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Feedwater Iron Optimization: Peach Bottom Atomic Power Station

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REPORT SUMMARY

This report describes feedwater iron optimization efforts at Peach Bottom Atomic Power Station and includes information on condensate septa and precoat material selection, feedwater iron trends, reactor water cobalt-60 trends, drywell radiation dose trends, cobalt source term, impact of feedwater iron on activity transport, and recommendations for continued feedwater iron optimization.

Background

Peach Bottom 2 and 3 are medium and high cobalt source term plants, respectively, with a significant cobalt source term from their low-pressure turbines. Both Peach Bottom units have been able to achieve feedwater iron less than 0.5 ppb using commercially available septa with a lower particle retention rating than used in the past. As feedwater iron has decreased, reactor water cobalt-60 (Co-60) has increased, requiring higher feedwater zinc (Zn) concentrations to maintain reactor water Co-60(s)/Zn(s) less than the 2E-5 μCi/ml/ppb recommended for control of shutdown radiation fields. The zinc concentration factor (the ratio of reactor water to feedwater zinc) has increased with lower feedwater iron, making depleted zinc oxide (DZO) usage more efficient, although increased feedwater zinc has been required to compensate for the increased reactor water soluble Co-60.

Lower feedwater iron results in a lower mass of fuel crud deposit that can incorporate cobalt; thus, less Co-59 is activated to Co-60 on the fuel. Data indicate that a ratio of feedwater Zn/Fe > 0.6 will minimize the cobalt incorporation in the crud deposited on the fuel, resulting in less Co-60 that can be released during shutdown operations and transient conditions.

When there is a significant inventory of crud on the fuel with Co-60 incorporated and the feedwater iron is lowered, there may be an initial operating period where, if the feedwater Zn/Fe ratio exceeds 0.6, significant Co-60(s) is released from the fuel. During the interim period, initially controlling the Zn/Fe ratio in the range of 0.4–0.6 may be appropriate.

Objective

- To describe feedwater iron optimization efforts at Peach Bottom Atomic Power Station

Approach

The reactor coolant Co-60(s)/Zn(s) ratio needs to be controlled to prevent Co-60 incorporation into the piping films, particularly in the first cycle after noble metal chemical addition (NMCA). For Online NobleChem™ (OLNC), the period during and after the annual injection may be important. Limited data exist to date on post-OLNC activated corrosion product transport.

Over the long term, less cobalt incorporation in the fuel crud deposit may result in somewhat higher concentrations in the reactor coolant (assuming the same mass input to the reactor vessel), which will result in increased removal by reactor water cleanup (RWCU) during the operating cycle.

Results

Peach Bottom has committed to cobalt source term reduction efforts. In the interim, use of a higher dosage of cation-rich precoat along with cylindrical surface septa will aid in the removal of soluble Co-60 by the condensate system. Removal of as much insoluble Co-60 as possible (along with iron) in condensate, with cobalt-free injected iron as needed for the desired feedwater iron concentration (as low as possible to achieve the desired reactor water soluble Co-60), is recommended. A chemical decontamination followed by low temperature NobleChem™ (LTNC) may be needed to achieve lower drywell dose rates.

EPRI Perspective

The EPRI *BWR Water Chemistry Guidelines - 2004 Revision* (1008192) recommends feedwater iron control in the range of 0.1–1.0 ppb for plants operating with reducing chemistry conditions for intergranular stress corrosion cracking (IGSCC) mitigation. Since all U.S. plants are now operating under moderate hydrogen water chemistry (HWC-M) or noble metal chemical addition and hydrogen water chemistry (NMCA+HWC), it is appropriate to target the lower end of the range (0.1–0.5 ppb) to minimize zinc requirements for dose control, thus reducing the potential for crud-related fuel anomalies. Plants with condensate filter demineralizers (CF/Ds) can face a greater challenge than plants with filters and deep beds to achieve optimum conditions.

Keywords

Feedwater iron
Fuel crud
Zinc/iron ratio
Hydrogen water chemistry
Noble metal chemical addition
IGSCC
NobleChem™

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1
INTRODUCTION

The EPRI BWR Water Chemistry Guidelines - 2004 Revision [1] recommends feedwater iron control in the range of 0.1 ppb - 1.0 ppb for plants operating with reducing chemistry conditions for IGSCC mitigation. Since all U.S. plants are now operating under Moderate Hydrogen Water Chemistry (HWC-M) or Noble Metal Chemical Addition and Hydrogen Water Chemistry (NMCA+HWC), it is appropriate to target the lower end of the range (0.1 - 0.5 ppb) to minimize zinc requirements for dose control, thus reducing the potential for crud-related fuel anomalies. As plants with only Deep Bed condensate polishers continue to retrofit full-flow prefilter systems, they have the capability of driving effluent iron down to <0.1 ppb. In some cases, iron addition may be needed to help stabilize Co-60 on the fuel or if desired to operate within the range of the most extensive industry experience. However, plants with CF/Ds (Condensate Filter Demineralizers) can face a greater challenge to achieve optimum conditions.

Data from the EPRI BWR Chemistry Summary - 2007 indicate that one plant of seventeen with CF/Ds operates with a median feedwater iron concentration greater than 1 ppb and seven CF/D plants now operate with feedwater iron in the 0.1 - 0.5 ppb range. Trend data also show seasonal variations in CF/D effluent (CDE) iron at some plants, including the Peach Bottom units, where CDE iron is highest in the summer months and lowest in the winter months. These seasonal variations may be significant for plants attempting to optimize feedwater iron.

BWR CF/D systems include a number of parallel vessels. Some plants operate with a mixture of septa types and precoat materials in an attempt to balance feedwater iron, reactor water chemistry and radwaste minimization objectives. Typically, individual CF/D vessel effluent iron is not monitored, although the sample taps normally exist. The reasons for this include: the lack of an extra corrosion products sampler; insufficient resources (chemistry technician labor) to perform the extra analysis; or a combination of these factors. Consequently, the relative performance of vessels with different septa and precoats is often based on inferences from feedwater and reactor water chemistry data responses when specific vessels are removed from service or returned to service. It normally takes a long time (sometimes months) to perform enough evolutions to obtain somewhat reliable data on which to base decisions for septa, precoat or other operating changes.

The cobalt source term at Peach Bottom 2 is in the medium category while at Peach Bottom 3, the source term is considered high [2]. Iron optimization efforts must consider the potential impact on Co-60 concentrations that are related to radiation dose rates. Peach Bottom 3 has been selected as the demonstration unit since soluble Co-60 and Co-60/ zinc ratio are high (~2E-4 μCi/ml and ~2E-5 μCi/ml/ppb, respectively) and zinc addition would be more effective with lower feedwater iron at Unit 3. Data from both Peach Bottom units are presented in this report.

2

PEACH BOTTOM CONDENSATE FILTRATION SYSTEM DESIGN

The condensate filter demineralizer (CF/D) system at Peach Bottom consists of ten 72" diameter Graver bottom tubesheet filter demineralizer (F/D) vessels per unit. All ten vessels are used during normal operation, with nine vessels in operation when a vessel is out of service for backwash and precoat (BW/PC). Each vessel contains 302 70" long, 2.5" O.D. Pall HGPPB upright pleated septa on 3.5-inch centers. Air Surge backwash is used. The nominal flow per vessel is 2880 gpm, and the flow among the vessels is balanced manually. The Graver SealFast™ attachment method with full flow permanent guide rods is used in 19 of 20 vessels; this method will be installed in the 3G vessel during its next regularly scheduled septa replacement.

Integrated flow distributors (IFDs), planned for all vessels, have been installed in six vessels in Unit 2. IFDs improve flow patterns within the vessel, resulting in better precoat distribution and longer run lengths to dP endpoint, with septa life.

Radwaste processing capabilities must be addressed in conjunction with efforts to achieve lower feedwater iron. Polyelectrolyte addition for improved settling of solids is planned but not yet implemented. Interim measures suggested by the station include operation with higher precoat dosages and shorter run lengths to increase the resin to iron ratio in the backwash waste. The typical precoat was 5 containers (60 dry pounds) of Epicor PD-11 in the past, but the quantity has been increased to 12 containers (144 dry pounds) for enhanced removal of cobalt.

Peach Bottom does not have post strainers (resin traps) downstream of the CF/Ds; therefore, septa structural integrity and effective sealing of the septa attachment method are important considerations to avoid reactor water sulfate excursions associated with resin leakage.

Pall HGPPB 4- and 10-micron upright pleated septa are used in all vessels at each unit, as shown in Table 2-1. Currently, 7 out of 10 vessels in Unit 2 contain 4-micron septa, as do 6 out of 10 vessels in Unit 3. One vessel in Unit 2 and four vessels in Unit 3 contain septa that are greater than 3 years old and are therefore candidates for replacement. Graver DualGuard™ III 1-micron septa are being considered for the replacement septa. This design provides excellent iron removal by the pleated media along with a cylindrical precoat retention layer for improved ion exchange performance compared with that of the Pall HGPPB upright pleated septa. Another option for better iron removal than the current septa configuration would be use of Pall HGPPB 2-micron septa, currently used at Susquehanna. Although Pall 2-micron septa would provide good iron removal, the upright pleated surface does not allow the uniform precoat distribution of cylindrical surface septa needed to optimize soluble cobalt removal.

Table 2-1
Peach Bottom CF/D Septa (Pall HGPPB/P) as of November 1, 2007

Vessel	Septa Installation Date	Septa Micron Rating	Age as of 11/1/07 (years)	Comments
2A	Nov-05	10	1.96	
2B	May-04	4	**3.47**	
2C	Dec-04	4	2.90	
2D	Jan-06	4	1.78	
2E	Mar-07	10	0.64	IFD
2F	Feb-05	4	2.75	IFD
2G	Jun-07	4	0.37	IFD
2H	Jan-07	4	0.80	IFD
2J	Apr-07	4	0.58	IFD
2K	Feb-06	10	1.68	IFD
3A	Mar-04	4	**3.59**	
3B	Apr-05	4	2.51	
3C	Apr-05	4	2.57	
3D	Apr-06	10	1.58	
3E	May-06	10	1.45	
3F	Feb-05	4	2.72	
3G	Aug-04	10	**3.24**	Old hardware
3H	Oct-04	4	**3.03**	
3J	Dec-03	4	**3.89**	
3K	May-05	4	2.47	

3
FEEDWATER IRON

Median feedwater iron in 2006 was 0.36 ppb at Peach Bottom 2 and 0.32 ppb at Peach Bottom 3. Peach Bottom 2 and 3 can achieve feedwater iron less than 0.1 ppb by gradually increasing the number of vessels with 4-micron Pall HGPPB septa and/or 1-micron Graver DualGuard™ septa during regularly scheduled septa replacements, or through use of lower particle retention rating Pall or DualGuard™ septa. Use of Pall HGPPB 4-micron septa without precoat has been shown to reduce feedwater iron to less than 0.1 ppb at River Bend and Nine Mile Point 1, while use of Graver DualGuard™ II and III 1-micron septa along with Pall HGPPB 4-micron septa has reduced feedwater iron to less than 0.1 ppb at Quad Cities 1.

