Restart Chemistry Control at the Point Lepreau Nuclear Generating Station After an Extended Refurbishment Outage

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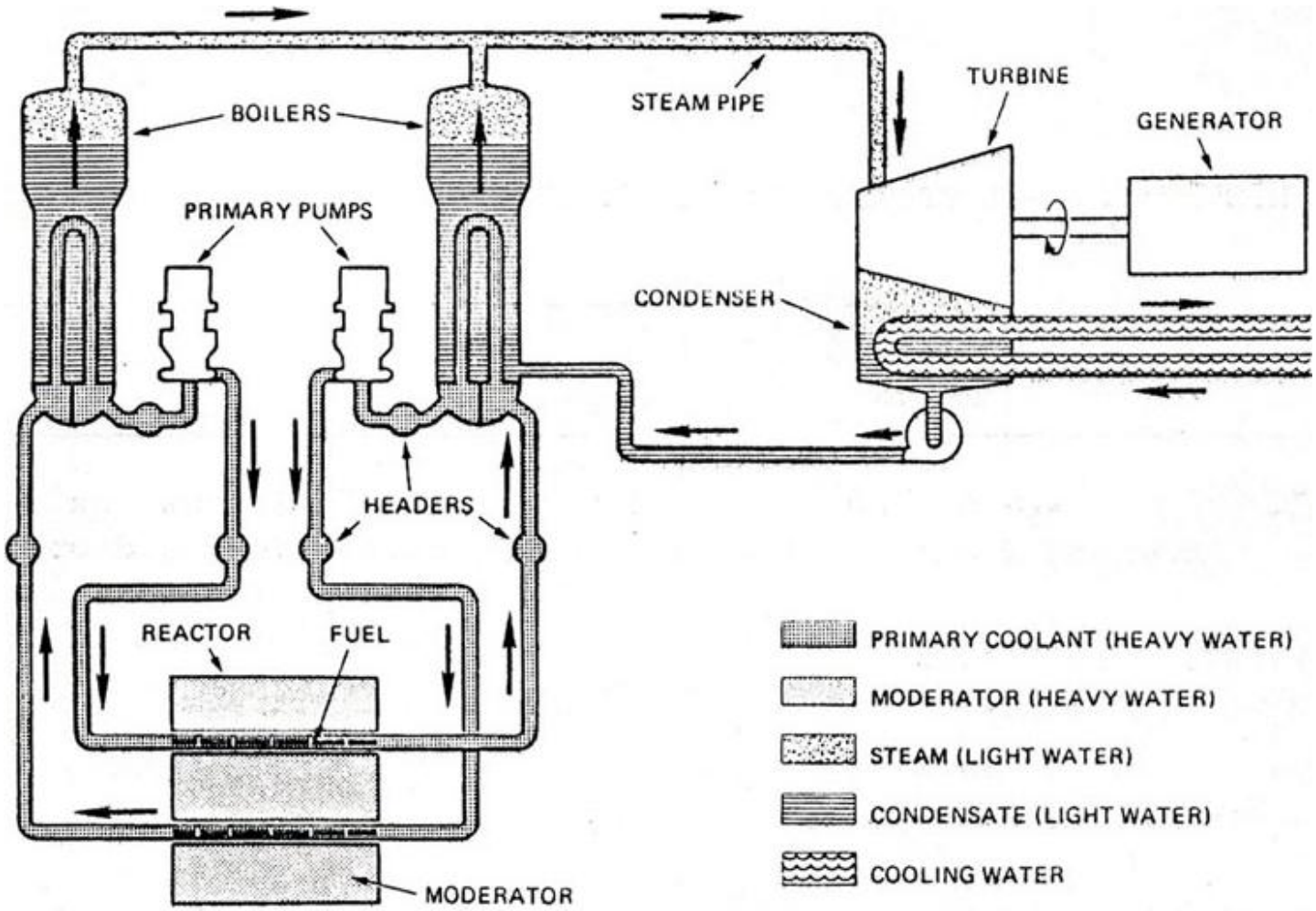
Outline

- Background information
- Refurbishment of CANDU reactors
  - Primary system components
  - Secondary system components
- PLGS Refurbishment timeline
  - Issues identified
- Secondary system return-to-service: chemical control strategies
- Summary
- Acknowledgements

Historical Information

- Point Lepreau NGS began commercial operation on February 1st, 1983 and was the first CANDU-6 reactor in the CANDU fleet.

