIN - WOUT + S -ExMass
```

```
      A11 = V*PRPH
      A12 = V*PRPP
      D1  = WIN - WOUT + S -ExMass
C**** energy equation
C     ( V*RO + V*HBAR*PRPH )*dhdt - V*(1.D0/AJ - HBAR*PRPP)*Pt =
C     EIN - EOUT + Q + DELZ*Ph*QPP + HS*S - ExEner
      A21 =  V*RO + V*HBAR*PRPH
      A22 =  - V*(1.D0/AJ - HBAR*PRPP)
      D2  =  EIN - EOUT + Q + DELZ*Ph*QPP + HS*S - ExEner
      DET = A11*A22 - A21*A12
C**** CALCULATE DHDT AND DPDT
      dhdt  = (D1*A22-D2*A12)/DET
      PtL   = (D2*A11-D1*A21)/DET
      FUN = ( PT - PTL )

      RETURN
      END


      Subroutine Jun1( W, A, C01, C02, Vgj1, Vgj2, alph1, alph2,
     &                 rog1, rog2, rol1, rol2, hg1, hg2,
     &                 hl1, hl2, sigma1, sigma2,
     &                 velg, vell, alph, rog, rol, hg, hl, Wg, Wl,
     &                 IREG, NODE )
C****
C     Input:  W      = mass flow rate at junction (lbm/sec)
C                      W>0 => flow from vol-1 to vol-2
C             A      = Junction flow area (ft2)
C             C01    = Concentration parameter for vol-1
C             C02    = Concentration parameter for vol-2
C             Vgj1   = Drift velocity for vol-1 (ft/sec)
C             Vgj2   = Drift velocity for vol-2 (ft/sec)
C             alph1  = void fraction in vol-1
C             alph2  = void fraction in vol-2
C             rog1   = vapor density in vol-1 (Lbm/ft3)
C             rog2   = vapor density in vol-2 (Lbm/ft3)
C             rol1   = liquid density in vol-1 (Lbm/ft3)
C             rol2   = liquid density in vol-2 (Lbm/ft3)
C             hg1    = vapor specific enthalpy in vol-1 (Btu/Lbm)
C             hg2    = vapor specific enthalpy in vol-2 (Btu/Lbm)
C             hl1    = liquid specific enthalpy in vol-1 (Btu/lbm)
C             hl2    = liquid specific enthalpy in vol-2 (Btu/Lbm)
C             sigma1= interfacial tension in vol-1 (Lbf/ft)
C             sigma2= interfacial tension in vol-2 (Lbf/ft)
C
C     Output: velg   = Gas velocity at junction (ft/sec)
C             vell   = Liquid velocity at junction (ft/sec)
C             alph   = void fraction at junction
C             rog    = vapor density at junction (Lbm/ft3)
C             rol    = Liquid density at junction (Lbm/ft3)
C             hg     = vapor specific enthalpy at junction (Btu/Lbm)
C             hl     = liquid specific enthalpy at junction (Btu/Lbm)
C             Wg     = Gas flow rate at junction (Lbm/sec)
C             Wl     = Liquid flow rate at junction (Lbm/sec)
C****
      Implicit Real*8(A-H,O-Z)
      COMMON /ALTTIM/ TIMEX,G1,G2,G,ALPHZ,DELTT,PRX3,FUNP
c 901 format(' MARKER-1 jun1 ')
c 902 format(' MARKER-2 Jun1 ')
      G = W/A

C**** Compute limits for co-current flow

C**** G1 is limit for downward co-current flow.
C     Note G1 < or = to zero.
C     If G < G1, then the flow rate is high enough to entrain vapor
C     downward from Vol 2 to Vol 1. IF Vol 2 contains only liquid,
C     then G1 is equal to -infinity.  If Vol 2 contains vapor only,
C     then G1 is equal to zero.  It follows that G1 is based on the
C     fluid conditions in Vol 2.
      G1 = -Vgj2*roL2/DMAX1(C02,1.D-10)
C     G11= -Vgj1*roL2/DMAX1(C01,1.D-10)
C     G1 = DMAX1( G1,G11 )


C**** G2 is limit for upward co-current flow.
C     Note that G2 is > or = to zero.
C     If G > G2 then the upward flow of vapor is sufficient to entrain
C     liquid upward from Vol 1 to Vol 2.  Thus G > G2 defines co-current
C     upward flow.  If Vol 1 contains only liquid, then G2=0.  If Vol 1
C     contains only vapor, then G2 exists but the expression becomes
C     indeterminant (i.e., 0/0).  However, G2 can be determined from
C     L'Hopitals' rule.
      IF ( alph1 .gt. 0.999d0 ) then
         CALL voidL( 0.999D0, ROL1, ROG1, SIGMA1, IREG, NODE,
     &               G, C0a, Vgja, Xa )
         G2 = 0.999D0*rog1*VGJA/( 1.D0 - 0.999D0*C0A )
      ELSE
         G2 = alph1*rog1*Vgj1/( 1.d0 - alph1*C01 )
      END IF


C**** Co-Current upward Flow
      IF ( G .GE. G2 ) Then
        C0 = C01
        Vgj = Vgj1
        Rog = rog1
        roL = roL1
        hg = hg1
        hL = hL1
        alph=alph1
```

```
      veLg = C0*G/roL + Vgj
      veLg = veLg/( 1.d0 - aLph*C0*( 1.d0 - rog/roL ) )
      IF (alph .gt. 0.999D0 ) Then
      CALL voidL( 0.999D0, ROL, ROG, SIGMA1, IREG, NODE,
     &            G, C0a, Vgja, Xa )
      veLL= ( 1.d0 - 0.999D0*C0A )*( G - 0.999D0*rog*VgjA/
     &       (1.d0-0.999D0*C0A))
      veLL=veLL/(roL*(1.d0-0.999D0)*(1.d0-0.999D0*C0A*(1.d0-rog/roL)))
      ELSE
      veLL = ( 1.d0 - aLph*C0 )*( G - aLph*rog*Vgj/(1.d0-alph*C0))
      veLL = veLL/(roL*(1.d0-aLph)*(1.d0-aLph*C0*(1.d0-rog/roL)))
      END IF
      Wg = veLg*aLph*rog*A
      WL = G*A - Wg
C     WL = veLL*( 1.d0 - aLph )*roL*A

c     IF ( IREG .EQ. 7 ) THEN
c     WRITE(4,5001) WG,WL,VELG,ALPH
c     WRITE(4,5002) ROG,A,C0,G
c5001 FORMAT(' WG,WL,VELG,ALPH= ', 4E14.5 )
c5002 FORMAT(' ROG,A,C0,G      = ', 4E14.5 )
c     end if

        GO TO 900
      END IF

C**** Co-current downward flow
      IF ( G .LE. G1 ) Then
        C0 = C02
        Vgj = Vgj2
        Rog = rog2
        roL = roL2
        hg = hg2
        hL = hL2
        alph=alph2
        veLg = C0*G/roL + Vgj
        veLg = veLg/( 1.d0 - aLph*C0*( 1.d0 - rog/roL ) )
        IF (alph .gt. 0.999D0 ) Then
        CALL voidL( 0.999D0, ROL, ROG, SIGMA1, IREG, NODE,
     &              G, C0a, Vgja, Xa )
        veLL= ( 1.d0 - 0.999D0*C0A )*( G - 0.999D0*rog*VgjA/
     &         (1.d0-0.999D0*C0A))
        veLL=veLL/(roL*(1.d0-0.999D0)*(1.d0-0.999D0*C0A*(1.d0-rog/roL)))
        ELSE
        veLL = ( 1.d0 - aLph*C0 )*( G - aLph*rog*Vgj/(1.d0-alph*C0))
        veLL = veLL/(roL*(1.d0-aLph)*(1.d0-aLph*C0*(1.d0-rog/roL)))
        END IF
        Wg = veLg*aLph*rog*A
        WL = G*A - Wg
C       WL = veLL*( 1.d0 - aLph )*roL*A
        GO TO 900
      END IF

C**** COUNTER-CURRENT FLOW
        rog = rog1
        roL = roL2
        hg = hg1
        hL = hL2
        Wg2 = G2*A
        Wg1 = 0.D0
        SLOPE = (Wg2-Wg1)/(G2-G1)
        Wg = Wg1 + SLOPE*(G-G1)
        WL = G*A - Wg
        SLOPE = (alph1-alph2)/(G2-G1)
        alph = alph2 + SLOPE*(G-G1)
        SLOPE = (Vgj1-Vgj2)/(G2-G1)
        Vgj = Vgj2 + SLOPE*(G-G1)
        IF ( alph .LT. 1.D-4 ) Then
          veLg = Wg/( 1.D-4*rog*A )
        ELSE
          veLg = Wg/(alph*rog*A)
        END IF
        IF ( alph .GT. 0.999D0 ) Then
          veLL = WL/( roL*(1.D0-0.999D0)*A )
        ELSE
          veLL = WL/( roL*(1.D0-alph)*A )
        END IF
        GO TO 900


  900 Continue
      ALPHZ=ALPH

      RETURN
      End
```

APPENDIX F

Base SABRE Input Deck for Power Uprate Conditions with 9x9 Core (U2C9)

The base SABRE input deck is listed below. Following the input listing, references are provided for all of the inputs.

```
   (00) Base Case Input Deck for U2C9
*                          Notes
* Initial Power = 3441 MWth
* Initial Core flow = 100 MLb/hr
* Initial steam dome pressure = 1050 psia
*
* 10 second Steady-State Run
*
*****************************************************************************
*     CALCULATIONAL FLAGS AND CONVERGENCE CRITERIA
*
* W1-I KPRMX = MAXIMUM NUMBER OF TIME STEPS BETWEEN DETAILED EDITS.
*
* W2-I KPRMN = MINIMUM NUMBER OF TIME STEPS BETWEEN DETAILED EDITS.
*
* W3-R ERRINF= RELATIVE ERROR ON INLET FLOW ITERATION.
*
* W4-R RLXC  = RELAXATION PARAMETER USED IN FLOW CALCULATION.
*
* W5-R RTOL  = RELATIVE ERROR PARAMETER FOR KINETICS SOLUTION
*
* W6-R ATOL  = ABSOLUTE ERROR PARAMETER FOR KINETICS SOLUTION
*
*    KPRMX  KPRMN    ERRINF    RLXC    RTOL     ATOL
      20     5       9.D-5     0.20    1.D-05   1.D-05
*****************************************************************************
*     END TIME, TIME STEP DATA, AND PRINT INTERVAL
*
* W1-R  TEND = END TIME (SEC)
*
*
* W2-I  NNP . = NO. OF PRINT INTERVAL SETS SUPPLIED
*
*.
* W3-I  NTIME= NUMBER OF TIME STEP SETS SUPPLIED
*
* W4-R  DTKINMAX = MAX STEP SIZE FOR KINETICS SOLUTION (SEC)
*
*     TEND            NNP     NTIME     DTKINMAX
       10.             5        5         1.0
*****************************************************************************
*                     TIME STEP DATA
*
* W1-I  IDDT= ID NO. FOR TIME STEP DATA
*
* W2-R  HMAX  = Max STEP SIZE (MSEC)
*
* W3-R  HMIN  = Min step size (msec)
*
* W4-R  TSTART = Starting time for time step data (sec)
*
*      IDDT        HMAX    HMIN     TSTART(J)
*                  (MSEC)  (msec)   (SEC)
         1          30.     15.       0.
         2          30.     15.      10.
         3          30.     15.      20.
         4          30.     15.     200.
         5          30.     15.     300.
*****************************************************************************
*     PRINT INTERVAL DATA
*
* W1-R  TPRNT1 = PRINT INTERVAL BETWEEN GENERAL EDITS (SEC)
*
* W2-R  TSTRTP = STARTING TIME FOR PRINT INTERVAL (SEC)
*
*           TPRNT1           TSTRTP
              5.               0.
             40.              10.
            100.             100.
            250.             500.
            250.            1000.
*****************************************************************************
*     INITIAL REACTOR CONDITIONS AND MODEL OPTIONS
*
```

```
* W1-R   QC     =  INITIAL CORE THERMAL POWER (MWt)
*                  100% power = 3441 MWt
*
* W2-R   RCTHP =   Rated Core Thermal Power (MWt)
*
* W3-R   WCTOT =   INITIAL TOTAL CORE FLOW  (MLb/hr).  This is the
*                  combined active-core and bypass flow.
*                  RATED FLOW = 2.77778D4 LBM/SEC = 100 MLb/hr
*
*
* W4-R   WCORE =   Initial guess for core channel flow (MLb/hr)
*
* W5-R   PRX    =  INITIAL STEAM DOME PRESSURE (PSIA)
*
* W6-R   DLVL   =  INITIAL DOWNCOMER LEVEL (INCHES ABOVE INSTR ZERO)
*                  Normal level is 30 to 35 inches.
*
* W7-R   DSUB   =  INITIAL SUBCOOLING IN DOWNCOMER REGION (BTU/LBM)
*               =  HF - (ENTHALPY IN DOWNCOMER) (Btu/Lbm)
*
* W8-I   INITLZ=   INITIALIZATION FLAG
*              =   1 IF THIS IS AN INITIALIZATION CASE
*              =   0 IF THIS IS A TRANSIENT RUN
*
* W9-R   QFRAC1=   FRACTION OF TOTAL CORE POWER THAT IS DEPOSITED
*                  IN THE CORE CHANNEL AS GAMMA HEATING
*
* W10-R  QFRAC2=   FRACTION OF TOTAL CORE POWER THAT IS DEPOSITED
*                  IN THE BYPASS CHANNEL AS GAMMA HEATING
*
* W11-R  TMPCST=   Temperature of water in CST (F).  Used for HPCI
*                  and RCIC injection.
*
* W12-R  TMPHW =   Temperature of water in Hot Well (F).  Used
*                  for final FW temp upon loss of FW heating.  FW heating
*                  is lost after MSIV closure, turbine trip, or manual
*                  trip of FW heaters. Also used for suction temperature when
*                  condensate sytem is injecting at low Rx pressure.
*
* W13-R  VCST =    CST Volume (gal)
*
* W14-R  VTCST=    CST Vol (gal) at which HPCI & RCIC Tranasfer suction
*                  from CST to SP
*
* W15-R  HTCLIQ=   Heat transfer coefficient (BTU/hr-ft2-F) for submerged part
*                  of reactor vessel & internals.
*
* W16-R  HTCSTM=   Heat transfer coefficient (BTU/hr-ft2-F) for part
*                  of reactor vessel & internals exposed to steam.
*
*
*
*
*
*        QC       RCTHP     WCTOT     WCORE     PRX
         3441.    3441.     100.      90.       1050.
*
*        DLVL     DSUB      INITLZ    QFRAC1    QFRAC2
         35.      25.1      0         0.0175    0.0175
*
*        TMPCST   TMPHW     VCST      VTCST     HTCLIQ    HTCSTM
         123.     129.      225000.   35250.    200.      10.
*
*
*
***********************************************************************
*                        LOCA Data
*
* W1-R ABREAK = Break area (ft2)
* W2-I IBREAK = 1 => Liquid break (in downcomer)
*             = 2 => Steam break (in steam dome)
* W3-R FBREAK = Flow coefficient. When flow is choked, break flow
*               is Gcrit*ABREAK*FBREAK, where Gcrit is critical mass
*               flux.
* W4-R AKBRK  = loss coefficient for break.
* W5-I ILTBL  = 1 => Override break flow calc. with break flow/enthalpy
*                    vs. time table.
*             = 0 => Break flow will be calculated.
* W6-I NLTBL  = Number of points in break flow vs. time table.
*
*      ABREAK         IBREAK    FBREAK   AKBRK   ILTBL   NLTBL
       0.0000         1         1.0d0    1.d0    0       3
*
*              Time           Break Flow       Break Enthalpy
*              (sec)          (Lbm/sec)        (Btu/Lbm)
               0.0000d0       0.d0             525.1d0
```

```
            10.0000d0                  0.d0          525.1d0
             1.0000d9                  0.d0          525.1d0
*****************************************************************************
*                       TRIP LOGIC
*
*********************** SCRAM LOGIC ***
*******************************************
     1          * 1=> SCRAM ENABLED,    0=> SCRAM FAILED (ATWS),
*                -1=> SCRAM & ARI Failed.
    13.D0       * LOW LEVEL SCRAM SET POINT (INCHES)
  1087.D0       * HIGH REACTOR PRESSURE SCRAM SET POINT (PSIG)
     1.72D0     * HIGH DRYWELL SCRAM SET POINT (PSIG)
   118.D0       * SCRAM ON HIGH NEUTRON FLUX (% OF RATED)
     1.D+09     * MANUAL SCRAM ON TIME (SEC)
     1          * SCRAM ON MSIV CLOSURE (1=>ENABLED, 0=>OFF)
     1          * SCRAM ON TURBINE TRIP (1=>ENABLED, 0=>OFF)
     2.8          Control rod insertion time for scram (sec)
*
*********************** HPCI DATA ***
*****************************************
**** Trip Logic
     1          * 1=> HPCI OPERABLE, 0=> HPCI INOPERABLE
   -38.         * HPCI INITIATION ON LOW WATER LEVEL (INCHES)
     1.72       * HPCI INITIATION ON HIGH DRYWELL PRESSURE (PSIG)
   +54.         * HPCI TRIP ON HIGH WATER LEVEL (INCHES)
   118.7        * HPCI TRIP ON LOW REACTOR PRESSURE (PSIA)
     1.D+09     * MANUAL TRIP OFF ON TIME (SEC)
    23.83       * SP LEVEL AT WHICH HPCI SUCTION TRANSFERS TO SP (FT)
**** HPCI Flow
     3.3        * Time constant (sec) for HPCI flow vs. demand response
    20.0        * Delay from HPCI init signal to start of flow to RPV (sec)
   500.         * Minumum HPCI flow (gpm)
  5000.         * Maximum HPCI flow (gpm)
     3          * Number of points in Table of HPCI demand flow vs. time
*               * (Demand flow is setpoint dialed in on flow controller)
**** Table of HPCI Demand flow vs. time
*
*    Time (sec)           HPCI Demand Flow (gpm)
      0.d0                      5000.d0
      1.d3                      5000.d0
      1.d9                      5000.d0
**** Operator Control
      1         * 1=> ENABLE LEVEL CONTROL MODE OF HPCI OPERATION, 0=> OFF
      1.D+09    * TIME AT WHICH OPERATOR TAKES CONTROL OF INJECTION (SEC)
      2         * Number of points in target-level-versus-time table
*    Time (sec)          Target Level (inches)
      0.0                    +35.
      1.D+09                 +35.
    500.        * GAIN (GPM/INCH) USED IN SIMULATING OPERATOR CONTROL OF FLOW
*
*********************** RCIC DATA ***
*******************************************
**** trips
      1         * 1=> RCIC OPERABLE, 0=> RCIC INOPERABLE
    -38.        * RCIC INITIATION ON LOW WATER LEVEL (INCHES)
    +54.        * RCIC TRIP ON HIGH WATER LEVEL (INCHES)
     75.        * RCIC TRIP ON LOW REACTOR PRESSURE (PSIA)
      1.D9      * MANUAL TRIP OFF ON TIME (SEC)
**** flow data
      3.3       * Time constant (sec) for RCIC flow vs. demand response
     20.        * Delay from RCIC init signal to start of flow to RPV (sec)
    600.        * RCIC injection rate (gpm)
     60.        * Minimum RCIC flow (gpm)
    600.        * Maximum RCIC flow (gpm)
**** Operator Control
      1         * 1=> ENABLES OPERATOR-CONTROL MODE FOR RCIC, 0=> OFF.
      1.D+09    * TIME AT WHICH OPERATOR TAKES CONTROL OF RCIC INJ (SEC)
      2         * Number of points in target-level-versus-time table
*    Time (sec)          Target Level (inches)
      0.0                    +35.
      1.D+09                 +35.
    500.D0      * GAIN (GPM/INCH) USED IN SIMULATING OPERATOR CONTROL OF FLOW
*
*********************** CONDENSATE SYSTEM ***
************************************************
      0             0 => LOW-PRESS CONDENSATE INJECTION INOPERABLE
*                   1 => LOW-PRESS CONDENSATE INJECTION OPERABLE
     20.            RAMP TIME FOR INJECTION, I.E., THE TIME
*                   FROM INITIATION OF INJECTION UNTIL PUMP REACHES
*                   FULL FLOW (SEC).
      5.            COAST-DOWN TIME WHEN FLOW IS TRIPPED OFF (SEC)
    514.7           LOW PRESSURE PERMISSIVE FOR FLOW INJECTION. PRESSURE
*                   MUST BE LESS THAN THIS VALUE (PSIA)
*                   OR INJECTION WILL NOT OCCUR.
```

```
  524.7       HIGH PRESSURE CUT OFF FOR INJECTION FLOW.  IF FLOW IS
*             ON AND PRESSURE EXCEEDS THIS VALUE (PSIA) FLOW WILL STOP.
 5000.        CONDENSATE INJ FLOW RATE (GPM)
*
********************** CORE SPRAY SYSTEM ***
*********************************************
   1          0 => CORE SPRAY INJECTION INOPERABLE
*             1 => CORE SPRAY INJECTION OPERABLE
   10         Number of points in flow vs. pressure table
*                  CS Flow          [Rx P - Cont. P]
*                  (gpm)              (Psi)
                   7790.               0.
                   7000.              56.
                   6000.             122.
                   5000.             172.
                   4000.             214.
                   3000.             245.
                   2000.             266.
                   1000.             277.
                     0.              289.
                     0.             1500.0
*
********************* RECIRCULATION SYSTEM LOGIC ***
***************************************************
    1.D9      * TRIP RECIRC PUMP-A ON TIME (SEC)
    1.D9      * TRIP RECIRC PUMP-B ON TIME (SEC)
*               No delay for trip on time
*
  -38.        * TRIP RECIRC PUMP-A ON LOW WATER LEVEL (INCHES)
    9.        * Delay for Pump-A trip on low level (sec)
*
  -38.        * TRIP RECIRC PUMP-B ON LOW WATER LEVEL (INCHES)
    9.        * Delay for Pump-B trip on low level (sec)
*
  1149.7      * TRIP RECIRC PUMP-A ON HIGH REACTOR PRESS (PSIA)
     0.23     * Delay for Pump-A trip on high reactor pressure (sec)
*
  1149.7      * TRIP RECIRC PUMP-B ON HIGH REACTOR PRESS (PSIA)
     0.23     * Delay for Pump-B trip on high reactor pressure (sec)
*
   20.0       * RUNBACK PMP-A (TO 30% SPEED) ON FW FLOW (% OF RATED FLOW)
   15.0       * Delay for Pump-A runback on low FW flow (sec)
*
   20.0       * RUNBACK PMP-B (TO 30% SPEED) ON FW FLOW (% OF RATED FLOW)
   15.0       * Delay for Pump-B runback on low FW flow (sec)
*
   13.0       * RUNBACK PMP-A (TO 30% SPEED) ON LOW WATER LEVEL (INCHES)
    3.0       * Delay for Pump-A runback on low Rx water level (sec)
*
   13.0       * RUNBACK PMP-B (TO 30% SPEED) ON LOW WATER LEVEL (INCHES)
    3.0       * Delay for Pump-B runback on low Rx water level (sec)
*
    4.0       * TIME CONSTANT FOR PUMP-A TRIP (SEC)
    4.0       * TIME CONSTANT FOR PUMP-B TRIP (SEC)
*
   20.        * TIME CONSTANT FOR PUMP-A RUNBACK (SEC)
   20.        * TIME CONSTANT FOR PUMP-B RUNBACK (SEC)
*
   65.        * CORE FLOW WITH 1 PUMP TRIPPED & 1 AT 100% SPEED (MLB/HR)
   42.        * CORE FLOW WITH 2 PUMPS AT 30% SPEED (MLB/HR)
   36.        * CORE FLOW WITH 1 PMP TRIPPED AND 1 PUMP AT 30% SPEED (MLB/HR)
*               = (55/87) * 42
*
********************* FEEDWATER DATA ***
******************************************
**** Trip Data
    1.D+09  * MANUAL TRIP OF FEEDWATER PUMPS (SEC)
   54.        * FEEDWATER TRIP ON HIGH WATER LEVEL (INCHES)
  175.        * FEEDWATER TRIP ON LOW STEAM LINE PRESS (PSIA)
    1.D+09  * Initiate Manual isolation of FW heaters (sec)
**** FW Controller
  200.        * FW CONTROLLER GAIN
    1.        * FW CONTROLLER TIME CONSTANT (SEC)
   14.476     * Maximum FW flow (MLb/hr)
   14.151     * Rated FW flow (MLb/hr)
   60.        * Time constant for decay of FW enthalpy following a
*               a turbine trip, MSIV closure, or manual isolation
*               of feedwater heaters (sec).
   13.        * water level at which level setpoint setdown occurs (in.)
   18.        * level setpoint (inches) after setdown occurs
   11.        * time delay for level setpoint setdown (sec)
**** Operator Control
    1.D+09  * TIME AT WHICH OPERATOR CONTROL OF FW IS INITIATED (SEC)
   35.        * TARGET LEVEL FOR OPERATOR CONTROL OF FW FLOW (INCHES)
```

```
**** Specified FW flow vs. time
   0        1 => FW flow vs. time is specified. 0 => FW flow is calc.
*                If value is 0 any data supplied in table is not used.
   2        Number of data points in FW flow vs. time table
**** FW flow vs. time table
*
*    Time (sec)   FW Flow (MLb/hr)
     0.0D+00       14.151
     1.0D+09       14.151
 *
********************** MSIV CLOSURE DATA ***
**************************************************
    1.D+09  * CLOSURE ON TIME (SEC)
  -129.     * CLOSURE ON LOW REACTOR LEVEL (INCHES)
   875.7    * CLOSURE ON LOW REACTOR PRESSURE (PSIA)
     4.0    * MSIV stroke time (sec)
    14      * NO. OF PTS. IN MULTIPLIER TABLE
 *            MSIV loss coeff mult vs stem position
 *   Stem Position     Multiplier
        0.000            2.71D+13
        0.021           200.
        0.042           100.
        0.0625           58.80
        0.083            37.00
        0.125            22.20
        0.167            13.30
        0.250             6.99
        0.333             4.44
        0.458             2.79
        0.500             2.41
        0.667             1.41
        0.833             1.14
        1.000             1.00
  *
********************** PRESSURE REGULATOR AND TURBINE TRIP DATA ***
**********************************************************************
**** Turbine Trips
     1.D9     * MANUAL TRIP ON TIME (SEC)
    54.       * TRIP ON HIGH LEVEL (INCHES)
**** Pressure Regulator
     1.D+09  * TRIP TO FAIL OPEN PRESS REG (PREGO)
    14.631   * Max turbine steam flow (VWO) at initial Rx press (MLb/hr)
   997.0     * Initial turbine inlet pressure (psia)
     3.33    * PRESSURE REGULATOR GAIN (% OF RATED FLOW/PSI)
     3.0     * tau1 = time constant 1 in lag-lead filter (sec)
     7.4     * tau2 = time constant 2 in lag-lead filter (sec)
     1.60    * tau3 = time constant in lag filter (sec)
    18.29    * Max combined steam flow at initial Rx press (MLb/hr)
  3610.5     * STEAM LINE VOL BEYOND INBOARD MSIV (FT3)
   180.2     * Steam line volume between stop and control valves (ft3)
    46.5     * STEAM LINE INERTIA (ft-1)
     9.6212  * FULL-OPEN MSIV FLOW AREA (FT2)
     0.727   * LOSS COEFF FOR FULL-OPEN MSIV
     0.10    * TURBINE STOP VALVE STROKE TIME (SEC)
     3.66    * Turbine bypess capacity at initial Rx press (MLb/hr)
     0.16    * TIME CONST FOR BYPASS VALVE OPERATION (SEC)
     0.05    * TIME CONST FOR TURB CONTROL VALVE OPERATION (SEC)
  *
********************** ADS LOGIC ***
****************************************
     1        * 1=> ADS ENABLED, 0=> ADS DEFEATED
  -129.d0     * Level setpoint for ADS (inches)
     6        * Number of valves
   102.       * Delay timer (sec) - Hi DW press assumed.
  *
********************** MANUAL CONTROL ROD INSERTION ***
******************************************************
     1.D9     * TIME AT WHICH OPERATOR INITIATES MRI (SEC)
     1.D9     * TIME AT WHICH OPERATOR STOPS MRI (SEC)
    90.0      * CONTROL ROD INSERTION RATE (SEC PER ROD)
  *
********************** STANDBY LIQUID CONTROL ***
**************************************************
     1.D+09       TIME AT WHICH SLCS IS INITIATED (SEC)
    75.0          Effective transit time from SLC tank to core (sec)
     2            NUMBER OF SLCS PUMPS OPERABLE (1 OR 2 )
     0.28         Inj rate of elemental B with 2 SLCS pumps operable (Lbm/sec)
  1140.7          VOLUME OF EXTERNAL RECIRC LOOPS (FT3) - FOR B DILUTION
   494.           Hot Shutdown Boron Conc. (ppm at Hot conditions,
  *               no voids, and full power Zenon concentration).
    15.           If total core flow (Mlb/hr) is greater than this value,
  *               then stagnated boron (in lower plenum) will begin to remix.
     6.           If total core flow (MLb/hr) is less than this value,
  *               then some of the boron injected into the lower plenum will begin
```

```
*             to settle to the bottom of vessel.
   4.         If the total core flow (MLb/hr) is less than this value,
*             then all of the boron injected into the lower plenum will
*             settle to the bottom of the vessel.
   1.         Interpolation exponent for boron mixing when core flow
*             is between the two total core flows specified above.
*             exponent = 1 => linear interpolation
*             exponent > 1 => less mixing than linear model
*             exponent < 1 => more mixing than linear
   10         Number of nodes in active core for boron mixing (1 to 10)
 4800.d0      Initial volume of sodium pentaborate solution
*             in SLC tank (gal)
  200.        SLC tank vol at which SLC pumps trip (gal)
   82.4       Injection rate of boron solution (gpm) with 2 pumps
   90.        Temperature of solution in SLC tank (F)
*
************************ REACTOR COOLDOWN ***
   1.D+09     Time (sec) at which controlled cooldown of RPV is init.
  100.        Cooldown Rate (Deg F/hr)
   98.        Target press of cooldown (psig), i.e., the cooldown is
*             over when Rx pressure reaches this value.
**************************************************************************
*          SAFETY/RELIEF VALVE DATA (PART 1)
*
* W1-I  NSRV  = NUMBER OF SRVS
*
* W2-R  DTSRV = SRV STROKE TIME (SEC)
*
* W3-R  FCOEF = Flow coefficient.  SRV flow is
*               FCOEF*Gcrit*VAREA, where Gcrit is critical mass flux.
*
*
*
*     NSRV      DTSRV       FCOEF
       16       0.5         0.884
**************************************************************************
*          SAFETY/RELIEF VALVE DATA (PART 2)
*
* W1-R  VAREA(1) = FLOW AREA FOR VALVE 1 (FT2)
*
* W2-R  PRESH(1) = PRESSURE AT WHICH VALVE OPENS (PSIA)
*
* W3-R  PRESL(1) = PRESSURE AT WHICH VALVE RE-SEATS (PSIA)
*         .
*         .
*         .
* SUPPLY NVALV LINES OF DATA WITH EACH LINE CONTAINING THESE three
* PARAMETERS
*
*  VALVE ID#    VAREA          PRESH        PRESL
*  UAL values
*      1        0.11192        1143.        1017.
*      2        0.11192        1146.        1020.
*      3        0.11192        1156.        1029.
*      4        0.11192        1157.        1030.
*      5        0.11192        1159.        1032.
*      6        0.11192        1165.        1037.
*      7        0.11192        1167.        1039.
*      8        0.11192        1168.        1040.
*      9        0.11192        1175.        1046.
*     10        0.11192        1176.        1047.
*     11        0.11192        1178.        1048.
*     12        0.11192        1181.        1051.
*     13        0.11192        1186.        1056.
*     14        0.11192        1191.        1060.
*     15        0.11192        1194.        1063.
*     16        0.11192        1204.        1072.
*
*  Nominal values
       1        0.11192        1113.         987.
       2        0.11192        1116.         990.
       3        0.11192        1126.         999.
       4        0.11192        1127.        1000.
       5        0.11192        1129.        1002.
       6        0.11192        1135.        1007.
       7        0.11192        1137.        1009.
       8        0.11192        1138.        1010.
       9        0.11192        1145.        1016.
      10        0.11192        1146.        1017.
      11        0.11192        1148.        1018.
      12        0.11192        1151.        1021.
      13        0.11192        1156.        1026.
      14        0.11192        1161.        1030.
      15        0.11192        1164.        1033.
      16        0.11192        1174.        1042.
```

```
******************************************************************************
*              Time-Dependent Actuation of SRVs (Part 1)
*
* W1-I  NTRIP  = Number of valves to be tripped open/closed at
*                specified time.
*
*
*         NTRIP
           3
******************************************************************************
*              Time-Dependent Actuation of SRVs (Part 2)
*
* W1-I  IDTRIP =  ID# OF TRIP.  THIS INPUT PARAMETER MUST BE
*                 SEQUENTIAL STARTING WITH THE VALUE ONE.
*
* W2-I  IDVALV =  SRV IDENTIFICATION NUMBER (1-10 only)
*
* W3-R  TVTRIP =  TIME AT WHICH VALVE IS TRIPPED OPEN/CLOSED (SEC)
*
* W4-I  IVIN   =  1 if valve is triped open at t=TVTRIP
*              =  2 if valve is tripped closed at t =TVTRIP.
*
*
*   TRIP ID#    VALVE ID#     TOPEN/TCLOSE   1=OPEN 2=CLOSE
      1            1             1.D9          1
      2            2             1.D9          1
      3            3             1.D9          1
******************************************************************************
* NUMBER OF DATA POINTS DESCRIBING DOWNCOMER CONDENSATION EFFICIENCY
*
*      NPTSE
        12
******************************************************************************
*   DOWNCOMER CONDENSATION EFFICIENCY AS A FUNCTION OF REACTOR
*   PRESSURE AND DOWNCOMER WATER LEVEL.
*
*   This table specifies the condensation efficiency on cold makeup
*   flow which is injected
*   through the feedwater spargers.  When the downcomer water level
*   drops below the spargers (which are located at -23.7 in.) feedwater
*   is injected directly into a region occupied by saturated steam.
*   Feedwater, HPCI, RCIC, and Condensate systems all inject through
*   the feedwater spargers.
*
*    Water Level (in.)     Pressure (PSIA)    Condensation Efficiency
           -23.7              1500.              0.00d0
           -63.1              1500.              0.95D0
          -250.               1500.              0.95D0
           -23.7              1000.              0.00d0
           -63.1              1000.              0.95D0
          -250.               1000.              0.95D0
           -23.7               500.              0.00d0
           -63.1               500.              0.95D0
          -250.                500.              0.95D0
           -23.7               100.              0.00d0
           -63.1               100.              0.95D0
          -250.                100.              0.95D0
******************************************************************************
*    CRD INJECTION FLOW AND ENTHALPY DATA
*
* W1-R CRDFN  = Normal CRD flowrate (gpm)
*
* W2-R CRDTM  = CRD water temperature (DegF)
*
* W3-R CRDT   = Time at which makeup mode of CRD operation is initiated
*               (sec).  CRD flow can be maximized to provide increased
*               makeup if necessary.  The makeup flow depends on reactor
*               pressure.
*
* W4-I NCRD   = Number of data points describing CRD flow as a function
*               of pressure for operation in makeup mode
*
*        CRDFN        CRDTM       CRDT         NCRD
          64.          80.        1.D+09        11
*
*
*                   CRD Flow in          Reactor
*                  in Makeup Mode        Pressure
*                      (gpm)              (Psia)
                      340.d0              14.7d0
                      335.d0             100.0d0
                      320.d0             200.0d0
                      307.d0             300.0d0
                      285.d0             400.0d0
                      280.d0             500.0d0
```