Median feedwater insoluble iron and septa configuration are shown in Table 3-1. The feedwater iron trends at Peach Bottom 2 and 3 are shown in Figure 3-1 and Figure 3-2, respectively.

Table 3-1
Peach Bottom Median Feedwater Iron and Septa Configuration (2003 – 2006)

Year	Unit 2			Unit 3		
	Median FW Insol Fe (ppb)	# of Pleated Septa at Year End	# of 4-μm Septa at Year End	Median FW Insol Fe (ppb)	# of Pleated Septa at Year End	# of 4-μm Septa at Year End
2003	0.68	8	1	0.97	8	0
2004	0.63	10	5	0.76	9	2
2005	0.32	10	5	0.48	10	6
2006	0.36	10	6	0.32	10	6
2007	0.50 (Note 1)	10	7	0.57 (Note 1)	10	7

Notes
1. Twelve month rolling average for total FW Fe through November 2007.

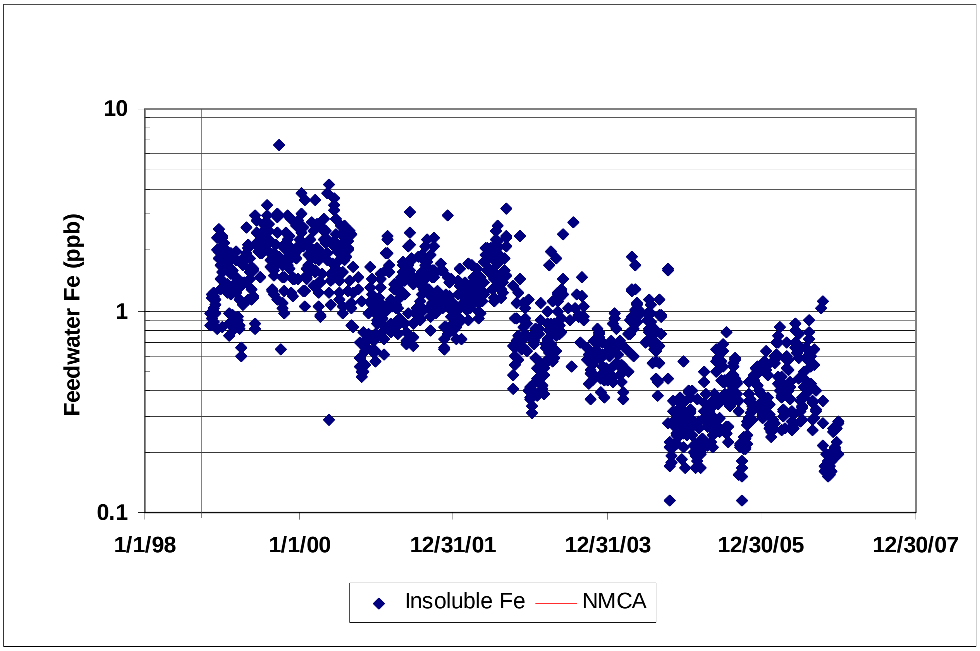

Figure 3-1
Peach Bottom 2 Feedwater Iron Trend

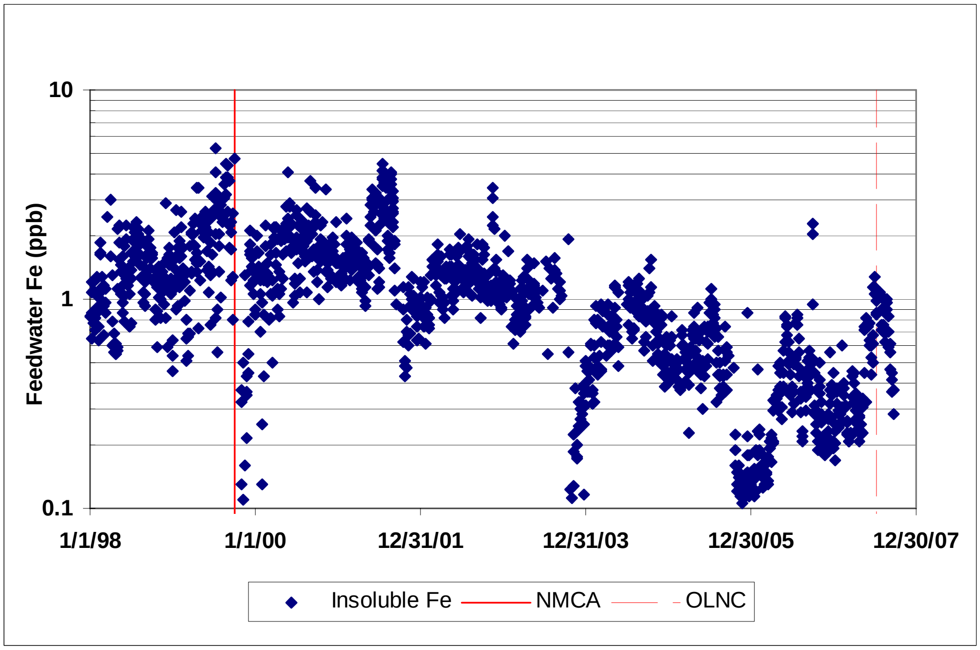

Figure 3-2
Peach Bottom 3 Feedwater Iron Trend

4

COBALT SOURCE TERM

Cobalt in condensate from wear of the LPT (low pressure turbine) Stellite™ erosion shields is a major source term in production of reactor water Cobalt-60, which is the main radioactive isotope responsible for increasing primary system dose rates and personnel radiation exposure during plant shutdowns. Cobalt-60 is formed by activation of non-radioactive cobalt (Co-59), which is the major component of Stellite™.

Cobalt in Condensate

Chemistry samples indicate that the highest concentration of Co-59 occurs at the CF/D inlet (CDI). As shown in Figure 4-1, Peach Bottom CDI Co-59 concentrations are the highest reported in the industry. The data show that between 60-70% of Co-59 is soluble (non-filterable), and is removed by ion exchange membranes in the corrosion products sampler. The percent of total CDI cobalt that is filterable (insoluble) is shown in Figure 4-2.

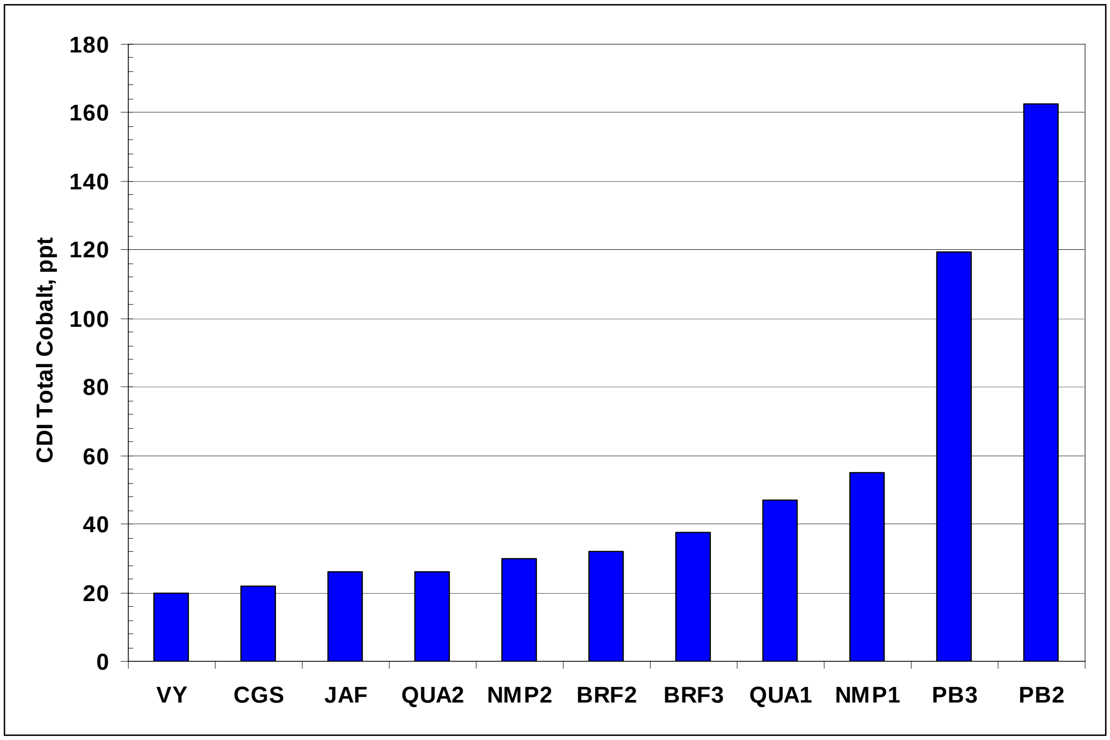

Figure 4-1
BWR Fleet CDI Total Cobalt

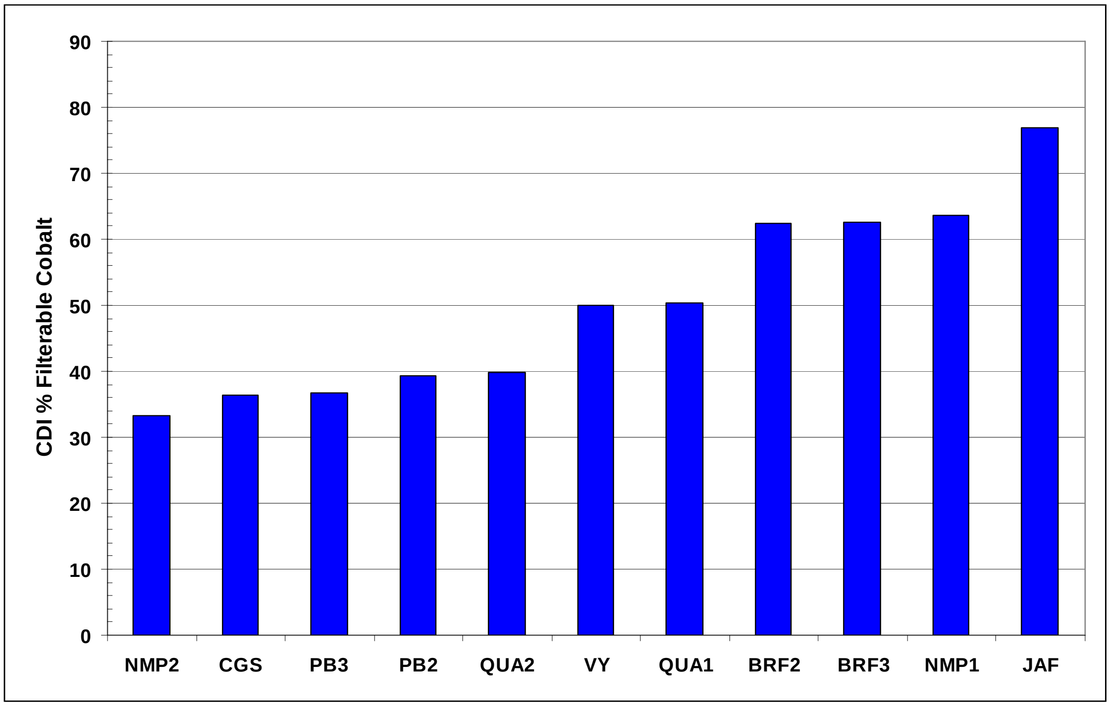

Figure 4-2
BWR Fleet CDI Total Cobalt (% of Total that is Filterable)