- Major design parameters:
  - Gross power output – 680 MWe
  - Core inlet temperature – 260°C
  - Core outlet temperature – 300 – 310°C
  - Primary system pressure ~ 10 MPa
  - 4 Steam generators (B&W – U-tube design)
  - 1 HP, 3 LP turbines with moisture separator and reheater
  - Full flow condensate polishers used for start-up


BOILERS
STEAM PIPE
TURBINE
GENERATOR
PRIMARY PUMPS
CONDENSER
HEADERS
REACTOR
FUEL
MODERATOR
PRIMARY COOLANT (HEAVY WATER)
MODERATOR (HEAVY WATER)
STEAM (LIGHT WATER)
CONDENSATE (LIGHT WATER)
COOLING WATER

CANDU Refurbishment

- Mid-life refurbishment is required for all CANDU reactors because of elongation and sagging of the Zr-alloy pressure tubes and calandria tubes due to material creep.

- At PLGS, core internals (380 pressure and calandria tubes) and the 760 associated feeder pipes were removed and replaced.

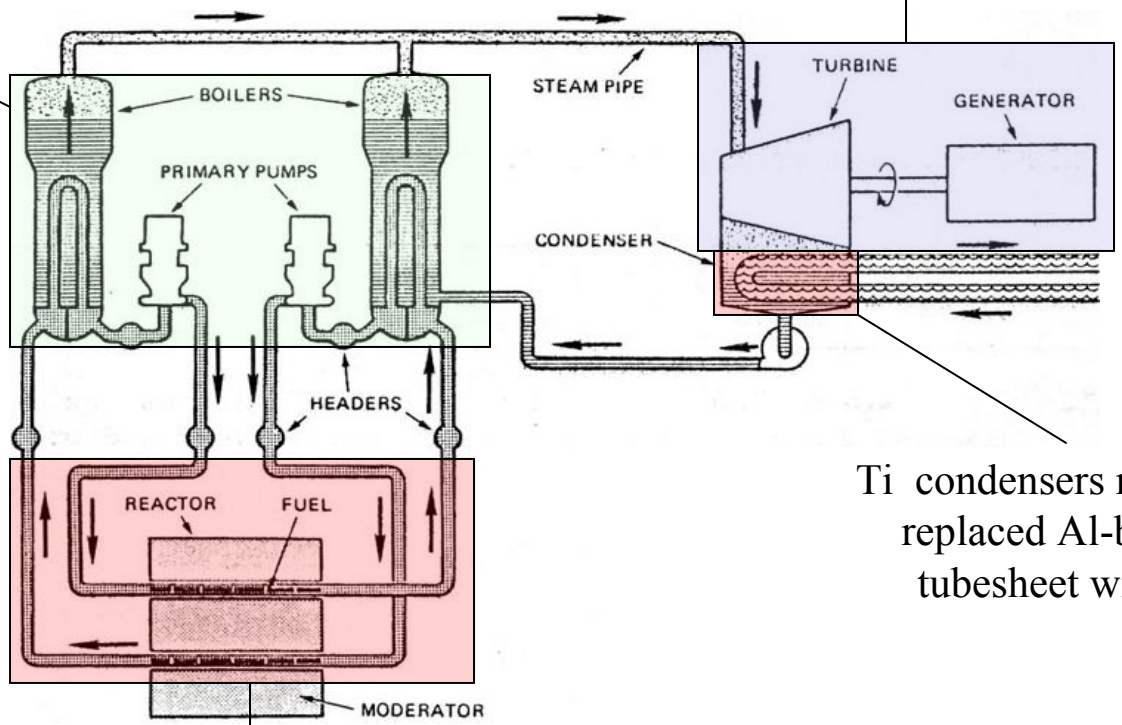
- Steam generators (Alloy 800 at PLGS) were cleaned and left in place.

Note: from initial operation until 2000, secondary chemistry was congruent phosphate treatment – has been morpholine-based AVT since 2000.

