Thermalhydraulic Assessment of the Pickering NGS 'B' Feed and Bleed System for the Hot Boiler Chemical Clean (Siemens Process)

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ABSTRACT.
The Hot Boiler Chemical Clean (HBCC) process from Siemens, to be used in PNGS, requires that the Heat Transport System (HTS) temperature be maintained in the range 160 to 170 ^{o}C for several days. To achieve these thermalhydraulic condition, the core decay power and the pump power of the main circulating pumps in a 3-3 configuration are employed to warm up the HTS from approximately 38 ^{o}C to 170 ^{o}C. At this point, high Bleed bias is applied to the signal of the HTS pressure controller to provide high Feed and Bleed flows, which are used to control the HTS temperature by means of the Bleed Cooler.
To address any concern posed by these infrequently used HTS thermalhydraulic conditions, a detailed thermalhydraulic model of the Feed and Bleed System, that also includes the Gland Supply, Gland Return and Purification systems, was developed for the TUF code to determine the suitability of the Feed and Bleed System to conduct the HBCC. The model was then used to estimate the parameters such as Feed and Bleed flows, valve openings, pressure and temperature distributions throughout the Feed and Bleed System required for the application of HBCC.

INTRODUCTION.
In the past 10 years, it became apparent that the lack of a well organized maintenance program for the Steam Generators and an inadequate chemistry control of the feedwater have caused a number of forced (unplanned) outages due to Steam Generator tube leaks in PNGS. As indicated in the available literature [1, 2], ingress of impurities is one of the main factors that accelerate the growth of corrosion products in the internal components of the Steam Generators.

Attempts to correct the situation were conducted in 1992, when the Steam Generators of Units 5 and 6 were cleaned by means of a low-temperature (93 ^{o}C) modified EPRI/SGOG chemical clean process. Later in 1995, the Steam Generators of Units 1 and 2 were cleaned with the same EPRI/SGOG process supplemented with a higher temperature (107 ^{o}C) crevice cleaning step. In both occasions, secondary side deposits were effectively removed within acceptable corrosion limits and boilers were returned to service immediately. However, the major disadvantages were that the process required nearly 100 days to complete and generated approximately 2.5 million liters of waste.

In contrast to this, the Siemens process (or Hot Boiler Chemical Clean – HBCC) produces significantly less waste and the duration of a typical application is 30 to 45 days. Also, it involves a high temperature (170 ^{o}C) magnetite dissolution process called the Iron Step, and a low temperature Copper Step addressed to plants such as PNGS with copper-containing deposits.

The application of the HBCC in PNGS requires that the Heat Transport System (HTS) temperature be maintained in the neighbourhood of 170 ^{o}C for several days. The use of the Shutdown Cooling System (SDCS) for this purpose was almost immediately discarded since it is not designed to hold the HTS at this temperature (boiling of the coolant in the shell side of the SDCS heat exchangers would occur if attempted [3, 4]). The other only viable alternative was to use high Feed and Bleed flows in conjunction with the Bleed Cooler for HTS temperature control. Since high Feed and Bleed flows for purification purposes are occasionally used, it became apparent that a detailed review and modeling of the Feed and Bleed System was required.

RESULTS and DISCUSSION.

To address any concern posed by these uncommon HTS thermalhydraulic conditions to conduct the HBCC, a detailed model of the Feed and Bleed System that also includes the Gland Supply, Gland Return and Purification systems was developed for the TUF code [5]. (The early suggestion of employing the PNGS 'B' TUF model available was rejected because the verification of the Reference Data Set has not been completed.)

Figure 1 shows the Module/Node-Link diagram for Pickering NGS 'B' Feed, Bleed, Purification and Gland Supply systems. Tables 1 and 2 provide the Node and Link data that summarize the constitution of the model.