Cobalt in Feedwater

The final feedwater total cobalt concentration is 8 - 9 ppt, measured as mainly soluble (non-filterable), indicating that increased resin dosage and more effective removal by ion exchange will reduce cobalt transport to the reactor. Unit 2 and Unit 3 final feedwater and CDE cobalt concentrations are similar, indicating that there is no major feedwater source downstream of the CF/Ds. In comparison, Hope Creek, a low dose, low Co-60 plant, has feedwater cobalt concentrations of about 4 ppt. Quad Cities 1 lowered coolant Co-60 concentrations after reducing CDE cobalt to ≤4 ppt through turbine bucket replacement.

Cobalt Reduction Strategy

Peach Bottom is planning to implement upgrades to the condensate filter demineralizers (CF/Ds) as the most cost effective approach to enhancing cobalt removal until the LPTs can be replaced with new turbines constructed of low-cobalt materials. While retrofitting deep bed demineralizers and converting CF/Ds to prefilters has been considered, this is not a long term cost effective alternative due to the high capital cost. An effective strategy for managing the cobalt source term at Peach Bottom until the low pressure turbines are replaced involves the following steps:

1. Optimize the CF/D configuration and operation to reduce cobalt transport to the reactor by removal of as much of the soluble and insoluble corrosion products from condensate as possible:

  - Replace current Pall upright pleated septa with a design better suited for cobalt removal by ion exchange and for insoluble species (iron and cobalt) removal by filtration.
  - Use a precoat loading of 12 to 16 ft^3 for enhanced soluble Co-60 removal.
2. Install an iron injection skid to provide the ability to add cobalt-free iron to the feedwater as required for reactor water Co-60 control.

In implementing the above strategy, an accelerated septa replacement schedule is appropriate to achieve the desired configuration by the end of 2009. Septa replacements should be coordinated with the planned IFD installation schedule to minimize labor cost and vessel out of service time.

5

REACTOR WATER COBALT-60

Reactor water Co-60 trends at Peach Bottom 2 and 3 are shown in Figure 5-1 and Figure 5-2, respectively. At Unit 2, soluble Co-60 has been on an increasing trend during each cycle since late 2001, while insoluble Co-60 concentrations have been more stable. A step decrease in insoluble Co-60 occurred during Cycle 16, prior to NMCA reapplication, coincident with increased use of higher efficiency septa in the CF/Ds. Insufficient data are available to determine trends after the classic NMCA reapplication, which was performed in September 2006.

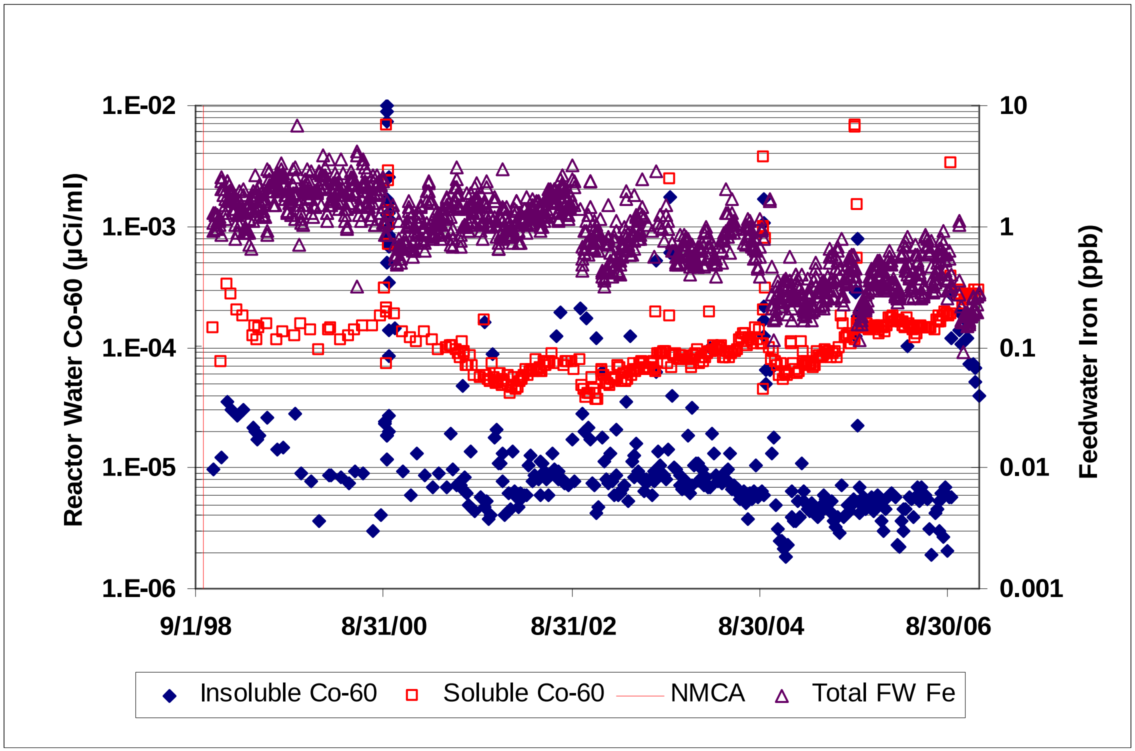

Figure 5-1
Peach Bottom 2 Reactor Water Co-60 Trend

At Peach Bottom 3, soluble Co-60 increased during the second and third cycles after NMCA and remained steady during Cycle 16 prior to OLNC. In contrast, insoluble Co-60 decreased during Cycle 16, coincident with use of higher efficiency septa in the CF/Ds.

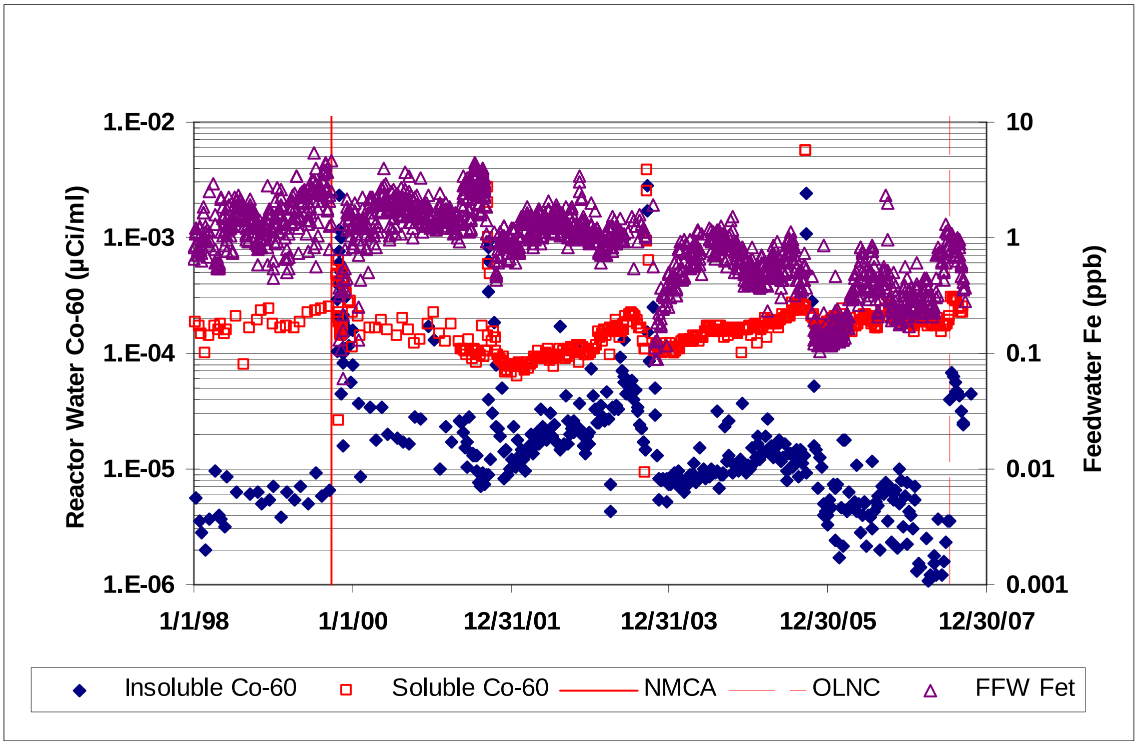

Figure 5-2
Peach Bottom 3 Reactor Water Co-60 Trend

Peach Bottom 2 Reactor Water Co-60 and Feedwater Iron

Unit 2 reactor water soluble Co-60 is plotted versus feedwater iron in Figure 5-3 and Figure 5-4. As shown in Figure 5-3, there is a little change in soluble Co-60 at Unit 2 during the years 1995 through 2006. There is also little change in Figure 5-4, which includes Cycle 16 data only. Most of the data points less than 0.5 ppb feedwater iron have occurred during the last two cycles (15 and 16), as shown in Figure 3-1.

This analysis is complicated by the fact that one third of the fuel rods and associated fuel crud deposits are replaced every cycle and the soluble Co-60 concentration is determined by the equilibrium with the whole core. Changes in Co-60 trends may occur slowly, while feedwater iron changes more quickly (e.g., as a result of septa replacement or seasonal effects). The reactor water zinc target also has an impact on soluble Co-60.