```
                 265.d0                  600.0d0
                 239.d0                  700.0d0
                 230.d0                  800.0d0
                 187.d0                 1000.0d0
                   0.d0                 1300.0d0
*****************************************************************
*  DELAYED-NEUTRON PRECURSOR DECAY CONSTANTS FOR SIX GROUPS
*
* W1-R   SLAMDA(1) = DECAY CONSTANT (1/SEC) FOR FIRST DELAYED GROUP
*   .
*   .
*   .
* W6-R  SLAMDA(6)  = DECAY CONSTANT (1/SEC) FOR SIXTH DELAYED GROUP
*
*  SLAMDA(1)  SLAMDA(2)  SLAMDA(3)  SLAMDA(4)  SLAMDA(5)  SLAMDA(6)
   0.0128      0.0316      0.122      0.324      1.400      3.87
*****************************************************************
*     GROUP FRACTIONS FOR SIX DELAYED GROUPS
*
* W1-R  BETAN(1) = (BETA FOR GROUP 1)/BETA
*   .
*   .
*   .
* W6-R  BETAN(6) = (BETA FOR GROUP 6)/BETA
*
*  BETAN(1)  BETAN(2)  BETAN(3)  BETAN(4)  BETAN(5)  BETAN(6)
   0.032     0.205      0.185     0.395     0.147     0.036
*****************************************************************
*   DATA FOR FUEL AND CLADDING HEAT TRANSFER MODEL
*
* W1-R  RF     = FUEL PELLET RADIUS (INCHES)
*
* W2-R  RCI    = INSIDE RADIUS OF CLADDING (INCHES)
*
* W3-R  RCO    = OUTSIDE RADIUS OF CLADDING (INCHES)
*
* W4-R  HGAP   = GAP CONDUCTANCE (BTU/SEC-FT2-DEGF)
*
* W5-R  RODL   = LENGTH OF ACTIVE FUEL (FT)
*
* W7-I  NBUND = NUMBER OF BUNDLES IN CORE
*
* W8-R  RF1    = RADIUS OF INNER FUEL NODE (INCHES)
*
* W9-R  PHI1   = (VOLUMETRIC HEAT GENERATION IN FUEL NODE 1)/(PELLET
*                AVERAGE VOLUMETRIC HEAT GENERATION RATE).  This
*                parameter accounts for self-shielding effects within
*                the fuel.
*
*
*    RF      RCI     RCO    HGAP    RODL    NBUND    RF1     PHI1
   0.1783  0.182  0.212   988.    12.5     764    0.1261   0.90
*****************************************************************
*   Number of FUEL Rods per Axial Core Node
*
*        Axial Node        No. of Rods
            1                 79    * BAF
             2                 79
             3                 79
             4                 79
             5                 79
             6                 79
             7                 79
             8                 79
             9                 79
            10                79
             11                79
             12                79
             13                79
             14                79
             15                79
             16                79
             17                79
             18                79
             19                79
             20                79
             21                79
             22                79
             23                79
             24                79
             25                79      *TAF
*****************************************************************
*   DOWNCOMER INERTIA
*
```

```
* W1-R   AID    = DOWNCOMER INERTIA (1/FT)
*
*          AID
         0.00D0
***************************************************************************
*   JET-PUMP REGION PHYSICAL AND HYDRAULIC PARAMETERS
*
* W1-R   AJ     = JET PUMP FLOW AREA (FT2)
*
* W2-R   ALENJ  = JET PUMP FLOW PATH LENGTH (FT)
*
* W3-R   DHJ    = JET PUMP HYDRAULIC DIAMETER (FT)
*
* W4-R   FJ     = Jet pump region friction factor.
*
* W5-R   AIJ    = Jet pump fluid inertia (effective L/A) [ ft**(-1) ]
*
*
*    AJ        ALENJ          DHJ          FJ        AIJ
   15.16      16.495         0.98        0.013      1.1
***************************************************************************
*   LOWER PLENUM PHYSICAL AND HYDRAULIC PARAMETERS
*
* W1-R   AL     = FLOW AREA OF LOWER PLENUM (FT2)
*
* W2-R   ALENL  = FLOW PATH LENGTH OF LOWER PLENUM (FT)
*
* W3-R   DHL    = HYDRAULIC DIAMETER FOR LOWER PLENUM (FT)
*
* W4-R   FL     = Friction factor for lower plenum region.
*
* W5-R   ALENL1= (ELEVATION AT CORE INLET) - (ELEVATION AT BOTTOM OF
*                JET PUMP REGION)  (FT)
*
* W6-R   AIL    = Lower plenum fluid inertia [ ft**(-1) ]
*
*    AL        ALENL         DHL       FL      ALENL1      AIL
   132.33     17.28        1.014     0.013     6.94       0.13
***************************************************************************
*   REACTOR CORE HYDRAULIC PARAMETERS
*
* W1-R   AC     = CORE FLOW AREA (FT2)
*
* W2-R   ALENC  = Length of active core (ft)
*
* W3-R   DHC    = CORE HYDRAULIC DIAMETER (FT)
*
* W4-R   AIC    = Core fluid inertia [ ft**(-1) ]
*
* W5-R   ALLR   = Length of lower reflector region (ft)
*
* W6-R   ALUR   = Length of Upper Reflector Region (FT)
*
*
*    AC        ALENC         DHC        AIC       ALLR     ALUR
   87.2       12.5         0.0425     0.17D0     1.15     1.218
***************************************************************************
*   BY-PASS CHANNEL HYDRAULIC PARAMETERS
*
* W1-R   AB     = BY-PASS CHANNEL FLOW AREA (FT2)
*
* W2-R   ALENB  = FLOW PATH LENGTH (FT)
*
* W3-R   DHB    = BY-PASS CHANNEL HYDRAULIC DIAMETER (FT)
*
* W4-R   FB     = Bypass friction factor.
*
* W5-R   AIB    = Bypass fluid inertia [ ft**(-1) ]
*
*
*    AB        ALENB          DHB          FB        AIB
   67.87      14.87         0.196       0.0185     0.22
***************************************************************************
*   UPPER PLENUM HYDRAULIC PARAMETERS
*
* W1-R   AU     = UPPER PLENUM FLOW AREA (FT2)
*
* W2-R   ALENU  = FLOW PATH LENGTH OF UPPER PLENUM (FT)
*
* W3-R   DHU    = HYDRAULIC DIAMETER FOR UPPER PLENUM (FT)
*
* W4-R   FU     = Upper plenum friction factor.
*
* W5-R   AIU    = Upper plenum fluid inertia [ ft**(-1) ]
```

```
*
*
*
*   AU       ALENU    DHU     FU      AIU
  191.84     4.98     3.97    0.01    0.015
*****************************************************************************
*   RISER HYDRAULIC PARAMETERS
*
* W1-R  AR     =  RISER/SEPARATOR FLOW AREA (FT2)
*
* W2-R  ALENR  =  RISER/SEPARATOR FLOW PATH LENGTH (FT)
*
* W3-R  DHR    =  HYDRAULIC DIAMETER FOR RISER/SEPARATOR REGION (FT)
*
* W4-R  FR     =  Friction factor for risers.
*
* W5-R  AIR    =  Fluid inertia in riser region [ ft**(-1) ]
*
*
*   AR       ALENR      DHR      FR       AIR
  39.66     10.156     0.505    0.015    0.85
*****************************************************************************
*   SEPARATOR HYDRAULIC PARAMETERS
*
* W1-R  AS     =  SEPARATOR FLOW AREA (FT2)
*
* W2-R  ALENS  =  SEPARATOR FLOW PATH LENGTH (FT)
*
* W3-R  DHS    =  HYDRAULIC DIAMETER FOR SEPARATOR REGION (FT)
*
* W4-R  FS     =  Separator region friction factor.
*
* W5-R  AIS    =  Separator region fluid inertia [ ft*(-1) ].
*
*
*   AS       ALENS      DHS      FS       AIS
  71.06      6.167     0.514    0.015    0.84
*****************************************************************************
*   Combined volume of steam dome (up to inboard MSIV) and downcomer
*   region (ft3)
*
*    VOO
*   (FT3)
   14334.
*****************************************************************************
*   REACTOR CORE SPACER LOSS COEFFICIENT DATA
*
* W1-I  NSPACE = NUMBER OF SPACERS PER CHANNEL
* FUEL SPACER LOSS COEFFICIENT CALCULATED BY THE CODE BASED ON INITIAL
* CONDITIONS
*
*     NSPACE
        7
*****************************************************************************
*              JUNCTION FLOW AREAS AND LOSS COEFFICIENT DATA
*
*
*          K        AREA
         0.24       6.18     * (1)  Downcomer to Jet Pump
         1.04      39.4      * (2)  Jet Pump Exit
         1.57      22.67     * (3)  Fuel Bundle Orifice
         1.37      49.8      * (4)  Lower tie plate
         0.5065     0.976    * (5)  Lower Reflector to Bypass
         3.64     139.8      * (6)  Upper Reflector to Upper Plenum
         0.00      48.98     * (7)  Bypass to Upper Plenum
         0.41      45.10     * (8)  Upper plenum to Riser
        -1.00      35.67     * (9)  Riser to Separator
        -1.00      40.73     * (10) Separator Exit
*****************************************************************************
********************** CONTAINMENT DATA**************************************
*
*
* W1-R  SPWLO = INITIAL SUPPRESSION POOL level (ft)
*
* W2-R  SPTO = INITIAL SUPPRESSION POOL TEMPERATURE (DEGF)
*
* W3-R  TWW  = Initial Wetwell Temp (F)
*
* W4-R  THXON1 = Time AT WHICH RHR HX-1 TURNS ON (sec)
*
* W5-R  THXON2 = Time AT WHICH RHR HX-2 TURNS ON (sec)
*
* W6-R  TDWSPI = TIME at which Dry Well Spray is initiated (sec)
*                (Keep at 1.D+09; Model not complete)
```

```
*
*      SPWL0     SPT0      TWW       THXON1     THXON2      DWSPI
        23.0      90.       90.       1.D+09     1.D+09      1.D+09
******************************************************************************
*
*   SUPPRESSION POOL FREE AREA AS A FUNCTION OF ELEVATION
*
* W1-I  NSPAVL= Number of SP area vs. level points.
* W2-R  SPELEV = ELEVATION ABOVE BOTTOM OF SUPPRESSION POOL (FT)
* W3-R  SPAREA = SP FREE AREA (FT2)
*
*        NSPAVL
           4
*
*        Elev. above bottom of pool            Free Area
*                    (ft)                        (ft2)
                        0.00                         5851.3
                       12.00                         5851.3
                       12.01                         5277.0
                       52.50                         5277.0
******************************************************************************
* W1-R  QRDW = Initial heat load from from RPV to drywell (BTU/sec)
* W2-R  QDWC = Initial cooling capacity of DW Cooling (BTU/sec)
* W3-R  TCWDW= Inlet Temp of cooling water for DW coolers (F)
* W4-R  DWCTP= Drywell coolers trip if DW press exceeds this value (psig)
* W5-R  DWCTL= Drywell coolers trip if Rx level drops below value (in.)
* W6-R  VDW  = Drywell free volume (ft3)
* W7-R  TDW  = Initial DW temp (F)
* W8-R  TEMPSW=Service Water Temperature (F)
*
*   QRDW      QDWC      TCWDW  DWCTP    DWCTL     VDW        TDW      TEMPSW
   1043.     1043.      50.D0  1.72     -129.    239600.    120.      88.
******************************************************************************
*   Containment Data (Cont'd) -- Vacuum Breaker Data
*
* W1-R  AREAVB = full open vac breaker flow area (ft2)
* W2-R  AKVB   = vacuum breaker loss coeff based on AREAVB
* W3-R  DP1VB  = DP at which vac breaker begins to lift (psi)
* W4-R  DP2VB  = DP at which vac breaker is full open (psi)
*
*     AREAVB    AKVB       DP1VB      DP2VB
      10.25     3.57       0.5        3.22
******************************************************************************
*   Containment Data (Cont'd) -- Downcomer Vent Data
*
* W1-R  ADOWN0 = downcomer vent flow area (ft2)
* W2-R  AKDOWN = downcomer vent loss coefficient based on ADOWN0
* W3-R  ALDOWN = Elevation of bottom of DC vent w/r to bottom of SP (ft)
*
*     ADOWN0    AKDOWN     ALDOWN
      242.0     2.17       12.0
******************************************************************************
*   Containment Data (Cont'd) -- Initial Humidity and pressure
*
* W1-R  RHDW = Initial Relative humidity in DW (%)
* W2-R  RHWW = Initial Relative Humidity in WW (%)
* W3-R  PDW  = Initial pressure in DW (psia)
* W4-R  PWW  = Initial pressure in Wetwell (F)
*
*    RHDW       RHWW         PDW       PWW
     48.        100.         15.2      15.2
******************************************************************************
*   Containment Data (Cont'd) -- SRV tailpipe/Downcomer data
*
* W1-R  DSRVP= Diameter of SRV tail pipe (ft)
* W2-R  AKQUEN= loss coefficient for SRV quencher
* W3-R  HVENT= Height of downcomer vents above drywell floor (ft)
* W4-R  FCN2 = 0.0 => nitrogen bubbles through SP with no heat transfer.
*            = 1.0 => nitrogen reaches thermal equil with SP.
*            ( 0<FCN2<1 => interpolation between the two limits ).
*
*         DSRVP                AKQUEN     HVENT     FCN2
           1.0                  1.0        1.5       1.0
******************************************************************************
*   Containment Data (Cont'd) -- SP Letdown
*
* W1-R TSPLD1= Time at which SP letdown is started (sec)
* W2-R TSPLD2= Time at which SP letdown is terminated (sec)
* W3-R WSPLD = SP letdown flow (lbm/sec)
*
*     TSPLD1      TSPLD2      WSPLD
       1.d9        1.d9       120.d0
******************************************************************************
*   Containment Data (Cont'd) -- Area of Drywell steel structures
```