The following assumptions were employed in this analysis:

a) Feed and Bleed System capabilities are determined based on hydraulic resistances limitations, Feed pump net positive suction head requirement (NPSHR) limitations and maximum allowable pump flow limitations.
b) In the TUF simulations, the Colebrook equation with piping roughness included is used to calculate the single phase friction factor for turbulent flow.
c) The D_2O Storage Tank pressure was assumed to be 200 kPa(a) and constant.
d) The Spray and Reflux valves CV111 and CV113, respectively, in the Bleed Condenser are maintained closed.
e) The Supply and Return valves CV10 and CV9, respectively, to the Fuelling Machine are closed.
f) The Purification Bypass Valve CV22 is under automatic control so that the pressure at its location does not exceed 800 kPa(a).
g) Only one Purification Line is open at a time. In this assessment, the MV15 valve is assumed fully open and MV31 is kept closed.

h) The hand controlled switches 63332-L1A-HC1 and 63332-L2B-HC1 controlling the Bleed Condenser Level Control Valves CV122 and CV123, respectively, are placed on "Manual" control. Therefore, the valves will be directly throttled by the manual outputs of these manual controllers, regardless of the bleed cooler outlet temperature.
i) To simulate steady state conditions when the Bleed Condenser is bypassed, the steady state Feed and Bleed flows are obtained by adjusting the feed and Bleed valves such as the following condition is satisfied:

$$W_{FEED} + W_{GLAND\ SUPPLY} = W_{BLEED} + W_{GLAND\ RETURN}$$

j) The pressure in Pump Suction Header was 3740 kPa(a).
k) The RCWS was able to maintain the outlet of the Bleed Cooler at 40 ^{o}C.
l) The HTS Reactor Outlet Header pressures considered in this assessment were 2.7, 4.0 and 8.7 MPa(g).
m) Decay power after 60 days of shutdown (1.7 MW) and main circulating pump power of 12.0 MW were the only heat sources.
n) The temperature in the HTS was 170 ^{o}C, and that heat losses in the HTS were minor and not included in the numerical model.

The results of the simulation of the Feed and Bleed System are summarized in Tables 3, 4 and 5, which include the results for Feed and Bleed valves positions and flows for HTS pressures of 2.7, 4.0 and 8.7 MPa(g), respectively. As shown in Table 3, the Bleed flows obtained with a HTS pressure of 2.7 MPa(g) are not high enough to transfer the thermal load to the Bleed Cooler since the Bleed valves are almost fully opened. Similarly, as illustrated in Table 5, the predicted Feed flows with a HTS pressure of 8.7 MPa(g) are hardly enough to transfer the thermal load because the Feed valves are fully opened. Therefore, these results confirmed that the HBCC should be conducted with a HTS pressure of 4.0 MPa(g) because at this condition the required flows to transfer the thermal load are achieved with Feed and Bleed valves openings in the range of 70 to 80% (see Table 4).

The first attempt of commissioning the HBCC process was performed in Unit 8 on January 31, 2000. It was aborted when severe vibrations in the Feed lines were observed for high Feed flows and valve openings. To determine the regions of safe operation, Feed line vibration tests were conducted in Unit 8 in February 2000 with low (65 ^{o}C) and high (165 ^{o}C) HTS temperatures. The most relevant conclusion of the tests was that with a HTS pressure of 4.0 MPa(g), Feed line vibrations are experienced whenever the Feed valve exceeds an opening of approximately 72% [6]. Since these severe vibrations represent a major threat to the physical integrity of the pressure boundary (with the likelihood of causing a small LOCA without possibility of isolation) and since this opening is less than necessary to conduct the HBCC, the whole project was postponed indefinitely while solutions were sought.

In an attempt to decrease the required Feed valve opening, it was suggested to

- change to a 2-2 main pump configuration to reduce the thermal load

- employ the SDCS in the "warm-up mode" in conjunction with the Bleed Cooler; it was estimated [4] that each SDC heat exchanger could remove 1.5 MW with no boiling in the shell side,
- estimate the decay power with the new decay power curve specific for a 28-element fuel bundle [7],
- increase the Gland Supply flow to a maximum and
- lower the Bleed Cooler outlet temperature to 30 ^{o}C.