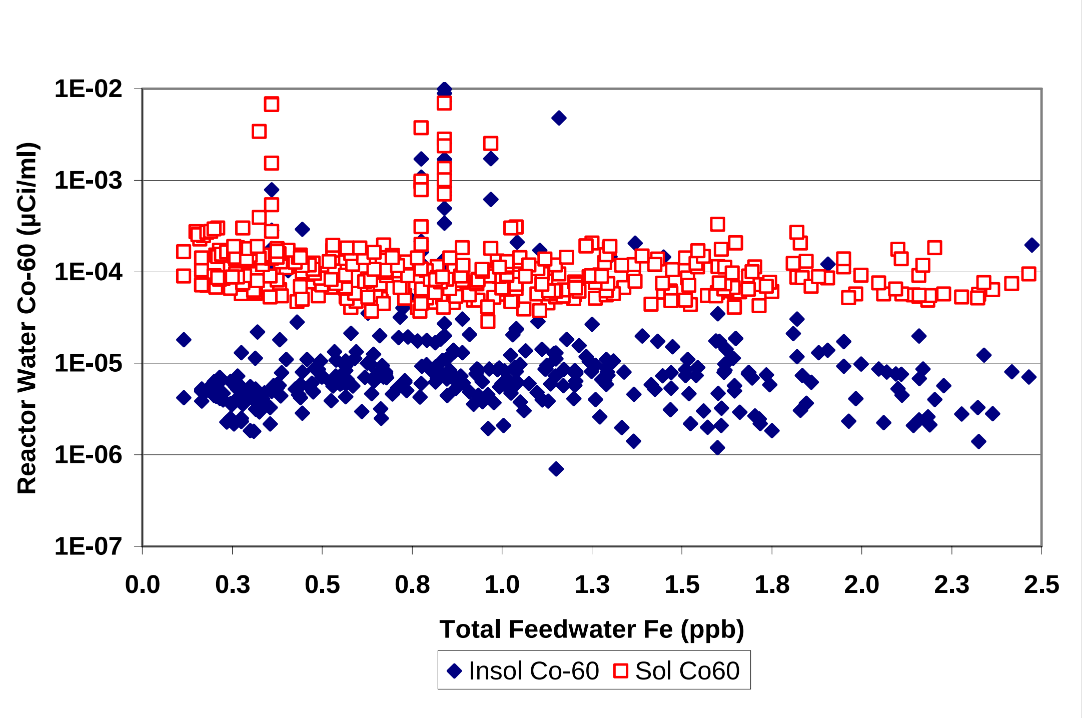

Figure 5-3
Peach Bottom 2 Reactor Water Co-60 vs. Feedwater Iron (1996-2006)

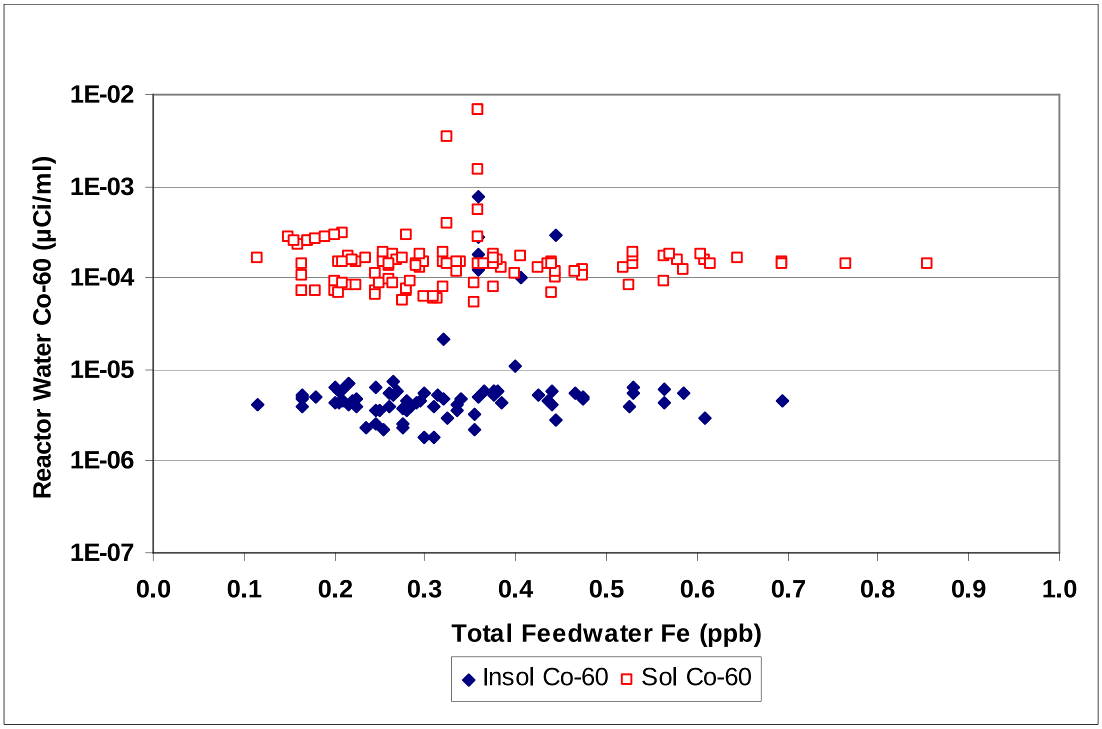

Figure 5-4
Peach Bottom 2 Reactor Water Co-60 vs. Feedwater Iron (Cycle 16)

A plot of Peach Bottom 2 cycle median Co-60 by range of feedwater iron concentrations is shown in Figure 5-5. This figure indicates slightly increased soluble Co-60 as feedwater iron decreases below 0.4 ppb. However, since most of the data points below 0.4 ppb are recent, it is difficult to determine cause and effect. Increased Co-60 could result from increased wear of cobalt-containing components.

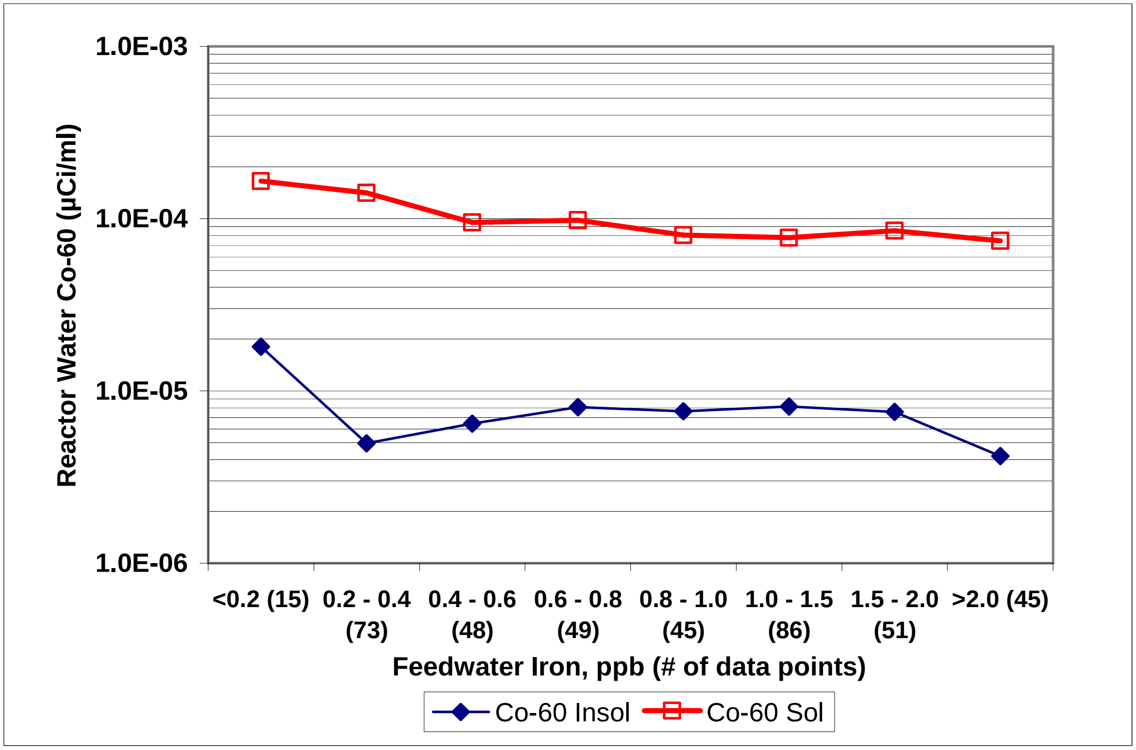

Figure 5-5
Peach Bottom 2 Median Reactor Water Co-60 vs. Feedwater Iron (1995 - 2006)

Peach Bottom 3 Reactor Water Co-60 and Feedwater Iron

Unit 3 reactor water soluble Co-60 is plotted versus feedwater iron in Figure 5-6. There is a slight increase in soluble Co-60 at Unit 3 during the period when feedwater iron is less than 0.6 ppb, with a complementary decrease in insoluble Co-60. Most of the data points less than 0.6 ppb have occurred during the last two cycles (15 and 16), as shown in Figure 3-2.

Unit 3 reactor water soluble Co-60 versus feedwater iron for Cycles 15 and 16 is shown in Figure 5-7. This plot indicates little change in soluble Co-60 as feedwater iron decreases. The results for insoluble Co-60 are less clear; however, it appears that a lower percentage of insoluble Co-60 values are greater than 1E-5 µCi/ml as feedwater iron decreases.