PLGS Refurbishment – Major Items

New turbines and rewinding of generator to give additional 3% power output

SG's cleaned and placed in wet lay-up



Ti condensers retubed – replaced Al-bronze tubesheet with Ti

All 380 pressure/calandria tubes replaced along with the associated 760 carbon steel feeder pipes

Refurbishment timeline

- The outage was planned to proceed for 18-months, starting in April 2008.

- Several unplanned events led to a considerable extension in the outage timeframe:
  - 2 LP turbine rotors tipped the barge and fell into the bay at the Port of St. John (Oct. 2008).
    - Recovered and sent back to manufacturer for inspection, complete disassembly, cleaning, reassembly and balancing.
  - Leak testing of the rolled-joint seal between the reactor end fittings and calandria tubes revealed many connections were failing (Oct. 2010).
    - Decision made to remove all calandria tubes and reinstall with a new procedure to prepare the sealing surfaces prior to reinstallation.

Refurbishment timeline (cont'd)

- Major construction activities completed in March 2012.
- Systems sequentially refilled, pressure tested and brought back to service.
- First criticality after refurbishment on July 25th, 2012 … 30 years to the day from first criticality.
- Currently performing engineering testing on the turbine/generator and confirming response of reactor from nuclear physics.

Secondary System Chemistry

- Other major maintenance activities in the secondary system included:
  - Grinding and inspection of welds in the reheaters;
  - Replacement of select sections of steam piping;
  - Mechanical cleaning of the condenser hotwells;
  - Complete retube of the Ti condensers and replacement of the original Al-bronze tubesheet with titanium.

- With the duration of the outage and the magnitude of the work performed, it was expected that secondary side clean-up would be challenging … desirable to run the CPP in full-flow operation.

- Standard secondary chemistry at PLGS:
  - 25 ppm morpholine
  - 20 – 25 ppb N_2H_4
  - ~ 1 ppm NH_3 (from hydrazine decomposition)

- Polisher runtimes under standard chemistry to avoid morpholine break are ~ 12 hours.
  - 4 parallel polisher vessels;
  - Procedures not in place to operate in amine-saturated conditions;
  - IX resin regeneration performed off-site with ~ 1 week turnaround time.

- Choice was made to switch to ammonia-AVT chemistry for the plant start up to prolong polisher runtimes. Also investigated mixed morpholine-ammonia AVT …

- Concerns about:
  - FAC in MSR and two-phase steam lines;
  - Effects of impurity (Na) removal and/or potential throw from ammoniated resin.

- To evaluate these concerns, the steam cycle was modelled and comparisons made between the base case (normal morpholine AVT) and various concentrations of ammonia.

Condensate Polisher runtime

- All calculations were performed assuming a 100% effective full power flow rate through the polisher vessel (~ 250 kg/s).

- Polisher runtime to amine break calculated as:

$$t = \frac{abV_{polisher}C_{cation}}{C_{\text{amine}}Q}$$

Where: a = %H form on cation resin (assumed to be 90% following regeneration)

b = typical % of cation total capacity observed (assumed to be 62%)