Simulation results obtained with this new configuration are shown in Table 6 and 7 for a HTS pressure and temperature of 4.0 MPa(g) and 170 ^{o}C, respectively, employing either two or four SDC heat exchangers. Therefore, the results of this assessment suggest that HBCC should be conducted employing both the Bleed Cooler and either two SDCS quadrants after 21 days into the Unit outage (see Table 6) or the four SDCS quadrants after 7 days into the outage (see Table 7). Both options require a reduced Feed valve opening (≤55%), which provides a safety margin from the instability region experienced when the Feed valves were approximately 72% opened.

This new HTS configuration to conduct HBCC will be tested in Unit 5 in October 2000.

CONCLUSIONS.

Based on the results obtained in this analysis, it is concluded that the Feed and Bleed System is capable of supplying a flow high enough to transfer the HTS thermal load to the Bleed Cooler during the HBCC without jeopardizing the physical integrity of the Feed lines. The results of this assessment suggest that HBCC should be conducted employing both the Bleed Cooler and either two SDCS quadrants after 21 days into the Unit outage or the four SDCS quadrants after 7 days into the outage.

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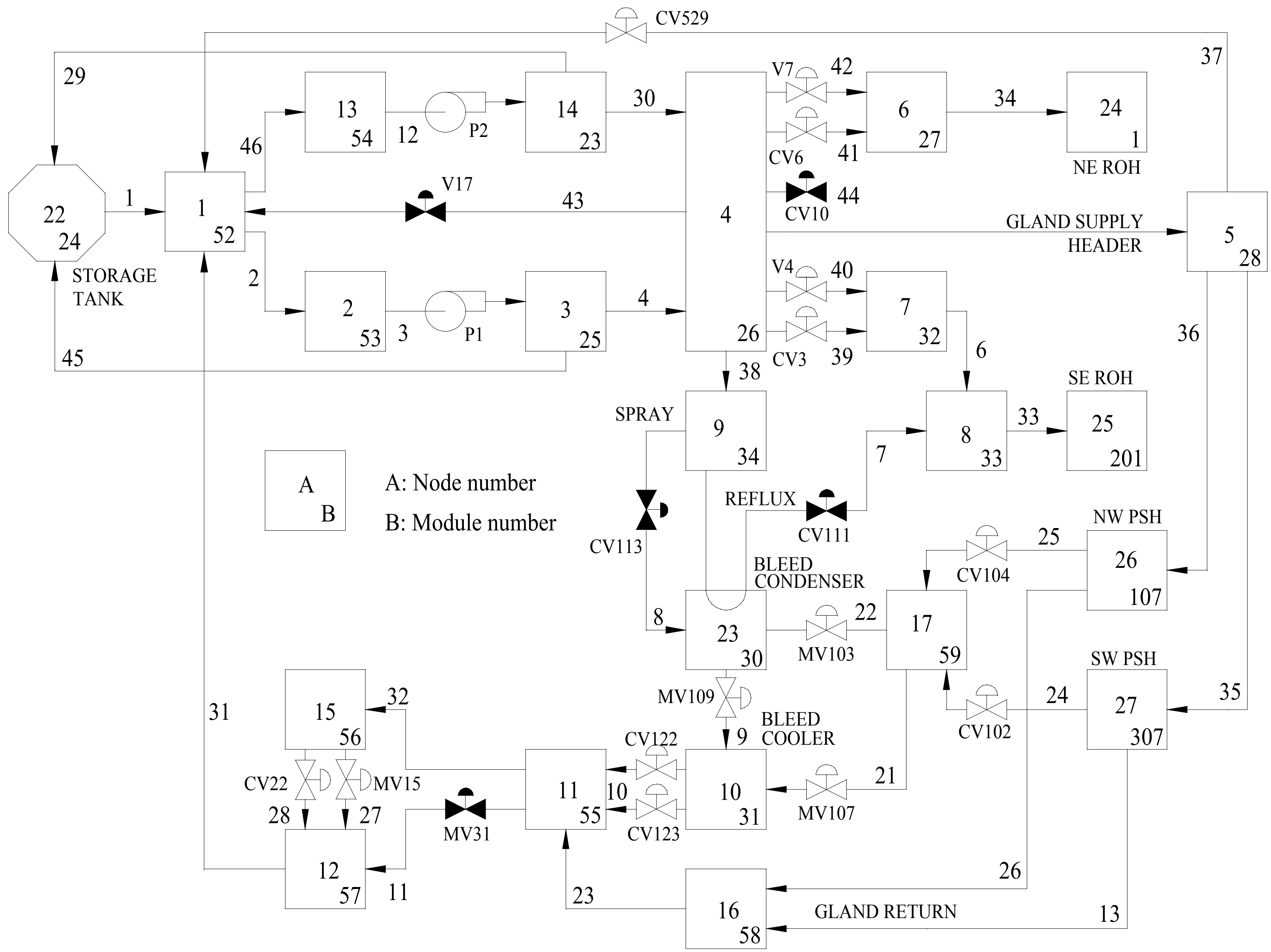