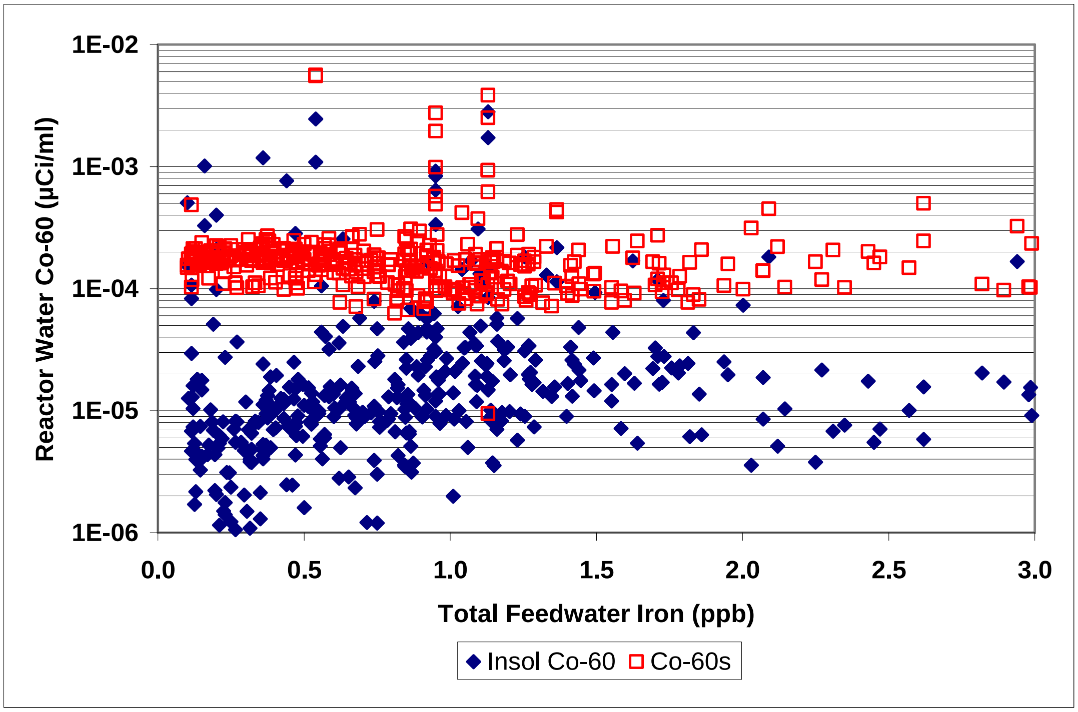

Figure 5-6
Peach Bottom 3 Reactor Water Co-60 vs. Feedwater Iron (1998 – September 2007)

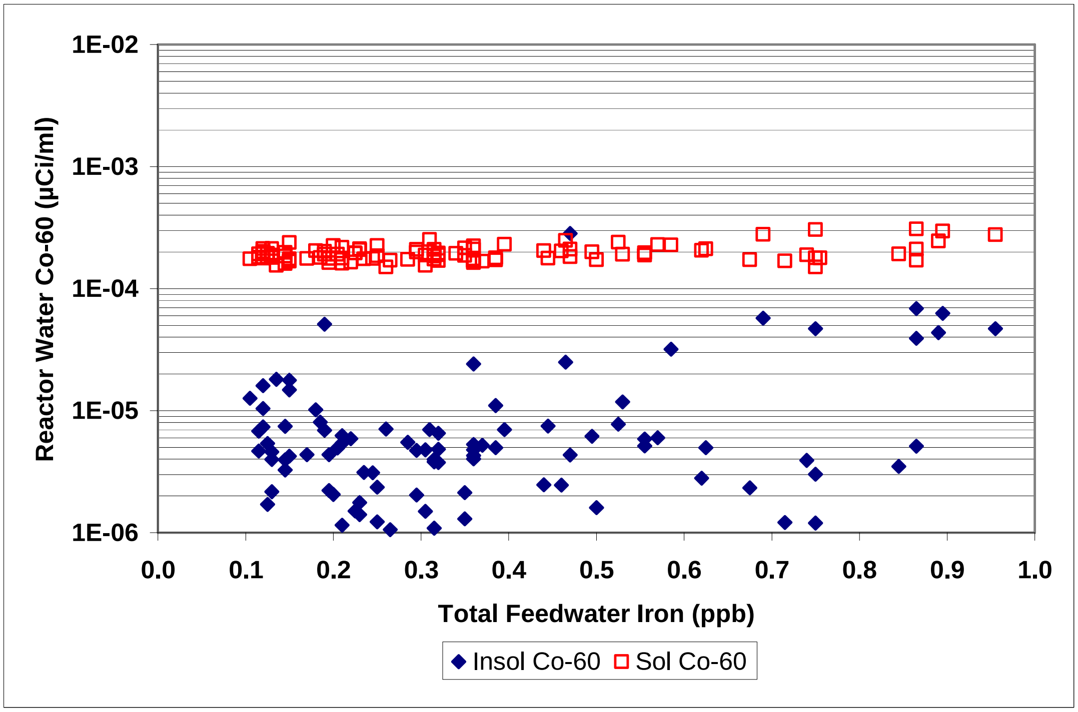

Figure 5-7
Peach Bottom 3 Reactor Water Co-60 vs. Feedwater Iron (Cycle 16)

Peach Bottom 3 median Co-60 by range of feedwater iron concentrations is shown in Figure 5-8. This figure indicates little change in soluble Co-60 as feedwater iron decreases below 1.5 ppb, with essentially no change below 0.4 ppb. Unlike Unit 2 data (Figure 5-5), there is a more pronounced decrease in insoluble Co-60 throughout most of the feedwater iron range.

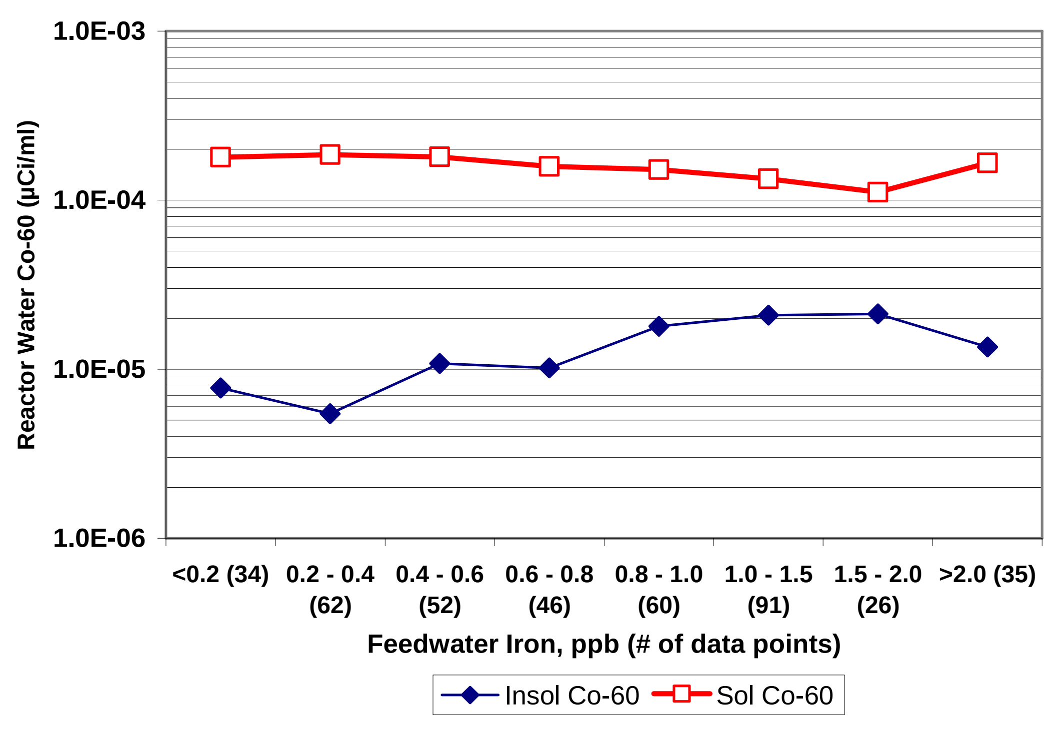

Figure 5-8
Peach Bottom 3 Median Reactor Water Co-60 vs. Feedwater Iron (1998 - 2007)

6

CYCLE SUMMARY DATA

Cycle summary data for Peach Bottom 2 and 3 are shown in Table 6-1 and in Figure 6-1 and Figure 6-2. Cycle ratios are shown in Table 6-2.

Table 6-1
Peach Bottom 2 and 3 Cycle Median Data

Cycle	Cycle Start	Post NMCA Cycle	End of Cycle BRAC (mR/hr)	RCI Zn sol (ppb)	RCI Co60i (µCi/ml)	RCI Co60s (µCi/ml)	RCI Co60t (µCi/ml)	Rx Co60s/Zns (µCi/ml/ppb)	FFW Fet (ppb)	FFW Znt (ppb)	RCI Zn sol/FFW Znt
Unit 2											
12	Oct-96	0	130.75	2.80	6.90E-06	9.16E-05	1.44E-04	3.27E-05	1.379	0.164	17.1
13	Nov-98	1	214.25	2.40	1.44E-05	1.46E-04	1.48E-04	6.07E-05	1.820	0.100	24.0
14	Oct-00	2	177.5	8.30	7.93E-06	6.61E-05	1.01E-04	7.97E-06	1.205	0.530	15.7
15	Sep-02	3	139	9.400	8.51E-06	7.96E-05	9.56E-05	8.47E-06	0.725	0.510	18.4
16	Oct-04	4	252.5	11.900	4.92E-06	1.40E-04	1.45E-04	1.18E-05	0.340	0.525	22.7
Unit 3											
12	Jan-98	0	255	3.15	5.51E-06	1.73E-04	1.82E-04	5.49E-05	1.455	0.149	21.1
13	Oct-99	1	232.5	4.20	4.00E-05	1.63E-04	3.34E-04	3.88E-05	1.735	0.205	20.5
14	Oct-01	2	205	8.800	2.31E-05	1.03E-04	1.72E-04	1.17E-05	1.127	0.770	11.4
15	Oct-03	3	260	11.250	9.78E-06	1.64E-04	1.74E-04	1.46E-05	0.605	0.465	24.2
16	Oct-05	4	267.5	11.100	4.80E-06	1.91E-04	1.96E-04	1.72E-05	0.315	0.390	28.4

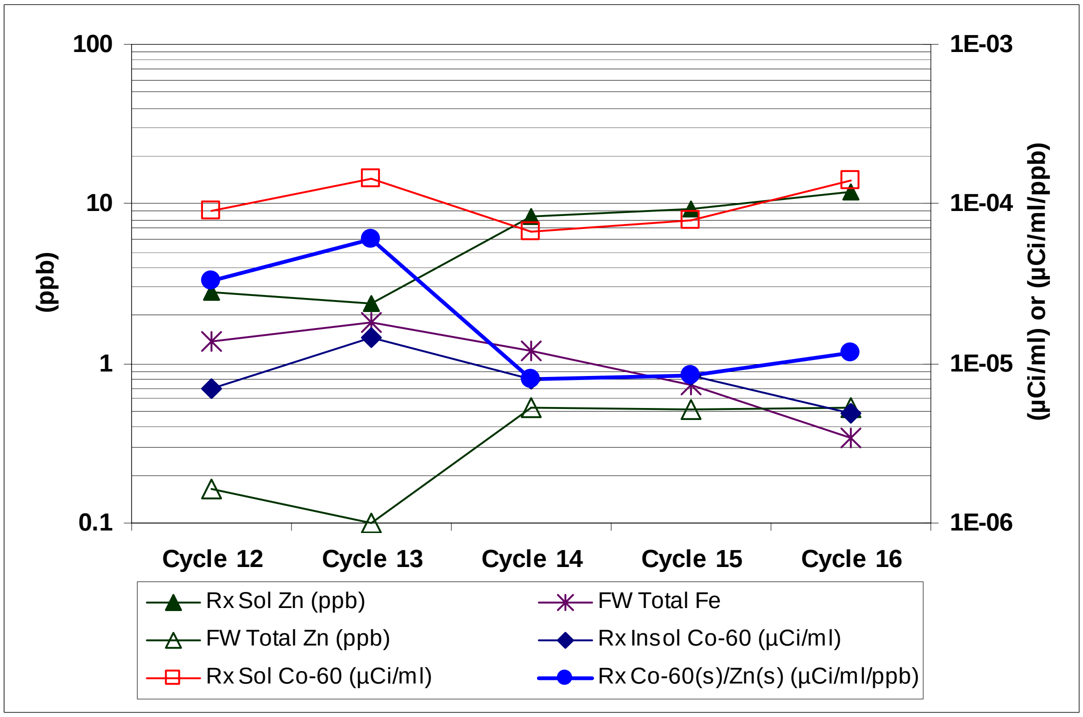

Figure 6-1
Peach Bottom 2 Cycle Median Summary (NMCA at beginning of Cycle 13)