```
*
* W1-R  ADWW = surface area of drywell liner wall (ft2)
* W2-R  ADWR = surface area of drywell liner roof (ft2)
* W3-R  ADWF = surface area of drywell liner floor (ft2)
* W4-R  ADWI = surface area of internal steel structures (structures
*              excluding the liner) in drywell (ft2)
*
*
*
*    ADWW          ADWR          ADWF          ADWI
   17870.         1039.         6082.         66000.
***************************************************************************
*  Containment Data (Cont'd) -- Volume of Drywell steel structures
*
* W1-R  VDWW = volume of wall segment of drywell liner (ft3)
* W2-R  VDWR = volume of roof segment of drywell liner (ft3)
* W3-R  VDWF = volume of floor segment of drywell liner (ft3)
* W4-R  VDWI = volume of internal steel structures in drywell (ft3)
*
*    VDWW          VDWR          VDWF          VDWI
     372.           22.           127.          2750.
***************************************************************************
*  Containment Data (Cont'd) -- Area of Wetwell steel structures
*
* W1-R  AWWW = ht area of wetwell wall (ft2)
* W2-R  AWWI = ht area of wetwell internal structures (ft2).
*
*       AWWW                   AWWI
       8156.                  30048.
***************************************************************************
*  Containment Data (Cont'd) -- Volume of Wetwell steel structures
*
* W1-R  VWWW = Vol. of wetwell wall within air space (ft3)
* W2-R  VWWI = Vol. of wetwell internal structures (ft3)
*
*       VWWW                   VWWI
        170.                   1252.
***************************************************************************
*  Containment Data (Cont'd) -- Characteristic lenght of steel struc.
*
* W1-R  CLDW = Characteristic length of drywell wall = height (ft)
* W2-R  CLDR = Characteristic length of drywell roof
*            = (Heat transfer area)/(Perimeter)  (ft)
* W3-R  CLDF = Characteristic length of drywell floor
*            = (Heat transfer area)/(Perimeter)  (ft)
* W4-R  CLDI = Characteristic length of drywell internal steel struc.
*            = Height (ft)
* W5-R  CLWW = Characteristic length of wetwell wall in air space
*            = Height (ft)
* W6-R  CLWI = Characteristic length of wetwell internal steel struc.
*            = Height (ft)
*
*   CLDW     CLDR     CLDF     CLDI      CLWW       CLWI
    87.75    9.1      22.      10.       29.5       10.
***************************************************************************
```

Documentation for Base Case SABRE Inputs for U2C9 Core

F.1 Calculation Flags and Convergence Criteria

F.1.1 Maximum number of time steps between detailed edits
= 20

F.1.2 Minimum number of time steps between detailed edits
= 5

F.1.3 Relative error on inlet flow iteration
= 9.D-05. This is the convergence criteria for calculation of core inlet and jet pump inlet flows.

F.1.4 Relaxation parameter used in inlet-flow calculation
= 0.20. This parameter is used in Newton's Method calculation of core and jet pump inlet flows. (adds numerical stability).

F.1.5 Relative error parameter for kinetics solution
= 1.D-05

F.1.6 Absolute error parameter for kinetics solution
= 1.D-05

F.2 Problem end time, print intervals, and time step sets

F.2.1 End time
= 10 seconds. (Run 10 second transient).

F.2.2 Number of print interval sets supplied
= 5 These are the print intervals for General Edits. General edits are printed in file Generl.out.

F.2.3 Number of time step sets supplied
= 5

F.2.4 Max step size for kinetics solution
= 1 second

F.3 Time Step Data

Five cards must be supplied (see F.2.3).

ID	Max Step Size (msec)	Min Step Size (msec)	Start Time (sec)
1	30.	15.	0.
2	30.	15.	10.
3	30.	15.	30.
4	30.	15.	200.
5	30.	15.	300.

A maximum time step size of 30 msec is specified for this problem. The maximum step size will be used in the calculation unless convergence of the numerical calculation cannot be obtained. In this case, the step size will be halved until the minimum value specified (15 msec) is reached.

F.4 (Parameter not used with 1-D kinetics model)

F.5 Print Intervals for General Edits

In the base deck, General Edits are printed at the intervals shown below:

Print Interval (sec)	Start Time for Print Interval (sec)
5.	0.
40.	10.
100.	100.
250.	500.
250.	1000.

F.6 Core Power

F.6.1 Initial Core Thermal Power

Core thermal power = 3441 MWth= 100% of uprated rated core thermal power.[1]

F.6.2 Rated Core Thermal Power

= 3441 MWth (see F.6.1)

F.7 Core Flow

F.7.1 Initial Total Core Flow

Core Flow (bypass plus core channel flow) = 100 MLb/hr.(Ref. 1)

F.7.2 Initial Guess for Core Channel Flow

= 90 MLb/hr. (Ref. 1)

F.8 Initial Steam Dome Pressure

Initial reactor steam dome pressure = 1050 psia. (Ref. 1)

F.9 Initial Downcomer Water Level

Initial downcomer water level = 562.5 inches above vessel zero.[2] = +35 inches above intrument zero. This is normal operating water level at rated conditions.

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[1] NEDC-32161P, "Power Uprate Engineering Report For Susquehanna Steam Electric Station Units 1 and 2," p. A.7-3, December 1993.

[2] GE-NE-187-22-0992, "Susquehanna Steam Electric Station Units 1 and 2 SAFER/GESTR-LOCA Analysis Basis Documentation," p. 4-4, September 1993.

F.10 Initial Downcomer Subcooling
Core inlet enthalpy at 100% power, 100 Mlb/hr core flow, and 1050 psia steam dome pressure is 525.0 Btu/Lbm (Ref. 1). The saturated liquid enthalpy at 1050 psia is 550.1 Btu/Lbm. Therfore, the core-inlet subcooling (and downcomer subcooling) is 550.1-525.0 = 25.1 Btu/Lbm.

F.11 Fraction of Total Power Deposited in Moderator as Gamma Heating
3.5% of the total core power is deposited directly to the moderator as gamma heating.[3] The gamma heating is assumed to be equally distributed between the coolant within the channels and the coolant within the bypass region. That is 1.75% is deposited to the coolant within the core channels, and 1.75% is deposited within the bypass channel.

F.12 Temperature of Water in Condensate Storage Tank (CST)
The HPCI and RCIC suction water temperatures correspond to the CST water temperature as these systems take suction from the CST during an ATWS event and during plant transients. Therefore, the CST temperature is set to 123 °F which is the HPCI/RCIC suction temperature used by GE in the power-uprate ATWS analysis.[4]

F.13 Hot Well Temperature
This paramerter defines the final feedwater temperature upon loss of feedwater heating. Feedwater heating is lost following an MSIV closure or turbine trip. Hotwell temperature = 129 °F.[5]

F.14 Initial CST Water Volume
Initial CST water volume = nominal value = 225,000 gallons.[6]

F.15 CST Volume for HPCI/RCIC Auto-Transfer to Suppression Pool
HPCI and RCIC auto-transfer suction from the CST to the SP on low CST level. Tech. Specs. (Tables 3.3.3-2 & 3.3.5-2) indicate that the transfer must occur with CST level >36". Calculations EC-037-1001 & EC-037-1002 state the the process set point for the transfer is 45". CST volume is 9400 gallons/ft (EC-037-1001). Therefore the suction transfer occurs when CST volume falls to (9400 gal/ft)*(3.75 ft) = 35,250 gallons.

F.16 Heat Transfer Coefficient for Submerged Part of Reactor Vessel and Vessel Internals
= 200 Btu/hr-ft^2-°F (Section D.2 of this calculation)

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[3] GENE-637-024-0893, "Evaluation of Susquehanna ATWS Performance for Power Uprate Conditions," Table 2.1, October 1993.
[4] GENE-637-024-0893, "Evaluation of Susquehanna ATWS Performance for Power Uprate Conditions," Table 2.2, October 1993.
[5] NEDC-32161P, "Power Uprate Engineering Report for Susquehanna Steam Electric Stations 1 and 2," p. A.4-13, December 1993.
[6] NPE-91-001, Susquehanna Steam Electric Station Individual Plant Evaluation," Volume 2, p. A-71.

F.17 Heat Transfer Coefficient for Part of Reactor Vessel and Internals Exposed to Steam
= 10 Btu/hr-ft^2-°F (Section D.2 of this calculation)

F.18 LOCA Data
Break flow is specified as 0.0 (No break in base input deck).

F.19 Scram Logic

F.19.1 Status of scram system
= 1 which indicates that scram is enabled.

F.19.2 Low reactor level scram set point
= +13 inches with respect to instr. zero. [7]

F.19.3 High reactor pressure scram set point
= 1087 psig.(Ref. 7)

F.19.4 High drywell pressure scram set point
= 1.72 psig.[8]

F.19.5 High neutron flux scram set point
= 118 % of rated power. (Ref. 7)

F.19.6 Time at which manual scram is initiated
= 1.D+09 sec (No manual scram for base case)

F.19.7 Scram on MSIV Closure
= +1 (scram signal is generated on MSIV closure).[9]

F.19.8 Scram on Turbine Trip
= +1 (scram signal is generated on turbine trip). (Ref. 8)

F.19.9 (Parameter not used with 1-D kinetics model)

F.19.10 Control rod insertion time for scram
= 2.8 seconds. (Ref. 7)

F.20 HPCI Data

F.20.1 HPCI operability flag
= +1 (HPCI is operable).

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[7] PP&L Calculation EC-FUEL-0520.
[8] NPE-91-001, Susquehanna Steam Electric Station Individual Plant Evaluation," Volume 2, p. A-34.
[9] NPE-91-001, Susquehanna Steam Electric Station Individual Plant Evaluation," Volume 2, p. A-33.

F.20.2 **Low water level initiation set point**
= -38 inches. (Ref. 18)

F.20.3 **High drywell pressure initiation**
= 1.72 psig.[10]

F.20.4 **High water level trip set point**
= 54 inches. (Ref. 18)

F.20.5 **Low steam supply pressure trip**
= 104 psig = 118.7 psia (Unit 1 TRM Table 2.2-1, p. 3 of 7, 04/02/1999)

F.20.6 **Manual trip off on specified time**
= 1.D+09 seconds. (No trip on time as this parameter depends on details of particular case)

F.20.7 **Suppression pool level at which HPCI suction transfers to pool**
= 23 feet 10 inches = 23.83 ft. (Unit 1 TRM Table 2.2-1, p. 4 of 7, 04/02/1999)

F.20.8 **Time constant used to simulate HPCI flow vs. demand response**
HPCI is required to reach rated flow within 30 seconds of the initiation signal.[11] From the plant data in benchmark problem 1 (Section 5.1), a 20-second delay is occurs before HPCI begins injecting to the vessel. The time constant is chosen so that HPCI is essentially at rated flow in 30 seconds:
$3(\tau_{HPCI}) + 20$ sec delay = 30 seconds, or
$\tau_{HPCI} = 10$ sec/3 = 3.3 seconds.

F.20.9 **Delay from HPCI initiation signal to start of flow to vessel**
= 20 seconds. (From F.20.8)

F.20.10 **Minimum HPCI flow**
= 500 gpm. The minimum flow at which the operator can effectively control HPCI injection is assumed to be 10% of rated flow.

F.20.11 **Maximum HPCI flow**
= 5000 gpm. It is assumed that HPCI flow will not exceed its rated value which is 5000 gpm.[12]

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[10] NPE-91-001, Susquehanna Steam Electric Station Individual Plant Evaluation," Volume 2, p. A-69.
[11] HPCI DBD004, Rev. 2, 2.2.3.1.11.
[12] HPCI DBD004, Rev. 2, 2.2.3.1.9.

F.20.12 **HPCI Demand Flow Table**

In demand flow vs. time table, HPCI flow is set to 5000 gpm for all time. As a result, when HPCI auto-initiates the system will inject at 5000 gpm until operator action is taken to reduce flow. (Maximum number of points in table is 20.)

F.20.13 **Operator control flag**

= 1. This value allows for the simulation of operator control of HPCI.

F.20.14 **Time at which operator takes control of HPCI injection**

= 1.D+09 seconds (Time at which operator takes control of HPCI depends on details of transient)

J20.15 **Target level table for operator control of HPCI**

Time (sec)	Target Level (inches)
0.0	+35.
1.D+09	+35.

In the target level versus time table for HPCI, the target level is set to +35" (normal level). The maximum number of points in the Table is 20.

F.20.16 **Controller gain used in simulating operator control of HPCI**

= 500 gpm/inch. This value has been found to give satisfactory simulation results.

F.21 RCIC Data

F.21.1 **Operability flag**

= +1. This indicates that RCIC is operable.

F.21.2 **RCIC initiation on low water level**

= -38 inches. (Ref. 18)

F.21.3 **RCIC trip on high water level**

= Level 8 = +54 inches. (Ref. 7)

F.21.4 **RCIC trip on low steam supply pressure**

= 75 psia.[13]

F.21.5 **Manual trip off on specified time**

= 1.D+09 seconds. Manual trip of RCIC depends on details of transient.

---

[13] Technical Specification Table 3.3.2-2.

F.21.6 Time constant used to simulate RCIC flow vs. demand response
RCICI is required to reach rated flow within 30 seconds of the initiation signal.[14] A 20-second delay is assumed before RCIC begins injecting to the vessel (see F.21.7). The time constant is chosen so that RCIC reaches rated flow in 30 seconds:

$3\,(\tau_{RCIC}) + 20$ sec delay = 30 seconds, or

$\tau_{RCIC} = 10$ sec/3 = 3.3 seconds.

F.21.7 Delay from RCIC initiation signal to start of flow to vessel
= 20 seconds.

F.21.8 RCIC injection rate
= 600 gpm. (This is rated RCIC flow).[15]

F.21.9 Minimum RCIC flow
= 60 gpm. The minimum flow at which the operator can effectively control RCIC injection is assumed to be 10% of the rated flow.

F.21.10 Maximum RCIC flow
= 600 gpm. (Maximum flow is assumed to be equal to rated flow.)

F.21.11 Operator control flag
= 1. This value indicates that the operator takes manual control of RCIC. It is assumed that initially RCIC injects at full flow (600 gpm) and the operator throttles RCIC to maintain level at some target value.

F.21.12 Time at which operator takes control of RCIC
= 1.D+09 seconds. Value is specific to the particular transient.

F.21.13 Target level table for operator control of RCIC

Time (sec)	Target Level (inches)
0.0	+35.
1.D+09	+35.

In the target level versus time table for RCIC, the target level is set to +35" (normal level). The maximum number of points in the Table is 20.

F.21.14 Controller gain used to simulate operator control of RCIC
= 500 gpm/inch. This value has been found to give satisfactory simulation results.

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[14] DBD041, Rev. 0, 2.2.2.1.5.
[15] DBD041, Rev. 0, 2.2.2.1.3.

F.22 Use of Condensate system for low-pressure injection

F.22.1 Operability flag

= 0. This value indicates that condensate system will not inject to vessel when reactor pressure drops below shutoff head of condensate pump.

F.22.2 Ramp time for injection

= 20 seconds. This is the time from initiation of injection until the pump reaches full flow. (This value is assumed).

F.22.3 Coast-down time when pump is tripped off

= 5 seconds. This value is based on feedwater coast-down time in event with loss of offsite power.[16]

F.22.4 Reactor pressure at which flow will initiate

= 500 psig = 514.7 psia. Condensate system can inject 5000 gpm at reactor pressure of 500 psig.[17]

F.22.5 Reactor pressure at which condensate injection will cease

=510 psig = 524.7 psia. The shut-off pressure is set slightly higher than the initiation pressure in order to avoid numerical instabilities.

F.22.5 Condensate injection rate

= 5000 gpm Injection available from a single condensate pump with reactor pressure at 500 psig. (Ref. 17)

F.22a Core Spray Flow

F.22a.1 Operability Flag for Core Spray

= 1 (1=> operable; 0=> inoperable)

F.22a.2 Core Spray flow rate as a function of ΔP (psi) between reactor vessel and suppression chamber atmosphere.

The following data is for 1 division of Core Spray. Data is from Section D.20.

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[16] GE-NE-187-22-0992, "Susquehanna Steam Electric Station Units 1 and 2 SAFER/GESTR-LOCA Analysis Basis Documentation," p. 6-28, September 1993.

[17] NPE-91-001, Susquehanna Steam Electric Station Individual Plant Evaluation," Volume 2, p. A-96.

Core Spray Flow (gpm)	[Rx Press - Supp. Chamber Press.] (psi)
7790.	0.
7000.	56.
6000.	122.
5000.	172.
4000.	214.
3000.	245.
2000.	266.
1000.	277.
0.	289.
0.	1500.

F.23 Recirculation System Logic

F.23.1 Time that pump 'A' is tripped
= 1.D+09 seconds. (No manual or spurious trip of pump in base deck)

F.23.2 Time that pump 'B' is tripped
= 1.D+09 seconds. (No manual or spurious trip of pump in base deck)

F.23.3 Low water level trip set point for 'A' pump
= -38 inches.[18]

F.23.4 Delay for 'A' pump trip on low level
= 9 seconds. (Ref. 7)

F.23.5 Low water level trip set point for 'B' pump
= -38 inches. (Ref. 18)

F.23.6 Delay for 'B' pump trip on low level
= 9 seconds. (Ref. 7)

F.23.7 High reactor pressure trip set point for 'A' pump
= 1149.7 psia. (Ref. 18)

F.23.8 Delay for 'A' pump trip on high reactor pressure
= 0.23 seconds. (Ref. 7)

F.23.9 High reactor pressure trip set point for 'B' pump
= 1149.7 psia. (Ref. 18)

F.23.10 Delay for 'B' pump trip on high reactor pressure
= 0.23 seconds. (Ref. 7)

---

[18] Unit 1 TRM, Table 2.2-1, 04/02/1999.

F.23.11 Feedwater flow at which pump 'A' runback (to 30% speed) occurs
= 20% of rated feedwater flow.[7,19]

F.23.12 Time delay for pump 'A' runback on low FW flow
= 15 seconds. (Ref. 19)

F.23.13 Feedwater flow at which pump 'B' runback (to 30% speed) occurs
= 20% of rated feedwater flow.[7,19]

F.23.14 Time delay for pump 'B' runback on low FW flow
= 15 seconds.[19]

F.23.15 Low water level setpoint for 'A' pump runback to 30% speed
= +13 inches.[19]

F.23.16 Time delay for 'A' pump runback to 30% speed on low level
= 3 seconds. This delay was obtained from a review of PICSY data for the Unit 2 reactor scram of 7/14/96.

F.23.17 Low water level setpoint for 'B' pump runback to 30% speed
= +13 inches.[19]

F.23.18 Time delay for 'B' pump runback to 30% speed on low level
= 3 seconds. This delay was obtained from a review of PICSY data for the Unit 2 reactor scram of 7/14/96.

F.23.19 Time constant for pump coastdown following pump 'A' trip
= 4 seconds. This value was determined by fitting SABRE-calculated core flow to plant data for Unit 2 scram of 7/14/96.[20]

F.23.20 Time constant for pump coastdown following pump 'B' trip
= 4 seconds. This value was determined by fitting SABRE-calculated core flow to plant data for Unit 2 scram of 7/14/96.[20]

F.23.21 Time constant for pump 'A' runback to 30% speed
= 20 seconds. This value was obtained empirically be comparing SABRE calculations to plant data.

F.23.22 Time constant for pump 'B' runback to 30% speed
= 20 seconds. This value was obtained empirically be comparing SABRE calculations to plant data.

---

[19] EC-FUEL-0969, "SSES RETRAN Controller Model," Section A.5.1.
[20] PLI-82336.

F.23.23 Total Core Flow with 1 recirculation pump tripped
= 65 Mlb/hr. Value obtained from PICSY data for Unit 2 scram of 7/14/96.[20] In the 7/14/96 event, the total core flow prior to pump trip was 102 MLb/hr.

F.23.24 Total Core Flow with 2 pumps at 30% speed
= 42 Mlb/hr.[21] (Value corresponds to 100% rod line.)

F.23.25 Total Core flow with 1 pump tripped and 1 pump at 30% speed.
Natural curculation core flow on 100% rod line = 30 Mlb/hr
Core flow with 2 pumps at 30% speed = 42 Mlb/hr (Section F.18.24).
With 1 pump tripped and 1 pump at 30% speed, core flow is estimated to be 30 +(42-30)/2 = 36 MLb/hr.

F.24 Feedwater System Data

F.24.1 Time at which manual trip of feedwater pumps occurs
= 1.D+09 seconds (no FW trip in base deck).

F.24.2 High water level setpoint for FW trip
= +54 inches.[7]

F.24.3 Minimum steam line pressure for FW operation
= 175 psia.[22]

F.24.4 Time at which isolation of FW heaters occurs
= 1.D+09 seconds (no FW heater isolation in base deck).

F.24.5 Gain used to model FW system response
= 200 Lbm/sec-inch. (Section D.15)

F.24.6 Time constant used to model FW system response
= 1 second. (Section D.15)

F.24.7 Maximum feedwater flow
= 14.476 Mlb/hr. This value puts an upper limit on feedwater flow rate computed by SABRE FW model. This value corresponds to 102% uprated power and 100 Mlb/hr core flow.[23]

F.24.8 Rated feedwater flow
= 14.151 MLb/hr.[24]

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[21] NEDC-32161P, p. A.3-3.
[22] PP&L Calculation SA-MAC-003.
[23] NEDC-32161P, p. A.7-6.
[24] NEDC-32161P, p. A.7-4.

F.24.9 Time constant for decay of FW enthalpy upon isolation of FW heaters
= 60 seconds.[25]

F.24.10 Water level setpoint for water level setpoint set down
= +13 inches. Following a scram on Level 3 (+13"), the water level setpoint is automatically setdown to a lower value.[26]

F.24.11 Water level setpoint after setdown occurs
= +18 inches.[26]

F.24.12 Time delay for level setpoint setdown
= 11 seconds.[26]

F.24.13 Time at which operator takes manual control of FW flow
= 1.D+09 seconds. No manual control of FW in base case.

F.24.14 Target water level when operator has manual control of FW
= +35 inches = normal water level.

F.24.15 FW flow versus time flag
= 0. This value indicates that input-specified FW flow vs. time will not be used in the simulation. In the base case, FW flow is computed by the controller model.

F.24.16 Number of data points in FW flow vs. time table
= 2. In the base model, the FW flow table has rated feedwater flow specified at t=0 and t=1.D9 seconds. If F.24.15 is set to 1, then FW flow will be equal to the values in the data table.

F.25 MSIV Closure Data

F.25.1 Time at which MSIV closure is initiated
= 1.D+09 seconds. (No MSIV closure in base deck).

F.25.2 Setpoint for MSIV closure on low water level
= -129 inches.[7]

F.25.3 Setpoint for MSIV closure on low reactor pressure
= 875.7 psia.[7]

F.25.4 MSIV stroke time
= 4 seconds.[27]

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[25] EC-FUEL-0969, Section E.7.
[26] EC-FUEL-0969, Section A.10.
[27] GENE-637-024-0893, "Evaluation of Susquehanna ATWS Performance for Power Uprate Conditions," Table 2.2, October 1993.

F.25.5 **Number of points in MSIV loss coefficient multiplier vs stem position table**
= 14

F.25.6 **MSIV closure loss coefficient multiplier versus steam position**

Steam Position	Multiplier[7]
0.000	2.71D+13
0.021	200.
0.042	100.
0.0625	58.80
0.083	37.00
0.125	22.20
0.167	13.30
0.250	6.99
0.333	4.44
0.458	2.79
0.500	2.41
0.667	1.41
0.833	1.14
1.00	1.00

F.26 Pressure Regulator and Turbine Trip Data

F.26.1 **Time at which turbine trip is initiated**
= 1.D+09 seconds (no turbine trip in base case).

F.26.2 **High water level set point for turbine trip**
= +54 inches.[7]

F.26.3 **Time at which pressure regulator failure-open (PREGO) is initiated**
= 1.D+09 seconds (no PREGO in base case).

F.26.4 **Maximum turbine steam flow at initial reactor pressure**
= 14.631 MLb/hr.[28]

F.26.5 **Turbine inlet pressure at initial conditions**
= 997psia[28]

F.26.6 **Pressure regulator gain**
= 3.33 % of rated flow/psi.[29]

F.26.7 **Value of τ_1 in lag-lead frequency filter of pressure regulator**
= 3.0 seconds.[29]

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[28] NEDC-32161P, p. A.4-6
[29] EC-FUEL-0969, Section D.4.

F.26.8 Value of τ_2 in lag-lead frequency filter of pressure regulator
= 7.4 seconds.[29]

F.26.9 Value of τ_3 in lag filter of pressure regulator
= 1.60 seconds.[29]

F.26.10 Maximum combined steam flow at initial reactor pressure
= 125% of rated steam flow.[30]
= 14.631 + (0.25)(14.631) = 18.29 MLb/hr.[28]

F.26.11 Steam line volume beyond inboard MSIVs
This value is obtained from control-volume data for the SSES RETRAN model.[31] This is volume beyond inboard MSIV up to control valves and bypass valves
Volume = $V_{330} + V_{341} + V_{342} + V_{343} + V_{350} + V_{360} + V_{370} + V_{380}$
Volume = 306.44 + 729.08 + 729.08 + 712.83 + 159.76 + 367.76 + 180.22 + 425.35 = 3610.5 ft^3.

F.26.12 Steam line volume between stop valve and control valve
= 180.2 ft^3. (Ref. 31)

F.26.13 Steam line inertia
= (steam line length)/(steam line flow area). Main steam can flow through two different paths: through the control valves to the turbine or through the bypass valves directly to the main condenser. Referring to Figure 3.1-2 of Ref. 31, the inertia for the path to the turbine is calculated as

$I_{Turb} = (L/A)_{330} + (L/A)_{341} + (L/A)_{342} + (L/A)_{343} + (L/A)_{350} + (L/A)_{360} + (L/A)_{370}$
= (24.730/12.3914) + (70.0/10.4156) + (70.0/10.4156) + (68.439/10.4156) + (15.340/10.4156) + (17.392/21.145) + (10.017/13.304) = 1.996 + 6.721 + 6.721 + 6.571 + 1.473 + 0.823 + 0.753 = 25.1 ft^{-1}.

The inertia for the path to the bypass valves is (see Ref. 31)
$I_{BP} = I_{Turb} - (L/A)_{360} - (L/A)_{370} + (L/A)_{380}$ = 25.1 -0.823 - 0.753 +(137.241/3.099) = 25.1 - 0.823 - 0.753 + 44.286 = 67.8 ft^{-1}.

The steam line inertia is taken to be the average of the values for the two flow paths,
$I = (I_{Turb} + I_{BP})/2$ = (25.1+67.8)/2 = 46.5 ft^{-1}.

F.26.14 Full open MSIV flow area
= 9.6212 ft^2.[7]

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[30] GO-100-102, Section 6.72.1, Rev. 25.
[31] PL-NF-89-005-A, "Qualification of Transient Analysis Methods for BWR Design and Analysis," pp. 18,27.

F.26.15 **Loss coefficient for full-open MSIV**

= 0.727 (output of control block -707 in RETRAN model[7]). Loss coefficient is based on flow area for full-open MSIVs.

F.26.16 **Turbine stop valve stroke time**

= 0.1 seconds.[32]

F.26.17 **Turbine bypass capacity at initial conditions**

= (0.258)(14.183 Mlb/hr) = 3.659 Mlb/hr.[33]

F.26.18 **Time constant for bypass valve operation**

The time constant for valve operation is approximated by 1/3 of the valve stroke time (plus any delay). In the case of a turbine trip, the bypass valves reach 80% open in about 0.4 seconds (0.1 sec delay plus 0.3 sec stroke time).[34] The time to reach full open is estimated to be 0.1 sec + 0.3/0.8 sec = 0.475 sec. Therefore, the bypass valve time constant is τ_{BP} = 0.475/3 = 0.16 seconds.

F.26.19 **Time constant for turbine control valve operation**

The valve time constant is approximated by 1/3 of the valve stroke time. τ_{CV} = 0.15/3 = 0.05 seconds.[35]

F.27 ADS Logic

F.27.1 **ADS operability flag**

=1 (ADS is enabled)

F.27.2 **Reactor water level setpoint for initiation of ADS**

= -129 inches.[36]

F.27.3 **Number of SRVs in ADS system**

= 6.[37]

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[32] GEZ-7127, "Susquehanna Steam Electric Station Unit Numbers 1 and 2 Transient Safety Analysis Design Report," p. 2-51, September 1981.

[33] NEDC-32161P, p. A.4-6.

[34] NPE-85-001, "Selected Transient Predictions for Susquehanna Steam Electric Station Unit 2 Startup Test Program," p. 18.

[35] EC-FUEL-0969, Section B.7.

[36] NPE-91-001, Susquehanna Steam Electric Station Individual Plant Evaluation," Volume 2, p. A-131.

[37] NPE-91-001, Susquehanna Steam Electric Station Individual Plant Evaluation," Volume 2, p. A-130.

F.27.4 **Delay timer**
= time delay from low-reactor water level signal to initiation of ADS.
= 102 seconds.[38]
It is assumed that a high-drywell pressure signal is present when the low water level signal is generated. If this is not the case, the time delay should be adjusted so that the logic is consistent with that shown in Ref. 38.

F.28 Data for Manual Control Rod Insertion (MRI)

F.28.1 Time at which operator initiates MRI
= 1.D+09 seconds. (No MRI in base case.)

F.28.2 Time at which operator terminates MRI
= 1.D+09 seconds. (This value allows MRI to continue until all rods are inserted).

F.28.3 Control rod insertion rate
= 90 seconds/control rod.
The time required to manually insert a control rod is ≤ 60 seconds (Section 2.4.3 of this calc.). An additional 30 seconds is allowed for the operator to select each control rod prior to insertion. Thus the total time required to insert a single control rod is 90 seconds.[39]

F.29 Standby Liquid Control System (SLCS) Data

F.29.1 Time at which SLCS is initiated by operator.
= 1.D+09 seconds. (No SLCS initiation in base case).

F.29.2 Effective liquid boron transit time from SLCS tank to core
= 75 seconds.
The time consists of two contributions:
1.) The actual transport time from the SLCS tank to the vessel = 30 seconds,[27] and
2.) The time required for boron injected below the core to travel once around the natural circulation loop and re-enter the core. This value is calculated by SABRE and has been found to be about 45 seconds under natural circulation conditions.

F.29.3 Number of SLCS pumps operable
= 2. The SLCS contains two pumps[40] and both are assumed operable.

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[38] GE-NE-187-22-0992, "Susquehanna Steam Electric Station Units 1 and 2 SAFER/GESTR-LOCA Analysis Basis Documentation," p. 5-25, September 1993
[39] NPE-91-001, Susquehanna Steam Electric Station Individual Plant Evaluation," Volume 4, p. F-251.
[40] NPE-91-001, Susquehanna Steam Electric Station Individual Plant Evaluation," Volume 2, p. A-46.

F.29.4 Injection rate of elemental boron with two SLCS pumps operable
= 0.28 Lbm/sec.[27]

F.29.5 Volume of external recirculation loops used for boron dilution
Boron is assumed to be uniformly distributed within the downcomer and the external recirculation loops. The volume of the recirculation loops is[41]
Volume = $V_{210} + V_{215} + V_{220} + V_{211} + V_{216} + V_{221}$
Volume = 218.775 + 49.743 + 301.831 + 218.775 + 49.743 + 301.831 = 1,140.7 ft^3.

F.29.6 Hot shutdown boron concentration
= 494 ppm.[42]

F.29.7 Remixing threshold for stagnated boron
Any boron stagnated within the lower plenum will remix when total core flow exceeds this value. The NRC has concluded that rapid boron remixing is likely to occur with flow rates greater than 15 percent of rated flow.[43] Therefore a value of 15 Mlb/hr is used for the remixing threshold.

F.29.8 Total core flow corresponding to the onset of boron stratification
= 6 MLb/hr.[43]

F.29.9 Total core flow below which all injected boron settles to bottom of reactor vessel
= 4 MLb/hr.[43]

F.29.9a Boron entrainment exponent in stratification model
= 1.0[43]

F.29.10 Number of control volumes used to model boron transport within core
= 10 (This is the maximum value that can be used in code.)

F.29.11 Initial volume of sodium pentaborate solution in SLC tank
= 4800 gallons (This is a nominal value).[44]

F.29.12 SLC tank volume at which SLC pumps are tripped
= 200 gallons. SLC pumps are manually tripped when SLC tank volume drops to 200 gallons.[45]

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[41] PL-NF-89-005-A, "Qualification of Transient Analysis Methods for BWR Design and Analysis," pp. 18,26.
[42] Calculation NFE-2-09-003 "Unit 2 Cycle 9 Nuclear Fuels Engineering ATWS Analysis."
[43] Section 2.4.6.
[44] PLA-4308, File R41-2, May 4, 1995.
[45] EO-100/200-113.

F.29.13 **Injection rate of boron solution with two SLCS pumps operable**
= 82.4 gpm.[44]

F.29.14 **Temperature of boron solution in SLCS tank**
= 90 °F.[46]

F.30 Reactor Cooldown Data

F.30.1 Time at which controlled cooldown of RPV is initiated
= 1.D+09 seconds (No cooldown in base case).

F.30.2 Cooldown Rate
= 100 °F/hr. This is the maximum RPV cooldown rate following a plant transient or accident.[47]

F.30.3 Target pressure of cooldown
= 98 psig. This value is specified because the Shutdown Cooling mode of RHR can be established when reactor pressure drops below 98 psig.[48]

F.31 Safety/Relief Valve Data

F.31.1 Number of Safety/Relief valves
= 16

F.31.2 SRV stroke time
This value is used for the opening and closing time of an SRV. Since the SABRE code does not allow for a delay on SRV actuation, the appropriate delay is included in the stroke time. The SRV opening delay is 0.4 sec, and the closure delay is 0.3 seconds.[27] The valve opening time is 0.15 seconds.[27] The valve closure time is assumed equal to the opening time. Using an average delay of 0.35 seconds with an opening/closure time of 0.15 seconds gives an effective stroke time of <u>0.5 seconds</u>.

F.31.3 SRV critical flow correction
SRV flow is calculated as (flow multiplier)(Critical mass flux)(Valve area)
Flow multiplier = 0.884 (Section D.6 of this calculation)

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[46] DBD042 "Standby Liquid Control System," Rev. 0, Section 2.8.1.1.1.
[47] EO-100/200-102, EO-100/200-113.
[48] NPE-91-001, Susquehanna Steam Electric Station Individual Plant Evaluation," Volume 2, p. A-137.

F.31.4 SRV Area and actuation setpoints

Nominal opening and closing setpoints are used in the base deck.

ID#	Valve Area[49] (ft²)	Opening Pressure[50] (psia)	Closing Pressure[50] (psia)
1	0.11192	1113.	987.
2	0.11192	1116.	990.
3	0.11192	1126.	999.
4	0.11192	1127.	1000.
5	0.11192	1129.	1002.
6	0.11192	1135.	1007.
7	0.11192	1137.	1009.
8	0.11192	1138.	1010.
9	0.11192	1145.	1016.
10	0.11192	1146.	1017.
11	0.11192	1148.	1018.
12	0.11192	1151.	1021.
13	0.11192	1156.	1026.
14	0.11192	1161.	1030.
15	0.11192	1164.	1033.
16	0.11192	1174.	1042.

F.31.5 Number of SRVs to tripped open/closed at specified time

= 3 (Data provided for 3 valves in following section).

F.31.6 Data defining time-dependent trips of SRVs

Data for three valves are specified. The Valve ID#s correspond to the values identified in F.31.4. The ID# must be in the range of 1 to 10. Valves 11 through 16 are reserved for ADS. The data below shows that the valves are to be tripped open at 10^9 seconds.

Trip ID#	Valve ID#	Time(Open/Close)	1=Open/2=Close
1	1	1.D+09	1
2	2	1.D+09	1
3	3	1.D+09	1

F.32 Downcomer Condensation Efficiency

F.32.1 Number of data points defining efficiency vs. level and pressure

= 12

[49] Section D.6 of this calculation.

[50] GENE-637-024-0893, Supp. 1, p. 2.

F.32.2 Condensation efficiency as a function of pressure and level

This table defines the condensation efficiency on makeup flow which is injected through the feedwater spargers. The elevation of the feedwater nozzles is -23.7 inches (Section D.5 of this calc.). When level is approximately 1 meter below the nozzles, there is a large steam-water mixing efficiency.[51] Condensation efficiency is specified as 95% for level 1 m or more below the feedwater sparger nozzles (Section D.4 of this calc.). The SABRE code sets the condensation efficiency equal to zero for reactor level greater than the first entry in the following data table.

Level (in.)	Reactor Pressure (psia)	Cond. Efficiency
-23.7	1500.	0.00
-63.1	1500.	0.95
-250.	1500.	0.95
-23.7	1000.	0.00
-63.1	1000.	0.95
-250.	1000.	0.95
-23.7	500.	0.00
-63.1	500.	0.95
-250.	500.	0.95
-23.7	100.	0.00
-63.1	100.	0.95
-250.	100.	0.95

F.33 CRD Flow Data

F.33.1 Normal CRD flow rate

The normal CRD flow rate and enthalpy are 32,000 Lbm/hr 48 Btu/Lbm (80 °F)[52]. The density of the CRD water is 62.2 Lbm/ft^3. The volumetric flow rate is

$$\left(\frac{32{,}000\ \text{Lbm}}{\text{hr}}\right)\left(\frac{\text{hr}}{60\,\text{min}}\right)\left(\frac{\text{ft}^3}{62.2\ \text{Lbm}}\right)\left(\frac{7.4805\ \text{gal}}{\text{ft}^3}\right) = 64\ \text{gpm}$$

F.33.2 CRD water temperature

CRD water temperature = 80 °F (see F.33.1).

F.33.3 Time at which makeup mode of CRD is inititiated

CRD flow can be maximized to provide additional makeup flow to the vessel during accident conditions.[53]

Time at which flow is maximized = 1.D+09 seconds.

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[51] NEDO-32047-A, "ATWS Rule Issues Relative to BWR Core Thermal-Hydraulic Stability," p. 11 of 70, June 1995.

[52] NEDC-32161P, "Power Uprate Engineering Report for Susquehanna Steam Electric Stations 1 and 2," p. A.7-4, December 1993.

[53] NPE-91-001, Susquehanna Steam Electric Station Individual Plant Evaluation," Volume 2, p. A-62.

F.33.4 **Number of data points describing maximized CRD flow vs. pressure = 11**

F.33.5 **Maximized CRD flow vs. reactor pressure**

Maximized CRD Flow[54] (gpm)	Reactor Pressure (psia)
340.	14.7
335.	100.
320.	200.
307.	300.
285.	400.
280.	500.
265.	600.
239.	700.
230.	800.
187.	1000.
0.0	1300.

F.34 Delayed-Neutron Precursor Decay Constants for Six Groups

Values are taken from GE power uprate analysis.[55]

Group	λ_i (sec^{-1})
1	0.0128
2	0.0316
3	0.122
4	0.324
5	1.40
6	3.87

F.35 Group Fractions for Six Delayed Groups

Values are taken from GE power uprate analysis.[55]

Group	β_i
1	0.032
2	0.205
3	0.185
4	0.395
5	0.147
6	0.036

[54] NPE-91-001, Susquehanna Steam Electric Station Individual Plant Evaluation," Volume 2, p. A-64

[55] GENE-637-024-0893, "Evaluation of Susquehanna ATWS Performance for Power Uprate Conditions," Supplement 1, p. 2, October 1993.

F.36 Fuel and Cladding Data

For U2C9, the dominant fuel type is ANF 9x9. There are 452 bundles of ANF 9x9 fuel and 312 bundles of ATRIUM-10 fuel (Ref. 42). Therefore, ANF 9x9 fuel parameters, except for gap conductance, are used. The gap conductance is chosen so that a core loaded with ANF 9x9 fuel will have the same thermal response as the U2C9 mixed. Thus the gap conductance is used to account for the presence of the 10x10 fuel.

F.36.1 Fuel Pellet Radius

= 0.3565 in/2 = 0.1783 in[(56)]

F.36.2 Cladding inside radius

= [0.424 in - (2)(0.030) in]/2 = 0.182 in.[56]

F.36.3 Cladding outside radius

0.424 in/2 = 0.212 in.[56]

F.36.4 Gap Conductance

= 988 Btu/hr-ft^2-°F for U2C9 mixed 9x9-10x10 core.[57]

F.36.5 Length of active fuel

= 150 inches = 12.5 ft.[56]

F.36.6 Number of fuel rods per bundle

= 79[56]

F.36.7 Number of fuel bundles in core

= 764

F.36.8 Radius of inner fuel node

Equal volume fuel nodes are used. Therefore,

$$\pi r_a^2 = \pi r_b^2 - \pi r_a^2$$

where

r_a = radius of inner fuel node, and

r_b = radius of fuel pellet.

Solving for r_a gives

$r_a = r_b / (2)^{1/2}$ = 0.1783 in / 1.414 = 0.1261 in.

F.36.9 Self-shielding parameter

= volumetric heat generation rate in inner fuel node divided by pellet-average volumetric heat generation rate.

= 0.90 (see Section 2.3 of this calc.)

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[56] GE-NE-187-22-0992, "Susquehanna Steam Electric Station Units 1 and 2 SAFER/GESTR-LOCA Analysis Basis Documentation," pp. 4-12, 4-13, September 1993.

[57] Calc. EC-ATWS-1001.

F.37 Downcomer Fluid Inertia
= 0.0 (Inertia in downcomer is neglected).

F.38 Jet Pump Region Parameters

F.38.1 Jet pump flow area
= 15.16 ft^2 (Section D.1.1)

F.38.2 Jet pump flow path length
= 16.495 ft (Section D.1.1)

F.38.3 Jet pump region hydraulic diameter
= 0.98 ft. (Section D.1.1)

F.38.4 Jet pump region friction factor
= 0.013 (Section D.1.1)

F.38.5 Jet pump fluid inertia
1.1 ft^{-1} (Section D.1.1)

F.39 Lower Plenum Region Parameters

F.39.1 Lower plenum flow area
= 132.33 ft^2 (Section D.1.2)

F.39.2 Lower plenum flow path length
= 17.28 ft (Section D.1.2)

F.39.3 Lower plenum region hydraulic diameter
= 1.014 ft. (Section D.1.2)

F.39.4 Lower plenum region friction factor
= 0.013 (Section D.1.1)

F.39.5 [Elevation at core inlet] - [elevation at bottom of jet pump]
= 6.94 ft. (Section D.1.2)

F.39.5 Lower plenum fluid inertia
0.13 ft^{-1} (Section D.1.2)

F.40 Core Region Parameters

F.40.1 Core flow area
= 87.2 ft^2 (Section D.1.3)

F.40.2 Length of active core
= 12.5 ft (Section D.1.3)

F.40.3 **Core region hydraulic diameter**
= 0.0425 ft. (Section D.1.3)

F.40.5 **Core fluid inertia**
0.17 ft^{-1} (Section D.1.3)

F.40.6 **Length of lower reflector region**
= 1.15 ft (Section D.1.3)

F.40.7 **Length of upper reflector region**
= 1.218 ft. (Section D.1.3)

F.41 Bypass Region Parameters

F.41.1 **Bypass flow area**
= 67.87 ft^2 (Section D.1.4)

F.41.2 **Bypass flow path length**
= 14.87 ft (Section D.1.4)

F.41.3 **Bypass region hydraulic diameter**
= 0.196 ft. (Section D.1.4)

F.41.4 **Bypass region friction factor**
= 0.0185 (Section D.1.4)

F.41.5 **Bypass fluid inertia**
= 0.22 ft^{-1} (Section D.1.4)

F.42 Upper Plenum Region Parameters

F.42.1 **Upper Plenum flow area**
= 191.84 ft^2 (Section D.1.5)

F.42.2 **Upper Plenum flow path length**
= 4.98 ft (Section D.1.5)

F.42.3 **Upper Plenum region hydraulic diameter**
= 3.97 ft. (Section D.1.5)

F.42.4 **Upper Plenum region friction factor**
= 0.01 (Section D.1.5)

F.42.5 **Upper Plenum fluid inertia**
= 0.015 ft^{-1} (Section D.1.5)

F.43 Riser Region Parameters

F.43.1 Riser flow area
= 39.66 ft^2 (Section D.1.6)

F.43.2 Riser flow path length
= 10.156 ft (Section D.1.6)

F.43.3 Riser region hydraulic diameter
= 0.505 ft. (Section D.1.6)

F.43.4 Riser region friction factor
= 0.015 (Section D.1.6)

F.43.5 Riser fluid inertia
= 0.85 ft^{-1} (Section D.1.6)

F.44 Separator Region Parameters

F.44.1 Separator flow area
= 71.06 ft^2 (Section D.1.7)

F.44.2 Separator flow path length
= 6.167 ft (Section D.1.7)

F.44.3 Separator region hydraulic diameter
= 0.514 ft. (Section D.1.7)

F.44.4 Separator region friction factor
= 0.015 (Section D.1.7)

F.44.5 Separator fluid inertia
= 0.84 ft^{-1} (Section D.1.7)

F.45 Combined Volume of Steam Dome and Downcomer
= 14,334 ft^3 (Section D.1.8)

F.46 Number of Fuel Spacers per Bundle
= 7[56]

F.47 Junction Flow Areas and Loss Coefficients

F.47.1 Downcomer to Jet Pump
Flow Area = 6.18 ft^2 (Section D.1.1)
K = 0.24 (Section D.1.1)

F.47.2 Jet Pump to Lower Plenum
Flow Area = 39.40 ft^2 (Section D.1.1)
K = 1.04 (Section D.1.1)

F.47.3 Fuel Bundle Orifice (Lower plenum to Lower Reflector)
Flow Area = 22.67 ft^2 (Section D.1.3)
K = 1.57 (Section D.1.4)

F.47.4 Lower Tie Plate (Lower Reflector to Active Core)
Flow Area = 49.8 ft^2 (Section D.1.3)
K = 1.37 (Section D.1.3)

F.47.5 Lower Reflector to Bypass
Flow Area = 0.976 ft^2 (Section D.1.4)
K = 0.5065 (Section D.1.4)

F.47.6 Upper Reflector to Upper Plenum
Flow Area = 139.8 ft^2 (Section D.1.3)
K = 3.64 (Section D.1.3)

F.47.7 Bypass to Upper Plenum
Flow Area = 48.98 ft^2 (Section D.1.4)
K = 0.0 (Section D.1.4)

F.47.8 Upper Plenum to Riser
Flow Area = 45.10 ft^2 (Section D.1.6)
K = 0.41 (Section D.1.6)

F.47.9 Riser to Separator
Flow Area = 35.67 ft^2 (Section D.1.7)
Loss coefficient is calculated by code. (Specify as -1.0)

F.47.10 Separator Exit
Flow Area = 40.73 ft^2 (Section D.1.7)
Loss coefficient is calculated by code. (Specify as -1.0)

F.48 Initial Suppression Pool Level
Initial suppression pool level = 23 ft. This is the nominal value for suppression pool level.[58]

F.49 Initial Suppression Pool Temperature
= 90 °F This is maximum allowed by Technical Specifications for normal operation.[58]

F.50 Time at which Loop 1 of Suppression Pool Cooling Becomes Effective
= 1.D+09 seconds (No SPC in base case)

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[58] Tech. Spec. 3.6.2.1.

F.51 Time at which Loop 2 of Suppression Pool Cooling Becomes Effective
= 1.D+09 seconds (No SPC in base case)

F.52 Time at which Drywell Sprays are Initiated
= 1.D+09 seconds (Keep this value as is because model is incomplete.)

F.53 Number of Data Points in Suppression Pool Free Area vs. Level Table
= 4

F.54 Suppression Pool (SP) Area vs. Level
Because of the presence of the downcomer pipes within the suppression chamber (the bottom of the downcomers correspond to 12 feet above the bottom of the pool), the free surface area of the pool is dependent on pool level. That is, the free surface area changes at 12 feet above the bottom of the pool. The free surface area of the SP is 5277 ft^2 at normal pool level.[59] Therefore, this is the free area for level > 12 feet. The volume of water in the SP at 24 feet is 133,540 ft^3 (Ref. 58). Therefore the pool free area for level less than 12 feet is calculated from
133,540 ft^3 = (12 ft)A + (24-12)(5277 ft^2) or,
A = [133,540 - 12(5277)]/12 = 5851.3 ft^2.
The following data table accounts for the area change with SP level:

Elevation above Bottom of SP (ft)	Free Area (ft^2)
0.00	5851.3
12.00	5851.3
12.01	5277.0
52.50	5277.0

F.55 Initial Heat Load from RPV to Drywell
= 1043 Btu/sec (Section D.18.5)

F.56 Initial Drywell Cooling Load
= 1043. Btu/sec (Section D.18.6)

F.57 Inlet Temperature of Cooling Water for Drywell Coolers
= 50 °F (Section D.18.6)

F.58 Set Point for Loss of Drywell Cooling on High Drywell Pressure
= 1.72 psig.[60]

F.59 Set Point for Loss of Drywell Cooling on Low Reactor Level
= -129 inches.[60]

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[59] SSES FSAR, Table 6.2-23.
[60] NPE-91-001, Susquehanna Steam Electric Station Individual Plant Evaluation," Volume 2, p. A-301

F.60 Drywell Free Volume
= 239,600 ft^3 (Section D.18.7)

F.61 Initial Drywell Temperature
= 120 °F (Section D.18.8)

F.62 Service Water Temperature
= 88 °F[4]

F.63 Vacuum Breaker Data

F.63.1 Full-Open Vacuum Breaker Flow Area