Fig. 1. Module/Node-Link diagram for Pickering NGS ‘B’ Feed, Bleed, Purification and Gland Supply systems.

Table 1. Feed, Bleed, Purification, Gland Supply and Gland Return Systems Node Data

NODE NUMBER	NODE TYPE	DESCRIPTION	MODULE NUMBER	MODULE VOLUME (m3)	NODE LENGTH (m)	NODE AREA (m2)	NODE EQUIVALENT DIAMETER (m)	NODE ELEVATION CHANGE (m)
1	1	D_2O Recovery Connection	52	0.09298	2.4928	0.01865	0.15410	0.000
2	1	Feed Pump P1 Suction	53	0.07210	2.5432	0.00742	0.09720	- 2.1876
3	1	Feed Pump P1 Discharge	25	0.02270	2.4034	0.00742	0.09720	1.3494
4	1	Feed Pump Discharge Header	26	0.21347	3.219	0.00191	0.04930	- 1.968
5	1	Gland Supply Header	28	0.00973	12.192	0.000279	0.01885	3.048
6	1	North Feed/Bypass Junction	27	0.03910	20.4820	0.00191	0.04930	0.3938
7	1	South Feed/Bypass Junction	32	0.02394	12.5400	0.00191	0.04930	0.3682
8	1	BC Reflux/South Feed Junction	33	0.03322	17.4050	0.00191	0.04930	- 0.1555
9	1	BC Reflux/Spray Junction	34	0.13674	35.5170	0.00191	0.04930	- 4.7010
10	1	Bleed Cooler	31	0.93573	38.5060	0.00742	0.09720	- 11.768
11	1	East/West Purification Split	55	1.58470	19.2330	0.00430	0.02760	1.5494
12	1	Strainers	57	0.27785	37.4450	0.00742	0.09720	14.275
13	1	Feed Pump P2 Suction	54	0.07210	2.5432	0.00742	0.09720	- 2.188
14	1	Feed Pump P2 Discharge	23	0.02373	2.6428	0.00742	0.09720	1.3494
15	1	East Purification/CV22 Junction	56	1.59220	20.456	0.00450	0.02660	1.5494
16	1	East/West Gland Return Junction	58	0.001276	4.5720	0.000279	0.01885	0.000
17	1	North/South Bleed Junction	59	0.05315	12.457	0.00427	0.07370	0.000
22	201	D_2O Storage Tank	24	0.09050	4.8503	0.01865	0.15410	- 2.602
23	201	Bleed Condenser Shell	30	4.04619	6.2250	0.00742	0.09720	- 1.1180
24	201	NE ROH	1	0.9203	2.4209	0.4258	0.3254	0.00
25	201	SE ROH	201	0.9444	2.4209	0.4258	0.3254	0.00
26	201	NW PSH	107	1.4535	21.041	0.00191	0.0493	3.942
27	201	SW PSH	307	1.4821	36.062	0.00191	0.0493	3.942