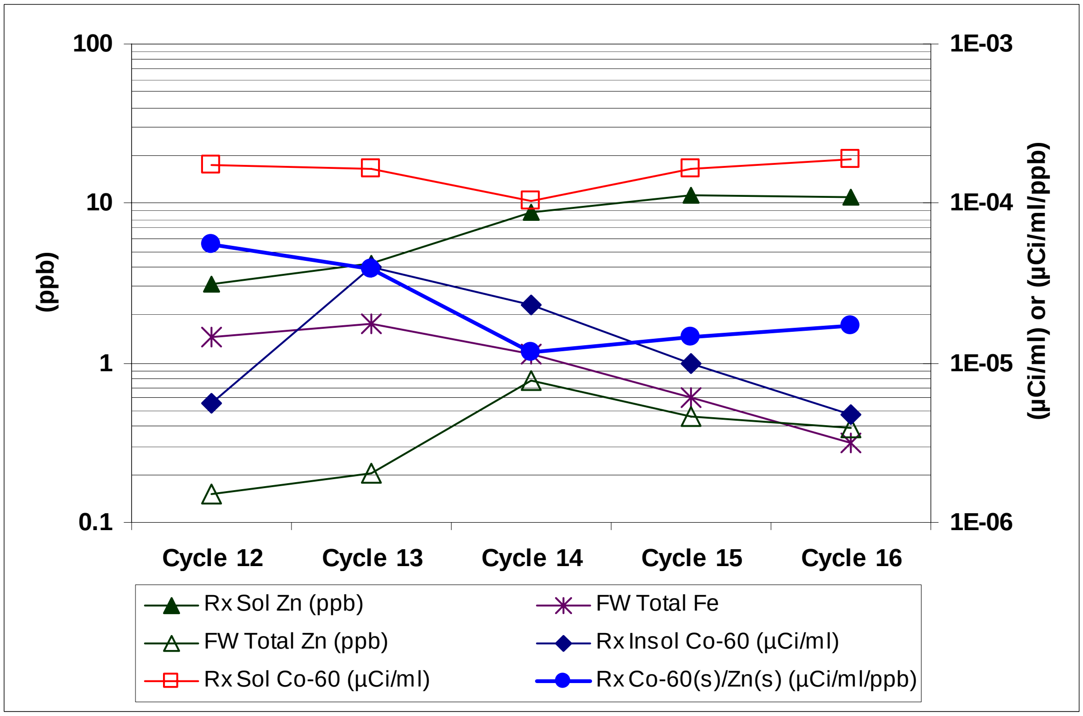

Figure 6-2
Peach Bottom 3 Cycle Median Summary (NMCA at beginning of Cycle 13)

Table 6-2
Peach Bottom 2 and 3 Cycle Median Data (Ratio to Prior Cycle)

Cycle	Post NMCA Cycle	EOC BRAC	RCI Zn sol	RCI Co60i	RCI Co60s	RCI Co60t	Rx Co60s/Zns	FFW Fet	FFW Znt
Unit 2									
Cycle 13/12	1	1.64	0.86	2.08	1.59	1.03	1.86	1.32	0.61
Cycle 14/13	2	0.83	3.46	0.55	0.45	0.69	0.13	0.66	5.30
Cycle 15/14	3	0.78	1.13	1.07	1.20	0.94	1.06	0.60	0.96
Cycle 16/15	4	1.82	1.27	0.58	1.76	1.52	1.39	0.47	1.03
Unit 3									
Cycle 13/12	1	0.91	1.33	7.26	0.94	1.83	0.71	1.19	1.37
Cycle 14/13	2	0.88	2.10	0.58	0.63	0.52	0.30	0.65	3.76
Cycle 15/14	3	1.27	1.28	0.42	1.59	1.01	1.24	0.54	0.60
Cycle 16/15 (OLNC at EOC 15)	4	1.03	0.99	0.49	1.16	1.12	1.18	0.52	0.84

As shown above, the relationship between lower feedwater iron and other parameters is not consistent, nor is the behavior between the two units. Although cycle median data seem to suggest a relationship between lower feedwater iron and higher soluble Co-60 for cycles 15 and 16 at both units, the parameter vs. parameter charts do not indicate that there is a relationship even for cycles when reactor water zinc has been high. There has been a small increase (about 33%) in reactor water to feedwater zinc ratio with lower feedwater iron, allowing the reactor water Co-60(sol)/Zn(sol) ratio to be maintained with a lower feedwater zinc concentration. The current zinc concentration factor is within the experience range of other stations with similar feedwater iron levels [5], and may increase as the inventory of iron in the system decreases over time. There also seems to be some correlation at Unit 3 between lower insoluble Co-60 and lower feedwater iron. This may be the result of the increased CF/D precoat dosage, which began in 2007 (2007 data for Unit 2 is not available), and/or of the use of higher efficiency septa in the CF/Ds.

Peach Bottom 2 and Peach Bottom 3 cycle median results from cycles 14 through 16, when reactor water zinc was greater than 5 ppb, are plotted in Figure 6-3 and Figure 6-4, respectively. In both units, soluble Co-60 has increased while insoluble Co-60 has decreased as feedwater iron has decreased. The cycle median Co-60(sol)/Zn(sol) ratio has been maintained below 2E-5 μCi/ml/ppb for both units.

In both units, the zinc concentration factor has increased with decreasing feedwater iron, as shown in Table 6-1.

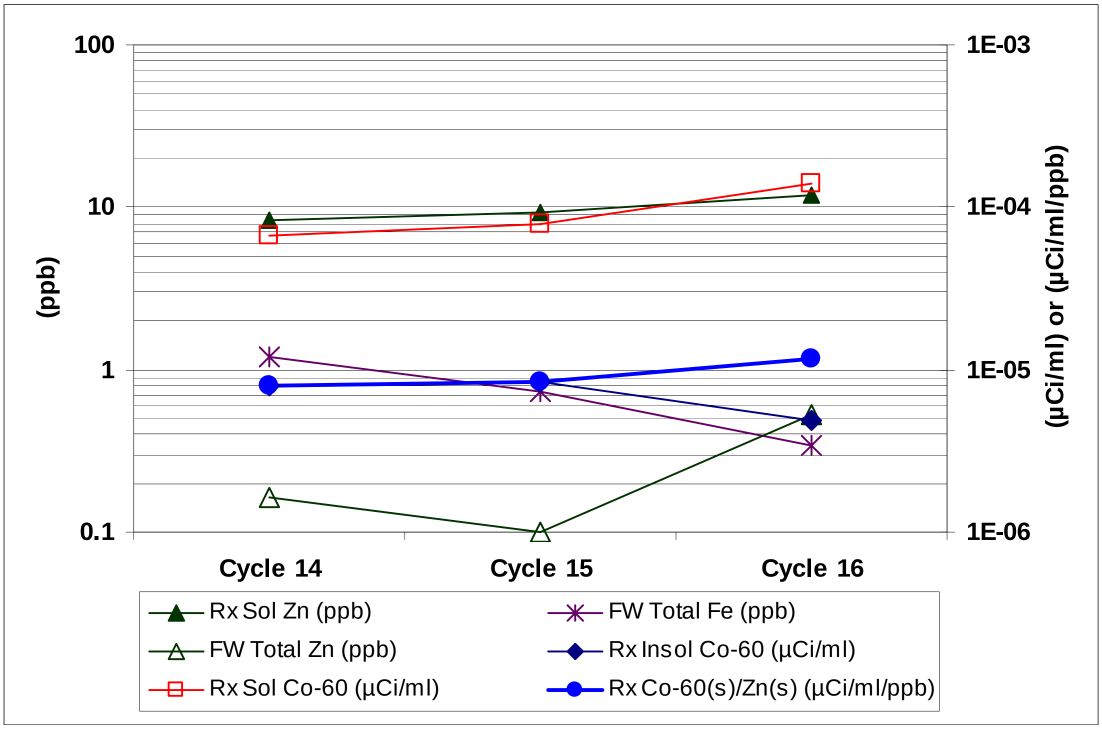

Figure 6-3
Peach Bottom 2 Cycle Median Summary (NMCA at beginning of Cycle 13)

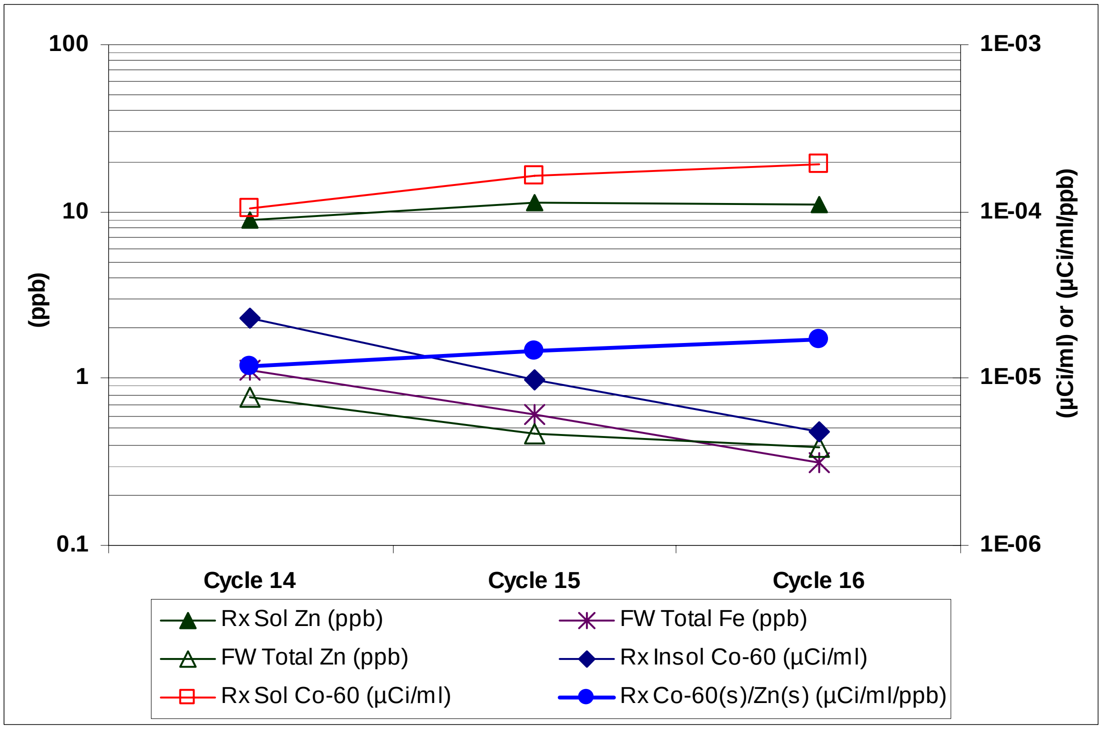

Figure 6-4
Peach Bottom 3 Cycle Median Summary (NMCA at beginning of Cycle 13)