There are five vacuum breakers with a total flow area of 5(2.05 ft^2).[61]
Full Open Area = 10.25 ft^2.

F.63.2 Vacuum breaker Loss Coefficient Based on Full-Open Area
= 3.57 (Based on vacuum breaker full-open area)[62]

F.63.3 DP at which Vacuum Breaker Begins to Lift
= 0.5 psid (When drywell pressure is 0.5 psi lower than wetwell pressure, vacuum breaker will open.)[62]

F.63.4 DP at which Vacuum Breaker is Full-Open
= 3.22 psid.[62]

F.63a Downcomer Vent Data

F.63a.1 Downcomer vent flow area
= (0.274 m^2)(82 vents) = 22.47 m^2 = 242 ft^2
(Calc. EC-THYD-1001, Rev. 1)

F.63a.2 Downcomer vent loss coefficient
= 2.17 (Based on vent area) (Calc. EC-THYD-1001, Rev. 1)

F.63a.3 Elevation of bottom of downcomer vent with respect to bottom of suppression pool
= 12 ft. (Calc. EC-THYD-1001, Rev. 1)

F.64 Containment Atmosphere Data

F.64.1 Initial Relative Humidity in Drywell
= 48% (Section D.18.9)

F.64.2 Initial Relative Humidity in Wetwell
= 100% (Section D.18.10)

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[61] EC-THYD-1001, Section 2.3.
[62] EC-THYD-1013, Section 3.4.

F.64.3 **Initial Drywell Pressure**
= 15.2 psia (Section D.18.11)

F.64.4 **Initial Wetwell Pressure**
= 15.2 psia (Section D.18.12)

F.65 SRV Tailpipe/Downcomer Data

F.65.1 **Diameter of SRV Tailpipe**
= 1.0 ft (Section D.18.13)

F.65.2 **Loss coefficient for SRV Quencher**
= 1.0 (Section D.18.13)

F.65.3 **Height of Downcomer Pipes Above Drywell Floor**
= 1.5 ft.[63]

F.65.4 **Nitrogen-Suppression Pool Heat Transfer Flag**
= 1.0 (Nitrogen reaches thermal equilibrium with SP as it bubbles through pool)
If 0.0 is used, then there is no heat transfer between nitrogen and pool. Interpolation between the two limits is obtained by using a value between 0.0 and 1.0.

F.66 Suppression Pool Letdown Data

F.66.1 **Time at which SP Letdown is Started**
= 1.D+09 seconds (No SP Letdown in base case)

F.66.2 **Time at which SP Letdown is Terminated**
= 1.D+09 seconds

F.66.3 **SP Letdown Flow**
= 120. Lbm/sec. This is the suppression pool letdown flow that can be achieved through RHR system to Liquid Radwaste.[64]

F.67 Surface Area of Drywell Steel Structures

F.67.1 **Surface Area of Wall Portion of Drywell Liner Plate**
= 17,870. ft^2 (Section D.18.14)

F.67.2 **Surface Area of Roof Portion of Drywell Liner Plate**
= 1039 ft^2 (Section D.18.14)

F.67.3 **Surface Area of Floor Portion of Drywell Liner Plate**
= 6082. ft^2 (Section D.18.14)

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[63] EC-THYD-1001, Section 2.5.9.
[64] EC-THYD-1007.

F.67.4 Surface Area of Drywell Internal Steel Structures
= 66,000 ft^2 (Section D.18.14)

F.68 Volume of Drywell Steel Structures

F.68.1 Volume of Wall Portion of Drywell Liner Plate
= 372. ft^3 (Section D.18.15)

F.68.2 Volume of Roof Portion of Drywell Liner Plate
= 22. ft^3 (Section D.18.15)

F.68.3 Volume of Floor Portion of Drywell Liner Plate
= 127. ft^3 (Section D.18.15)

F.68.4 Volume of Drywell Internal Steel Structures
= 2,750. ft^3 (Section D.18.15)

F.69 Surface Area of Wetwell Steel Structures

F.69.1 Surface Area of Wall Portion of Wetwell Liner Plate
= 8156. ft^2 (Section D.18.16)

F.69.2 Surface Area of Wetwell Internal Steel Structures
= 30,048. ft^2 (Section D.18.16)

F.70 Volume of Wetwell Steel Structures

F.70.1 Volume of Wall Portion of Wetwell Liner Plate
= 170. ft^3 (Section D.18.17)

F.70.2 Volume of Wetwell Internal Steel Structures
= 1,252. ft^3 (Section D.18.17)

F.71 Characteristic Lenghts of Containment Steel Structures

F.71.1 Characteristic Length of Drywell Wall
= 87.75 ft (Section D.18.18)

F.71.2 Characteristic Length of Drywell Roof
= 9.1 ft (Section D.18.18)

F.71.3 Characteristic Length of Drywell Floor
= 22. ft (Section D.18.18)

F.71.4 Characteristic Length of Drywell Internal Structures
= 10. ft (Section D.18.18)

F.71.5 Characteristic Length of Wetwell Wall in Air Space
= 29.5 ft (Section D.18.18)

F.71.6 Characteristic Length of Drywell Internal Structures
= 10. ft (Section D.18.18)

APPENDIX G
Base SABRE Input Deck for Power Uprate Conditions with 10x10 Core (U2C10)

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  (00) Base Case Input Deck for U2C10
*                         Notes
* Initial Power = 3441 MWth
* Initial Core flow = 100 MLb/hr
* Initial steam dome pressure = 1050 psia
*
* 10 second Steady-State Run
*
*****************************************************************************
*      CALCULATIONAL FLAGS AND CONVERGENCE CRITERIA
*
* W1-I KPRMX = MAXIMUM NUMBER OF TIME STEPS BETWEEN DETAILED EDITS.
*
* W2-I KPRMN = MINIMUM NUMBER OF TIME STEPS BETWEEN DETAILED EDITS.
*
* W3-R ERRINF= RELATIVE ERROR ON INLET FLOW ITERATION.
*
* W4-R RLXC  = RELAXATION PARAMETER USED IN FLOW CALCULATION.
*
* W5-R RTOL  = RELATIVE ERROR PARAMETER FOR KINETICS SOLUTION
*
* W6-R ATOL  = ABSOLUTE ERROR PARAMETER FOR KINETICS SOLUTION
*
*    KPRMX  KPRMN    ERRINF     RLXC     RTOL      ATOL
      20      5      9.D-5      0.20     1.D-05    1.D-05
*****************************************************************************
*      END TIME, TIME STEP DATA, AND PRINT INTERVAL
*
* W1-R  TEND = END TIME (SEC)
*
*
* W2-I  NNP  = NO. OF PRINT INTERVAL SETS SUPPLIED
*
*
* W3-I  NTIME= NUMBER OF TIME STEP SETS SUPPLIED
*
* W4-R  DTKINMAX = MAX STEP SIZE FOR KINETICS SOLUTION (SEC)
*
*  . TEND          NNP     NTIME     DTKINMAX
     10.             5       5         1.0
*****************************************************************************
*                    TIME STEP DATA
*
* W1-I  IDDT= ID NO. FOR TIME STEP DATA
*
* W2-R  HMAX  = Max STEP SIZE (MSEC)
*
* W3-R  HMIN  = Min step size (msec)
*
* W4-R  TSTART = Starting time for time step data (sec)
*
*      IDDT          HMAX    HMIN      TSTART(J)
*                    (MSEC)  (msec)    (SEC)
        1             30.     15.        0.
        2             30.     15.       10.
        3             30.     15.       20.
        4             30.     15.      200.
        5             30.     15.      300.
*****************************************************************************
*      PRINT INTERVAL DATA
*
* W1-R  TPRNT1 = PRINT INTERVAL BETWEEN GENERAL EDITS (SEC)
*
* W2-R  TSTRTP = STARTING TIME FOR PRINT INTERVAL (SEC)
*
*            TPRNT1             TSTRTP
               5.                 0.
              40.                10.
             100.               100.
             250.               500.
             250.              1000.
*****************************************************************************
*      INITIAL REACTOR CONDITIONS AND MODEL OPTIONS
*
* W1-R   QC    =  INITIAL CORE THERMAL POWER (MWt)
*                 100% power = 3441 MWt
*
* W2-R   RCTHP =  Rated Core Thermal Power (MWt)
*
* W3-R   WCTOT =  INITIAL TOTAL CORE FLOW  (MLb/hr).  This is the
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*               combined active-core and bypass flow.
*               RATED FLOW = 2.77778D4 LBM/SEC = 100 MLb/hr
*
* W4-R  WCORE =  Initial guess for core channel flow (MLb/hr)
*
* W5-R  PRX   =  INITIAL STEAM DOME PRESSURE (PSIA)
*
* W6-R  DLVL  =  INITIAL DOWNCOMER LEVEL (INCHES ABOVE INSTR ZERO)
*                Normal level is 30 to 35 inches.
*
* W7-R  DSUB  =  INITIAL SUBCOOLING IN DOWNCOMER REGION (BTU/LBM)
*             =  HF - (ENTHALPY IN DOWNCOMER) (Btu/Lbm)
*
* W8-I  INITLZ=  INITIALIZATION FLAG
*             =  1 IF THIS IS AN INITIALIZATION CASE
*             =  0 IF THIS IS A TRANSIENT RUN
*
* W9-R  QFRAC1=  FRACTION OF TOTAL CORE POWER THAT IS DEPOSITED
*                IN THE CORE CHANNEL AS GAMMA HEATING
*
* W10-R QFRAC2=  FRACTION OF TOTAL CORE POWER THAT IS DEPOSITED
*                IN THE BYPASS CHANNEL AS GAMMA HEATING
*
* W11-R TMPCST=  Temperature of water in CST (F).  Used for HPCI
*                and RCIC injection.
*
* W12-R TMPHW =  Temperature of water in Hot Well (F).  Used
*                for final FW temp upon loss of FW heating.  FW heating
*                is lost after MSIV closure, turbine trip, or manual
*                trip of FW heaters. Also used for suction temperature when
*                condensate sytem is injecting at low Rx pressure.
*
* W13-R VCST  =  CST Volume (gal)
*
* W14-R VTCST=   CST Vol (gal) at which HPCI & RCIC Transfer suction
*                from CST to SP
*
* W15-R HTCLIQ=  Heat transfer coefficient (BTU/hr-ft2-F) for submerged part
*                of reactor vessel & internals.
*
* W16-R HTCSTM=  Heat transfer coefficient (BTU/hr-ft2-F) for part
*                of reactor vessel & internals exposed to steam.
*
*
*
*
*      QC        RCTHP     WCTOT     WCORE     PRX
*     3441.      3441.     100.      90.       1050.
*
*      DLVL      DSUB      INITLZ    QFRAC1    QFRAC2
*      35.       25.1      0         0.0150    0.0200
*
*      TMPCST    TMPHW     VCST      VTCST     HTCLIQ    HTCSTM
*      123.      129.      225000.   35250.    200.      10.
*
*
*
*********************************************************************
*                          LOCA Data
*
* W1-R ABREAK = Break area (ft2)
* W2-I IBREAK = 1 => Liquid break (in downcomer)
*             = 2 => Steam break (in steam dome)
* W3-R FBREAK = Flow coefficient. When flow is choked, break flow
*               is Gcrit*ABREAK*FBREAK, where Gcrit is critical mass
*               flux.
* W4-R AKBRK  = loss coefficient for break.
* W5-I ILTBL  = 1 => Override break flow calc. with break flow/enthalpy
*                    vs. time table.
*             = 0 => Break flow will be calculated.
* W6-I NLTBL  = Number of points in break flow vs. time table.
*
*     ABREAK          IBREAK     FBREAK    AKBRK    ILTBL    NLTBL
*     0.0000             1        1.0d0     1.d0      0        3
*
*               Time            Break Flow       Break Enthalpy
*               (sec)           (Lbm/sec)          (Btu/Lbm)
             0.0000d0               0.d0             525.1d0
            10.0000d0               0.d0             525.1d0
             1.0000d9               0.d0             525.1d0
*********************************************************************
*                         TRIP LOGIC
*
********************** SCRAM LOGIC ***
```

```
*******************************************
    1       * 1=> SCRAM ENABLED,   0=> SCRAM FAILED (ATWS),
*            -1=> SCRAM & ARI Failed.
   13.D0    * LOW LEVEL SCRAM SET POINT (INCHES)
 1087.D0    * HIGH REACTOR PRESSURE SCRAM SET POINT (PSIG)
    1.72D0  * HIGH DRYWELL SCRAM SET POINT (PSIG)
  118.D0    * SCRAM ON HIGH NEUTRON FLUX (% OF RATED)
    1.D+09  * MANUAL SCRAM ON TIME (SEC)
    1       * SCRAM ON MSIV CLOSURE (1=>ENABLED, 0=>OFF)
    1       * SCRAM ON TURBINE TRIP (1=>ENABLED, 0=>OFF)
    2.8       Control rod insertion time for scram (sec)
*
********************** HPCI DATA ***
*****************************************
**** Trip Logic
    1       * 1=> HPCI OPERABLE, 0=> HPCI INOPERABLE
  -38.      * HPCI INITIATION ON LOW WATER LEVEL (INCHES)
    1.72    * HPCI INITIATION ON HIGH DRYWELL PRESSURE (PSIG)
  +54.      * HPCI TRIP ON HIGH WATER LEVEL (INCHES)
  118.7     * HPCI TRIP ON LOW REACTOR PRESSURE (PSIA)
    1.D+09  * MANUAL TRIP OFF ON TIME (SEC)
   23.83    * SP LEVEL AT WHICH HPCI SUCTION TRANSFERS TO SP (FT)
**** HPCI Flow
    3.3     * Time constant (sec) for HPCI flow vs. demand response
   20.0     * Delay from HPCI init signal to start of flow to RPV (sec)
  500.      * Minumum HPCI flow (gpm)
 5000.      * Maximum HPCI flow (gpm)
    3       * Number of points in Table of HPCI demand flow vs. time
*           * (Demand flow is setpoint dialed in on flow controller)
**** Table of HPCI Demand flow vs. time
*
*   Time (sec)          HPCI Demand Flow (gpm)
    0.d0                   5000.d0
    1.d3                   5000.d0
    1.d9                   5000.d0
**** Operator Control
    1       * 1=> ENABLE LEVEL CONTROL MODE OF HPCI OPERATION, 0=> OFF
    1.D+09  * TIME AT WHICH OPERATOR TAKES CONTROL OF INJECTION (SEC)
    2       * Number of points in target-level-versus-time table
*   Time (sec)          Target Level (inches)
    0.0                    +35.
    1.D+09                 +35.
  500.      * GAIN (GPM/INCH) USED IN SIMULATING OPERATOR CONTROL OF FLOW
*
********************** RCIC DATA ***
*******************************************
**** trips
    1       * 1=> RCIC OPERABLE, 0=> RCIC INOPERABLE
  -38.      * RCIC INITIATION ON LOW WATER LEVEL (INCHES)
  +54.      * RCIC TRIP ON HIGH WATER LEVEL (INCHES)
   75.      * RCIC TRIP ON LOW REACTOR PRESSURE (PSIA)
    1.D9    * MANUAL TRIP OFF ON TIME (SEC)
**** flow data
    3.3     * Time constant (sec) for RCIC flow vs. demand response
   20.      * Delay from RCIC init signal to start of flow to RPV (sec)
  600.      * RCIC injection rate (gpm)
   60.      * Minimum RCIC flow (gpm)
  600.      * Maximum RCIC flow (gpm)
**** Operator Control
    1       * 1=> ENABLES OPERATOR-CONTROL MODE FOR RCIC, 0=> OFF.
    1.D+09  * TIME AT WHICH OPERATOR TAKES CONTROL OF RCIC INJ (SEC)
    2       * Number of points in target-level-versus-time table
*   Time (sec)          Target Level (inches)
    0.0                    +35.
    1.D+09                 +35.
  500.D0    * GAIN (GPM/INCH) USED IN SIMULATING OPERATOR CONTROL OF FLOW
*
********************** CONDENSATE SYSTEM ***
***********************************************
    0         0 => LOW-PRESS CONDENSATE INJECTION INOPERABLE
*             1 => LOW-PRESS CONDENSATE INJECTION OPERABLE
   20.        RAMP TIME FOR INJECTION, I.E., THE TIME
*             FROM INITIATION OF INJECTION UNTIL PUMP REACHES
*             FULL FLOW (SEC).
    5.        COAST-DOWN TIME WHEN FLOW IS TRIPPED OFF (SEC)
  514.7       LOW PRESSURE PERMISSIVE FOR FLOW INJECTION. PRESSURE
*             MUST BE LESS THAN THIS VALUE (PSIA)
*             OR INJECTION WILL NOT OCCUR.
  524.7       HIGH PRESSURE CUT OFF FOR INJECTION FLOW.  IF FLOW IS
*             ON AND PRESSURE EXCEEDS THIS VALUE (PSIA) FLOW WILL STOP.
 5000.        CONDENSATE INJ FLOW RATE (GPM)
*
********************** CORE SPRAY SYSTEM ***
***********************************************
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```
        1         0 => CORE SPRAY INJECTION INOPERABLE
*                 1 => CORE SPRAY INJECTION OPERABLE
       10         Number of points in flow vs. pressure table
*                          CS Flow        [Rx P - Cont. P]
*                          (gpm)              (Psi)
                           7790.               0.
                           7000.              56.
                           6000.             122.
                           5000.             172.
                           4000.             214.
                           3000.             245.
                           2000.             266.
                           1000.             277.
                              0.             289.
                              0.            1500.0
*
********************** RECIRCULATION SYSTEM LOGIC ***
******************************************************************
      1.D9     * TRIP RECIRC PUMP-A ON TIME (SEC)
      1.D9     * TRIP RECIRC PUMP-B ON TIME (SEC)
*                No delay for trip on time
*
     -38.      * TRIP RECIRC PUMP-A ON LOW WATER LEVEL (INCHES)
       9.      * Delay for Pump-A trip on low level (sec)
*
     -38.      * TRIP RECIRC PUMP-B ON LOW WATER LEVEL (INCHES)
       9.      * Delay for Pump-B trip on low level (sec)
*
   1149.7      * TRIP RECIRC PUMP-A ON HIGH REACTOR PRESS (PSIA)
      0.23     * Delay for Pump-A trip on high reactor pressure (sec)
*
   1149.7      * TRIP RECIRC PUMP-B ON HIGH REACTOR PRESS (PSIA)
      0.23     * Delay for Pump-B trip on high reactor pressure (sec)
*
     20.0      * RUNBACK PMP-A (TO 30% SPEED) ON FW FLOW (% OF RATED FLOW)
     15.0      * Delay for Pump-A runback on low FW flow (sec)
*
     20.0      * RUNBACK PMP-B (TO 30% SPEED) ON FW FLOW (% OF RATED FLOW)
     15.0      * Delay for Pump-B runback on low FW flow (sec)
*
     13.0      * RUNBACK PMP-A (TO 30% SPEED) ON LOW WATER LEVEL (INCHES)
      3.0      * Delay for Pump-A runback on low Rx water level (sec)
*
     13.0      * RUNBACK PMP-B (TO 30% SPEED) ON LOW WATER LEVEL (INCHES)
      3.0      * Delay for Pump-B runback on low Rx water level (sec)
*
      4.0      * TIME CONSTANT FOR PUMP-A TRIP (SEC)
      4.0      * TIME CONSTANT FOR PUMP-B TRIP (SEC)
*
     20.       * TIME CONSTANT FOR PUMP-A RUNBACK (SEC)
     20.       * TIME CONSTANT FOR PUMP-B RUNBACK (SEC)
*
     65.       * CORE FLOW WITH 1 PUMP TRIPPED & 1 AT 100% SPEED (MLB/HR)
     42.       * CORE FLOW WITH 2 PUMPS AT 30% SPEED (MLB/HR)
     36.       * CORE FLOW WITH 1 PMP TRIPPED AND 1 PUMP AT 30% SPEED (MLB/HR)
*                = (55/87) * 42
*
********************** FEEDWATER DATA ***
*********************************************
**** Trip Data
    1.D+09  * MANUAL TRIP OF FEEDWATER PUMPS (SEC)
     54.    * FEEDWATER TRIP ON HIGH WATER LEVEL (INCHES)
    175.    * FEEDWATER TRIP ON LOW STEAM LINE PRESS (PSIA)
    1.D+09  * Initiate Manual isolation of FW heaters (sec)
**** FW Controller
    200.    * FW CONTROLLER GAIN
      1.    * FW CONTROLLER TIME CONSTANT (SEC)
    14.476  * Maximum FW flow (MLb/hr)
    14.151  * Rated FW flow (MLb/hr)
     60.    * Time constant for decay of FW enthalpy following a
*             a turbine trip, MSIV closure, or manual isolation
*             of feedwater heaters (sec).
     13.    * water level at which level setpoint setdown occurs (in.)
     18.    * level setpoint (inches) after setdown occurs
     11.    * time delay for level setpoint setdown (sec)
**** Operator Control
    1.D+09  * TIME AT WHICH OPERATOR CONTROL OF FW IS INITIATED (SEC)
     35.    * TARGET LEVEL FOR OPERATOR CONTROL OF FW FLOW (INCHES)
**** Specified FW flow vs. time
     0         1 => FW flow vs. time is specified. 0 => FW flow is calc.
*                    If value is 0 any data supplied in table is not used.
     2         Number of data points in FW flow vs. time table
**** FW flow vs. time table
*
```

```
*    Time (sec)   FW Flow (MLb/hr)
      0.0D+00         14.151
      1.0D+09         14.151
*
********************** MSIV CLOSURE DATA ***
**************************************************
      1.D+09  * CLOSURE ON TIME (SEC)
    -129.     * CLOSURE ON LOW REACTOR LEVEL (INCHES)
     875.7    * CLOSURE ON LOW REACTOR PRESSURE (PSIA)
       4.0    * MSIV stroke time (sec)
     14       * NO. OF PTS. IN MULTIPLIER TABLE
*               MSIV loss coeff mult vs stem position
*    Stem Position      Multiplier
          0.000            2.71D+13
          0.021          200.
          0.042          100.
          0.0625          58.80
          0.083           37.00
          0.125           22.20
          0.167           13.30
          0.250            6.99
          0.333            4.44
          0.458            2.79
          0.500            2.41
          0.667            1.41
          0.833            1.14
          1.000            1.00
*
********************** PRESSURE REGULATOR AND TURBINE TRIP DATA ***
*****************************************************************
**** Turbine Trips
      1.D9     * MANUAL TRIP ON TIME (SEC)
     54.       * TRIP ON HIGH LEVEL (INCHES)
**** Pressure Regulator
      1.D+09  * TRIP TO FAIL OPEN PRESS REG (PREGO)
     14.631   * Max turbine steam flow (VWO) at initial Rx press (MLb/hr)
    997.0     * Initial turbine inlet pressure (psia)
      3.33    * PRESSURE REGULATOR GAIN (% OF RATED FLOW/PSI)
      3.0     * tau1 = time constant 1 in lag-lead filter (sec)
      7.4     * tau2 = time constant 2 in lag-lead filter (sec)
      1.60    * tau3 = time constant in lag filter (sec)
     18.29    * Max combined steam flow at initial Rx press (MLb/hr)
   3610.5     * STEAM LINE VOL BEYOND INBOARD MSIV (FT3)
    180.2     * Steam line volume between stop and control valves (ft3)
     46.5     * STEAM LINE INERTIA (ft-1)
      9.6212  * FULL-OPEN MSIV FLOW AREA (FT2)
      0.727   * LOSS COEFF FOR FULL-OPEN MSIV
      0.10    * TURBINE STOP VALVE STROKE TIME (SEC)
      3.66    * Turbine bypass capacity at initial Rx press (MLb/hr)
      0.16    * TIME CONST FOR BYPASS VALVE OPERATION (SEC)
      0.05    * TIME CONST FOR TURB CONTROL VALVE OPERATION (SEC)
*
********************** ADS LOGIC ***
****************************************
      1       * 1=> ADS ENABLED, 0=> ADS DEFEATED
   -129.d0    * Level setpoint for ADS (inches)
      6       * Number of valves
    102.      * Delay timer (sec) - Hi DW press assumed.
*
********************** MANUAL CONTROL ROD INSERTION ***
*******************************************************
      1.D9    * TIME AT WHICH OPERATOR INITIATES MRI (SEC)
      1.D9    * TIME AT WHICH OPERATOR STOPS MRI (SEC)
     90.0     * CONTROL ROD INSERTION RATE (SEC PER ROD)
*
********************** STANDBY LIQUID CONTROL ***
**************************************************
      1.D+09    TIME AT WHICH SLCS IS INITIATED (SEC)
     75.0       Effective transit time from SLC tank to core (sec)
      2         NUMBER OF SLCS PUMPS OPERABLE (1 OR 2 )
      0.28      Inj rate of elemental B with 2 SLCS pumps operable (Lbm/sec)
   1140.7       VOLUME OF EXTERNAL RECIRC LOOPS (FT3) - FOR B DILUTION
    494.        Hot Shutdown Boron Conc. (ppm at Hot conditions,
*               no voids, and full power Zenon concentration).
     15.        If total core flow (Mlb/hr) is greater than this value,
*               then stagnated boron (in lower plenum) will begin to remix.
      6.        If total core flow (MLb/hr) is less than this value,
*               then some of the boron injected into the lower plenum will begin
*               to settle to the bottom of vessel.
      4.        If the total core flow (MLb/hr) is less than this value,
*               then all of the boron injected into the lower plenum will
*               settle to the bottom of the vessel.
      1.        Interpolation exponent for boron mixing when core flow
*               is between the two total core flows specified above.
```

```
*             exponent = 1 => linear interpolation
*             exponent > 1 => less mixing than linear model
*             exponent < 1 => more mixing than linear
   10         Number of nodes in active core for boron mixing (1 to 10)
 4800.d0      Initial volume of sodium pentaborate solution
*             in SLC tank (gal)
  200.        SLC tank vol at which SLC pumps trip (gal)
   82.4       Injection rate of boron solution (gpm) with 2 pumps
   90.        Temperature of solution in SLC tank (F)
*
*********************** REACTOR COOLDOWN ***
   1.D+09     Time (sec) at which controlled cooldown of RPV is init.
  100.        Cooldown Rate (Deg F/hr)
   98.        Target press of cooldown (psig), i.e., the cooldown is
*             over when Rx pressure reaches this value.
**************************************************************************
*          SAFETY/RELIEF VALVE DATA (PART 1)
*
* W1-I  NSRV  = NUMBER OF SRVS
*
* W2-R  DTSRV = SRV STROKE TIME (SEC)
*
* W3-R  FCOEF = Flow coefficient.  SRV flow is
*               FCOEF*Gcrit*VAREA, where Gcrit is critical mass flux.
*
*
*      NSRV       DTSRV       FCOEF
        16         0.5         0.884
**************************************************************************
*          SAFETY/RELIEF VALVE DATA (PART 2)
*
* W1-R  VAREA(1) = FLOW AREA FOR VALVE 1 (FT2)
*
* W2-R  PRESH(1) = PRESSURE AT WHICH VALVE OPENS (PSIA)
*
* W3-R  PRESL(1) = PRESSURE AT WHICH VALVE RE-SEATS (PSIA)
*         .
*         .
*         .
* SUPPLY NVALV LINES OF DATA WITH EACH LINE CONTAINING THESE three
* PARAMETERS
*
*  VALVE ID#        VAREA          PRESH          PRESL
*  UAL values
*       1          0.11192         1143.          1017.
*       2          0.11192         1146.          1020.
*       3          0.11192         1156.          1029.
*       4          0.11192         1157.          1030.
*       5          0.11192         1159.          1032.
*       6          0.11192         1165.          1037.
*       7          0.11192         1167.          1039.
*       8          0.11192         1168.          1040.
*       9          0.11192         1175.          1046.
*      10          0.11192         1176.          1047.
*      11          0.11192         1178.          1048.
*      12          0.11192         1181.          1051.
*      13          0.11192         1186.          1056.
*      14          0.11192         1191.          1060.
*      15          0.11192         1194.          1063.
*      16          0.11192         1204.          1072.
*
*  Nominal values
        1          0.11192         1113.           987.
        2          0.11192         1116.           990.
        3          0.11192         1126.           999.
        4          0.11192         1127.          1000.
        5          0.11192         1129.          1002.
        6          0.11192         1135.          1007.
        7          0.11192         1137.          1009.
        8          0.11192         1138.          1010.
        9          0.11192         1145.          1016.
       10          0.11192         1146.          1017.
       11          0.11192         1148.          1018.
       12          0.11192         1151.          1021.
       13          0.11192         1156.          1026.
       14          0.11192         1161.          1030.
       15          0.11192         1164.          1033.
       16          0.11192         1174.          1042.
**************************************************************************
*              Time-Dependent Actuation of SRVs (Part 1)
*
* W1-I  NTRIP  = Number of valves to be tripped open/closed at
*                specified time.
*
```

```
*        NTRIP
           3
****************************************************************************
*             Time-Dependent Actuation of SRVs (Part 2)
*
* W1-I  IDTRIP =  ID# OF TRIP.  THIS INPUT PARAMETER MUST BE
*                 SEQUENTIAL STARTING WITH THE VALUE ONE.
*
* W2-I  IDVALV =  SRV IDENTIFICATION NUMBER (1-10 only)
*
* W3-R  TVTRIP =  TIME AT WHICH VALVE IS TRIPPED OPEN/CLOSED (SEC)
*
* W4-I  IVIN   =  1 if valve is triped open at t=TVTRIP
*              =  2 if valve is tripped closed at t =TVTRIP.
*
*
*    TRIP ID#     VALVE ID#      TOPEN/TCLOSE    1=OPEN 2=CLOSE
        1            1              1.D9            1
        2            2              1.D9            1
        3            3              1.D9            1
****************************************************************************
* NUMBER OF DATA POINTS DESCRIBING DOWNCOMER CONDENSATION EFFICIENCY
*
*     NPTSE
       12
****************************************************************************
*   DOWNCOMER CONDENSATION EFFICIENCY AS A FUNCTION OF REACTOR
*   PRESSURE AND DOWNCOMER WATER LEVEL.
*
*   This table specifies the condensation efficiency on cold makeup
*   flow which is injected
*   through the feedwater spargers.  When the downcomer water level
*   drops below the spargers (which are located at -23.7 in.) feedwater
*   is injected directly into a region occupied by saturated steam.
*   Feedwater, HPCI, RCIC, and Condensate systems all inject through
*   the feedwater spargers.
*
*     Water Level (in.)      Pressure (PSIA)    Condensation Efficiency
           -23.7               1500.               0.00d0
           -63.1               1500.               0.95D0
          -250.                1500.               0.95D0
           -23.7               1000.               0.00d0
           -63.1               1000.               0.95D0
          -250.                1000.               0.95D0
           -23.7                500.               0.00d0
           -63.1                500.               0.95D0
          -250.                 500.               0.95D0
           -23.7                100.               0.00d0
           -63.1                100.               0.95D0
          -250.                 100.               0.95D0
****************************************************************************
*    CRD INJECTION FLOW AND ENTHALPY DATA
*
* W1-R CRDFN  = Normal CRD flowrate (gpm)
*
* W2-R CRDTM  = CRD water temperature (DegF)
*
* W3-R CRDT   = Time at which makeup mode of CRD operation is initiated
*               (sec).  CRD flow can be maximized to provide increased
*               makeup if necessary.  The makeup flow depends on reactor
*               pressure.
*
* W4-I NCRD   = Number of data points describing CRD flow as a function
*               of pressure for operation in makeup mode
*
*       CRDFN        CRDTM        CRDT         NCRD
         64.          80.         1.D+09        11
*
*
*                   CRD Flow in          Reactor
*                  in Makeup Mode        Pressure
*                      (gpm)              (Psia)
                      340.d0              14.7d0
                      335.d0             100.0d0
                      320.d0             200.0d0
                      307.d0             300.0d0
                      285.d0             400.0d0
                      280.d0             500.0d0
                      265.d0             600.0d0
                      239.d0             700.0d0
                      230.d0             800.0d0
                      187.d0            1000.0d0
                        0.d0            1300.0d0
****************************************************************************
```

```
*  DELAYED-NEUTRON PRECURSOR DECAY CONSTANTS FOR SIX GROUPS
*
* W1-R   SLAMDA(1) = DECAY CONSTANT (1/SEC) FOR FIRST DELAYED GROUP
*  .
*  .
*  .
* W6-R  SLAMDA(6)  = DECAY CONSTANT (1/SEC) FOR SIXTH DELAYED GROUP
*
*  SLAMDA(1)  SLAMDA(2)  SLAMDA(3)  SLAMDA(4)  SLAMDA(5)  SLAMDA(6)
   0.0128      0.0316      0.122      0.324       1.41       3.86
*****************************************************************************
*     GROUP FRACTIONS FOR SIX DELAYED GROUPS
*
* W1-R  BETAN(1) = (BETA FOR GROUP 1)/BETA
*  .
*  .
*  .
* W6-R  BETAN(6) = (BETA FOR GROUP 6)/BETA
*
*  BETAN(1)  BETAN(2)  BETAN(3)  BETAN(4)  BETAN(5)  BETAN(6)
   0.032      0.206      0.185      0.394      0.146      0.036
*****************************************************************************
*   DATA FOR FUEL AND CLADDING HEAT TRANSFER MODEL
*
* W1-R  RF    = FUEL PELLET RADIUS (INCHES)
*
* W2-R  RCI   = INSIDE RADIUS OF CLADDING (INCHES)
*
* W3-R  RCO   = OUTSIDE RADIUS OF CLADDING (INCHES)
*
* W4-R  HGAP  = GAP CONDUCTANCE (BTU/SEC-FT2-DEGF)
*
* W5-R  RODL  = LENGTH OF ACTIVE FUEL (FT)
*
* W7-I  NBUND = NUMBER OF BUNDLES IN CORE
*
* W8-R  RF1   = RADIUS OF INNER FUEL NODE (INCHES)
*
* W9-R  PHI1  = (VOLUMETRIC HEAT GENERATION IN FUEL NODE 1)/(PELLET
*               AVERAGE VOLUMETRIC HEAT GENERATION RATE).  This
*               parameter accounts for self-shielding effects within
*               the fuel.
*
*
*    RF      RCI      RCO     HGAP    RODL   NBUND    RF1     PHI1
   0.1707  0.1740  0.1979  1090.    12.5    764   0.1207   0.90
*****************************************************************************
*   Number of FUEL Rods per Axial Core Node
*
*        Axial Node       No. of Rods
            1                 83    * BAF
            2                 91
            3                 91
            4                 91
            5                 91
            6                 91
            7                 91
            8                 91
            9                 91
           10                 91
           11                 91
           12                 91
           13                 91
           14                 91
           15                 91
           16                 91
           17                 83
           18                 83
           19                 83
           20                 83
           21                 83
           22                 83
           23                 83
           24                 83
           25                 83    *TAF
*****************************************************************************
*
*   DOWNCOMER INERTIA
*
* W1-R   AID    = DOWNCOMER INERTIA (1/FT)
*
*        AID
        0.0000
*****************************************************************************
```

```
*   JET-PUMP REGION PHYSICAL AND HYDRAULIC PARAMETERS
*
* W1-R  AJ    = JET PUMP FLOW AREA (FT2)
*
* W2-R  ALENJ = JET PUMP FLOW PATH LENGTH (FT)
*
* W3-R  DHJ   = JET PUMP HYDRAULIC DIAMETER (FT)
*
* W4-R  FJ    = Jet pump region friction factor.
*
* W5-R  AIJ   = Jet pump fluid inertia (effective L/A) [ ft**(-1) ]
*
*
*    AJ       ALENJ        DHJ        FJ       AIJ
   15.16    16.495        0.98      0.013     1.1
*****************************************************************************
*    LOWER PLENUM PHYSICAL AND HYDRAULIC PARAMETERS
*
* W1-R  AL    = FLOW AREA OF LOWER PLENUM (FT2)
*
* W2-R  ALENL = FLOW PATH LENGTH OF LOWER PLENUM (FT)
*
* W3-R  DHL   = HYDRAULIC DIAMETER FOR LOWER PLENUM (FT)
*
* W4-R  FL    = Friction factor for lower plenum region.
*
* W5-R  ALENL1= (ELEVATION AT CORE INLET) - (ELEVATION AT BOTTOM OF
*                 JET PUMP REGION)  (FT)
*
* W6-R  AIL   = Lower plenum fluid inertia [ ft**(-1) ]
*
*   AL      ALENL      DHL      FL     ALENL1    AIL
  132.33    17.28     1.014   0.013    6.94     0.13
*****************************************************************************
*   REACTOR CORE HYDRAULIC PARAMETERS
*
* W1-R  AC    = CORE FLOW AREA (FT2)
*
* W2-R  ALENC = Length of active core (ft)
*
* W3-R  DHC   = CORE HYDRAULIC DIAMETER (FT)
*
* W4-R  AIC   = Core fluid inertia [ ft**(-1) ]
*
* W5-R  ALLR  = Length of lower reflector region (ft)
*
* W6-R  ALUR  = Length of Upper Reflector Region (FT)
*
*
*    AC       ALENC       DHC      AIC     ALLR    ALUR
   78.19      12.5      0.0326   0.190   1.154   1.231
*****************************************************************************
*     BY-PASS CHANNEL HYDRAULIC PARAMETERS
*
* W1-R AB    = BY-PASS CHANNEL FLOW AREA (FT2)
*
* W2-R ALENB = FLOW PATH LENGTH (FT)
*
* W3-R DHB   = BY-PASS CHANNEL HYDRAULIC DIAMETER (FT)
*
* W4-R FB    = Bypass friction factor.
*
* W5-R AIB   = Bypass fluid inertia [ ft**(-1) ]
*
*
*    AB       ALENB        DHB        FB       AIB
   66.04     14.885       0.196     0.0185    0.23
*****************************************************************************
*     UPPER PLENUM HYDRAULIC PARAMETERS
*
* W1-R AU    =  UPPER PLENUM FLOW AREA (FT2)
*
* W2-R ALENU =  FLOW PATH LENGTH OF UPPER PLENUM (FT)
*
* W3-R DHU   =  HYDRAULIC DIAMETER FOR UPPER PLENUM (FT)
*
* W4-R FU    =  Upper plenum friction factor.
*
* W5-R AIU   =  Upper plenum fluid inertia [ ft**(-1) ]
*
*
*
*    AU       ALENU      DHU      FU        AIU
   191.84     4.98      3.97     0.01      0.015
```

```
*****************************************************************************
*    RISER HYDRAULIC PARAMETERS
*
* W1-R  AR     =  RISER/SEPARATOR FLOW AREA (FT2)
*
* W2-R  ALENR  =  RISER/SEPARATOR FLOW PATH LENGTH (FT)
*
* W3-R  DHR    =  HYDRAULIC DIAMETER FOR RISER/SEPARATOR REGION (FT)
*
* W4-R  FR     =  Friction factor for risers.
*
* W5-R  AIR    =  Fluid inertia in riser region [ ft**(-1) ]
*
*
*      AR      ALENR        DHR         FR          AIR
     39.66    10.156       0.505       0.015       0.85
*****************************************************************************
*    SEPARATOR HYDRAULIC PARAMETERS
*
* W1-R  AS     =  SEPARATOR FLOW AREA (FT2)
*
* W2-R  ALENS  =  SEPARATOR FLOW PATH LENGTH (FT)
*
* W3-R  DHS    =  HYDRAULIC DIAMETER FOR SEPARATOR REGION (FT)
*
* W4-R  FS     =  Separator region friction factor.
*
* W5-R  AIS    =  Seperator region fluid inertia [ ft*(-1) ].
*
*
*      AS      ALENS        DHS          FS          AIS
     71.06    6.167        0.514        0.015       0.84
*****************************************************************************
*    Combined volume of steam dome (up to inboard MSIV) and downcomer
*    region (ft3)
*
*     V00
*    (FT3)
     14334.
*****************************************************************************
*    REACTOR CORE SPACER LOSS COEFFICIENT DATA
*
* W1-I  NSPACE = NUMBER OF SPACERS PER CHANNEL
* FUEL SPACER LOSS COEFFICIENT CALCULATED BY THE CODE BASED ON INITIAL
* CONDITIONS
*
*     NSPACE
        7
*****************************************************************************
*                   JUNCTION FLOW AREAS AND LOSS COEFFICIENT DATA
*
*
*
*        K         AREA
       0.24        6.18       * (1)  Downcomer to Jet Pump
       1.04       39.4        * (2)  Jet Pump Exit
       1.57       22.67       * (3)  Fuel Bundle Orifice
       1.549      51.73       * (4)  Lower tie plate (Lower Reflector to Core)
       0.37        0.881      * (5)  Lower Reflector to Bypass
       1.073     139.8        * (6)  Upper Reflector to Upper Plenum
       0.00       48.98       * (7)  Bypass to Upper Plenum
       0.41       45.10       * (8)  Upper plenum to Riser
      -1.00       35.67       * (9)  Riser to Separator
      -1.00       40.73       * (10) Separator Exit
*****************************************************************************
********************** CONTAINMENT DATA*************************************
*
*
* W1-R  SPWL0 = INITIAL SUPPRESSION POOL level (ft)
*
* W2-R  SPT0 = INITIAL SUPPRESSION POOL TEMPERATURE (DEGF)
*
* W3-R  TWW  = Initial Wetwell Temp (F)
*
* W4-R  THXON1 = Time AT WHICH RHR HX-1 TURNS ON (sec)
*
* W5-R  THXON2 = Time AT WHICH RHR HX-2 TURNS ON (sec)
*
* W6-R  TDWSPI = TIME at which Dry Well Spray is initiated (sec)
*                (Keep at 1.D+09; Model not complete)
*
*
*       SPWL0     SPT0     TWW      THXON1     THXON2     DWSPI
        23.0      90.      90.      1.D+09     1.D+09     1.D+09
*****************************************************************************
*
```

```
*   SUPPRESSION POOL FREE AREA AS A FUNCTION OF ELEVATION
*
* W1-I  NSPAVL= Number of SP area vs. level points
* W2-R  SPELEV = ELEVATION ABOVE BOTTOM OF SUPPRESSION POOL (FT)
* W3-R  SPAREA = SP FREE AREA (FT2)
*
*       NSPAVL
          4
*
*       Elev. above bottom of pool          Free Area
*                 (ft)                        (ft2)
                       0.00                       5851.3
                      12.00                       5851.3
                      12.01                       5277.0
                      52.50                       5277.0
*************************************************************************
* W1-R  QRDW = Initial heat load from from RPV to drywell (BTU/sec)
* W2-R  QDWC = Initial cooling capacity of DW Cooling (BTU/sec)
* W3-R  TCWDW= Inlet Temp of cooling water for DW coolers (F)
* W4-R  DWCTP= Drywell coolers trip if DW press exceeds this value (psig)
* W5-R  DWCTL= Drywell coolers trip if Rx level drops below value (in.)
* W6-R  VDW  = Drywell free volume (ft3)
* W7-R  TDW  = Initial DW temp (F)
* W8-R  TEMPSW=Service Water Temperature (F)
*
*    QRDW     QDWC     TCWDW  DWCTP    DWCTL    VDW       TDW     TEMPSW
    1043.    1043.    50.D0  1.72    -129.   239600.    120.      88.
*************************************************************************
*   Containment Data (Cont'd) -- Vacuum Breaker Data
*
* W1-R  AREAVB = full open vac breaker flow area (ft2)
* W2-R  AKVB   = vacuum breaker loss coeff based on AREAVB
* W3-R  DP1VB  = DP at which vac breaker begins to lift (psi)
* W4-R  DP2VB  = DP at which vac breaker is full open (psi)
*
*    AREAVB    AKVB      DP1VB      DP2VB
     10.25     3.57      0.5        3.22
*************************************************************************
*   Containment Data (Cont'd) -- Downcomer Vent Data
*
* W1-R  ADOWN0 = downcomer vent flow area (ft2)
* W2-R  AKDOWN = downcomer vent loss coefficient based on ADOWN0
* W3-R  ALDOWN = Elevation of bottom of DC vent w/r to bottom of SP (ft)
*
*    ADOWN0    AKDOWN    ALDOWN
     242.0     2.17      12.0
*************************************************************************
*   Containment Data (Cont'd) -- Initial Humidity and pressure
*
* W1-R  RHDW = Initial Relative humidity in DW (%)
* W2-R  RHWW = Initial Relative Humidity in WW (%)
* W3-R  PDW  = Initial pressure in DW (psia)
* W4-R  PWW  = Initial pressure in Wetwell (F)
*
*    RHDW      RHWW      PDW      PWW
     48.       100.      15.2     15.2
*************************************************************************
*   Containment Data (Cont'd) -- SRV tailpipe/Downcomer data
*
* W1-R  DSRVP= Diameter of SRV tail pipe (ft)
* W2-R  AKQUEN= loss coefficient for SRV quencher
* W3-R  HVENT= Height of downcomer vents above drywell floor (ft)
* W4-R  FCN2 = 0.0 => nitrogen bubbles through SP with no heat transfer.
*            = 1.0 => nitrogen reaches thermal equil with SP.
*            ( 0<FCN2<1 => interpolation between the two limits ).
*
*        DSRVP               AKQUEN      HVENT     FCN2
         1.0                 1.0         1.5       1.0
*************************************************************************
*   Containment Data (Cont'd) -- SP Letdown
*
* W1-R TSPLD1= Time at which SP letdown is started (sec)
* W2-R TSPLD2= Time at which SP letdown is terminated (sec)
* W3-R WSPLD = SP letdown flow (lbm/sec)
*
*      TSPLD1        TSPLD2       WSPLD
        1.d9          1.d9         120.d0
*************************************************************************
*   Containment Data (Cont'd) -- Area of Drywell steel structures
*
* W1-R  ADWW = surface area of drywell liner wall (ft2)
* W2-R  ADWR = surface area of drywell liner roof (ft2)
* W3-R  ADWF = surface area of drywell liner floor (ft2)
* W4-R  ADWI = surface area of internal steel structures (structures
```

```
*            excluding the liner) in drywell (ft2)
*
*
*
*   ADWW            ADWR           ADWF         ADWI
  17870.          1039.          6082.        66000.
*****************************************************************************
*  Containment Data (Cont'd) -- Volume of Drywell steel structures
*
* W1-R  VDWW = volume of wall segment of drywell liner (ft3)
* W2-R  VDWR = volume of roof segment of drywell liner (ft3)
* W3-R  VDWF = volume of floor segment of drywell liner (ft3)
* W4-R  VDWI = volume of internal steel structures in drywell (ft3)
*
*    VDWW            VDWR           VDWF         VDWI
     372.            22.            127.         2750.
*****************************************************************************
*  Containment Data (Cont'd) -- Area of Wetwell steel structures
*
* W1-R  AWWW = ht area of wetwell wall (ft2)
* W2-R  AWWI = ht area of wetwell internal structures (ft2).
*
*     AWWW                     AWWI
     8156.                    30048.
*****************************************************************************
*  Containment Data (Cont'd) -- Volume of Wetwell steel structures
*
* W1-R  VWWW = Vol. of wetwell wall within air space (ft3)
* W2-R  VWWI = Vol. of wetwell internal structures (ft3)
*
*     VWWW                     VWWI
      170.                    1252.
*****************************************************************************
*  Containment Data (Cont'd) -- Characteristic lenght of steel struc.
*
* W1-R  CLDW = Characteristic length of drywell wall = height (ft)
* W2-R  CLDR = Characteristic length of drywell roof
*            = (Heat transfer area)/(Perimeter)  (ft)
* W3-R  CLDF = Characteristic length of drywell floor
*            = (Heat transfer area)/(Perimeter)  (ft)
* W4-R  CLDI = Characteristic length of drywell internal steel struc.
*            = Height (ft)
* W5-R  CLWW = Characteristic length of wetwell wall in air space
*            = Height (ft)
* W6-R  CLWI = Characteristic length of wetwell internal steel struc.
*            = Height (ft)
*
*   CLDW      CLDR      CLDF      CLDI      CLWW        CLWI
    87.75     9.1       22.       10.       29.5        10.
*****************************************************************************
```