Table 2. Feed, Bleed, Purification, Gland Supply and Gland Return Systems Link Data

LINK NUMBER	LINK TYPE	FROM NODE	TO NODE	LINK LENGTH (m)	LINK AREA (m^2)	LINK EQUIVALENT DIAMETER (m)	LINK ELEVATION CHANGE (m)	LINK RESISTANCE	LINK ROUGHNESS (m)	VALVE DISCHARGE COEFFICIENT
1	-9	22	1	4.8503	0.01865	0.1541	- 2.602	$2.55x10^{-3}$	$4.5x10^{-5}$	0.0591
2	-1	1	2	2.6515	0.01865	0.1541	0.000	$0.41x10^{-3}$	$4.5x10^{-5}$	
3	-57	2	3	2.5430	0.00742	0.0972	- 2.1876	0.000	$4.5x10^{-5}$	
4	-1	3	4	2.4034	0.00742	0.0972	1.3494	$1.988x10^{-3}$	$4.5x10^{-5}$	
5	-1	4	5	92.677	0.00101	0.0131	- 0.5840	$49.53x10^{-3}$	$4.5x10^{-5}$	
6	-1	7	8	12.540	0.00191	0.0493	0.3682	$3.38x10^{-3}$	$4.5x10^{-5}$	
7	-9	9	8	35.517	0.00191	0.0493	- 4.7010	$29.404x10^{-3}$	$4.5x10^{-5}$	$4.78x10^{-4}$
8	-9	9	23	5.480	0.00273	0.0590	1.0034	$1.754x10^{-3}$	$4.5x10^{-5}$	$3.41x10^{-4}$
9	-9	23	10	6.225	0.00742	0.0972	- 1.1180	$2.34x10^{-3}$	$4.5x10^{-5}$	0.01826
10	-9	10	11	38.506	0.00742	0.0972	- 11.768	$5.246x10^{-3}$	$4.5x10^{-5}$	$1.39x10^{-3}$
11	-9	11	12	19.233	0.00430	0.0276	1.5494	0.189	$4.5x10^{-5}$	0.02571
12	-57	13	14	2.5430	0.00742	0.0972	- 2.1876	0.000	$4.5x10^{-5}$	
13	-1	27	16	15.240	0.000279	0.01885	1.8290	5.750	$4.5x10^{-5}$	
21	-9	17	10	10.959	0.00427	0.0737	-4.861	$3.562x10^{-3}$	$4.5x10^{-5}$	0.0102
22	-9	17	23	1.4986	0.00427	0.0737	0.000	$1.47x10^{-3}$	$4.5x10^{-5}$	0.0102
23	-1	16	11	4.5720	0.000279	0.01885	0.000	$9.80x10^{-3}$	$4.5x10^{-5}$	
24	-9	27	17	36.062	0.00191	0.0493	3.9418	$7.98x10^{-3}$	$4.5x10^{-5}$	$3.08x10^{-4}$
25	-9	26	17	21.0414	0.00191	0.0493	3.9418	$6.19x10^{-3}$	$4.5x10^{-5}$	$3.08x10^{-4}$
26	-1	26	16	15.24	0.000279	0.01885	1.829	5.750	$4.5x10^{-5}$	
27	-9	15	12	20.456	0.00450	0.0266	1.5494	0.2062	$4.5x10^{-5}$	0.02571
28	-9	15	12	21.353	0.00742	0.0972	- 1.778	$4.14x10^{-3}$	$4.5x10^{-5}$	$2.11x10^{-3}$
29	-1	14	22	8.8750	0.000464	0.0243	4.9130	0.997	$4.5x10^{-5}$	
30	-1	14	4	2.6428	0.00742	0.0972	1.3494	$1.99x10^{-3}$	$4.5x10^{-5}$	
31	-1	12	1	37.445	0.00742	0.0972	14.2748	$8.43x10^{-3}$	$4.5x10^{-5}$	
32	-1	11	15	0.2095	0.00742	0.0972	0.000	$1.50x10^{-3}$	$4.5x10^{-5}$	
33	-1	8	25	17.405	0.00191	0.0493	- 0.1555	$3.93x10^{-3}$	$4.5x10^{-5}$	
34	-1	6	24	20.482	0.00191	0.0493	0.3938	$6.04x10^{-3}$	$4.5x10^{-5}$	
35	-1	5	27	12.192	0.000279	0.01885	3.0480	0.370	$4.5x10^{-5}$	
36	-1	5	26	12.192	0.000279	0.01885	3.0480	0.370	$4.5x10^{-5}$	