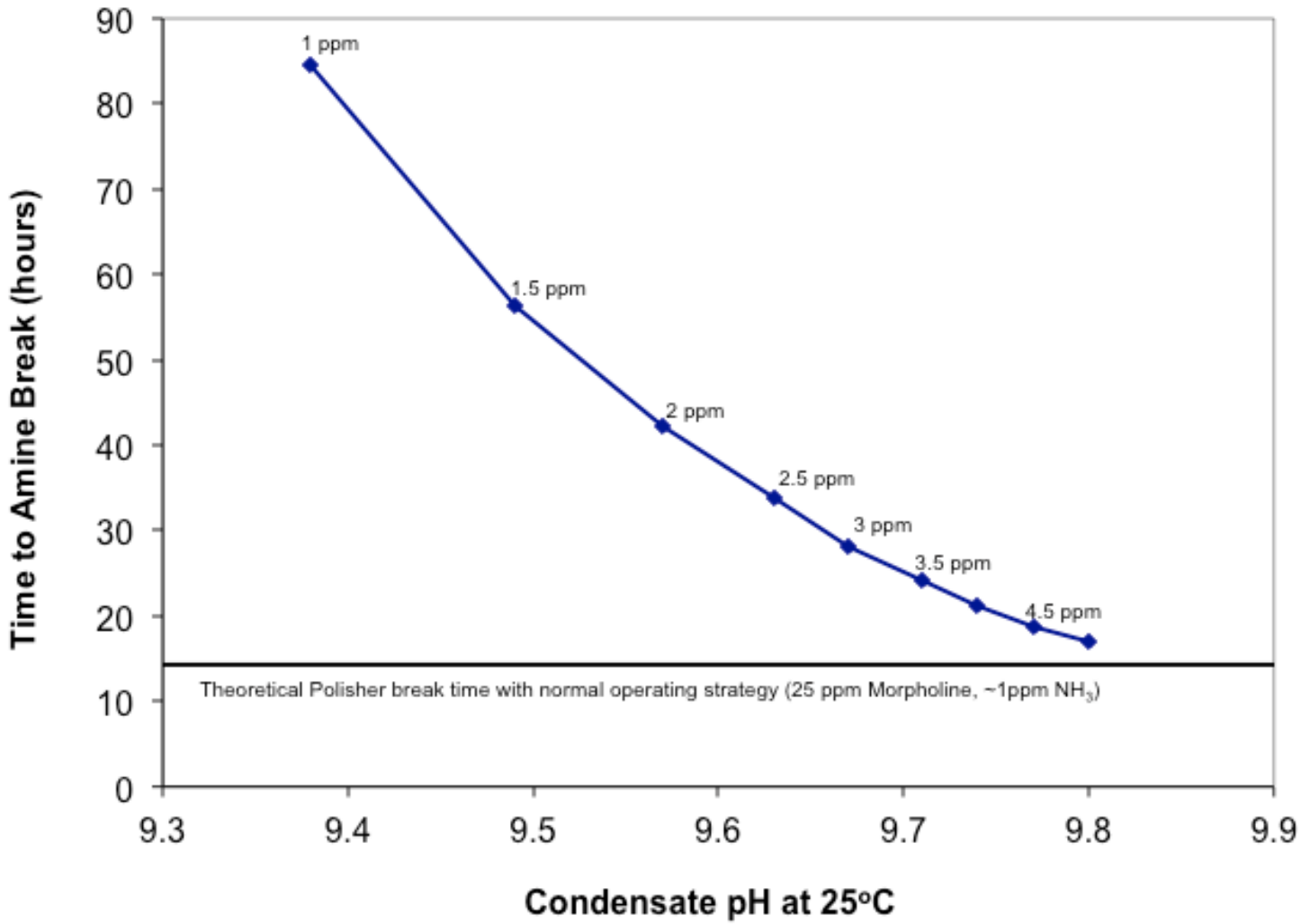
$V_{polisher}$ = cation volume in Polisher service vessel (4020 litres)

C_{cation} = typical cation resin capacity (2.0 meq/mL – manufacturer specification)