When there is a significant inventory of iron crud deposited on the fuel from operation with relatively high feedwater iron and feedwater Zn/Fe less than approximately 0.6 (mass ratio of Zn/Fe in zinc ferrite = 0.585), the fuel crud will have significant excess capacity to hold cobalt and zinc and will tend to be more fluffy. Co-59 held in the fuel crud will become activated to Co-60. When feedwater iron begins to significantly decrease and feedwater Zn/Fe ratio increases above 0.6, the predominant corrosion product depositing on the fuel will tend to be zinc ferrite, which is characterized as a tenacious (less fluffy) corrosion product form. Excess zinc will be available to compete with cobalt that has previously incorporated into the spinel structure, potentially causing cobalt release to the bulk coolant. Consequently, there may be a period during which the higher ratio of feedwater zinc to iron induces the release of Co-60 from the fuel crud.

To evaluate whether this has occurred at Peach Bottom, data for 5 cycles at Unit 2 and Unit 3 are shown in Figure 6-5, while in Figure 6-6, only data from 6 cycles when reactor water zinc was greater than 5 ppb are shown. For both Peach Bottom units, the limited amount of data indicate a possible relationship between reactor water soluble Co-60 and feedwater Zn/Fe. This may indicate that for moderate to high cobalt source term plants, as feedwater iron is lowered and the feedwater Zn/Fe is increased, there may be a transition period when reactor coolant soluble Co-60 will increase until the quantity of Co-60 held in the fuel crud becomes low and/or the crud layer structure has become sufficiently rich in zinc to minimize Co-60 release. During this transition, as long as the reactor coolant Co-60(s)/Zn(s) ratio is maintained <2E-5 µCi/ml/ppb, BRAC dose rates should not increase significantly. Also during this transition period, if the Co-60(s)/Zn(s) ratio is maintained <2E-5 µCi/ml/ppb, there is a greater likelihood that Co-60 released into the coolant will be removed by the RWCU system during power operating conditions.

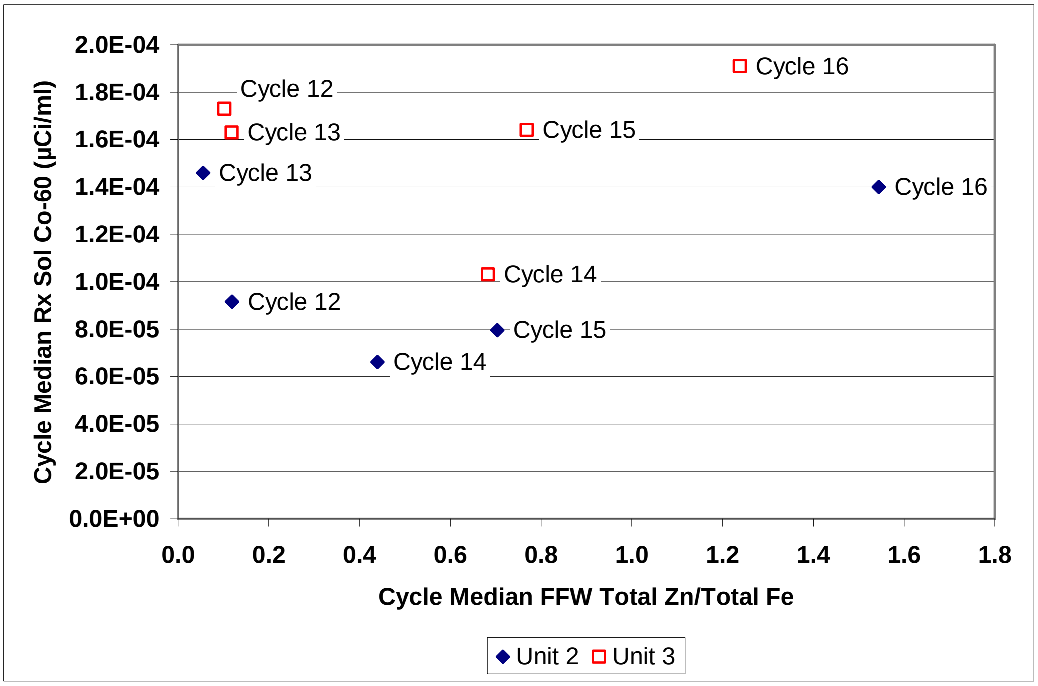

Figure 6-5
Peach Bottom 2 and 3 Soluble Co-60 vs. Feedwater Total Zn/Total Fe (NMCA at beginning of Cycle 13)

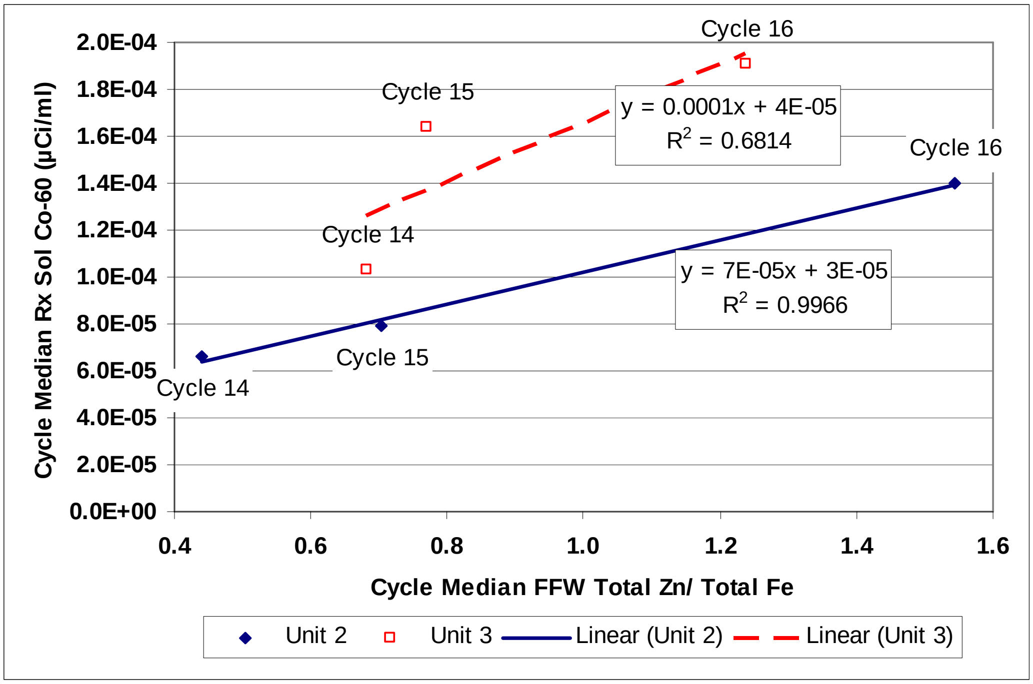

Figure 6-6
Peach Bottom 2 and 3 Soluble Co-60 vs. Feedwater Zn/Fe (Rx Zn > 5 ppb) (NMCA at beginning of Cycle 13)

7

SUMMARY OF LOW FEEDWATER IRON IMPACT ON ACTIVITY TRANSPORT

Some of the ways in which feedwater iron concentration may impact activity transport are listed below:

1. Lower feedwater iron results in a lower mass of fuel crud deposit that can incorporate cobalt.
2. A lower mass of cobalt in the fuel crud will result in less Co-59 that is activated to Co-60. Co-59 deposits on the fuel have a greater chance of activation to Co-60 by neutron absorption due to high residence time in the neutron flux. Co-59 ions and particulates in the bulk water have less chance of activation to Co-60 due to potentially lower residence times in the neutron flux.
3. A ratio of feedwater Zn/Fe >0.6 (mass ratio of Zn/Fe in zinc ferrite = 0.585) will minimize the cobalt incorporation in the crud deposited on the fuel. Japanese experience (with normal water chemistry and without zinc injection) in the 1990s found that reducing feedwater iron to <0.1 ppb resulted in increased reactor water nickel and soluble Co-60, with only minimal fuel deposits formed and most of the nickel and cobalt removed by RWCU [3]. Other tests have shown that the combination of nickel (from low iron operation) and zinc (from DZO) reduce cobalt deposition rates more effectively than either one separately, with tetrahedral sites preferring zinc over cobalt and octahedral sites preferring nickel over cobalt [3].
4. A lower inventory of Co-60 on the fuel will provide less Co-60 that can be released during shutdown operations and transient conditions.
5. When feedwater iron is lowered starting with a significant inventory of crud on the fuel with Co-60 incorporated, there may be an initial operating period where, if the feedwater Zn/Fe ratio exceeds 0.6, significant Co-60(s) is released from the fuel. During the interim period, initially controlling the Zn/Fe ratio in the range of 0.4 - 0.6 may be appropriate based on available data in Figure 6-6.
6. The reactor coolant Co-60(s)/Zn(s) ratio needs to be controlled to prevent Co-60 incorporation into the piping films, particularly in the first cycle after NMCA. For OLNC, the period during and after the annual injection may be important. Limited data exists to date on post-OLNC activated corrosion product transport.
7. Over the long term, less cobalt being held up in the fuel crud may result in somewhat higher concentrations in the reactor coolant (assuming the same mass input to the reactor vessel), which will result in increased removal by RWCU during the operating cycle.