Table 2: Feed, Bleed, Purification, Gland Supply and Gland Return Systems Link Data

LINK NUMBER	LINK TYPE	FROM NODE	TO NODE	LINK LENGTH (m)	LINK AREA (m2)	LINK EQUIVALENT DIAMETER (m)	LINK ELEVATION CHANGE (m)	LINK RESISTANCE	LINK ROUGHNESS	VALVE DISCHARGE COEFFICIENT
37	-9	5	1	10.492	0.000279	0.01885	1.5560	0.8568	$4.5\text{x}10^{-5}$	$2.88\text{x}10^{-5}$
38	-1	4	9	25.801	0.00273	0.05900	3.104	$2.97\text{x}10^{-3}$	$4.5\text{x}10^{-5}$	
39	-9	4	7	2.7870	0.00191	0.0493	- 1.968	$0.676\text{x}10^{-3}$	$4.5\text{x}10^{-5}$	$2.836\text{x}10^{-4}$
40	-9	4	7	3.0730	0.000279	0.01885	- 1.968	$1.65\text{x}10^{-3}$	$4.5\text{x}10^{-5}$	$1.20\text{x}10^{-5}$
41	-9	4	6	3.652	0.00191	0.0493	- 2.1460	$0.676\text{x}10^{-3}$	$4.5\text{x}10^{-5}$	$2.836\text{x}10^{-4}$
42	-9	4	6	2.9210	0.000279	0.01885	- 2.1460	$1.65\text{x}10^{-3}$	$4.5\text{x}10^{-5}$	$1.20\text{x}10^{-5}$
43	-9	4	1	4.350	0.00742	0.0972	0.8318	$5.026\text{x}10^{-3}$	$4.5\text{x}10^{-5}$	0.01826
44	-9	4	0	0.85344	0.000908	0.0340	0.000	$0.2\text{x}10^{-3}$	$4.5\text{x}10^{-5}$	$1.35\text{x}10^{-4}$
45	-1	3	22	9.564	0.000464	0.0243	4.913	0.995	$4.5\text{x}10^{-5}$	
46	-1	1	13	2.3340	0.018651	0.1541	0.00	$0.41\text{x}10^{-3}$	$4.5\text{x}10^{-5}$	

Table 3. Results of the TUF simulations of the Feed and Bleed thermalhydraulic capabilities with a HTS pressure of 2.7 MPa(g).

Feed Valve Position (frac)	Feed Flow per valve (kg/s)	Gland Supply Flow (kg/s)	Bleed Valve Position (frac)	Bleed Flow per valve (kg/s)	Gland Return Flow (kg/s)	Estimated Power Removed (MW)
0.10	1.04	2.00	0.37	1.60	0.90	1.75
0.20	1.65	2.00	0.42	2.20	0.90	2.40
0.30	2.52	2.00	0.47	3.40	0.92	3.71
0.40	3.75	2.00	0.51	4.32	0.91	4.72
0.50	5.51	2.00	0.60	6.15	0.92	6.72
0.60	7.93	1.96	0.72	8.50	0.89	9.29
0.70	11.50	1.90	0.97	12.40	0.88	13.54

Table 4. Results of the TUF simulations of the Feed and Bleed thermalhydraulic capabilities with a HTS pressure of 4.0 MPa(g).