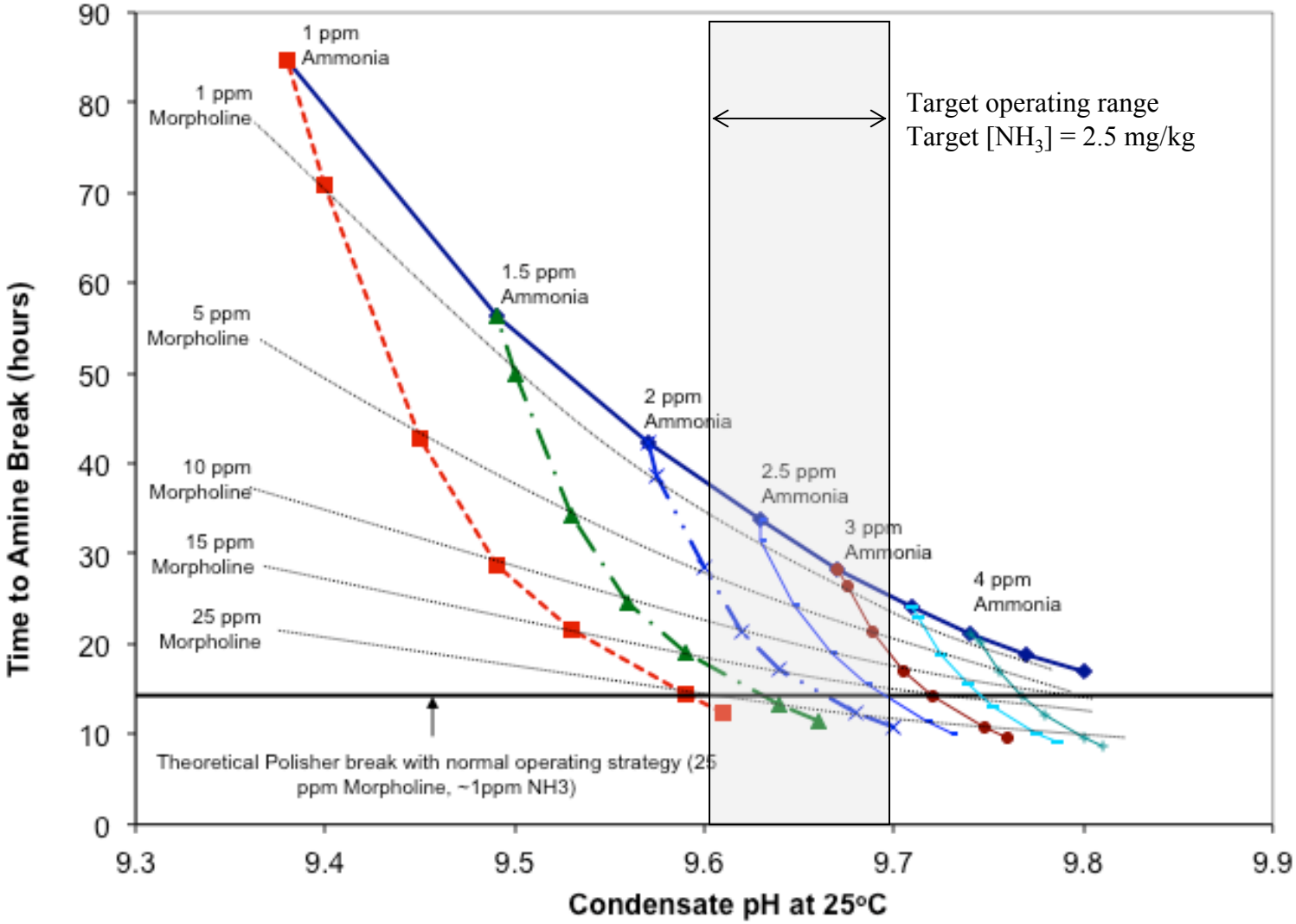
C_{amine} = total equivalents of amine in condensate (meq/mL)

Q = volumetric flow rate of condensate through Polisher service vessel (250 L/s in each vessel under 100% Full Power operation)