8

SHUTDOWN DOSE RATES

High activity levels and deposition on piping and component surfaces were experienced during RFO16 at Peach Bottom 3 in October 2007, resulting in higher than expected dose rates in work areas that caused delays and outage work scope changes. Online NobleChem™ (OLNC) was performed in July 2007, about three months prior to the outage. Although the lower feedwater iron may have exacerbated the activity release during shutdown and outage evolutions, it probably would not have been a significant factor had OLNC been performed on a schedule that allowed enough time to recover from crud restructuring prior to the RFO.

Low feedwater iron with DZO injection in the long term would result in lower mass of fuel crud deposit, less cobalt deposited in the fuel crud, less Co-60 production and less potential for activated corrosion products transport causing outage dose problems.

River Bend, operating with feedwater iron generally less than 0.1 ppb since early 2003, has not reported increased outage dose rates or exposure. River Bend has remained a high BRAC dose rate plant that has operated under HWC-M with limitations on zinc injection due to past fuel failures, and has a history of HWC cycling and RWCU outages. A chemical decontamination was performed during River Bend's 2008 refueling outage. If the chemical decontamination is successful and the Co-60(s)/Zn(s) ratio is maintained less than 2E-5 μCi/ml/ppb, recontamination of the recirculation piping should be minimized. The low feedwater iron concentration is expected to be beneficial after the chemical decontamination in maintaining the required reactor water Co-60(s)/Zn(s) ratio without exceeding BWR Water Chemistry Guidelines recommendations for feedwater zinc concentration.

Peach Bottom 2 and 3 BRAC and cycle median reactor water Co-60(s)/Zn(s) are shown in Figure 8-1 and Figure 8-2, respectively.

The data in Table 6-1 and in Figure 8-1 and Figure 8-2 indicate no correlation between Co-60(s)/Zn(s) and BRAC, or change in Co-60(s)/Zn(s) to change in BRAC, for either unit, which demonstrates the complexity of the relationship between chemistry and drywell dose rates, even for the same plant operating under the same chemistry regime for multiple cycles. At both units, reactor water Co-60(s)/Zn(s) was greater than 2E-5 μCi/ml/ppb (recommended value for shutdown dose rate control) during the first cycle after NMCA. At Unit 2, BRAC dose rates increased from 131 mR/hr to 214 mR/hr (64%) in Cycle 13, the first cycle after NMCA, while cycle median Co-60(s)/Zn(s) increased 86%. At Unit 3, where median Co-60(s)/Zn(s) during Cycle 13 (first cycle after NMCA) was 3.9E-5 μCi/ml/ppb, BRAC dose rates decreased 9% from 255 mR/hr at end of Cycle 12 to 233 mR/hr. Loss of noble metal from surfaces may have resulted in higher dose rates during the later cycles, particularly at Unit 2 during Cycle 16.

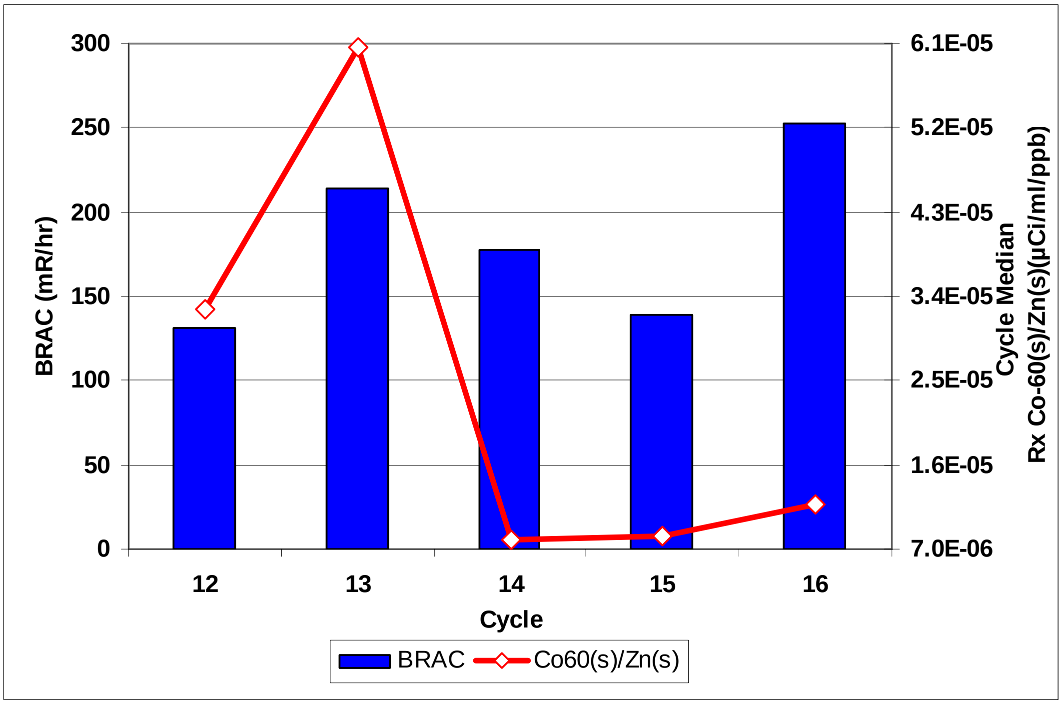

Figure 8-1
Peach Bottom 2 BRAC Trends and Reactor Water Co-60(s)/Zn(s)

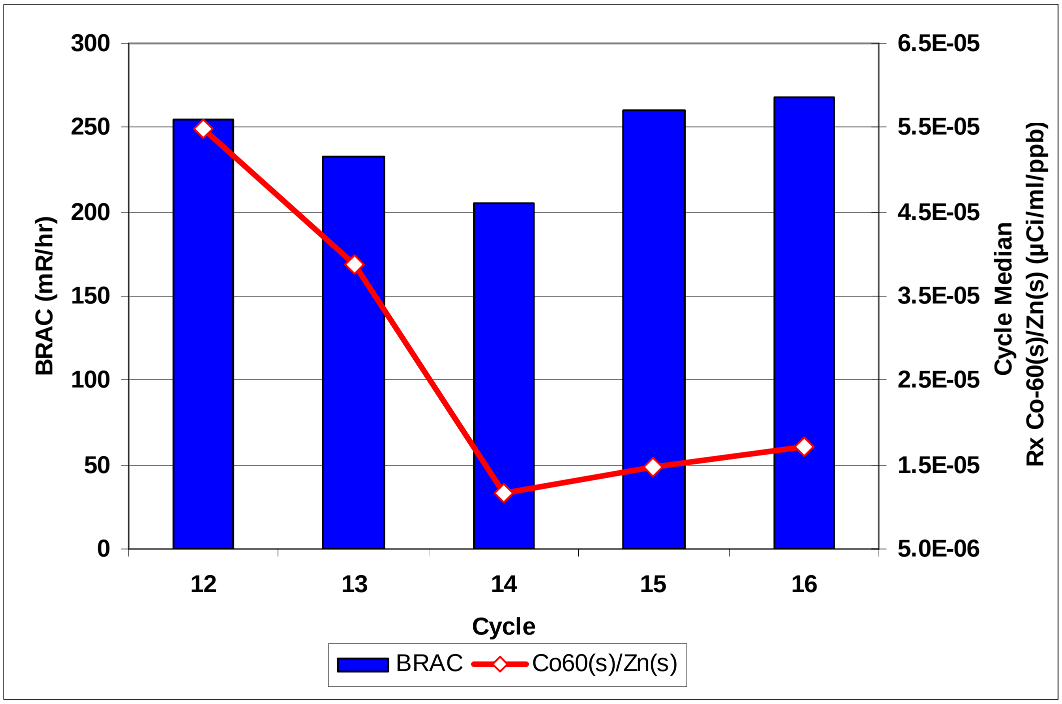

Figure 8-2
Peach Bottom 3 BRAC Trends and Reactor Water Co-60(s)/Zn(s)

For plants with high dose rates (greater than ~250 mR/hr, the highest quartile among BWRs that participate in the EPRI BWR Chemistry Monitoring program), such as Peach Bottom, it may be necessary to perform a chemical decontamination (followed by LTNC) before chemistry programs can be effective at maintaining low dose rates. Operating strategies should include [4]:

- Maintain high reactor water zinc concentrations during the last part of the fuel cycle to increase zinc inventory in the vessel

Maintain the highest possible feedwater zinc concentration during the early part of the fuel cycle to drive reactor water Co-60(s)/Zn(s) as low as possible. Industry data from recent chemical decontaminations show that the recontamination rate is reduced with operation at low reactor water Co-60(s)/Zn(s) [5].

9

RECOMMENDATIONS

1. Remove as much iron, along with cobalt (Co-59), as possible from the condensate by optimizing the removal efficiency of the condensate filter demineralizer system. This will reduce the cobalt source term.
2. If feedwater iron is indicated or perceived to be too low, particularly during the transition from relatively high to low iron, consider installation of an iron injection system to add iron to the feedwater. This allows addition of cobalt-free iron and the ability to reliably control the feedwater iron concentration as desired without making changes to the CF/D septa or precoats. "Adjusting" feedwater iron by means of filter septa selection is inexact and increased O&M costs result if septa need to be replaced early to change particle retention rating. An appropriate initial feedwater iron concentration is 0.5 ppb, with quarterly adjustments made in 0.1 ppb increments until reactor coolant soluble Co-60 reaches the desired level.
3. Replace upright pleated septa with 1-micron Graver DualGuard™ III design. In this design, an outer melt blown precoat retention layer surrounds a pleated inner core. The cylindrical surface outer layer allows more uniform precoating than that with upright pleated septa, resulting in more effective ion exchange while minimizing the chance for elevated reactor coolant sulfate released by cation resin trapped in older pleated septa. The inner pleated layer removes crud and fine particles to low levels (less than 0.1 ppb iron based on Quad Cities 1 experience).
4. Increase the precoat loading to 12 - 16 ft^3 (0.066 - 0.089 dry lbs/10" length), particularly to increase the removal of soluble cobalt.
5. With DualGuard septa, use a standard resin premix with a higher cation to anion (C/A) ratio to enhance soluble cobalt removal. Use of a higher C/A ratio with upright pleated septa is not recommended because cation resin trapped in pleats of older septa has been shown to contribute to elevated reactor water sulfate.
6. Continue cobalt source term reduction efforts. Accelerate plans for low pressure turbine replacement if possible.
7. Maintain reactor coolant Co-60(sol)/Zn(sol) ratio <2E-5 µCi/ml/ppb, if possible without exceeding 0.4 ppb feedwater zinc (or fuel vendor's plant-specific limit or recommendation).
8. Continue monitoring data trends, including elemental cobalt in condensate, feedwater, drains (if available) and reactor water samples, for better source term quantification.
9. Characterize deposits from removed fuel for iron, zinc, cobalt-59 and cobalt-60.

10
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