Feed Valve Position (frac)	Feed Flow per valve (kg/s)	Gland Supply Flow (kg/s)	Bleed Valve Position (frac)	Bleed Flow per valve (kg/s)	Gland Return Flow (kg/s)	Estimated Power Removed (MW)
0.10	0.96	2.00	0.33	1.32	1.04	1.44
0.20	1.50	2.00	0.36	1.70	1.04	1.86
0.30	2.30	2.00	0.42	2.74	1.04	3.00
0.40	3.46	1.86	0.46	4.00	1.04	4.37
0.50	5.09	1.84	0.51	5.45	1.04	5.95
0.60	7.30	1.80	0.59	7.65	1.04	8.35
0.70	10.60	1.80	0.72	11.00	1.04	12.00
0.80	14.65	1.80	0.93	15.20	1.04	16.60

Table 5. Results of the TUF simulations of the Feed and Bleed thermalhydraulic capabilities with a HTS pressure of 8.7 MPa(g).

Feed Valve Position (frac)	Feed Flow per valve (kg/s)	Gland Supply Flow (kg/s)	Bleed Valve Position (frac)	Bleed Flow per valve (kg/s)	Gland Return Flow (kg/s)	Estimated Power Removed (MW)
0.10	0.62	2.20	0.25	1.17	1.03	1.28
0.20	0.99	2.20	0.27	1.44	1.03	1.57
0.30	1.51	2.10	0.32	2.05	1.02	2.24
0.40	2.25	2.10	0.38	2.95	1.02	3.22
0.50	3.30	2.10	0.41	4.00	1.02	4.37
0.60	4.70	2.10	0.44	5.40	1.02	5.89
0.70	6.90	2.05	0.49	7.60	1.02	8.23
0.80	9.50	2.00	0.55	10.00	1.02	10.92
0.90	11.60	1.90	0.60	12.30	1.02	13.43
1.00	13.10	1.85	0.62	13.50	1.02	14.74

Table 6. Bleed flows and Feed Valve positions for different times after shutdown with 2 SDCS quadrants.

Time after Unit shutdown (days)	Core Decay Power (MW)	Pump Power (MW)	Power removed by two SDCS HXs (MW)	Total Power to be removed by the Feed & Bleed System (MW)	Total Bleed Flow required (kg/s)	Estimated Feed Valve position (%)
7.0	4.33	9.6	3.0	10.9	18.6	58.0
14.0	2.97	9.6	3.0	9.6	16.3	55.0
21.0	2.39	9.6	3.0	9.0	15.3	53.0
28.0	2.03	9.6	3.0	8.6	14.7	52.0
35.0	1.78	9.6	3.0	8.4	14.3	51.0
42.0	1.58	9.6	3.0	8.2	13.9	50.0
49.0	1.43	9.6	3.0	8.0	13.7	50.0

Table 7. Bleed flows and Feed Valve positions for different times after shutdown with 4 SDCS quadrants.

Time after Unit shutdown (days)	Core Decay Power (MW)	Pump Power (MW)	Power removed by four SDCS HXs (MW)	Total Power to be removed by the Feed & Bleed System (MW)	Total Bleed Flow required (kg/s)	Estimated Feed Valve position (%)
7.0	4.33	9.6	6.0	7.9	13.5	48.0
14.0	2.97	9.6	6.0	6.6	11.2	40.0
21.0	2.39	9.6	6.0	6.0	10.2	36.0
28.0	2.03	9.6	6.0	5.6	9.6	34.0
35.0	1.78	9.6	6.0	5.4	9.1	31.0
42.0	1.58	9.6	6.0	5.2	8.8	30.0
49.0	1.43	9.6	6.0	5.0	8.6	30.0