Polisher runtime - Ammonia



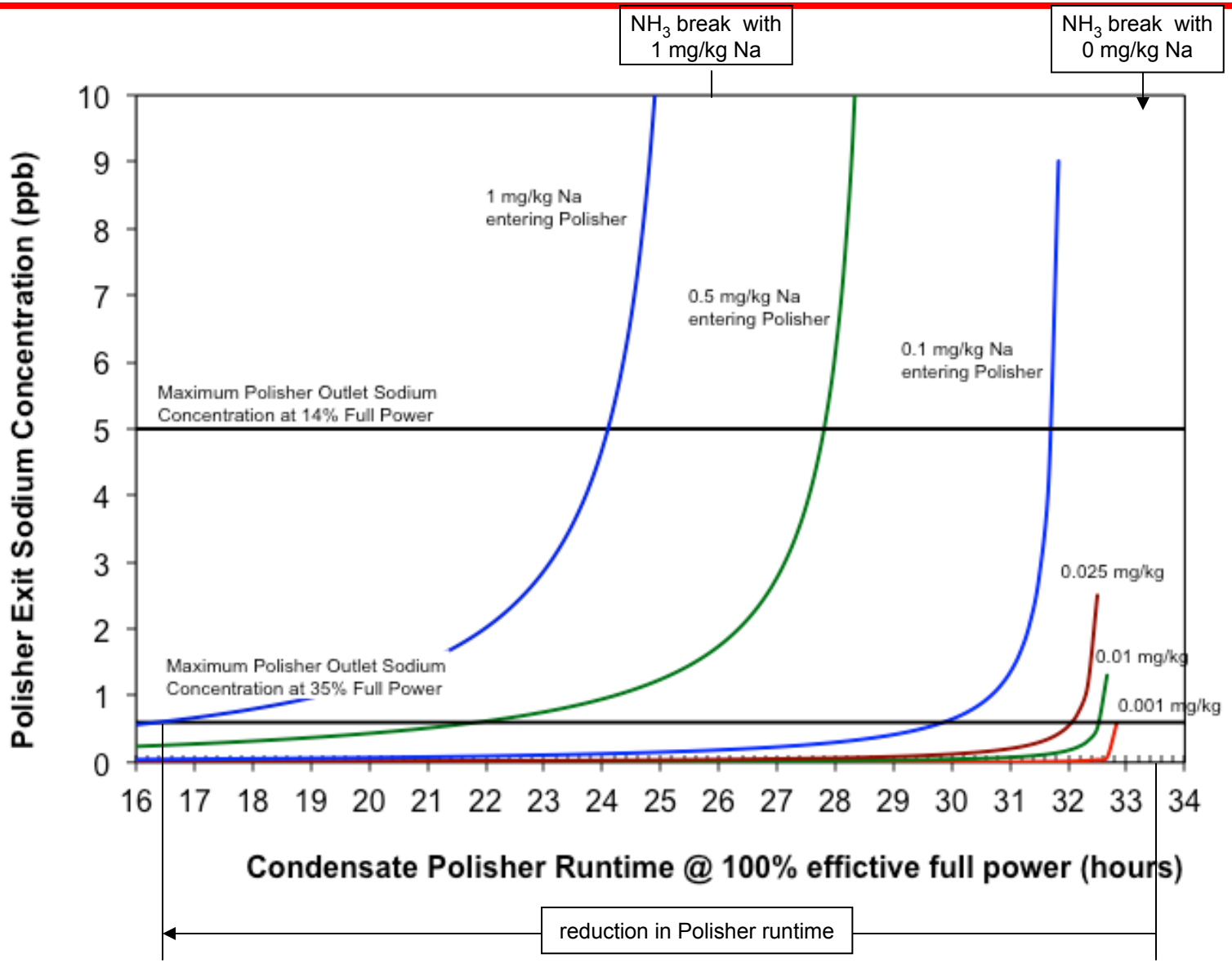
Polisher runtime – mixed NH_3 / morpholine