Documentation for Base Case SABRE Inputs for U2C10 Core

Appendix F presents the base SABRE input deck for U2C9 which consists of 312 ATRIUM-10 fuel assemblies, 448 SPC 9x9-2 assemblies, and 4 GE12 assemblies (Ref. G.4). Since the dominant fuel type for U2C9 is SPC 9x9 fuel, a 9x9 core model is used in Appendix F.

Appendix O presents the base input deck for U2C10 which consists of 592 ATRIUM-10 fuel assemblies, 168 SPC9x9-2 fuel assemblies, and 4 GE12 assemblies (Ref. G.3). The dominant fuel type for U2C10 is ATRIUM-10, and therefore, a 10x10 core model is used. An "effective" fuel gap conductance is employed to account for the mixed core composition. That is, the "effective" H_{gap} is chosen so that the thermal response of a full core of ATRIUM-10 fuel will be the same as that of the actual mixed U2C10 core. The effective H_{gap} is obtained from Ref. G.3.

This Appendix only documents changes from the U2C9 input deck. For ease of comparison, section numbers corresponding to those in Appendix F are used in this Appendix. Sections are omitted where no changes are necessary to convert the input deck from ANF 9x9-2 to ATRIUM-10 fuel.

The core region flow-dependent friction factor and flow-dependent spacer loss coefficients are not updated for ATRIUM-10 fuel. These correlations are contained within the SABRE source code (see Section D.1.3), and based on engineering judgement, it is expected that changes to these correlations with the transition from ANF 9x9-2 fuel to ATRIUM-10 fuel will not significantly affect the core flow behavior. Note that although the friction factor correlations are not updated, the hydraulic diameters and flow areas are updated.

G.11 Fraction of Total Power Deposited in Moderator as Gamma Heating

3.5% of energy produced is directly deposited in the water – 1.5% in fuel channels and 2% in bypass (Ref. G.1, p. 3.18). Therefore,

QFRAC1 = 0.015, and
QFRAC2 = 0.020.

G.29.6 Hot Shutdown Boron Concentration‡

= 494 ppm (Ref. G.8)

G.34 Delayed-Neutron Precursor Decay Constants for Six Groups

Decay constants for ATRIUM-10 fuel are from Ref. G.1, p. B.4.

‡ Value of this parameter is unchanged from U2C9, but reference has changed.

Group	λ_i (sec^{-1})
1	0.0128
2	0.0316
3	0.122
4	0.324
5	1.41
6	3.86

G.35 Group Fractions for Six Delayed Groups

Group fractions for ATRIUM-10 fuel are from Ref. G.1, p. B.4.

Group	β_i
1	0.032
2	0.206
3	0.185
4	0.394
5	0.146
6	0.036

G.36.1 Fuel Pellet Radius

Radius = 0.3413 in. / 2 = 0.1707 in. (Ref. G.2, p. 24)

G.36.2 Cladding Inside Radius

Inside radius = 0.3480 in / 2 = 0.1740 in. (Ref. G.2, p. 24)

G.36.3 Cladding Outside Radius

Outside radius = 0.3957 in. / 2 = 0.1979 in. (Ref. G.2, p. 24)

G.36.4 Gap Conductance

Hgap for U2C10 EOC core (16.635 GWD/MTU) = 1090 Btu/hr-ft^2-°F (Ref. G.3, p. 3.3)

G.36.6 Number of fuel rods in Fuel Bundle on 6" Nodal Basis

Active Core Node	Number of Fuel Rods in 1 Fuel Bundle
1 (Bottom of Active Fuel)	83‡
2	91
3	91
4	91
5	91
6	91
7	91
8	91
9	91
10	91
11	91
12	91
13	91
14	91
15	91
16	91
17	83
18	83
19	83
20	83
21	83
22	83
23	83
24	83
25 (Top of Active Fuel)	83

The number of fuel pins in each axial node were calculated from the heat transfer areas on p. 3.18 of Ref. G.1 and the fuel pin dimensions on p. 3.20 of Ref. G.1.

G.36.8 Radius of Inner Fuel Node

Equal volume fuel nodes are used. Therefore,

$$\pi r_a^2 = \pi r_b^2 - \pi r_a^2$$

where
r_a = radius of inner fuel node, and
r_b = radius of fuel pellet.

Solving for r_a gives

$$r_a = r_b / \sqrt{2} = 0.1707 / \sqrt{2} = 0.1207 \text{ inches (see Sec. G.36.1)}$$

G.40.1 Core Flow Area

In SABRE, only one flow area can be input for the entire core region. Therefore the flow area is computed by summing the RETRAN model volumes for the lower reflector, upper

‡ The number of rods in nodes 1 and 2 is the same, but in node 1 only 83 of the rods contain fuel.

reflector, and active core and then dividing by the total height associated with these regions. The data in the following table was obtained From Ref. G.1.

RETRAN Control Volume	RETRAN Volume (ft^3)	RETRAN Height (ft)	Hydraulic Diameter (ft)
Lower Reflector	61.85	1.154	
Active Core 1	38.83	0.5	0.0311
Active Core 2	38.83	0.5	0.0311
Active Core 3	38.83	0.5	0.0311
Active Core 4	38.83	0.5	0.0311
Active Core 5	38.83	0.5	0.0311
Active Core 6	38.83	0.5	0.0311
Active Core 7	38.83	0.5	0.0311
Active Core 8	38.83	0.5	0.0311
Active Core 9	38.83	0.5	0.0311
Active Core 10	38.83	0.5	0.0311
Active Core 11	38.83	0.5	0.0311
Active Core 12	38.83	0.5	0.0311
Active Core 13	38.83	0.5	0.0311
Active Core 14	38.83	0.5	0.0311
Active Core 15	38.83	0.5	0.0311
Active Core 16	38.83	0.5	0.0311
Active Core 17	38.83	0.5	0.0311
Active Core 18	41.45	0.5	0.0358
Active Core 19	41.45	0.5	0.0358
Active Core 20	41.45	0.5	0.0358
Active Core 21	41.45	0.5	0.0358
Active Core 22	41.45	0.5	0.0358
Active Core 23	41.45	0.5	0.0358
Active Core 24	41.45	0.5	0.0358
Active Core 25	41.45	0.5	0.0358
Upper Reflector	110.23	1.231	
Total	**1163.79**	**14.885**	

From the RETRAN data in the above table, the average core flow area for ATRIUM-10 fuel is 1163.79 ft^3 / 14.885 ft^2 = 78.19 ft^2.

G.40.3 Core Region Hydraulic Diameter

This is the hydraulic diameter for active core region. SABRE neglects wall friction in the lower and upper reflector regions. The active core region hydraulic diameter for SABRE is taken to be the average RETRAN hydraulic diameter for the active core region from the Table in Section G.40.1. Thus, Hydraulic Diameter =
[(17)(0.0311) + (8)(0.0358)]/25 = 0.0326 ft

G.40.5 Core Fluid Inertia

The fluid inertia for the core region is given by (see Section D.1.3)

$$I_c = \frac{L_c}{A_c},$$

where
L_c = combined length of active core lower reflector and upper reflector, and
A_c = core flow area.

From Sections J.40.2, G.40.6, and G.40.7, $L_c = 12.5 + 1.154 + 1.231 = 14.885$ ft, and from Section G.40.1, $A_c = 78.19$ ft^2. Therefore, $I_c = 14.885 / 78.19 = 0.190$ ft^{-1}.

G.40.6 Length of Lower Reflector Region

Length = 1.154 ft (Ref. G.1, p. 3.2)

G.40.7 Length of Upper Reflector Region

Length = 1.231 ft (Ref. G.1, p. 3.4)

G.41.1 Bypass Flow Area

The bypass region flow area is calculated by dividing the total bypass fluid volume from the RETRAN ATRIUM-10 system model (Ref. G.1) by the height of the bypass region given in §G.41.2. The only change in the bypass fluid volume is in control volumes 51 and 77 of the RETRAN system model. The fluid volumes for control volumes 52 through 76 of the RETRAN model remain unchanged from the Cycle 1 RETRAN model (Refs. G.1 and G.6).

$$\text{Total Vol.} = \sum_{i=51}^{77} V_i = 50.90 + (25)(33.94) + 83.55 = 982.95 \text{ ft}^3.$$

V_{52} through V_{76} are from Ref. G.7. V_{51} and V_{77} are from Ref. G.1.

Flow Area = 982.95 / 14.885 = 66.04 ft^2.

G.41.2 Bypass flow path length

The flow length of the bypass region is equal to the combined length of the active core, the lower reflector and the upper reflector. From Section G.40.1,
Bypass flow path length = 14.885 ft.

G.41.5 Bypass Fluid Inertia

I_B = (Flow Length) / (Flow Area) = 14.885 ft / 66.04 = 0.23 ft^{-1}. (§G.41.1 & §G.41.2)

G.47.4 Lower Tie Plate (Lower Reflector to Active Core)

Flow Area = 51.73 ft^2 (Ref. G.1, p. 3.11)
K = 1.549 (Ref. G.1, p. 3.12)

G.47.5 Lower Reflector to Bypass

Flow Area = 0.881 ft^2 (Ref. G.1, p.3.10)
K = 0.37

The value of K for the leakage path from the lower reflector to the bypass was calculated so that the bypass flow is ~9.645 Mlb/hr with a total core flow rate of 87 Mlb/hr, a core-inlet subcooling of 29.49 Btu/Lbm, and a reactor pressure of ~1050 psia. These U2C10 operating parameters are from the SIMULATE output in Table 2.2 of Ref. G.5. The SABRE results used to arrive at the value of K=0.37 were given in Rev. 6 of this Calc. (C62.out in Computer Case Summary for Calc. EC-ATWS-0505, Rev. 6).

G.47.6 Upper Reflector to Upper Plenum

Flow Area = 139.8 ft^2 (Ref. G.1, p. 3.14)
K = 1.073 (Ref. G.1, p. 3.14)

References for Appendix G

G.1 Calc. EC-FUEL-1375, Rev. 0, "RETRAN SYSTEM MODEL / ATRIUM-10 CORE MODEL," 10/20/98.

G.2 Calc. EC-ATWS-1001, Rev. 0, "Calculation of U2C9 Peak Suppression Pool Temperature for ATWS Conditions," 12/13/96.

G.3 Calc. EC-FUEL-1379, Rev. 0, "Unit 2 Cycle 10 ESCORE Gap Conductance for RETRAN," 12/8/98.

G.4 Susquehanna SES Unit 2 Cycle 9 Reload Summary Report, PL-NF-97-003, June 1998.

G.5 Calc. EC-ATWS-1004, Rev. 0, "U2C10 Peak Suppression Pool Temperature for ATWS Conditions."

G.6 Calc. EC-FUEL-0978, Rev. 0, "RETRAN 9x9 Core Model," 3/22/90.

G.7 PL-NF-89-005-A, Qualification of Transient Analysis Methods for BWR Design and Analysis," March 24, 1992.

G.8 Calc. NFE-2-10-015, Rev. 0, "Unit 2 Cycle 10 Nuclear Fuels Engineering ATWS Analysis."

APPENDIX H
Base CONTAIN Input Deck for SABRE Benchmark Studies

With the exception of the containment heat structure model, this CONTAIN input file was developed from data in PP&L calculation EC-THYD-1001, "CONTAIN Model for Primary Containment." The CONTAIN model in Calc. No. EC-THYD-1001 accounts for the thermal capacitance of the concrete walls of the containment. However, the SABRE model neglects the thermal capacitance of the concrete (see §2.10). Therefore, the concrete thermal capacitance is not included within the CONTAIN model given in this Appendix. Only the liner plate and the internal steel structures are modeled.

The CONTAIN input files for the benchmark studies in Sections 5.2 and 5.5 have two mass/energy source tables. The source in the suppression chamber accounts for the steam addition to the pool from SRV discharge. The source within the drywell accounts for the mass/energy addition due to a LOCA as well as the heat transfer from the reactor vessel to the drywell atmosphere and the heat removal by the drywell coolers. In the absence of a LOCA, energy addition to the drywell is accomplished by adding a small amount of mass with very high enthalpy. The amount of mass added is negligible compared to the total mass of gas and water vapor within the containment. This approach is used to model heat dissipation from the reactor vessel. The source tables in the present input deck are set to zero mass flow.

```
CDC
EOI
&&
&& ***** Global Input.  This input is common to all cells  ***************|
&&                                                                         |
CONTROL  NCELLS=2      && Number of cells                                  |
         NTITL=1       && Number of title cards                            |
         NTZONE=1      && Number of time zones                             |
         NUMTBG=1      && Number of global tables used                     |
         MAXTBG=4      && Max # of entries used in global table option     |
EOI &&                                                                     |
&&  *************** End of General Data **********************************|
&&
&&
&&
&&
&& ***** Global Material Data.  This input is used in all cells **********|
&&                                                                         |
MATERIAL               && Keyword that initates material block             |
         COMPOUND  H2 O2 N2 CO2 H2OL H2OV SS CONC   && Materials Used      |
         USERDEF       && Keyword to initiate specification of
                       && user-defined materials
             CSTEEL    && Name assigned to carbon steel
         USERDAT       && Keyword to begin specification of carbon steel
                       && properties.
             CSTEEL    && Name of material
             SOLID     && Phase of material
             MOLEW     && Keyword for specifying molec wt (use value for Fe)
             55.85     && Molec wt. (Use value for Fe)
             RHO       && Keyword indicating density input follows
             2         && No. of temp-density pairs
             273.15  7857.  && Temp (K),  Density (kg/m**3)
             475.    7857.  && Temp (K),  Density (kg/m**3)
             COND      && Keyword for specifying thermal conductivity
             2         && No. of Temp-Conductivity pairs
             273.15  34.86  && Temp (K),  Conductivity (W/m-K)
             475.    34.86  && Temp (K),  Conductivity (W/m-K)
             ENTH      && Keyword for specifying enthalpy input
             2         && No. of Temp-Enth pairs
             273.15  0.0    && Temp (K), Enthalpy (J/kg)
             475.    90348. && Temp (K), Enthalpy (J/kg)
             SPH       && Keyword for specifying specific heat
             2         && No. of Temp-Sp Heat pairs
             273.15  447.6  && Temp (K), Sp Heat (J/kg-K)
             475.    447.6  && Temp (K), Sp Heat (J/kg-K)
         EOI
&&                                                                         |
&&  *************** End of Material Data *********************************|
&&
&&
&&
&&
&& ***** Title block *****************************************************|
TITLE && Put Title below                                                   |
```

```
   PRIMARY CONTAINMENT RESPONSE TO UNMITIGATED ATWS
&&
&& **************** End of Title Block **********************************
&&
&&
&&
&&
&& ************ Time Step Data *******************************************
&&
TIMES               &&
          1.E5      && cput   = CPU time limit (seconds)
            0.      && tstart = Problem Start time (sec)
            1.0     && timinc = Maximum time step size (sec)
          100.0     && edtdto = Max interval for writing data to tapes (sec)
         2000.      && tstop  = Problem End Time (sec)
&&
&& **************** End of Time Step Data ********************************
&&
&&
&&
&&
&& ******* Edit Frequency ************************************************
&&
SHORTEDT=500  && Short edit printed every (SHORTEDT)*(timinc) seconds
LONGEDT=20    && Long edit printed every (LONGEDT)*(edtdto) seconds
&&
&& *************** End of Edit Frequency Data ****************************
&&
&&
&&
&&
&& ****** Specify Type of Output ****************************************
&&
PRLOW-CL  && Print detailed output from lower cell
PRFLOW    && Print detailed output from intercell flow
&&  PRHEAT    && Print output for heat transfer structure
&&
&& ******* End of Output Description Section *****************************
&&
&&
&&
&&
&& ****** Specify the reactor type ***************************************
&&
THERMAL  && Water-cooled reactor
&&
&& ******* End of reactor-type data **************************************
&&
&&
&&
&&
&& ******* Suppression Pool Vent Flow Path Model *************************
&&
SPVENT  && Activates the model
```

```
     NWET=1            && Cell # containing the wetwell pool
     NDRY=2            && Cell # representing the drywell
     NSVNTS=82         && Number of downcomer vent pipes
     AVNT=0.274        && Flow area of a single vent pipe (m**2)
     VNTLEN=13.87      && Vertical extent of the vent pipe (m)
     ELEVNT=3.66       && height of vent opening above bottom of pool (m)
     DPDRY=1.E4        && DP for area ramping of gas flow area (Pa)
     DPWET=1.E4        && DP for area ramping of gas flow area (Pa)
     FDW=2.17          && loss coeff for liq flow from DW to WW
     FWD=2.17          && loss coeff for liq flow from WW to DW
EOI                    &&
&& **************** End of SP Vent Data **********************************
&&
&&
&&
&&
&& ****** Data for Flow Path Model ******************************************
&&
FLOWS IMPLICIT         && Implicit integr method for flow calc
      DROPOUT          && Removes suspended droplets from atmosphere
      AVL(1,2)=0.645   && Ratio of flow path area to length (WW  to DW) (m)
      CFC(1,2)=0.495   && Flow loss coefficient (WW to DW)
      VAR-AREA(1,2)    && Specifies table for flow from (WW to DW)
      FLAG=2           && use linear interp in table below
      VAR-X=DELTA-P    && Delta-p is independent variable (Pa)
      X=4              && Specify 4 values of Delta-p
           -1.E9       &&
            0.345E4    &&
            1.943E4    &&
            1.E9       &&
      VAR-Y=AREA       && Flow area is dependent variable
      Y=4              && Specify 4 values of flow area (m**2)
            0.         &&
            0.         &&
            0.762      &&
            0.762      &&
EOI                    &&
&& ************* End of Data for Flow Path Model *************************
&&
&&
&&
&&
&& ************ Input Data for Cell #1 (Wetwell) **************************
&&
CELL=1     && Specifies the cell number
      CONTROL   && Allocates storage space for cell 1
      JPOOL=1   && Indicates presence of pool layer
      NHTM=4
      MXSLAB=21
      NSOSAT=1  &&
      NSPSAT=14000 && MAX NO. OF ENTRIES IN LOWER CELL SOURCE TABLE
EOI             &&
&& ************ End of Control Parameters ********************************
&&
```

```
&&
&& ******* Additional Data for Cell 1 **************************************
TITLE       && Next line is title for cell 1
   WETWELL CELL WITH WATER POOL (Cell 1)
GEOMETRY              && Geometry for Wetwell is on next two lines
         4357.        && Volume of Wetwell air space (m**3)
           8.99       && Height of wetwell air space (m)
ATMOS                 && Initial atmosphere cond in WW air space
            2         && Number of materials in atmosphere
            0.0       && Pressure will be calculated from eqn of state
         305.37       && Gas temperature (K)
      N2=5136.        && Initial mass of N2 in WW air space (kg)
    H2OV=148.7        && Initial mass of water vapor in WW air space (kg)
&& *********** SOURCE DATA FOR SUPPRESSION POOL (SRV FLOW) ***************
       SRVSOR         &&  SRV BLOWDOWN DATA
       ELESRV=1.07    &&  DISCHARGE ELEV. IN SUPPRESSION POOL (M)
       ATMOS
       SOURCE=1
&&
&& ***** Tabular Data for SRV DISCHARGE       *****************************
       H2OV=2  && Source is water and 2  points are supplied
       IFLAG=2    && Use linear interpolation between data points
&&
&& TABULAR Values for Source 1 in SP (Seconds)
&& srv
&&
&&
&&
T=        .000000E+00   .10000E+09
&&
MASS=     .000000E+00   .000000E+00
&&
ENTH=     .000000E+00   .000000E+00
&&
&&
&&
&&
&&
       EOI  && End of Tabular Data for SRV SOURCE IN SUPPRESS. POOL
       EOI
&&
&& **** End of Data Block for Wetwell air Space **************************
&&
&&
&&
&& ****** Heat Transfer Options for Wetwell ********************************
&&
   CONDENSE
   HT-TRAN    &&
          ON  && Atmosphere to Structure heat transfer is ON
          OFF && Heat trans from pool to substructure (at const T) is OFF
          OFF && Inter-layer heat trans in pool is OFF.
          ON  && Pool to Air space heat trans is ON.
          ON  && Radiative heat transfer is ON.
```

```
  RAD-HEAT      && Initiate radiadiation HT model
  EMSVT    0.85 && Dry-surface emissivties
           0.85 &&
           0.85 &&
           0.85 &&
           0.95 && Emissivity for the uppermost lower cell layer
  CESS          && Use Cess-Lian eqn for steam emittance
  GASWAL = 10.  && Mean beam lenght for the enclosure (m)
  EOI           && End of input block
&& ******* End of Heat Transfer Description for Cell 1 *******************
&&
&&
&& ******* WETWELL HEAT TRANSFER STRUCTURES ******************************
&&
   STRUC
&&  Total surface area of wetwell internals = 2792 m2
&&  Total volume of wetwell internals = 35.5 m3

&&  thickness = vol/area = (35.5/2)/1396 = 0.0127m
    NAME = WW-INS1  &&  Steel structures in wetwell air space
    TYPE = WALL
    SHAPE = SLAB
    NSLAB = 5
    CHRLEN = 3.0
    SLAREA = 1396.
    TUNIF = 305.37
    COMPOUND = CSTEEL CSTEEL CSTEEL CSTEEL CSTEEL
    X = 0.0  0.00254  0.00508  0.00762  0.01016  0.01270
    EOI
&&
    NAME = WW-INS2
    TYPE = WALL
    SHAPE = SLAB
    NSLAB = 5
    CHRLEN = 3.0
    SLAREA = 1396.
    TUNIF = 305.37
    COMPOUND = CSTEEL CSTEEL CSTEEL CSTEEL CSTEEL
    X = 0.0  0.00254  0.00508  0.00762  0.01016  0.01270
    EOI
&&
    NAME = WW-WALL1  &&  Outer wall of wetwell (1/2)
    TYPE = WALL
    SHAPE = CYLINDER
    NSLAB = 1
    CHRLEN = 9.0
    CYLHT = 9.0
    TNODE = 305.37
    COMPOUND = CSTEEL
    X = 13.4114  13.4178
    EOI
&&
    NAME = WW-WALL2  && Outer wall of wetwell (1/2)
    TYPE = WALL
```

```
    SHAPE = CYLINDER
    NSLAB = 1
    CHRLEN = 9.0
    CYLHT = 9.0
    TNODE = 305.37
    COMPOUND = CSTEEL
    X = 13.4114  13.4178
    EOI
&& **** Input for Pool Model in Wetwell ***********************************
&&
LOW-CELL  && Input for suppression pool follows
   GEOMETRY  490.26  && surface area of lower cell (m**2)
   POOL              && Initial configuration of pool layer follows
      TEMP=305.37    && Initial temperature of pool (K)
      COMPOS=1       && number of initial materials in the pool
      H2OL=3.6140E6  && Initial mass of liq water in pool (kg)
      PHYSICS        && Physics options for supp pool model
      BOIL           && Pool boiling is modelled
EOI                  && End of supp pool data
EOI                  &&
&&
&&
&& ****** Substructure Boundary Condition for Supp Pool ******************
&&
   BC=300.  && Temperature of layer beneath suppression pool
   EOI      &&
&& ***************** End of Subpool layer **********************************
&&
&&
&&
&& ****** CELL DATA FOR DRYWELL ********************************************
&&
 CELL=2           && Cell #2 is the Drywell
      CONTROL     && Allocates storage space for cell 2
      NSOATM=1    && Number of external sources to upper cell atmos
      NSPATM=14000 && Max number of entries in atmos source table
      NHTM  =6    && No. of heat transfer structures in cell
      MXSLAB=21   && No. of nodes in any heat transfer structure
      NAENSY=1    && No. of engineered systems
      JPOOL =1    && Indicates presence of pool layer
 EOI              &&
&& ******************* End of Control Data for Drywell ******************
&&
&&
&& ************* TITLE FOR CELL 2 *****************************************
&&
  TITLE                                                                  &&
    DRYWELL CELL
&& ***********************************************************************
&&
&&
&& ********** GEOMETRIC DATA FOR DRYWELL **********************************
&&
   GEOMETRY        &&
```

```
        6785.   && Drywell volume (m**3)
          26.75 && Characteristic height of the drywell (m)
&& ***********************************************************************
&&
&&
&& ************ DRYWELL ATMOSPHERE DATA ***********************************
&&
  ATMOS=2       && Number of materials in the atmosphere
        0.0     && Initial drywell press is calculated from Eqn of State
      322.04    && Initial gas temperature (K)
   N2=7040.     && Initial mass of N2 in Drywell (kg)
  H2OV=255.52   && Initial mass of Water Vapor in Drywell (kg)
&& ***********************************************************************
&&
&&
&& *************** Heat transfer options for DW  walls *******************
&&
  CONDENSE       && Natural Conv and Condensation HT is modelled
  HT-TRAN        ON  OFF  OFF  ON  ON
  RAD-HEAT       && Initiate radiadiation HT model
  EMSVT    0.85  && Dry-surface emissivties
           0.85  &&
           0.85  &&
           0.85  &&
           0.85  &&
           0.85  &&
           0.95  && Emissivity for the uppermost lower cell layer
  CESS           && Use Cess-Lian eqn for steam emittance
  GASWAL = 10.   && Mean beam lenght for the enclosure (m)
  EOI            && End of input block
&& ***********************************************************************
&&
&&
&&
&& ***************  Outer Wall of Drywell ********************************
&& Data must be entered twice because CONTAIN only models
&& one-half of a cylinder
&&
  STRUC
  NAME = DW-WALL1 && (1/2 of dw liner plate on wall)
  TYPE = WALL
  SHAPE = CYLINDER
  NSLAB = 1
  CHRLEN = 26.75
  CYLHT = 15.801
  TNODE = 322.04
  COMPOUND = CSTEEL
  X = 16.4430 16.4494
  EOI
&&
  NAME = DW-WALL2 && (1/2 of dw liner plate on wall)
  TYPE = WALL
  SHAPE = CYLINDER
  NSLAB = 1
```

```
   CHRLEN = 26.75
   CYLHT = 15.801
   TNODE = 322.04
   COMPOUND = CSTEEL
   X = 16.4430 16.4494
   EOI
&&
   NAME = DW-FLOOR  && Liner plate on Floor of drywell
   TYPE = FLOOR
   SHAPE = SLAB
   NSLAB = 1
   CHRLEN = 6.7
   SLAREA = 565.
   TNODE = 322.04
   COMPOUND = CSTEEL
   X = 0.     .0064
   EOI
&&
   NAME = DW-ROOF  && Liner plate on Roof of drywell
   TYPE = ROOF
   SHAPE = SLAB
   NSLAB = 1
   CHRLEN = 2.8
   SLAREA = 96.5
   TNODE = 322.04
   COMPOUND = CSTEEL
   X = 0.0    0.0064
   EOI
&&
&&
&& ****** Other heat structures in drywell ******************************
&&  Total steel volume of internals = 77.9 m3
&&  Total surface area of internals = 6132 m2
    NAME = DW-INS1  &&  Steel structures inside drywell
    TYPE = WALL
    SHAPE = SLAB
    NSLAB = 5
    CHRLEN = 3.0
    SLAREA = 3066.
    TUNIF = 322.04
    COMPOUND = CSTEEL CSTEEL CSTEEL CSTEEL CSTEEL
    X = 0.0  0.00254  0.00508  0.00762  0.01016  0.01270
    EOI
&&
    NAME = DW-INS2  &&  Steel structures inside drywell
    TYPE = WALL
    SHAPE = SLAB
    NSLAB = 5
    CHRLEN = 3.0
    SLAREA = 3066.
    TUNIF = 322.04
    COMPOUND = CSTEEL CSTEEL CSTEEL CSTEEL CSTEEL
    X = 0.0  0.00254  0.00508  0.00762  0.01016  0.01270
    EOI
```

```
&&
&&
&& **********************************************************************
&&
&&
&&
&& *********** SOURCE DATA FOR DRYWELL ***********************************
     SOURCE=1   && Number of Source tables for Drywell
&&
&& ***** Tabular Data for Source 1 in Drywell ****************************
     H2OV=1442  && Source is water and 1437 points are supplied
     IFLAG=2    && Use linear interpolation between data points
&&
&& TABULAR Values for Source 1 in Drywell (Seconds)
&&
&& break (actually accounts for reactor heat load)
&&
&&
&&
&&
T=       .000000E+00   .100000E+09
&&
MASS=    .000000E+00   .000000E+00

&&
ENTH=    .000000E+00   .000000E+00

&&
&&
&&
&&
&&
&&
&&
&&
      EOI  && End of Tabular Data for Source 1 in Drywell
&&
&&
&&
    ENGINEER   FLOV  1  2  1  17.07
      OVERFLOW   2  1  0.4572E0
    EOI

   LOW-CELL
     GEOMETRY  487.4
     POOL
       TEMP=322.04
       COMPOS=1   H2OL=0.1
       PHYSICS   BOIL   EOI
     EOI
    EOI
   EOF
```

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NUCLEAR ENGINEERING

CALCULATION / STUDY COVER SHEET
and
NUCLEAR RECORDS TRANSMITTAL SHEET

File # R2-1

1. Page 1 of 62 ~~65~~

*▷2. TYPE: CALC ▷3. NUMBER: EC - Ø52-Ø593 ▷4. REVISION: Ø

5. TRANSMITTAL#: K941Ø195 *▷6. UNIT: 3 *▷7. QUALITY CLASS: N *▷8. DISCIPLINE: 3

▷9. DESCRIPTION: HPCI and RCIC System Models for SABRE Code

SUPERCEDED BY: EC- -

10. Old Calculation#: SA-MAC-ØØ2-RØ Alternate#: SA-MAC-ØØ2 11. Cycle: ___

12. Computer Code or Model used: SABRE, FORTRAN Fiche [ ] Discs [ ] Amount ___

13. Application: ___

*▷14. AFFECTED SYSTEMS: Ø52, Ø5Ø

** If N/A then line 15 is mandatory.

*▷15. NON-SYSTEM DESIGNATOR: Risk

16. Affected Documents: ___

References: M-247, FF11Ø76ØSHØ1Ø1, M-1Ø8, FF127250SH62Ø1, FF12725ØSH56Ø1, FF12725ØSH63Ø1,

18. Equipment / Component #: ___

19. DBD Number: DBDØØ4, DBDØ41

▷20. PREPARED BY	▷21. REVIEWED BY
Print Name M.A.C.	Print Name R.A.L.
Signature *N/A BACKFIT EFFORT*	Signature *N/A BACKFIT EFFORT*
▷22. APPROVED BY / DATE	*23. ACCEPTED BY PP&L / DATE*
Print Name C. Kukielka 1Ø-23-94	Print Name
Signature *N/A BACKFIT EFFORT*	Signature *N/A BACKFIT EFFORT*

TO BE COMPLETED BY NUCLEAR RECORDS

NR-DCS SIGNATURE/DATE [signature] 10/10/94

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EPM-QA-216A, Rev.1

PP&L

CALCULATION COVER SHEET

CALC. NO. SA-MAC-002
FILE NO. R2-1
SUPERSEDED BY

SAFETY RELATED [ ]
ASME III OR XI [ ]
OTHER QUALITY [ ]
NON QUALITY [X]

PROJECT SSES EOP Ugrade to EPG Rev.4

ER/CTN NO. ______

DESIGN ACTIVITY/PMR NUMBER ______

PAGE 2 OF 65

TITLE/DESCRIPTION HPCI and RCIC System Models for SABRE Code

SYSTEMS AFFECTED N/A

STATEMENT OF PROBLEM

a model, based on pump and turbine performance data, is developed to simulate HPCI & RCIC system operation.

DESIGN BASIS (EPM-QA-208 or EPM-QA-400)

N/A

REFERENCES/FORMULAE

See Sections 2 (pp. 5-49) and 4 (p. 53).

SUMMARY/CONCLUSIONS

See Section 3, p. 50.

ENGINEERING TURNOVER

(ETO) BINDER AFFECTED? [ ] YES - If yes, enter: Binder# ______ Vol. ______

Calc. File ______ Pgs. ______

[✓] NO

Rev. No.	Date	Prepared By	Reviewed/ Checked By	Date	Approved By	Date
0	12/3/92	M.A. Chaiko	R.A. Kengel	12/8/92	C. Kukielka	12/11/92

PP&L Form 2454 (10/83)
Cat. #973401

SA-MAC-002

Dept. ______ Date ______ 19____ Designed by ______ Approved by ______

PENNSYLVANIA POWER & LIGHT COMPANY
CALCULATION SHEET

PROJECT ______

ER No. ______

Sht. No. 2A of ______

CONTENTS

Cat. #973401

SA-MAC-002

PENNSYLVANIA POWER & LIGHT COMPANY
CALCULATION SHEET

Dept. ______ Date ______ 19____ Designed by ______ Approved by ______

PROJECT ______

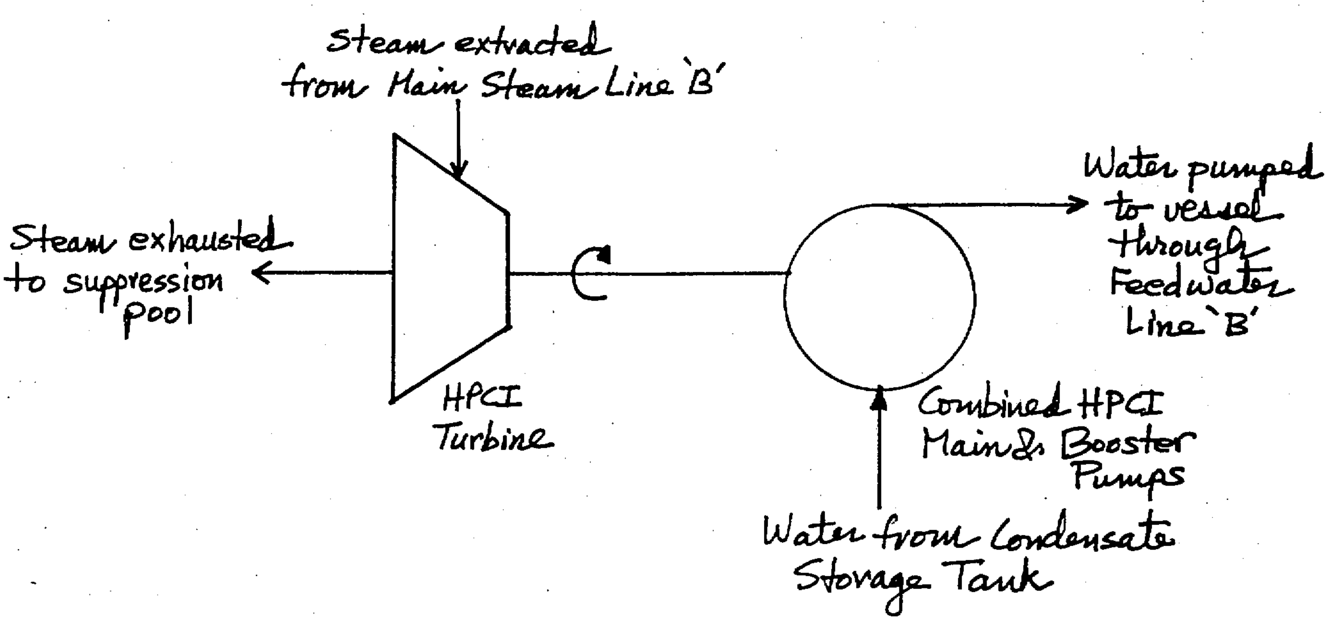
ER No. ______

Sht. No. 2B of ______

1. INTRODUCTION

In this calculation, models are developed to simulate operation of HPCI and RCIC systems. For a given reactor pressure and a specified pump flow rate, the turbine steam requirements are determined, and the mass and energy discharge rates to the suppression pool are computed.

The HPCI system flow paths are shown in the diagram below:



The HPCI pumps are modelled as a single pump capable of generating a combined total dynamic

Cat. #973401 | | SA-MAC-002

Dept. ______ Date ______ 19____ Designed by ______ Approved by ______

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CALCULATION SHEET

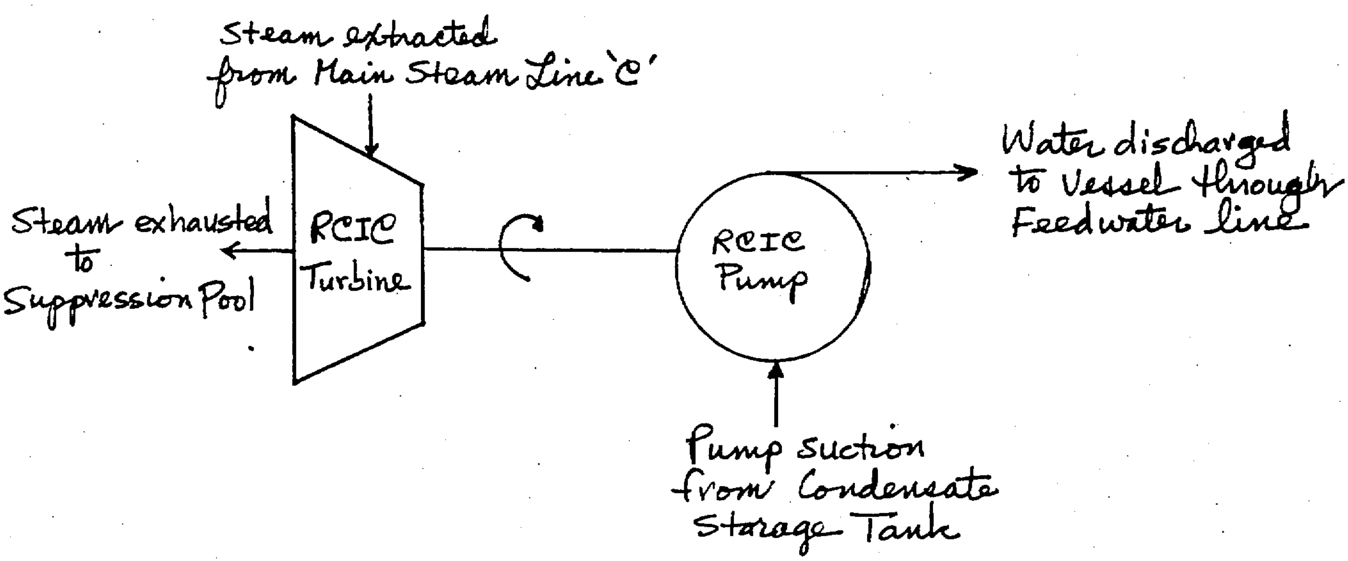
PROJECT ______

ER No. ______

Sht. No. 2C of ______

head equal to the sum of the HPCI main and booster pump TDHs. It is assumed that the HPCI system takes suction from the condensate storage tank (CST). A schematic diagram of the HPCI system, taken from ref. 1, is shown in Figure 1.1.

The overall flow paths for the RCIC system are shown in the following diagram.



A detailed schematic diagram of the RCIC System, taken from ref. 1, is given in Fig. 1-2.

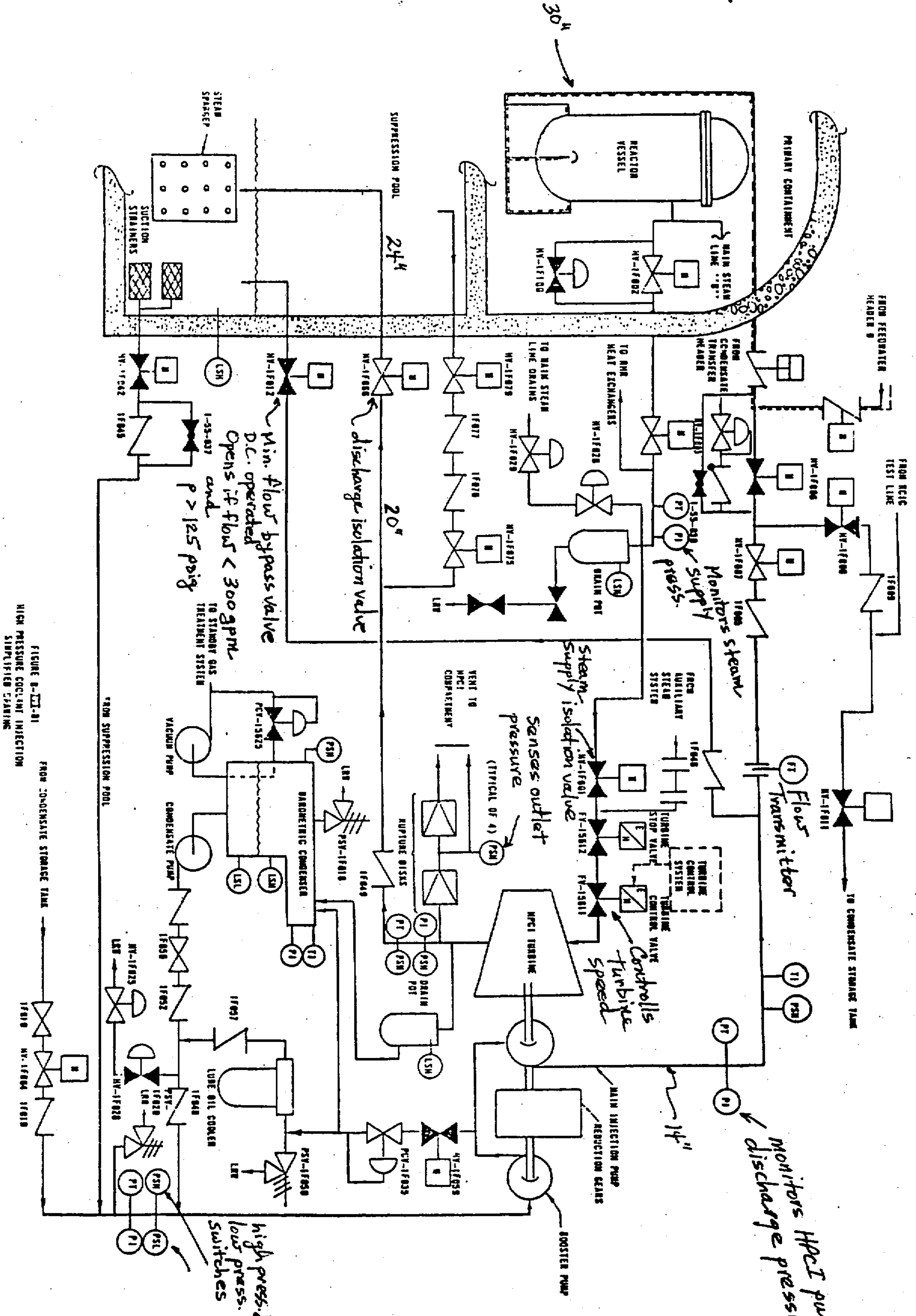


Figure 1.1 Schematic diagram of HPCI System (taken from ref. 1)

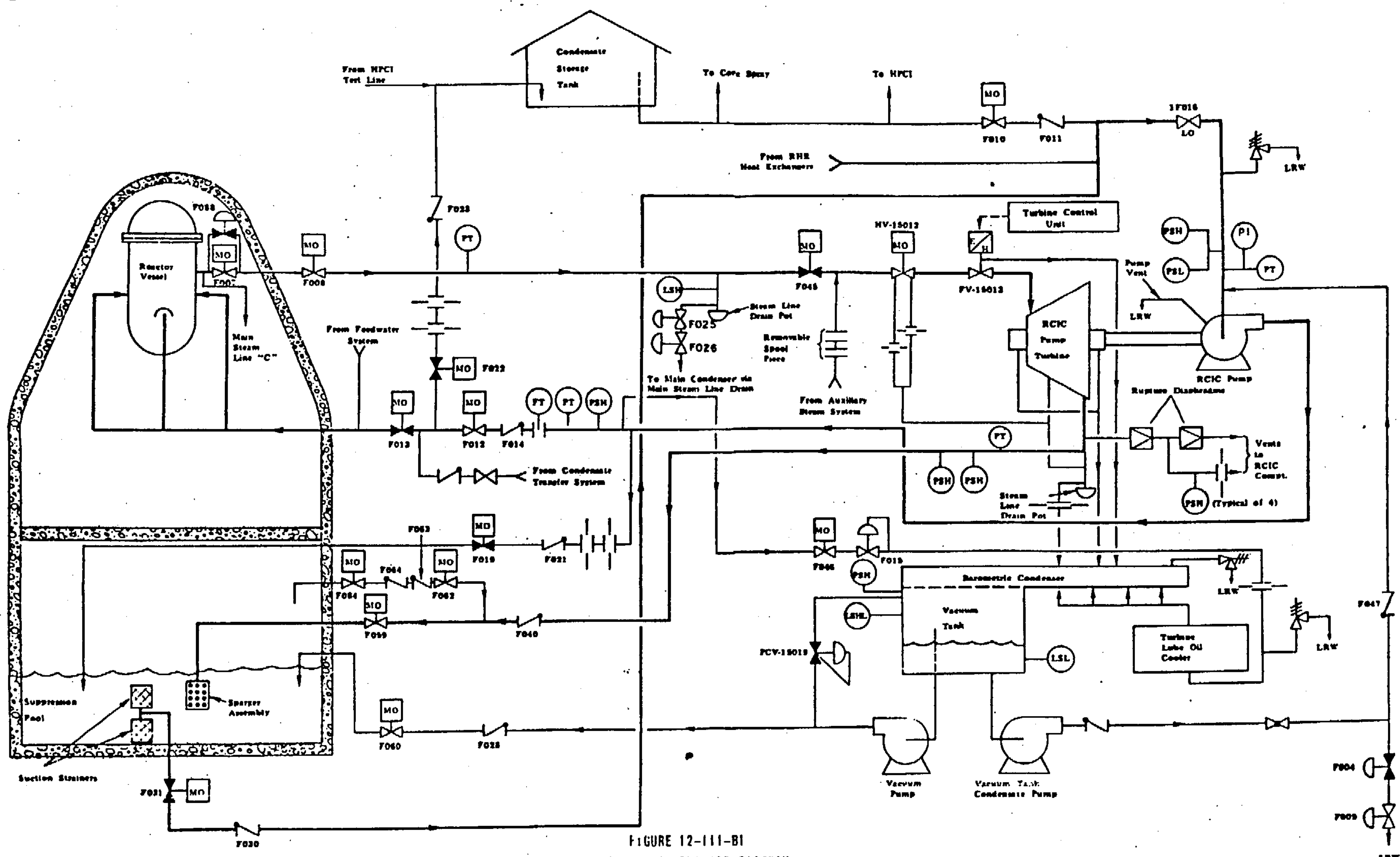


FIGURE 12-111-B1

RCIC SYSTEM SIMPLIFIED DIAGRAM

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Figure 1-2
(Taken from ref. 1)

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2. METHODOLOGY

2.1 HPCI System

For the model presented here, the reactor vessel pressure and the HPCI pump flowrate are specified, and the following parameters are computed:

- Pump Total dynamic head (TDH)
- Pump and turbine speed
- Turbine horsepower output
- Turbine steam flow
- Turbine discharge specific enthalpy

Calculational details for these operating parameters are given in the following subsections.

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2.1.1 Calculation of HPCI Pump TDH

In this analysis, the HPCI main and booster pumps are combined and treated as a single pump. The TDH requirement for the combined main and booster pumps is given by

$$TDH = \left(\frac{g_c}{g}\frac{P}{\rho} + z\right)_d - \left(\frac{g_c}{g}\frac{P}{\rho} + z\right)_s + H_f \qquad (2-1)$$

where
- P = pressure (lb_f/ft^2)
- ρ = fluid density (lbm/ft^3)
- z = elevation (ft)
- H_f = TDH required to overcome frictional resistance (ft)
- TDH = total dynamic head (ft).
- g = acceleration due to gravity = 32.2 ft/sec^2
- g_c = 32.2 $ft \cdot lbm / lb_f \cdot sec^2$

In (2-1), the subscripts "d" and "s" refer to "discharge" and "suction" respectively.

TDH due to Elevation

$$z_d - z_s = \left\{ \begin{matrix} \text{Elevation at HPCI} \\ \text{Pump Discharge to} \\ \text{Reactor Vessel} \end{matrix} \right\} - \left\{ \begin{matrix} \text{Elevation of} \\ \text{Condensate} \\ \text{Storage Tank} \end{matrix} \right\}$$

where

$$\left\{ \begin{matrix} \text{Elevation at HPCI} \\ \text{Pump Discharge to} \\ \text{Reactor Vessel} \end{matrix} \right\} = \left\{ \begin{matrix} \text{Elevation at} \\ \text{Bottom of} \\ \text{Vessel} \end{matrix} \right\} + \left\{ \begin{matrix} \text{Height of feedwater} \\ \text{Sparger above} \\ \text{bottom of vessel} \end{matrix} \right\}$$

$$= \underset{(\text{ref. }2)}{732'\text{-}4''} + \underset{(\text{ref. }3)}{498.5''} = 773.87'$$

$$\left\{ \begin{matrix} \text{Elevation of} \\ \text{Condensate} \\ \text{Storage Tank} \end{matrix} \right\} = 672'\text{-}0'' \quad (\text{ref. }4)$$

$$\therefore \quad z_d - z_s = 773.87' - 672.0' = \boxed{101.9 \text{ ft.}} \qquad (2\text{-}2)$$

TDH Due to Static Pressure

$$\frac{g_c}{g}\left(\frac{1}{\rho}\right)(p_d - p_s) = \left(\frac{g_c}{\rho g}\right)\left[p^* - p_{CST}\right] \qquad (2\text{-}3)$$

where

$p^* \cong$ reactor steam dome pressure (lb_f/ft^2)

p_{CST} = pressure in condensate storage tank

$= 1 \text{ atm} = (14.7)(144)\ lb_f/ft^2$

$p_{cst} = 2116.8\ lb_f/ft^2$

In (2-3), ρ is the fluid density in the CST.
Eqn. (2-3) becomes

$$\frac{g_c}{g}(P_d - P_s)/\rho = \left(\frac{g_c}{g}\right)\left[P^*(t) - 2116.8\right]/\rho_{CST} \qquad (2\text{-}4)$$

<u>TDH Required to Overcome Friction</u>

At this point, the TDH relation for the HPCI system is

$$TDH = 101.9\,ft. + \left(\frac{g_c}{g}\right)\left[P^*(t) - 2116.8\,\frac{lb_f}{ft^2}\right]/\rho_{CST} + H_f. \qquad (2\text{-}5)$$

The head-capacity curves for the HPCI main and booster pumps are shown in Figures 2-1 through 2-4. At 4100 rpm and a pump flow of 5000 gpm, the TDH of the main and booster pumps is

$$TDH\ (@\ 4100\,rpm\ \&\ 5000\,gpm) = 2250\,ft. + 725\,ft.$$
$$= 2975\,ft. \quad \text{(See Figures 2-1 \& 2-4)} \qquad (2\text{-}6)$$

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Approved by	HPCI Pump Parameters	

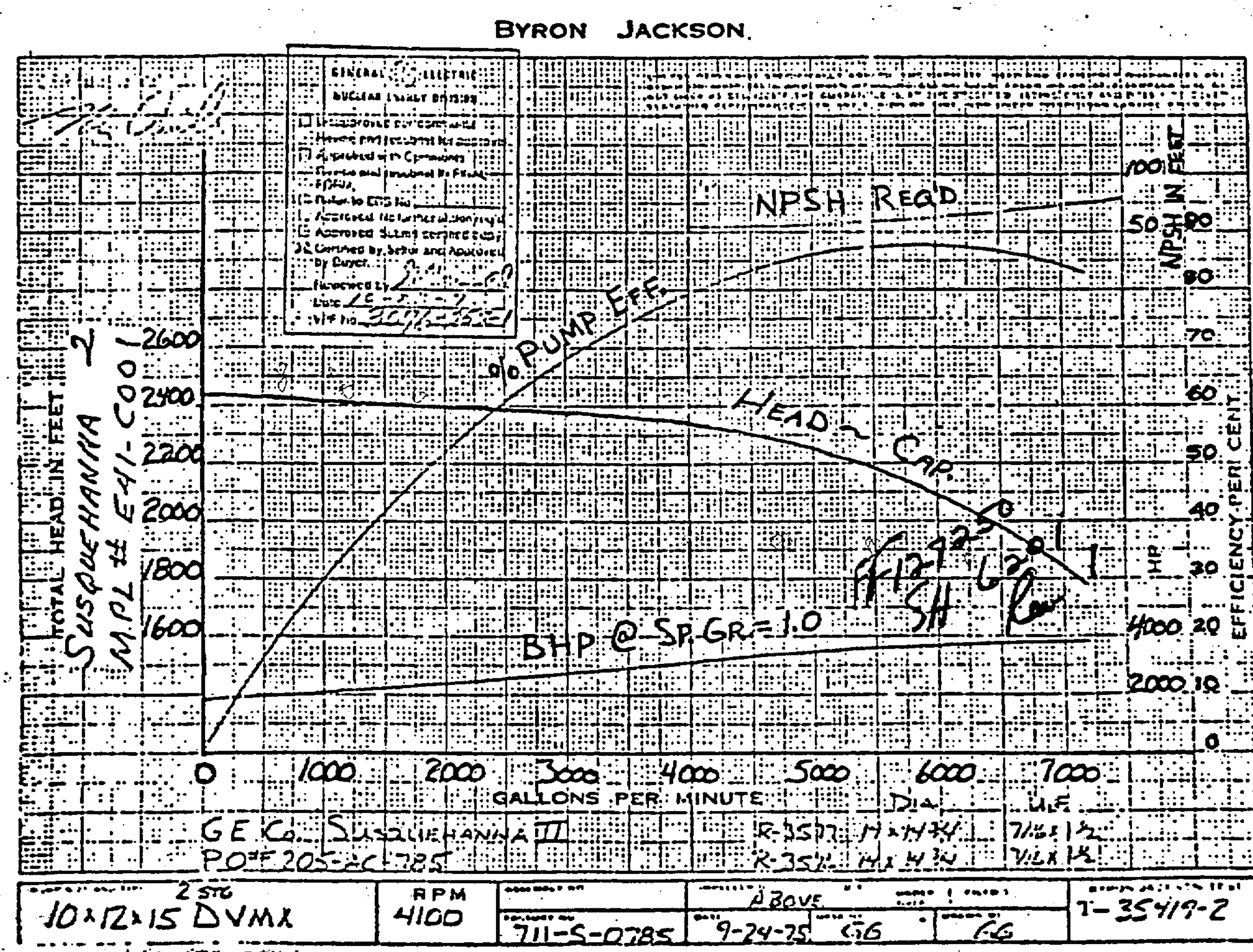

Figure 2-1

HEAD – CAPACITY CURVE FOR HPCI – MAIN PUMP AT PUMP SPEED OF 4100 RPM.
(taken from ref. 5)

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Approved by		

BYRON JACKSON

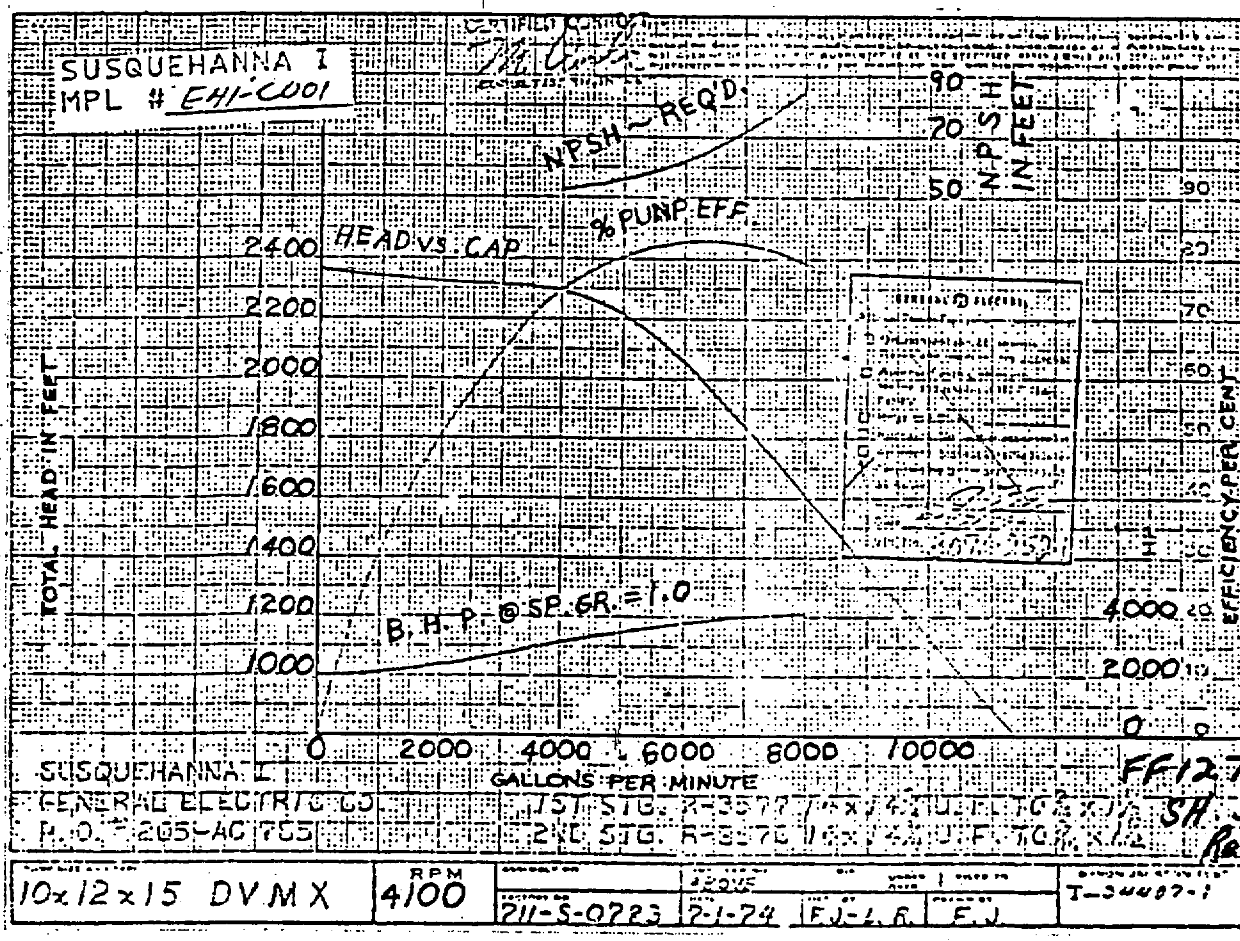

Figure 2-2

HEAD-CAPACITY CURVE FOR HPCI-MAIN PUMP AT PUMP SPEED OF 4100 RPM.

(taken from ref. 6)

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Byron Jackson Pump Division
BORG-WARNER CORPORATION

PUMP TEST DATA

Pump size and type: 12 X 15 X 15 DVMX

Impeller pattern	Diameter	Vanes			
2-3377	[illegible]	2	[illegible] 1½	[illegible]
[illegible]	[illegible]	7	[illegible] 1½	[illegible]

Guaranteed pumping conditions: R.P.M. 4140; G.P.M. 1900; [illegible] 1.0

Diff. vel. hd between gauges at 10 I.D. disch. and 12 I.D. suct. = 0.133 ft at 1900 G.P.M.

Test motor no. 35 [illegible] H.P. 2 poles 4160 volts

Motor eff. — Barometric pressure —

Tested by: [illegible] — Witnessed by: [illegible] — For: [illegible] Co. — Customer's order no.: [illegible] — Item no. — Job no. 711-S-0753

Notes: Vibration in mils:

	Vertical	Horiz.
Radial	4.4	3.6
Thrust	4.2	3.[illegible]

Reading No.	Suct. hd. Gauge #37 Head	Suct. corrected		Discharge head Gauge #55 2-1000 Head	Discharge corrected	ΔPSI	Elevation head	Differential velocity head	Total dynamic head in feet of water	Capacity (measured with 12×8 venturi) Head	Capacity G.P.M.	Water horse power	Brake horse power	Rel. reading	Equiv. H.P. input	Volts	Amps	Pump efficiency		Water temp. °F	Pump speed R.P.M.
1	16.0	16.6		545	545.5	528.9	1	6.5	1232.5	11.75	7090	2175	[illegible]	.448	2330			72.6		92	3531
2	16.2	16.81		375	375.4	[illegible]		7.1	840.1	12.80	7320	1547	2550	.420	2700			[illegible]		92	[illegible]
3	29.0	[illegible]		685	685.9	656.15		[illegible]	[illegible]	[illegible]	5450	[illegible]	[illegible]	.417	[illegible]			[illegible]		[illegible]	[illegible]
4	34.5	[illegible]		760	761.3	[illegible]		[illegible]	[illegible]	[illegible]	4350	[illegible]	[illegible]	[illegible]	2460			[illegible]		[illegible]	[illegible]
5	38.0	[illegible]		790	791.4	752.45		1.59	1753.37	2.85	3460	1520	[illegible]	[illegible]	2210			73.6		102	[illegible]
6	39.5	[illegible]		792	775.5	[illegible]		[illegible]	1762.22	2.15	3225	1350	[illegible]	[illegible]	2060			69.5		11[illegible]	[illegible]
7	42.0	[illegible]		805	806.5	763.60		[illegible]	1779.33	[illegible]	2300	[illegible]	[illegible]	[illegible]	1775			54.5		111	[illegible]
8	43.6	44.60		821	[illegible]	772.[illegible]	1	0	1213.0	0	0	0	[illegible]	[illegible]	1460			0		112	[illegible]
9																					
10																					
11													[illegible]								
12													[illegible]								
1									1615		8210		4100					72.6			4100
2									1100		7320		[illegible]					[illegible]			
3									2000		6240		[illegible]					[illegible]			
4									2215		4982		3475					[illegible]			
5									2290		3955		3105					[illegible]			
6									2310		3460		2895					[illegible]			
7									2320		2285		2460					54.3			
8									2360		0		2005					0			[illegible]
9																					
10																					
11																					
12																					

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Figure 2-3
HPCI - MAIN PUMP DATA
(taken from ref. 6)

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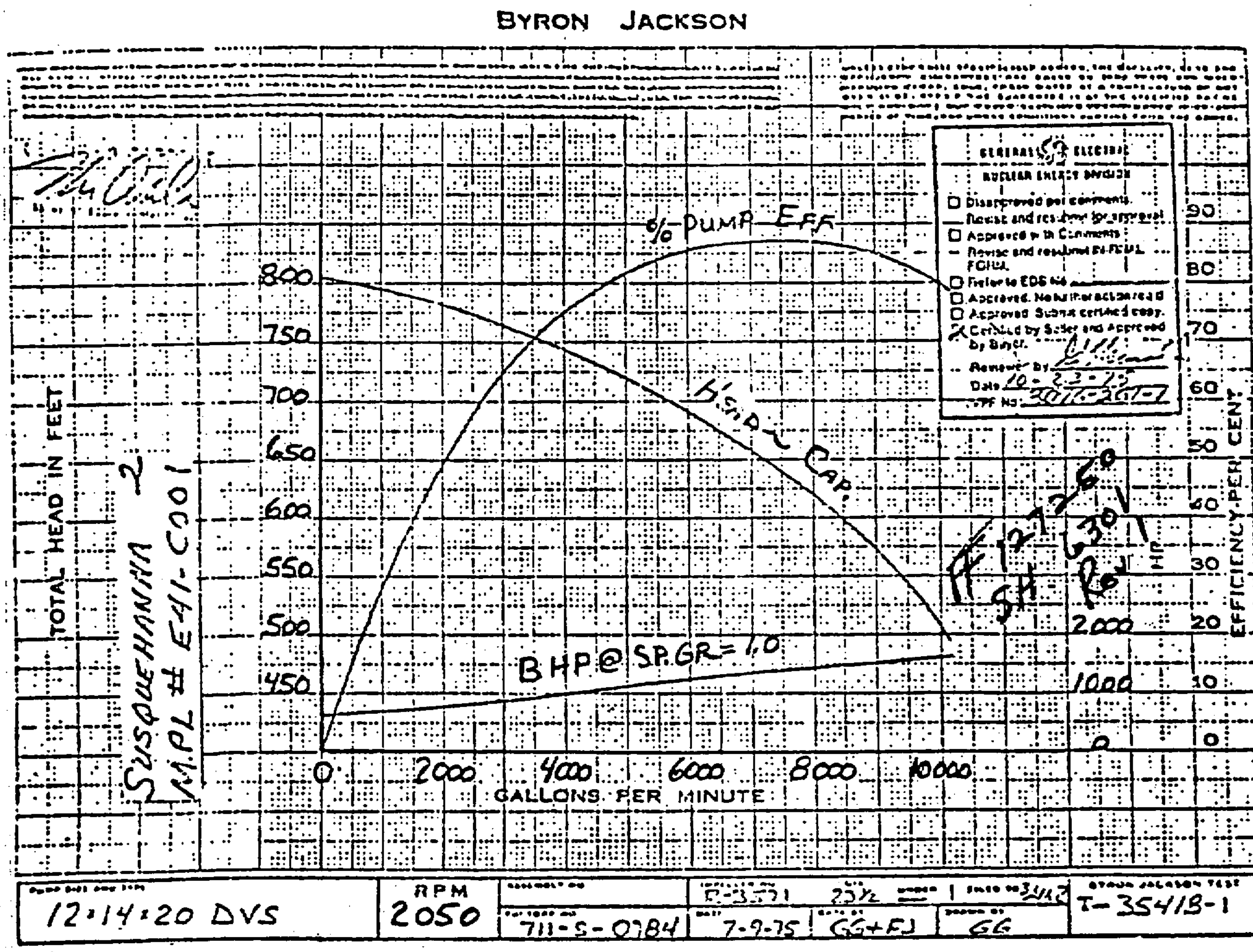

Figure 2-4

HEAD-CAPACITY CURVE FOR HPCI-BOOSTER PUMP AT PUMP SPEED OF 2050 RPM.

(taken from ref. 7)

In Eq. (2-5), the friction term can be expressed as

$$H_f = k W^2 \qquad (2\text{-}7)$$

where

W = HPCI pump flow (lbm/sec)
k = constant (ft·sec²/lbm²)

It is assumed that the condensate temperature is 120°F. Therefore,

$$\rho_{CST} = 61.7 \text{ lbm/ft}^3 \qquad (2\text{-}8)$$

and

$$W(@5000 \text{gpm}) = \frac{5000 \text{ gal}}{\text{min}} \left| \frac{\text{min}}{60 \text{ sec}} \right| \frac{\text{ft}^3}{7.4805 \text{ gal}} \left| \frac{61.7 \text{ lbm}}{\text{ft}^3} \right|$$

$$= 687.3 \text{ lbm/sec} \qquad (2\text{-}9)$$

Page 8-33 of ref. 1 indicates that the HPCI system can deliver 5000 gpm at ~4100 rpm with reactor pressure equal to 1172 psia. Substituting Eqs. (2-6), (2-7), (2-8), and (2-9) into (2-5) and setting P* equal to 1172 (144) psfa yields the following relation for the constant k:

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$$2975 = 101.9 + \left[(1172)(144) - 2116.8\right]/(61.7) + k(687.3)^2$$

$$\therefore \quad k = 3.64 \times 10^{-4} \qquad (2\text{-}10)$$

Thus, the required total dynamic head for the HPCI system as a function of flow rate and pressure is given by

$$(TDH)_{req} = 101.9 + \left[P^* - 2116.8\right]/(61.7) + (3.64 \times 10^{-4})\, W_{HPCI}^2 \qquad (2\text{-}11)$$

where

P^* = reactor pressure (lbf/ft²)

W_{HPCI} = HPCI pump flow rate (lbm/sec).