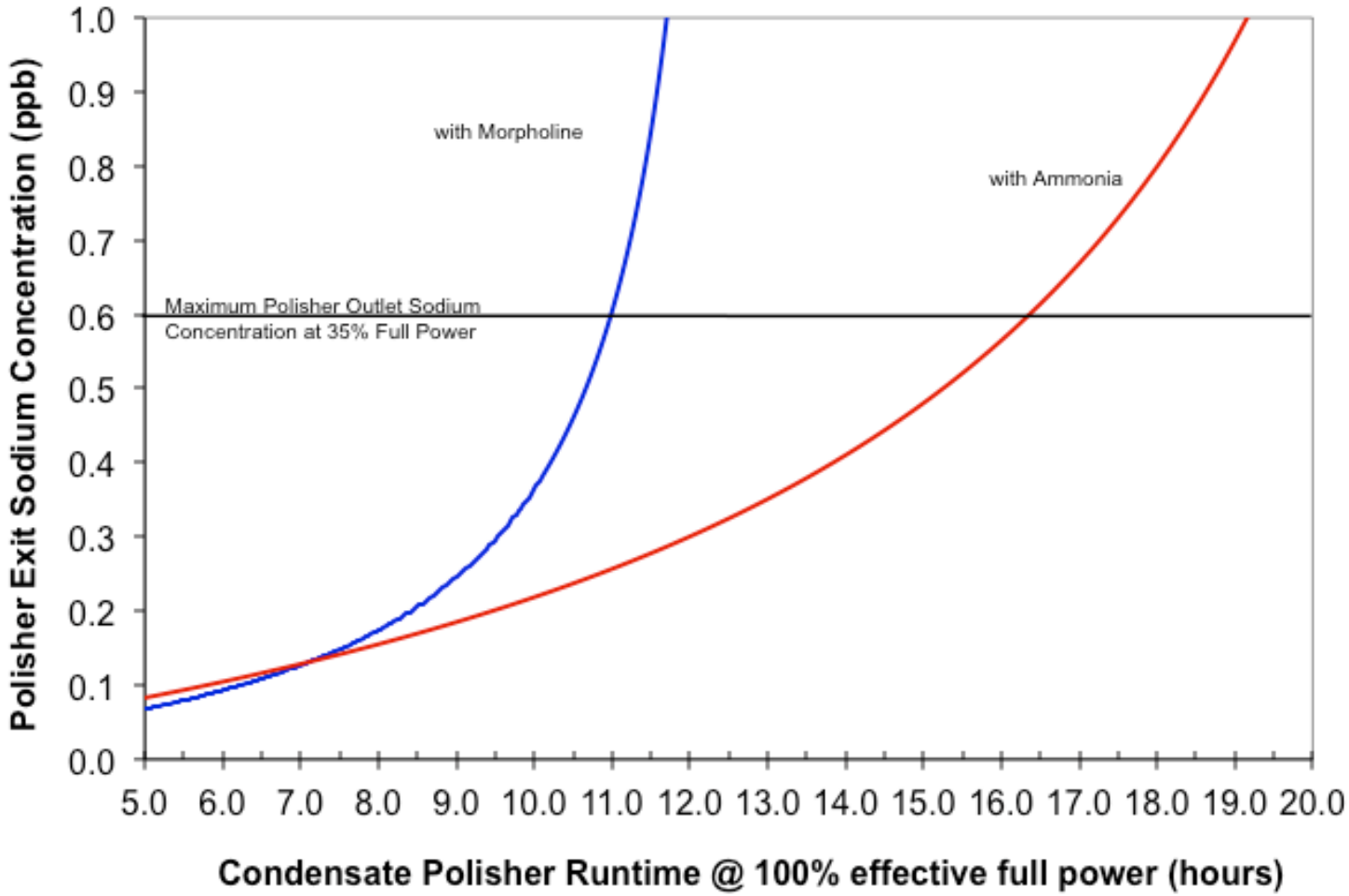
Sodium throw

- It is well known that the selectivity for NH_4^+ is higher than Na^+ for most strong cation exchange resins. Thus, polisher runtimes will ultimately be determined by the sodium concentration at the outlet.

- This was assessed using standard resin equilibrium equations to estimate the reduction in polisher runtimes …


NH3 break with 1 mg/kg Na
NH3 break with 0 mg/kg Na
Polisher Exit Sodium Concentration (ppb)
1 mg/kg Na entering Polisher
0.5 mg/kg Na entering Polisher
0.1 mg/kg Na entering Polisher
Maximum Polisher Outlet Sodium Concentration at 14% Full Power
Maximum Polisher Outlet Sodium Concentration at 35% Full Power
0.025 mg/kg
0.01 mg/kg
0.001 mg/kg
Condensate Polisher Runtime @ 100% effective full power (hours)
reduction in Polisher runtime

Polisher sodium break – NH_3 vs Morpholine (calculated for 1 mg/kg Na in to polisher)



Increase in FAC rates

- The increase in FAC rates using ammonia were assessed by:
  - Calculating the equilibrium pH_T at locations of interest in the steam cycle:
    - Complete model of steam cycle required including mass balances around primary components.
  - Evaluating the "delta-pH" and comparing to the base chemistry case (25 mg/kg morpholine, 1 mg/kg NH_3 and 0.025 mg/kg N_2H_4).

$$\Delta pH = pH_T - pH_{T\ neutral}$$

  - Several test cases were also run for various chemistries using EPRI's ChecWorks FAC code.