$(TDH)_{req}$ = required total dynamic head (ft)

2.1.2 Calculation of HPCI Pump Speed

The HPCI system consists of the main HPCI pump, a booster pump, a reduction gear unit, and a single stage turbine. The speed of the main pump corresponds exactly to the turbine speed since there is a direct coupling between them. The speed of the booster pump is reduced, relative to that of the turbine, by a ratio of 1.976:1 (ref. 1). This speed reduction is accomplished by means of the reduction gear unit.

In the following analysis, the HPCI pumps are treated as a single pump operating at a speed equal to the turbine speed. At rated conditions, about 80% of the TDH is generated by the main pump; therefore, the speed of the combined system is set equal to the speed of the main pump (i.e., the turbine speed).

In order to calculate the pump speed for a given TDH and flow rate, it is necessary to have a Head-Capacity curve for the combined pump system. This is formed by adding the Head-Capacity curves for the individual pumps which are shown in Figures 2-1 through 2-4. For computational purposes, a quadratic curve-fit of the combined Head-Capacity curve was developed. The curve-fit equation is given by

$$TDH = f_{4100}(Q) \qquad (2\text{-}12)$$

where

$$f_{4108}(Q) \equiv a_0 + a_1 Q + a_2 Q^2. \qquad (2\text{-}13)$$

The constants a_0, a_1, and a_2 are given by

$$\left.\begin{aligned} a_0 &= 3.112108 \times 10^{3} \\ a_1 &= 5.032516 \times 10^{-2} \\ \text{and} \quad a_2 &= -1.920122 \times 10^{-5}. \end{aligned}\right\} \qquad (2\text{-}14)$$

Note that (2-13) is valid only for a pump speed of 4100 rpm. The flow limits on (2-13) are

$$500 < Q < 10{,}500 \text{ gpm} \qquad (2\text{-}15)$$

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A plot of Eq (2-13) is shown in Figure 2-5.

In general, the pump flow rate will be specified, and the TDH can be determined from the system resistance curve, Eq. (2-11). Given Q and TDH, we want to calculate the pump speed N. Calculation of the pump speed can be accomplished by considering the pump affinity laws which are valid for geometrically similar pumps operating at constant specific speed N_S (see ref. 8, p.2-132). The affinity law relating TDH and Q at constant specific speed is

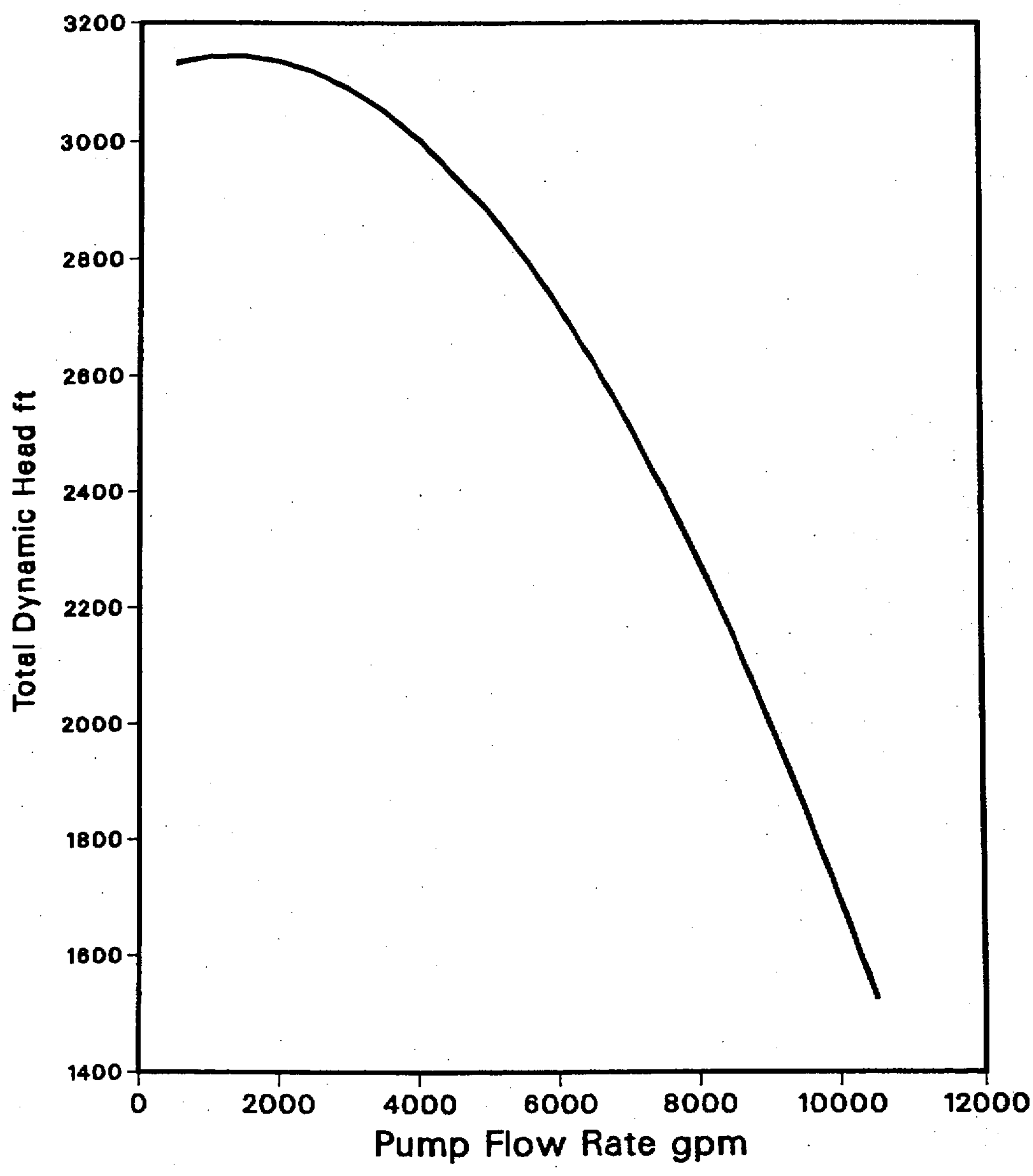
$$TDH = \left(\frac{TDH_0}{Q_0^2}\right) Q^2 \quad \text{for constant } N_S \qquad (2\text{-}16)$$

where the specific speed N_S is defined by (ref. 8, p. 2-131)

$$N_S = N Q^{1/2} / (TDH)^{3/4}. \qquad (2\text{-}17)$$

In (2-17), N is the pump speed (rpm).

Figure 2-5
Combined Head-Capacity Curve for HPCI Main and Booster Pumps
Pump Speed = 4100 rpm



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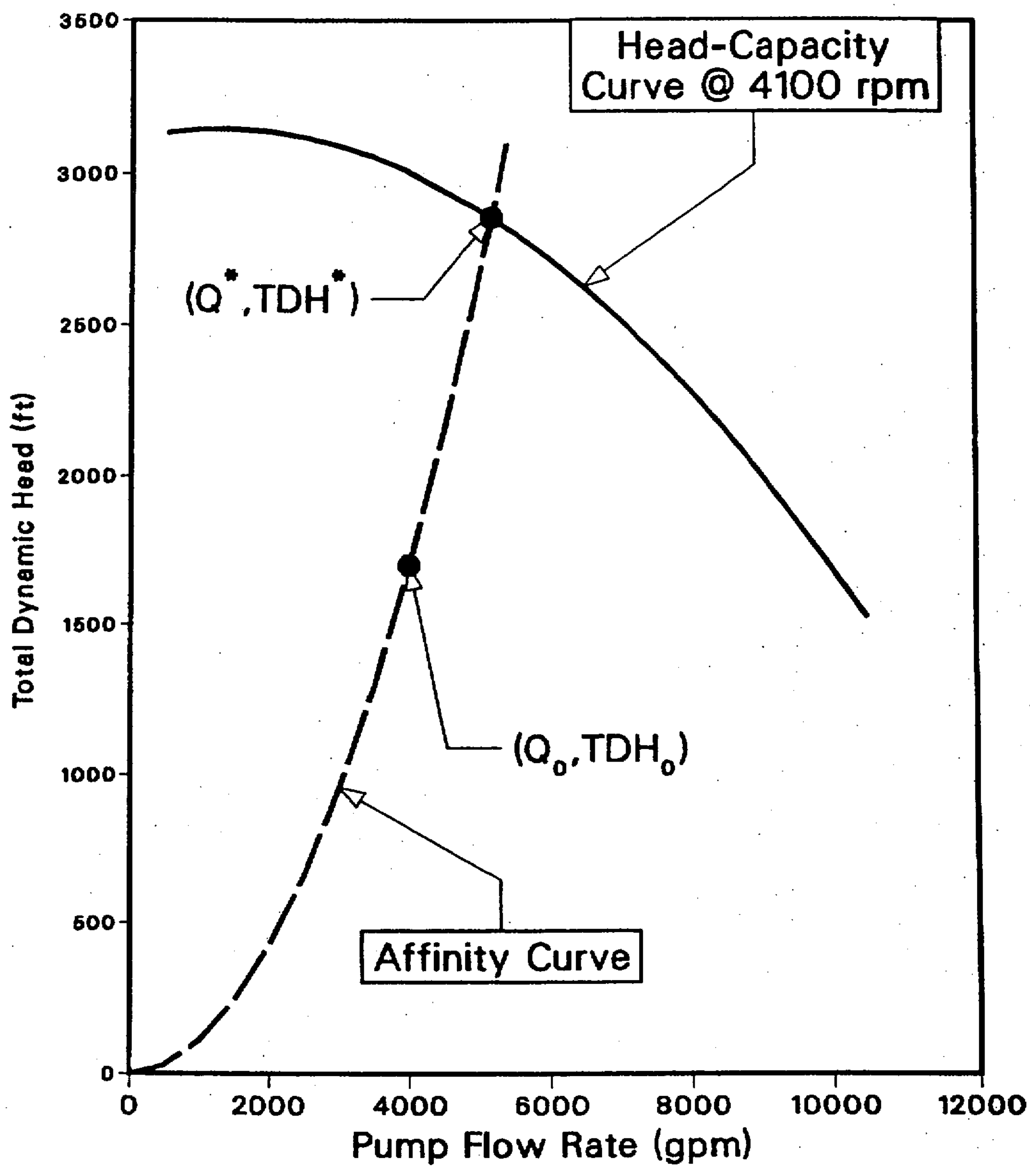
Reactor pressure and injection flow requirements define the HPCI operating point in the TDH-Q plane. In the following discussion, this operating point is denoted by (Q_0, TDH_0). In general, this operating point will not belong to the curve shown in Fig 2-5. For specificity, the operating point (Q_0, TDH_0) is taken as (4000, 1700). Figure 2-6 shows a plot of the TDH-Q curve for 4100 rpm along with the particular pump affinity equation, Eq. (2-16), passing through the point $(Q_0, TDH_0) = (4000, 1700)$. The objective is to calculate the pump speed N_0 associated with the point (Q_0, TDH_0).

Since the specific speed N_s is constant along the affinity curve, its value can be determined by computing this quantity on the Head-Capacity curve at the point where the TDH-Q curve intersects with the affinity curve. The equation for the affinity curve in Fig 2-6 is

Figure 2-6
HPCI Head-Capacity Curve and Affinity Law



$$TDH = \left(\frac{TDH_0}{Q_0^2}\right) Q^2 = \left(\frac{1700}{(4000)^2}\right) Q^2 \qquad (2\text{-}18)$$

Equating (2-18) and (2-13), and solving for Q gives the flow rate Q* at the intersection point for the two curves shown in Fig. 2-6. The result is

$$Q^* = \frac{-a_1 - \sqrt{a_1^2 - 4\left[a_2 - \left(\frac{TDH_0}{Q_0^2}\right)\right] a_0}}{2\left[a_2 - \left(\frac{TDH_0}{Q_0^2}\right)\right]} \qquad (2\text{-}19)$$

The TDH at the intersection point is given by

$$TDH^* = \left[\frac{TDH_0}{Q_0^2}\right] (Q^*)^2, \qquad (2\text{-}20)$$

and the pump specific speed at the intersection point is defined by

$$N_s^* = (4100)\,(Q^*)^{1/2} / (TDH^*)^{3/4}. \qquad (2\text{-}21)$$

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Since the specific speed is constant along the affinity curve, the speed N_0 corresponding to the point (Q_0, TDH_0) is given by

$$N_0 = N_s^* (TDH_0)^{3/4} / (Q_0)^{1/2}. \qquad (2\text{-}22)$$

Equations (2-19) to (2-22) gives a sequential prescription for computing the pump speed N_0 given the pump TDH and flow rate, (Q_0, TDH_0).

2.1.3 Calculation of HPCI-Pump Power Requirement

Brake horsepower (BHP) requirements for the HPCI main and booster pumps are given in Figures 2-2 and 2-4. These two curves define the pump power requirements as a function of flow for turbine speed equal to 4100 rpm. The associated pump TDH is also shown in these figures. The individual BHP curves were added to get a BHP-Q curve for the combined HPCI system. Here it is assumed that the speed of the combined system (i.e., the main and booster pumps combined together) is defined by the speed of the main HPCI pump. Data points for the combined system are given in Table 2-1. A fourth-order polynomial is used to represent the combined BHP as a function of flow rate Q for operation at 4100 rpm. The polynomial representation is given by

$$BHP = g_{4100}(Q) \qquad (2\text{-}23)$$

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Table 2-1

BHP vs. Q for Combined HPCI Main and Booster Pumps Operating at 4100 rpm.

Flow, Q (gpm)	Combined BHP
0	2655.
1000	2900
2000	3150
3000	3550.
4000	4200.
5000	4650.
6000	5050.
7000	5250
8000	5550
9000	5700
10,000	6000
11,000	6200
12,000	6400

where

$$g_{4100}(Q) \equiv b_0 + b_1 Q + b_2 Q^2 + b_3 Q^3 + b_4 Q^4 . \qquad (2\text{-}24)$$

The constants b_i were determined by a least-squares procedure and are defined by

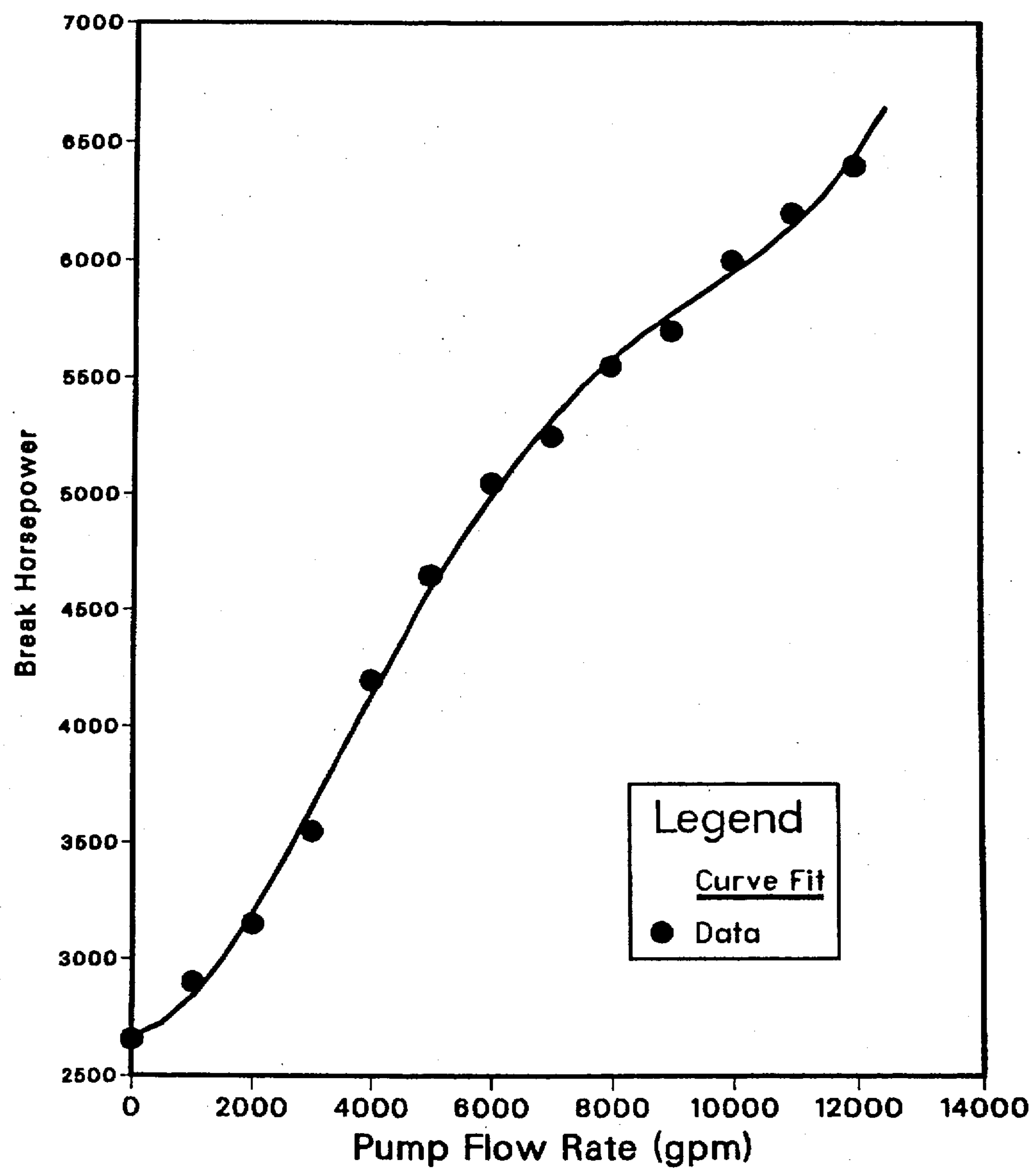
$$\left.\begin{aligned} b_0 &= 2.665284 \times 10^{3} \\ b_1 &= 5.022520 \times 10^{-2} \\ b_2 &= 1.417646 \times 10^{-4} \\ b_3 &= -1.851390 \times 10^{-8} \\ \text{and} \quad b_4 &= 7.112557 \times 10^{-13} . \end{aligned}\right\} \qquad (2\text{-}25)$$

Figure 2-7 shows a comparison of Eq. (2-23) with the data given in Table 2-1.

Equation (2-23) gives the HPCI pump power requirement for operating points belonging to the TDH-Q curve shown in Fig. 2-5. In order to determine the power requirement for any operating point (Q_0, TDH_0), the following pump affinity law is employed (ref. 8, p. 2-132):

$$BHP_0 = BHP^* \left(\frac{Q_0}{Q^*}\right)^3 \qquad (2\text{-}26)$$

Figure 2-7
HPCI BHP vs. Flow Curve for Combined Main
and Booster Pumps at Turbine Speed of 4100 rpm



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where Q^*, which is a function of Q_o and TDH_o, is given by Eq. (2-19). BHP^* is obtained from Eq. (2-23) with Q set equal to Q^*.

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2.1.4 Calculation of HPCI Turbine Steam Flow

Figure 2-8 gives a locus of operating states in (BHP, W_s, N) space where BHP is turbine horsepower, W_s is turbine steam flow rate, and N is turbine speed (which is equal to pump speed). In addition, Curve ③ in Fig. 2-8 gives the minimum pressure required for a particular operating condition.

For a given turbine speed, curve ① in Fig. 2-8 gives the power that the turbine can generate for the corresponding steam flow indicated on Curve ②. Since the turbine speed and power are already determined as part of the pump calculations (i.e., from Eqs. (2-22) and (2-26)), the power obtained from Fig. 2-8 will, in general, not match the power requirement of the pump. In order to force agreement between the pump power and the turbine power, the steam flow rate is adjusted while maintaining constant turbine

HPCI

(oval) => Notes added by MAE

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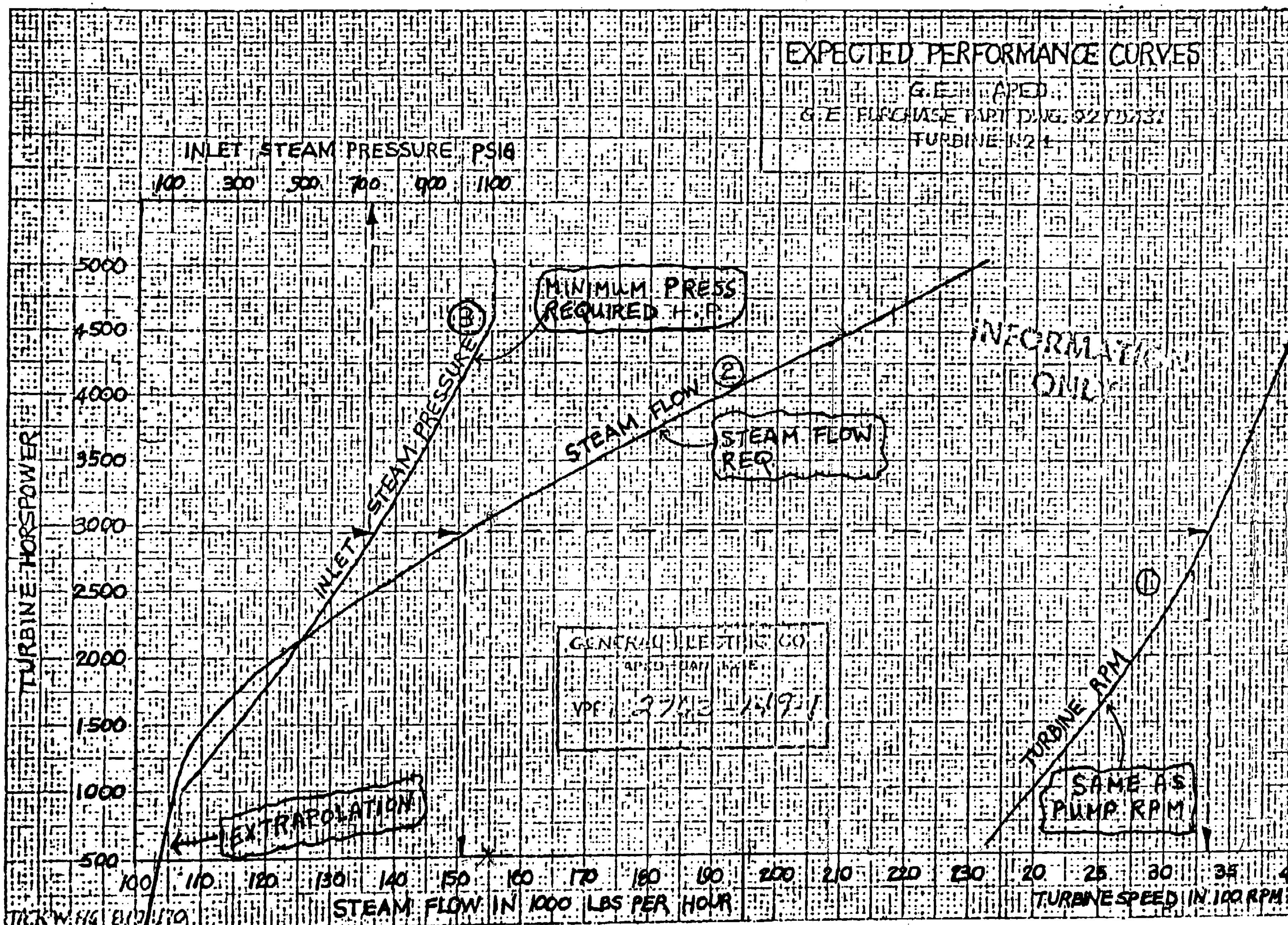

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speed. It is assumed that the turbine power output, at constant speed, is proportional to the mass flow rate of steam. This assumption implies that the turbine efficiency is relatively insensitive to flow when speed is held constant. The turbine steam flow rate is therefore obtained from (W_{so} and W_s' have units of lbm/hr)

$$W_{so} = W_s' \left(\frac{BHP_o}{BHP'} \right) \qquad (2\text{-}27)$$

where W_s' and BHP' are the steam flow rate and turbine horsepower obtained directly from Figure 2-8 using the pump speed N_o computed from Eq. (2-22). BHP_o is the power requirement for the pump computed from Eq. (2-26), and W_{so} is the desired steam flow rate which corresponds to N_o and BHP_o. An outline of the complete calculational procedure for W_{so} is given below:

1. Given the reactor pressure and the HPCI flow rate, the pump total dynamic head is calculated from Eq. (2-1).

2. The operating speed of the combined HPCI pump, which consists of the main and booster pumps, is obtained from Eq (2-22).

3. The horsepower requirement for the combined pump is computed from Eq. (2-26).

4. A curve-fit polynomial representation of curve ① in Figure 2-8 is used to compute the turbine power BHP′ from the pump speed N_o. The curve-fit polynomial is given by

$$BHP' = c_0 + c_1 N_o + c_2 N_o^2 + c_3 N_o^3 \qquad (2\text{-}28)$$

where

$$c_0 = -2.057844 \times 10^3$$

$$c_1 = 2.435237$$

$$c_2 = -7.184149 \times 10^{-4}$$

and

$$c_3 = 1.317793 \times 10^{-7}.$$

5. Using the value of BHP′ calculated in step 4, the turbine steam flow rate W_s' is obtained from a polynomial approximation to Curve ② of Fig. 2-8. The polynomial relation is

$$W_s' = d_0 + d_1 BHP' + d_2 (BHP')^2 + d_3 (BHP')^3 + d_4 (BHP')^4 + d_5 (BHP')^5 \qquad (2\text{-}29)$$

(W_s' has units of lbm/hr)

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where

$d_0 = 1.021897 \times 10^{5}$

$d_1 = 4.414625$

$d_2 = -6.261045 \times 10^{-3}$

$d_3 = 6.985182 \times 10^{-6}$

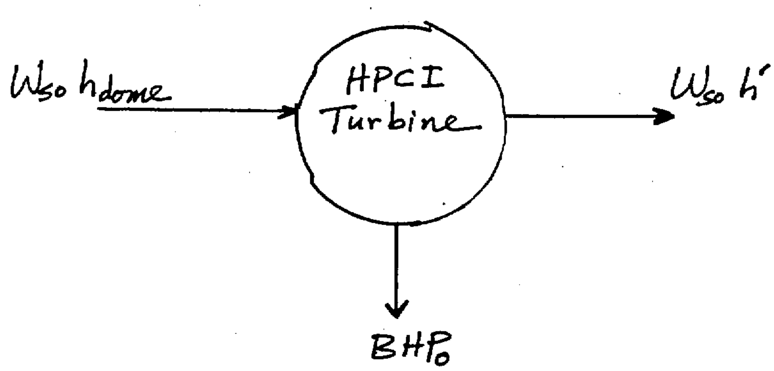
$d_4 = -1.454849 \times 10^{-9}$

and $d_5 = 9.563225 \times 10^{-14}$.

6. The actual turbine steam flow rate is then calculated from Eq (2-27).

2.1.5 Calculation of Energy Discharge Rate to Suppression Pool (from HPCI Turbine)

The steam-liquid mixture exiting the HPCI turbine is discharged directly to the suppression pool which contributes to pool heat-up. The specific enthalpy h' of the discharge stream is computed from the following energy balance:



$$W_{so}\, h_{dome} = BHP_o \cdot (2546.6) + W_{so}\, h' \qquad (2\text{-}30)$$

where

W_{so} = HPCI turbine steam flow (lbm/hr)

h_{dome} = specific enthalpy of steam-dome fluid (Btu/lbm)

BHP_o = turbine horsepower

h' = discharge specific enthalpy (Btu/lbm)

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In (2-30), the steam dome specific enthalpy is known from other calculations or is specified. The steam flow rate W_{SO} and the turbine horsepower BHP_o are computed from Eqs. (2-27) and (2-26) respectively.

2.2 RCIC System

As in the case of the HPCI system model discussed in Section 2.1, the reactor pressure and the RCIC injection flow rate are specified and the following system operating parameters are calculated:

- Pump total dynamic head
- Pump and turbine speed
- Turbine horsepower
- Turbine steam flow
- Turbine discharge specific enthalpy

Calculational details for each of these parameters are presented in the following sections.

2.2.1 Calculation of RCIC Pump Total Dynamic Head

The RCIC pump TDH can be calculated from

$$TDH = \left(\frac{g_c}{g}\frac{P}{\rho} + z\right)_d - \left(\frac{g_c}{g}\frac{P}{\rho} + z\right)_s + H_f \qquad (2\text{-}31)$$

where

P = pressure (lb_f/ft^2)
ρ = fluid density (lbm/ft^3)
z = elevation (ft)
g = acceleration due to gravity (32.2 ft/sec^2)
g_c = 32.2 $ft \cdot lbm/lb_f \cdot sec^2$
H_f = TDH required to overcome friction (ft.)
TDH = pump total dynamic head (ft.)

In (2-31), the subscripts "d" and "s" refer to "discharge" and "suction" respectively.

TDH due to Elevation

The elevation head for the RCIC system is the same as that for the HPCI system. Therefore,

$$z_d - z_s = 101.9 \text{ ft.} \qquad (\text{see Eq. } (2\text{-}2)) \qquad (2\text{-}32)$$

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TDH Due to Static Pressure

The TDH head due to static pressure is the same as that given previously for the HPCI system (see Eq. (2-3))

$$\therefore \quad \frac{g_c}{g}(P_d - P_s)/\rho = \left(\frac{g_c}{g}\right)\left[P^*(t) - 2116.8\right]/\rho_{CST} \qquad (2\text{-}33)$$

where P^* = reactor pressure (lb_f/ft^2)

ρ_{CST} = density of water in condensate storage tank (lbm/ft^3).

TDH Required to Overcome Friction

The friction term, H_f, in Eq. (2-31) is approximated by

$$H_f = k W_R^2 \qquad (2\text{-}34)$$

where k = friction constant

W_R = RCIC injection flow rate (lbm/sec).

Combining (2-32), (2-33), and (2-34) with (2-31) gives the RCIC TDH as

$$TDH = 101.9 + \left[P^* - 2116.8\right]/\rho_{CST} + k W_R^2 \qquad (2\text{-}35)$$

where TDH has units of (ft.), P^* is in (lb_f/ft^2), ρ_{CST} has units of (lbm/ft^3), and W_R is specified in (lbm/sec).

From p. 12-3 of ref. 1, the design TDH of the RCIC pump is 2940 ft. Apparently, this value of TDH corresponds to a reactor pressure of 1175 psia (see p. 12-19 of ref. 1). For a CST fluid density of 61.7 lbm/ft^3 (this corresponds to a fluid temperature of 120°F) and a RCIC flow rate of 600 gpm, Eq (2-35) reduces to

$$2940 = 101.9 + [(1175)(144) - 2116.8]/(61.7) + k(82.48)^2 \qquad (2\text{-}36)$$

Solving for the constant k gives

$$k = 0.0191. \qquad (2\text{-}37)$$

The TDH for the RCIC pump is then given by

$$TDH = 101.9 + [P^* - 2116.8]/(61.7) + (0.0191)W_R^2 \qquad (2\text{-}38)$$

where

TDH = total dynamic head (ft)
P^* = reactor pressure (lb_f/ft^2)
W_R = RCIC injection rate (lbm/sec).

2.2.2 Calculation of RCIC Pump Speed

The RCIC pump and turbine operate at the same speed. The method used to compute the pump/turbine speed is exactly the same as that outlined in Section 2.1.2 for the HPCI system. Therefore, only the major steps in the calculational process are presented here.

RCIC performance curves are given in Figures 2-9 and 2-10. Data points for TDH vs. flow at 3594 rpm, which were taken from Fig. 2-10, are listed in Table 2-2. The values listed in Table 2-2 were used to obtain a quadratic fit to the RCIC TDH vs. Q data at 3594 rpm. The curve-fit equation is

$$TDH = \bar{a}_0 + \bar{a}_1 Q + \bar{a}_2 Q^2 \qquad (2\text{-}39)$$

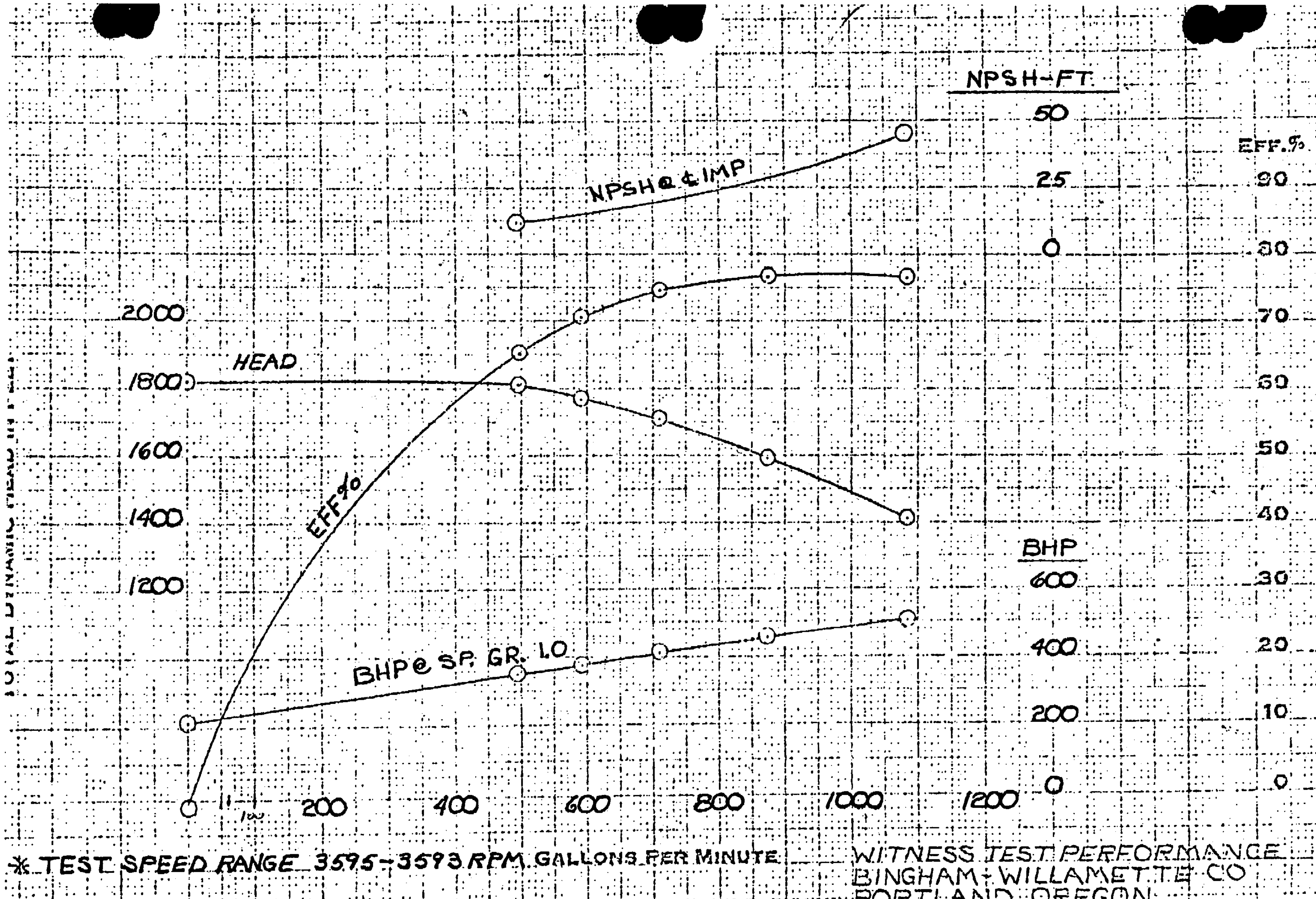
where TDH = RCIC pump Total dynamic head (ft)

Q = pump flow rate (gpm)

$\bar{a}_0 = 1.820796 \times 10^3$

$\bar{a}_1 = 2.657717 \times 10^{-1}$

$\bar{a}_2 = -5.953105 \times 10^{-4}$



GENERAL ELECTRIC CO

CHARACTERISTIC CURVE SHEET

BINGHAM PUMP DIVISION

BINGHAM-WILLAMETTE COMPANY

IMPELLER MAX DIA. 10 3/4	6X6X10 1/2 C.P. 4 STG. PUMP		
MIN. DIA	DIA. IMPELLER 10 1/4	IMPELLER PATT. (1) 413MSD-11 (4) 413MSD-2	3593* R.P.M.
EYE AREA 19.5 SQ IN	N.P.S.H REQUIRED	REFERENCE 31225	CURVE NO 31224

BINGHAM-WILLAMETTE CO ... OREGON SHREVEPORT LOUISIANA
BINGHAM PUMP CO BURNABY B.C. CANADA

6X6X10½ CP 4 — GENERAL ELECTRIC CO — T-210015-

HM-6 1250HP

3600 — C.H. — 10-

1	413MSD-11 5	10 ¾	10 ¼
2-4	413MSD-2 w/ 425VNS 5	10 ¾	10 ¼

H_A = 29.87 = 33.8
H_V ²/2G = 1.9/1000 GPM
HVP = 0.9 @ 73° & 1.0 @ 76°
HELEV = +0.2
CURVES No 31224, 31225

	Speed RPM	Suction Hg Col	Discharge Dwt "A"		C9 ft per 1000	Total Dynamic Head in Ft of Water	Capacity 4 Venturi GPM	Power 700	BHP			Constant Capacity 625 GPM		
1	3595	17.2	792	1830	0.2	1813.0	496	407	349	227	65.1	2878	4530	698
2	3595	17.8	772	1783	0.3	1765.5	591	433	375	264	70.3	1974	3802	443
3	3594	18.4	748	1728	0.5	1710.1	710	473	411	307	74.6	1325	3163	280
4	3594	19.2	698	1612	0.7	1593.5	874	523	459	352	76.6	815	2570	168
5	3593	17.0	618	1428	1.1	1412.1	1084	573	504	387	76.7	469	2071	97
6		* 10.0	610	1409	1.1	1400.1	1081	572	503	382	76.0			
7		⊕ -21.4	768	1774	0.2	1795.6	494	400	343	224	65.3			
8		10.2	792	1830	-	1819.8	0	255	210		0			
9														

10 NPSH = Hs + HA + Hv²/2G - HVP ± HELEV — WITNESS TESTED @ PORTLAND, OREGON OCT 9, 197

11 * NPSH = +10.0 + 33.8 + 2.2 - 0.9 + 0.2 = 45.3' @ ℄ IMP — [signature] FOR GENERAL ELECT. C

12 NPSH = 15.1' @ 625 GPM @ 2077 RPM — [signature] 10/9/72 FOR BINGHAM-WILLAMET

13 ⊕ NPSH = -21.4 + 33.8 + 0.5 - 1.0 + 0.2 = 12.1' @ ℄ IMP

14 NPSH = 19.4' @ 625 GPM @ 4548 RPM

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Table 2-2

RCIC TDH vs. Flow Data Used to Obtain Equation (2-39)

(Data taken from Fig. 2-10)

Pump Flow (gpm)	Pump TDH (ft.)
0	1819.8
496	1813.0
591	1765.5
710	1710.1
874	1593.5
1084	1412.1

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Following the methodology presented in Section 2.1.2, the RCIC pump speed is given by

$$N_0 = N_S^* \,(TDH_0)^{3/4} / (Q_0)^{1/2} \qquad (2\text{-}40)$$

where

Q_0 = the specified RCIC pump flow (gpm)

TDH_0 = the pump total dynamic head (ft) calculated from Eq. (2-38).

In (2-40) N_S^* is defined through

$$N_S^* = (3594)\,(Q^*)^{1/2} / (TDH^*)^{3/4} \qquad (2\text{-}41)$$

$$TDH^* = \left[\frac{TDH_0}{Q_0^2}\right] (Q^*)^2 \qquad (2\text{-}42)$$

and

$$Q^* = \frac{-\bar{a}_1 - \sqrt{\bar{a}_1^2 - 4\left[\bar{a}_2 - \left(\frac{TDH_0}{Q_0^2}\right)\right]\bar{a}_0}}{2\left[\bar{a}_2 - \left(\frac{TDH_0}{Q_0^2}\right)\right]} \,. \qquad (2\text{-}43)$$

2.2.3 Calculation of RCIC Pump Power Requirement

The pump power vs. flow data given in Fig. 2-9 was approximated with the following second-order polynomial:

$$BHP = \bar{b}_0 + \bar{b}_1 Q + \bar{b}_2 Q^2 \quad (\text{speed} = 3594\,\text{rpm}) \qquad (2\text{-}44)$$

where

$$\bar{b}_0 = 2.091550 \times 10^{2}$$
$$\bar{b}_1 = 2.967866 \times 10^{-1}$$
$$\bar{b}_2 = -2.019651 \times 10^{-5}.$$

In (2-44), Q is the RCIC pump flow in gpm, and BHP is the pump horsepower requirement. It is important to note that Eq. (2-44) holds only for operating points which belong to the Head-Capacity curve displayed in Fig. 2-9. For a general operating point the pump power requirement is determined as in Section 2.1.3. With this approach, the defining relation for the pump horsepower is

$$BHP_o = BHP^* \left(\frac{Q_o}{Q^*}\right)^3 \qquad (2\text{-}45)$$

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where Q_0 is the specified pump flow in gpm, Q^* is given by Eq. (2-43), and BHP^* is defined by

$$BHP^* = \bar{b}_0 + \bar{b}_1 Q^* + \bar{b}_2 (Q^*)^2 . \qquad (2\text{-}46)$$

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2.2.4 Calculation of RCIC Turbine Steam Flow

The performance curves shown in Fig. 2-11 give the RCIC turbine steam flow requirement as a function of turbine speed and turbine horsepower. Using a least-squares procedure, a third-order curve fit of this data was carried out. The curve fit equation is (W_{SO} has units of lb_m/hr)

$$W_{SO} = \bar{c}_0 + \bar{c}_1 N_0 + \bar{c}_2 BHP_0 + \bar{c}_3 N_0^2 + \bar{c}_4 BHP_0^2 + \bar{c}_5 N_0 BHP_0 + \bar{c}_6 N_0^2 BHP_0 + \bar{c}_7 BHP_0^2 N_0 + \bar{c}_8 BHP_0^3 + \bar{c}_9 N_0^3 \qquad (2\text{-}47)$$

where N_0 is the pump speed (rpm) obtained from Eq. (2-40) and BHP_0 is the pump horsepower requirement given by Eq. (2-45). The constants $\bar{c}_0$ through $\bar{c}_9$ are defined by

$$\bar{c}_0 = 1.498352 \times 10^4$$

$$\bar{c}_1 = -1.308682\ 10^1$$

$$\bar{c}_2 = 9.371714 \times 10^1$$

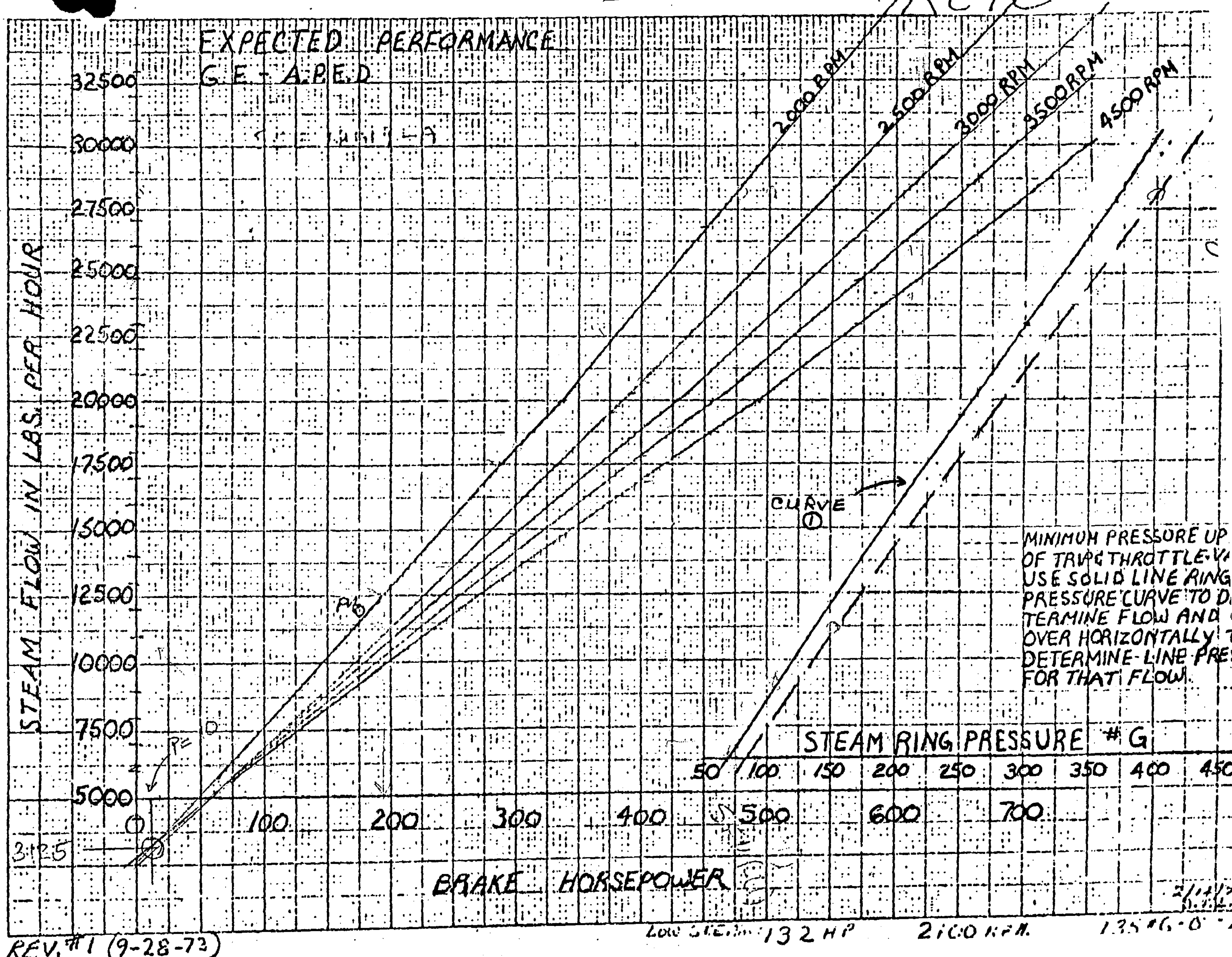
$$\bar{c}_3 = 4.382964 \times 10^{-3}$$

[redacted]

THE TERRY STEA[redacted]NE CO., HARTFORD, CONN.

[redacted]%

RCIC



$$\bar{c}_4 = 1.255254 \times 10^{-2}$$

$$\bar{c}_5 = -2.920010 \times 10^{-2}$$

$$\bar{c}_6 = 3.671393 \times 10^{-6}$$

$$\bar{c}_7 = -3.883010 \times 10^{-6}$$

$$\bar{c}_8 = 5.801522 \times 10^{-6}$$

$$\bar{c}_9 = -4.614200 \times 10^{-7}.$$

A summary of the calculational steps required to obtain the RCIC turbine steam flow rate are given below:

1. The RCIC pump flow Q_o is specified. For a given reactor pressure P^+, the pump TDH requirement is computed from Eq. (2-38)
2. The pump speed is then calculated from Eq. (2-40).
3. The horsepower requirement for the RCIC pump is obtained from Eq. (2-45).
4. the steam flow rate through the RCIC turbine is given by Eq. (2-47).

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2.2.5 Calculation of Energy Discharge Rate to Suppression Pool from RCIC Turbine

The specific enthalpy h' (Btu/lbm) of the steam-liquid mixture exiting the turbine is given by (see Section 2.1.5)

$$h' = h_{dome} - \frac{BHP_o\,(2546.6)}{W_{so}} \qquad (2\text{-}48)$$

where h_{dome} = steam dome enthalpy (Btu/lbm)
BHP_o = RCIC turbine horsepower
W_{so} = Inlet steam flow to turbine (lbm/hr)

Note that Eq. (2-48) assumes adiabatic steam flow from the reactor vessel to the inlet of the RCIC turbine.

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3. RESULTS

In order to exercise the methodology developed in the previous section, the computational steps (outlined in Section 2) were coded into a FORTRAN program. The source listing for this code is given in Appendix A. Tables 3-1 and 3-2 give calculated operating parameters for the HPCI and RCIC systems. In these calculations, the reactor pressure and the pump flow rate are specified; the turbine steam flow rate, turbine speed, and the turbine discharge enthalpy are then computed. A sample input file is given in Appendix B.

Table 3.1 HPCI Operating States

Rx Press (Psia)	HPCI Pump Flow (gpm)	Turb Steam Flow (Lbm/hr)	Turb Speed (rpm)	Turb Disch Enth (Btu/Lbm)
1200.0	5000.	222629.	4199.	1129.0
1200.0	4000.	189334.	4083.	1129.8
1200.0	3000.	159849.	3996.	1130.4
1200.0	2000.	135277.	3941.	1130.8
1200.0	1000.	117907.	3921.	1130.9
1000.0	5000.	191655.	3900.	1139.2
1000.0	4000.	160928.	3772.	1140.0
1000.0	3000.	133785.	3676.	1140.6
1000.0	2000.	111157.	3613.	1141.0
1000.0	1000.	95002.	3588.	1141.2
800.0	5000.	160002.	3577.	1147.7
800.0	4000.	132845.	3435.	1148.8
800.0	3000.	109149.	3326.	1149.8
800.0	2000.	89128.	3253.	1150.5
800.0	1000.	74394.	3221.	1150.9
600.0	5000.	130478.	3223.	1155.1
600.0	4000.	108227.	3062.	1157.2
600.0	3000.	88618.	2935.	1159.2
600.0	2000.	71307.	2849.	1160.7
600.0	1000.	57773.	2808.	1161.4
400.0	5000.	105607.	2828.	1161.9
400.0	4000.	88393.	2639.	1165.6
400.0	3000.	72787.	2486.	1168.9
400.0	2000.	57932.	2378.	1171.4
400.0	1000.	45066.	2323.	1172.7
200.0	5000.	85195.	2372.	1165.3
200.0	4000.	72591.	2139.	1170.9
200.0	3000.	61773.	1941.	1175.9
200.0	2000.	50714.	1792.	1179.8
200.0	1000.	38309.	1707.	1182.1

Table 3.2 RCIC Operating States

Rx Press (Psia)	RCIC Pump Flow (gpm)	Turb Steam Flow (Lbm/hr)	Turb Speed (rpm)	Turb Disch Enth (Btu/Lbm)
1200.0	600.	29068.	4620.	1120.9
1200.0	500.	26551.	4566.	1121.3
1200.0	400.	24335.	4526.	1121.8
1200.0	300.	22367.	4500.	1122.4
1200.0	200.	20602.	4489.	1123.1
1200.0	100.	18999.	4492.	1123.9
1000.0	600.	24109.	4260.	1130.6
1000.0	500.	21968.	4200.	1131.4
1000.0	400.	20083.	4154.	1132.3
1000.0	300.	18414.	4123.	1133.3
1000.0	200.	16923.	4108.	1134.4
1000.0	100.	15579.	4110.	1135.5
800.0	600.	19664.	3867.	1140.0
800.0	500.	17825.	3799.	1141.2
800.0	400.	16212.	3745.	1142.5
800.0	300.	14791.	3709.	1143.8
800.0	200.	13534.	3689.	1145.2
800.0	100.	12412.	3688.	1146.7
600.0	600.	15585.	3432.	1148.5
600.0	500.	13997.	3352.	1150.2
600.0	400.	12615.	3288.	1151.9
600.0	300.	11412.	3243.	1153.6
600.0	200.	10362.	3217.	1155.3
600.0	100.	9439.	3211.	1157.1
400.0	600.	11790.	2937.	1155.5
400.0	500.	10438.	2838.	1157.8
400.0	400.	9284.	2759.	1160.1
400.0	300.	8300.	2700.	1162.4
400.0	200.	7460.	2664.	1164.6
400.0	100.	6735.	2652.	1166.8
200.0	600.	8385.	2345.	1159.1
200.0	500.	7344.	2215.	1162.9
200.0	400.	6511.	2106.	1166.6
200.0	300.	5846.	2021.	1170.3
200.0	200.	5303.	1964.	1173.6
200.0	100.	4837.	1938.	1176.6

REFERENCES

1. "SSES Design Description Manual", Chapter 8, Pennsylvania Power & Light Co., Allentown, PA.

2. PP&L Drawing M-247.

3. PP&L Drawing "Primary System Weights & Volumes", FF110760, Sh. 0101, Rev. 1.

4. PP&L Drawing "Unit 1 P&ID Condensate & Refueling Water Storage", M-108.

5. PP&L Drawing FF127250, Sh. 6201, Rev. 1.

6. PP&L Drawing FF127250, Sh. 5601, Rev. 1.

7. PP&L Drawing FF127250, Sh. 6301, Rev. 1.

8. Karassik, I.J., Krutzsch, W.C., Fraser, W.H., and Messina, J.P., Pump Handbook, McGraw-Hill, New York, 1976.

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APPENDIX A

Listing of FORTRAN program for Calculation of HPCI and RCIC Operating Parameters

The FORTRAN program given in this appendix calculates the HPCI and RCIC pump speed, turbine steam flow, and turbine discharge enthalpy given the reactor pressure and the pump flow rate.

Table A.1 FORTRAN Program for Calculating HPCI and RCIC Operating Parameters

```
C***********************************************************************
C
C     PROGRAM FOR CALCULATING HPCI AND RCIC OPERATING PARAMETERS
C
C***********************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION P(100),QH(100),QR(100),T(100),WSTMH(100),SPDH(100),
     &          HDISH(100),HDISR(100),WSTMR(100),SPDR(100),
     &          HPH(100),HPR(100)

C**** READ NUMBER OF OPERATING POINTS
      READ(5,*) NSTATE

C**** SPECIFY INDEPENDENT PARAMETERS
      READ(5,*) ( KCASE,QH(J),QR(J),P(J),T(J), J=1,NSTATE )

C**** CALCULATE HPCI AND RCIC OPERATING PARAMETERS
      DO 10 J=1,NSTATE,1

      CALL SHPCI( P(J), QH(J), T(J), WSTMH(J), SPDH(J), HDISH(J),
     &            HPH(J) )
      CALL SRCIC( P(J), QR(J), T(J), WSTMR(J), SPDR(J), HDISR(J),
     &            HPR(J) )

   10 CONTINUE

C**** PRINT THE RESULTS
      WRITE(6,101)
      WRITE(6,102)
  101 FORMAT(' Rx Press  HPCI Pump Flow  Turb Steam Flow  Turb Speed   T
     &urb Disch Enth   Pump hp ')
  102 FORMAT(' (Psia)         (gpm)          (Lbm/hr)          (rpm)
     & (Btu/Lbm)      ')
      write(6,103)
  103 format('          ')

      DO 20 J=1,NSTATE,1
      WRITE(6,105) P(J),QH(J),WSTMH(J),SPDH(J),HDISH(J),HPH(J)
  105 FORMAT(' ', f7.1, f12.0, 5x, f12.0, 3x, f12.0, 2x, f12.1, 2X,
     &            f12.1 )
   20 continue

C**** PRINT THE RESULTS
      WRITE(7,301)
      WRITE(7,302)
  301 FORMAT(' Rx Press  RCIC Pump Flow  Turb Steam Flow  Turb Speed   T
     &urb Disch Enth   Pump hp ')
  302 FORMAT(' (Psia)         (gpm)          (Lbm/hr)          (rpm)
     & (Btu/Lbm)      ')
      write(7,303)
  303 format('          ')
```

```
      CC = A(2) - TDH0/Q0**2
      QSTAR = A(1)*A(1) - 4.D0*CC*A(0)
      QSTAR = - A(1) - DSQRT( QSTAR )
      QSTAR = 0.5D0*QSTAR/CC

      HSTAR = TDH0*QSTAR*QSTAR/Q0**2
      NSTAR = 4100.D0*DSQRT( QSTAR )/( HSTAR**0.75D0 )
      N0    = NSTAR*( TDH0**0.75D0 )/DSQRT( Q0 )

      PSTAR = (((B(4)*QSTAR + B(3))*QSTAR + B(2))*QSTAR + B(1))*QSTAR
     &        + B(0)
      P0    = PSTAR*( Q0/QSTAR )**3

      PPRIM = ((C(3)*N0 + C(2))*N0 + C(1))*N0 + C(0)
      WSPRIM = ((((D(5)*PPRIM + D(4))*PPRIM + D(3))*PPRIM + D(2))*PPRIM
     &         + D(1))*PPRIM + D(0)

      WS0 =  WSPRIM*P0/PPRIM

C**** DISCHARGE ENTHALPY FROM RCIC TURBINE (BTU/LBM)
      HDISCH = HDOME - P0*2546.6D0/WS0

      WSTM = WS0
      SPEED = N0
      HP = P0
  900 CONTINUE

      RETURN
      END


@PROCESS DC(CORBYP,UPRISE,JETLP,AVERGE,NUTRON)
      SUBROUTINE SRCIC( P, QINJ, TINJ, WSTM, SPEED, HDISCH, HP )
C**** INPUT PARATETERS:
C****    P      = REACTOR PRESSURE (PSIA)
C****    QINJ   = HPCI INJECTION RATE (GPM)
C****    TINJ   = TEMP OF INJECTION COOLANT (LBM/FT3)
C**** OUTPUT PARAMETERS:
C****    WSTM   = STEAM FLOW TO HPCI TURBINE (LBM/HR)
C****    SPEED  = HPCI PUMP/TURBINE SPEED (RPM)
C****    HDISCH= HPCI TURBINE DISCHARGE ENTHALPY (BTU/LBM)
C****    HP     = PUMP HORSEPOWER
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 N0,NSTAR
      DIMENSION A(0:2),B(0:2),C(0:9)
      DATA A / 1.820796D3, 2.657717D-1, -5.953105D-4 /
      DATA B / 2.091550D2, 2.967866D-1, -2.019651D-5 /
      DATA C / 1.498352D4, -1.308682D1, 9.371714D1, 4.382964D-3,
     &         1.255254D-2, -2.920010D-2, 3.671393D-6, -3.883010D-6,
     &         5.801522D-6, -4.614200D-7 /

      IF ( QINJ .LT. 1.D-2 ) THEN
         SPEED = 0.D0
         WSTM = 0.D0
```

```
         GO TO 900
      END IF

C**** COMPUTE STEAM DOME ENTHALPY (ASSUME SATURATED STEAM )
      HDOME = HGP( P )

C**** COMPUTE THE INJECTION ENTHALPY (BTU/LBM)
      CALL HCAL1( TINJ, 14.7D0, HINJ )

C**** CALCULATE THE INJECTION FLUID ENTHALPY (BTU/LBM)
      RO = 1.D0/VPHL( P, HINJ )

C**** COMPUTE THE PUMP TDH (FT)
      WINJ = QINJ*RO/( 60.D0*7.4805D0 )
      TDH0 = 101.9D0 + ( P*144.D0 - 2116.8D0 )/61.7D0 +
     &       (0.0191D0)*WINJ*WINJ

C**** Q0 = VOLUMETRIC INJECTION RATE (GPM)
      Q0 = QINJ

      CC = A(2) - TDH0/Q0**2
      QSTAR = A(1)*A(1) - 4.D0*CC*A(0)
      QSTAR = - A(1) - DSQRT( QSTAR )
      QSTAR = 0.5D0*QSTAR/CC

      HSTAR = TDH0*QSTAR*QSTAR/Q0**2
      NSTAR = 3594.D0*DSQRT( QSTAR )/( HSTAR**0.75D0 )
      N0    = NSTAR*( TDH0**0.75D0 )/DSQRT( Q0 )

      PSTAR = ( B(2)*QSTAR + B(1) )*QSTAR + B(0)
      P0    = PSTAR*( Q0/QSTAR )**3

      WS0 = ( ( C(8)*P0 +  C(4) )*P0 + C(2) )*P0 + C(0) +
     &      ( ( C(9)*N0 +  C(3) )*N0 + C(1) )*N0 +
     &      C(5)*N0*P0 + C(6)*N0*N0*P0 + C(7)*N0*P0*P0

C**** DISCHARGE ENTHALPY FROM RCIC TURBINE (BTU/LBM)
      HDISCH = HDOME - P0*2546.6D0/WS0

      WSTM = WS0
      SPEED = N0
      HP = P0
  900 CONTINUE

      RETURN
      END


      FUNCTION HGP(P)
      IMPLICIT REAL*8 (A-H,O-Z)
C****      SATURATED VAPOR ENTHALPY (BTU/LBM) AS A FUNCTION OF
C****      PRESSURE (LBF/IN2) - RETRAN02 PROP FIT
      DIMENSION CG1(12),CG2(9),CG3(7)
      DATA CG1 / .1105836875D4,.1436943768D2,.8018288621D0,
```

```
     1.1617232913D-1,-.1501147505D-2,4*0.0D0,-.1237675562D-4,
     2.3004773304D-5,-.2062390734D-6/
      DATA CG2 / -.2234264997D7,.1231247634D7,-.1978847871D6,
     1.1859988044D2,-.2765701318D1,.1036033878D4,-.2143423131D3,
     2.1690507762D2,-.4864322134D0/
      DATA CG3 / .9059978254D3,.5561957539D1,.3434189609D1,
     1-.6406390628D0,.5918579484D-1,-.2725378570D-2,.5006336938D-4/
      IF(P.GT.1200.D0)GO TO 15
      FLNP=DLOG(P)
      HGP=CG1(1)+CG1(2)*FLNP
      DO 10 J=3,12
      HGP=HGP+CG1(J)*FLNP**(J-1)
   10 CONTINUE
      RETURN
   15 CONTINUE
      IF(P.GT.2600.D0)GO TO 25
      FLNP=DLOG(P)
      HGP=CG2(1)+CG2(2)*FLNP
      DO 20 J=3,9
      HGP=HGP+CG2(J)*FLNP**(J-1)
   20 CONTINUE
      RETURN
   25 CONTINUE
      PDIF=(3208.2D0-P)**.41D0
      HGP=CG3(1)+CG3(2)*PDIF
      DO 30 J=3,7
      HGP=HGP+CG3(J)*PDIF**(J-1)
   30 CONTINUE
      RETURN
      END


      SUBROUTINE HCAL1( T, P, H )
      IMPLICIT REAL*8(A-H,O-Z)
C**** CALCULATES SUBCOOLED ENTHALPY AS A FUNCTION OF TEMPERATURE AND
C**** PRESSURE
C**** T = TEMPERATURE (DEGF)
C**** P = PRESSURE (PSIA)
      KOUNT=0
      H1= 0.020D0
      H2= 550.00D0
      F1= T - TPHL( P, H1 )
      F2= T - TPHL( P, H2 )
C**** CHECK IF ZERO IS TRAPPED
      IF ( F1*F2 .GT. 0.D0 ) THEN
      WRITE(6,101)
  101 FORMAT(' ZERO NOT TRAPPED IN SUBROUTINE HCAL1 -- HPCI ENTHALPY CAL
     &CULATION FAILED ')
      STOP
      END IF

   10 CONTINUE
      KOUNT = KOUNT + 1
```

```
      IF ( KOUNT .GT. 100 ) THEN
      WRITE(6,102)
  102 FORMAT(' HPCI ENTHALPY CALC DID NOT CONVERGE IN 100 ITERATIONS')
      STOP
      END IF

      IF ( DABS(H2-H1) .LT. 0.01D0 ) THEN
         H3= ( H1+H2 )*0.5D0
         GO TO 900
      END IF
      H3 = ( H2 + H1 )*0.5D0
      F3 = T - TPHL( P, H3 )
      IF ( F1*F3 .LT. 0.D0 ) THEN
          H2=H3
          F2=F3
          GO TO 10
      ELSE
          H1=H3
          F1=F3
          GO TO 10
      END IF

  900 CONTINUE
      H=H3

      RETURN
      END


      FUNCTION VPHL(P,H)
      IMPLICIT REAL*8 (A-H,O-Z)
C****    SATURATED OR SUBCOOLED SPECIFIC VOLUME (FT3/LBM) AS
C****    A FUNCTION OF PRESSURE (LBF/IN2) AND ENTHALPY
C****    (BTU/LBM) - RETRAN02 PROP FIT
      DIMENSION CN1(5,3)
      DATA CN1 / -.411796175D1,-.3811294543D-3,
     1.4308265942D-5,-.916012013D-8,.8017924673D-11,-.481606702D-5,
     2.7744786733D-7,-.6988467605D-9,.1916720525D-11,-.1760288590D-14,
     3-.1820625039D-8,.144078593D-10,-.2082170753D-13,-.3603625114D-16,
     4.7407124321D-19/
      H1=1.D0
      H2=H1*H
      H3=H2*H
      H4=H3*H
      H5=H4*H
      VPHL=CN1(1,1)*H1+CN1(2,1)*H2+CN1(3,1)*H3+CN1(4,1)*H4+CN1(5,1)*H5
      VPHL=VPHL+(CN1(1,2)*H1+CN1(2,2)*H2+CN1(3,2)*H3+CN1(4,2)*H4+CN1
     1(5,2)*H5)*P
      VPHL=VPHL+(CN1(1,3)*H1+CN1(2,3)*H2+CN1(3,3)*H3+CN1(4,3)*H4+CN1
     1(5,3)*H5)*P**2
      VPHL=DEXP(VPHL)
      RETURN
      END
```

APPENDIX B

Input Data File for Calculation of HPCI and RCIC Operating Parameters

This appendix gives the input data file used to generate the results displayed in Table 3.2. The results in Table 3.2 were computed with the computer program given in Appendix A.

Table B.1 Input Data File for Calculation of HPCI and RCIC Operating Parameters

36				
1	5000.	600.	1200.	120.
2	4000.	500.	1200.	120.
3	3000.	400.	1200.	120.
4	2000.	300.	1200.	120.
5	1000.	200.	1200.	120.
6	800.	100.	1200.	120.
7	5000.	600.	1000.	120.
8	4000.	500.	1000.	120.
9	3000.	400.	1000.	120.
10	2000.	300.	1000.	120.
11	1000.	200.	1000.	120.
12	800.	100.	1000.	120.
13	5000.	600.	800.	120.
14	4000.	500.	800.	120.
15	3000.	400.	800.	120.
16	2000.	300.	800.	120.
17	1000.	200.	800.	120.
18	800.	100.	800.	120.
19	5000.	600.	600.	120.
20	4000.	500.	600.	120.
21	3000.	400.	600.	120.
22	2000.	300.	600.	120.
23	1000.	200.	600.	120.
24	800.	100.	600.	120.
25	5000.	600.	400.	120.
26	4000.	500.	400.	120.
27	3000.	400.	400.	120.
28	2000.	300.	400.	120.
29	1000.	200.	400.	120.
30	800.	100.	400.	120.
31	5000.	600.	200.	120.
32	4000.	500.	200.	120.
33	3000.	400.	200.	120.
34	2000.	300.	200.	120.
35	1000.	200.	200.	120.
36	800.	100.	200.	120.
	HPCI FLOW (GPM)	RCIC FLOW (GPM)	RX PRESS (PSIA)	COOLANT TEMP (DEG F)

NUCLEAR ENGINEERING

PP&L

CALCULATION / STUDY COVER SHEET
and
NUCLEAR RECORDS TRANSMITTAL SHEET

File # R2-1

1. Page 1 of 29

*▷2. TYPE: CALC ▷3. NUMBER: EC-SIMU-Ø5Ø1 ▷4. REVISION: Ø

5. TRANSMITTAL#: K9412214 *▷6. UNIT: 3 *▷7. QUALITY CLASS: N *▷8. DISCIPLINE: 3

▷9. DESCRIPTION: Duration of Feedwater Flow Following Initiation of an MSIV-Closure ATWS

SUPERCEDED BY: EC- -

10. Old Calculation#: SA-MAC-ØØ3-RØ Alternate#: SA-MAC-ØØ3 11. Cycle: ___

12. Computer Code or Model used: ______ Fiche [ ] Discs [ ] Amount ______

13. Application: ______

*▷14. *AFFECTED SYSTEMS:* Ø45, Ø83B, , ,

** If N/A then line 15 is mandatory.

*▷15. NON-SYSTEM DESIGNATOR: SIMU, ATWS, ,

16. Affected Documents: , , , ,

References: GEK-38479, NSAC-7Ø, NEDO-32Ø47, FF11Ø76Ø SH1, ,

18. Equipment / Component #: , , ,

19. DBD Number: DBDØ3Ø, DBD Ø16

▷20. PREPARED BY	▷21. REVIEWED BY
Print Name M.A.C.	Print Name E.R.J.
Signature *N/A BACKFIT EFFORT*	Signature *N/A BACKFIT EFFORT*
▷22. APPROVED BY / DATE	*23. ACCEPTED BY PP&L / DATE*
Print Name C. Kukielka / 5-23-94	Print Name
Signature *N/A BACKFIT EFFORT*	Signature *N/A BACKFIT EFFORT*

TO BE COMPLETED BY NUCLEAR RECORDS

-DCS SIGNATURE/DATE 12-28-94

ADD A NEW COVER PAGE FOR EACH REVISION

* Verified Fields
▷ REQUIRED FIELDS

ORM NEPM-QA-0221-1, Revision 1 CALCLOG\NEPM\FORM221.R1A

EPM-QA-210A, Rev. 1

PP&L	CALCULATION COVER SHEET	CALC. NO. SA-MAC-003 FILE NO. R2-1 SUPERSEDED BY	SAFETY RELATED [ ] ASME III OR XI [ ] OTHER QUALITY [ ] NON QUALITY [X]

PROJECT SIMULATOR UPGRADE ER/CTN NO.

DESIGN ACTIVITY/PMR NUMBER PAGE 2 OF 31

TITLE/DESCRIPTION Duration of Feedwater Flow Following Initiation of an MSIV-Closure ATWS

SYSTEMS AFFECTED N/A

STATEMENT OF PROBLEM

The purpose of this calculation is to estimate the duration of feedwater injection during an MSIV-Closure ATWS.

DESIGN BASIS (EPM-QA-208 or EPM-QA-400)

N/A

REFERENCES/FORMULAE

See attached calculation.

SUMMARY/CONCLUSIONS

See attached calculation.

ENGINEERING TURNOVER

(ETO) BINDER AFFECTED? [ ] YES - If yes, enter: Binder# ______ Vol. ______
Calc. File ______ Pgs. ______

[✓] NO

Rev. No.	Date	Prepared By	Reviewed/ Checked By	Date	Approved By	Date
0	1/14/93	M.A. Chaiko	[signature]	1/19/93	[signature]	1/19/93