Assessment of Relative FAC rate using various NH_3 / morpholine chemistries

Ammonia (as NH_3) or Morpholine / NH_3 mixtures (mg/kg)	pH@25	Time to Amine Break (Hours)	Boiler pH @ 25°C	Relative FAC rate (this work / ChecWorks) % vs standard Morpholine chemistry (single number indicates value calculated from this work)					
				Blowdown	HTR 6 Drains	RHD & SD	HTR3 Drains	Extr. to HTR2	Extr. to HTR1
0.5	9.19	169.2	8.75	552	259	179	127	109	92
1.0	9.38	84.6	8.97	296 / 283.5	158 / 108.8	95 / 197.1	90 / 93.5	80 / 117.4	69 / 139.2
1.5	9.49	56.4	9.09	206.0	119	64	73	66	58
2.0	9.57	42.3	9.18	159 / 217.8	97 / 47.5	46 / 89.8	63 / 38.6	58 / 105.2	51 / 127.5
2.5	9.63	33.8	9.24	129.0	83	35	56	52	47
3.0	9.67	28.2	9.29	109 / 179.1	72 / 21.9	27 / 46.1	51 / 14.5	47 / 93.6	43 / 115.6
3.5	9.71	24.2	9.33	94.0	64	21	46	43	40
4.0	9.74	21.2	9.37	82.0	58	16	43	40	37
4.5	9.77	18.8	9.40	73.0	53	12	40	38	35
5.0	9.8	16.9	9.43	65 / 126	48 / -3.9	9 / 10.9	37 / -9.7	36 / 80.5	33 / 99.2
30 ppm M / 1 ppm NH_3	9.61	12.3	9.47	-5.0	-3	-4	-2	-2	-2
25 ppm M / 1 ppm NH_3	9.59	14.4	9.44	0.0	0	0	0	0	0
15 ppm M / 1 ppm NH_3	9.53	21.5	9.35	15.0	10	12	7	6	5
10 ppm M / 1 ppm NH_3	9.49	28.7	9.28	30.0	20	23	13	11	10
5 ppm M / 1 ppm NH_3	9.45	42.8	9.19	63.0	39	43	24	21	19
1 ppm M / 1 ppm NH_3	9.4	70.8	9.05	166.0	95	78	55	48	42
30 ppm M / 1.5 ppm NH_3	9.66	11.5	9.49	-5.0	-4	-3	-2	-2	-2
25 ppm M / 1.5 ppm NH_3	9.64	13.3	9.46	-1.0	0	0	0	0	0
15 ppm M / 1.5 ppm NH_3	9.59	19.1	9.38	14.0	10	8	6	6	5
10 ppm M / 1.5 ppm NH_3	9.56	24.5	9.32	28.0	19	16	12	11	10
5 ppm M / 1.5 ppm NH_3	9.53	34.2	9.25	57.0	36	30	23	20	18
1 ppm M / 1.5 ppm NH_3	9.5	49.9	9.15	133.0	81	66	50	44	39
30 ppm M / 2 ppm NH_3	9.7	10.8	9.51	-6.0	-4	-3	-2	-2	-2
25 ppm M / 2 ppm NH_3	9.68	12.3	9.48	-1.0	1	0	0	0	0
15 ppm M / 2 ppm NH_3	9.64	17.2	9.41	13.0	9	8	6	6	5
10 ppm M / 2 ppm NH_3	9.62	21.4	9.36	26.0	17	15	12	11	9
5 ppm M / 2 ppm NH_3	9.6	28.4	9.29	51.0	34	28	22	20	18
1 ppm M / 2 ppm NH_3	9.57	38.5	9.22	111.0	71	59	46	41	36

- ChecWorks results indicated that the highest FAC rate would result in an increased 4.8 mils of wear in the boiler blowdown lines over a 2 month operating period (using 1 mg/kg NH_3).

- For the recommended 2.5 mg/kg this would be reduced to ~ 3.3 mils.

- These increased metal loss rates were thought to be acceptable over a short duration during the plant restart and system clean-up.

Summary

- Secondary chemistry control was changed from morpholine- to ammonia-based AVT for the restart of PLGS (target [NH_3] = 2.5 mg/kg).
  - Currently controlling at an average of ~ 3 mg/kg
- This is predicted to increase CP runtimes by a factor of 3.
  - Observed polisher runtime ~ 23-25 hours (@ EFPF).
- Increased FAC in steam cycle components was evaluated through a simple delta-pH correlation and through ChecWorks code.
- Over the short time to bring the plant back to full power, the increased wear predicted over the base case with standard morpholine chemistry was deemed acceptable.

Acknowledgements

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