PRC Technology Delivers Compelling Source Term Reduction Results at Lead PWRs and Opens New Opportunities for BWRs

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Introduction

Contemporary management of nuclear power plant operations compel us to reduce costs through continuous examination of those processes which impede maximizing the economic operation of nuclear power reactors. Outage duration, fuel duty and performance, worker productivity, and radioactive source term are critical elements of that process. Florida Power & Light (FPL) Turkey Point-3,4, SCANA VC Summer and NMC Monticello nuclear power plants have participated in the identification of new opportunities to excel operation of nuclear power reactors through the reduction of radiation source term. The focus of this paper is to present an overview of the recent operating experience and related technical assessments of the impact of new technology and engineered solutions for reducing source term. While the technology has been integrated for use during 42 refueling outages (RFOs) in 21 different reactors, the data of most significance is the leading plants, who have sustained use for 4 RFOs for PWRs and the first BWR use of a re-engineered solution. Those plants are Turkey Pt 3,4 and VC Summer and Monticello. The lead 4 Loop PWR is DC Cook Unit 2 which will not complete their 4th RFO until Spring of 2006.

Starting in 1998, FPL and (n,p) Energy, Inc. (NPE), with scientists from the University of California, Los Alamos National Laboratory, completed a two year investigation into the cause of degraded radiation conditions at Turkey Point-3,4. NPE subsequently engineered a new solution and completed the first of kind engineering effort at Turkey Point-3, to provide a new solution to source term management. The science is now engineered into a small number of new reactor coolant purification media products, specifically and solely, customized for nuclear power plant applications that function in combination with optimization of reactor operations. (n,p) Energy, Inc. and Los Alamos

N.L. are solution providers, not resin manufacturers. These new media products easily integrate into existing plant reactor coolant clean-up systems at nuclear power plants. The science of the solution, combines the applied chemical engineering knowledge of the formation and transport of chemical species in reactor systems, the chemistry of selective binding of target contaminants, with optimized reactor systems operations, to effect the reduction of radiation source term and subsequently, the overall costs of operating nuclear power plants. NPE engages the utility in a collaborative process towards a successful source term reduction program.

The first full-scale applications of PRC-01 solutions in Westinghouse PWRs were completed at FPL Turkey Point-3 in February 2000, Turkey Point-4 and VC Summer September 2000. These nuclear power plants have focused their source reduction efforts on leveraging this new solution for source term reduction over the past 4 RFOs. The engineered solution has enabled the successful revision and acceleration of the shutdown sequence for refueling, greatly improved radiological work conditions, including substantial reduction in occupational radiation exposure, reduced contamination levels, reduced low level waste (LLW) costs, and personnel contamination events. All combining to reduce overall outage costs providing new opportunities to reduce critical path time. Thereby, improving the overall economics of outage refueling operations and maintenance. A summary of the PRC-01 source term reduction impacts for Turkey Point-3,4 are identified below and will be discussed in detail in this paper.

Turkey Point 3,4 aggregate impact of PRC-01 engineered solution:

- 325 REM (3.25 Sv) estimated of avoided occupational exposure for Turkey Pt U3
- 50 fold reduction in Peak Co-58 during shutdown forced oxygenation
- 30 fold reduction in at Power Co-58 14 month average concentration in Reactor Coolant
- 24 hours of critical path time reduction per RFO, estimated $720,000 every RFO, assigned directly to results of engineered solution; as much as 48 hours of critical path reduction per RFO in the future with new reactor vessel head and integrated head package installed.
- 26 hours earlier for last RCPs to be taken out of service (O/S)
- 93.3% reduction in effective dose rate for Containment RWPS
- 90% reduction in EDR for all RWPs
- 100% reduction in RCS shutdown Filters Usage
- $250,000 USD avoided per RFO in primary resin curie surcharge for LLW disposal
- 89.4 % Reduction in Co-58 Curies released at shutdown
- 91.8% Reduction in Co-60 Curies released at shutdown
- 4 hours of activity clean time required for U3R21, reduced from 60 hours U3R17
- 83.5% reduction in number of PCI's per 1,000 RWP hours, from 3R19 to 3R21
- 39.2% average reduction in SG channel head dose Rate from U3R18 to U3R21
- 61.5% reduction in number of High Radiation Areas
- 35% Reduction in contract HP staff, $400,000 avoided costs every RFO.
- 76% Reduction in Hot Spots
- 49 fold Reduction in annual effluent activity discharged for Co-58 and 15 fold for Co-60
- 87.7 % Reduction in Ni-63 annual effluent activity discharge, and 70% for Fe-55

- 500 fold reduction in contamination levels for accumulator check valves
- 50 fold reduction in cavity contamination levels
- 5.923 REM (59.23 mSv) Collective Occupational Radiation Exposure for U3 Reactor Vessel Head Replacement 1st World Record Low Dose Performance.
- 5.407 REM (54.07 mSv) Collective Occupational Radiation Exposure for U4 Reactor Vessel Head Replacement and 2nd World Record Low Dose Performance.

Recently, the technology has been engineered for application in BWR systems including: reactor water clean-up (RWCU), spent fuel pool system (SFP) and condensate polishing system (CPS). Monticello is the lead BWR for integration of this technology. They completed integration for shutdown refueling in RWCU and SFP systems in April 2005.

This paper will present the data generated over 4 refueling cycles at the lead PWRs and the aggregate benefit the utilities have attributed to the use of the new engineered solution which have been characterized is avoided occupational radiation exposure, reduction in critical path time, reduction in low level waste disposal costs, and reduction in contract health physics staff for refueling outages. The recent operating experience for the first full-scale integration of the technology at Monticello will be discussed.

PWR Lead Plant OE: FPL Turkey Point 3,4

It has taken 5 years of consistent source term improvement actions and benchmarking performance improvements at VC Summer, Turkey Point –3,4 to generate a compelling data set which now reveals that reducing source term ripples, both in cost and performance, throughout the plant and right down to the liquid radwaste management program. All 3 of these 3 Loop PWRs have completed there 4th sequential integration of PRC-01 technology for shutdown refueling source term reduction. None of these units have employed other methods for source term reduction including no zinc injection, no USC fuel, and elevated pH at power. Turkey Pt has increased fuel duty every cycle for the past 4 cycles and now operates with all Zirlo fuel and a HDCI index of 122, which is in the mid-range.

Turkey Point 3 and 4 started commercial operation on December 15th 1972 and September 15th 1973, respectively, and have operated for 30 years. The plant is rated for 2243 MWTh, 720 MWe and operations with 170 assemblies of Zirlo fuel. Steam Generators are Westinghouse Model 44F, Inconel 600 thermally treated and were changed in the 1983 and 1984.

The metrics and measures commonly used by plant personnel to assess radiological conditions for refueling outages, and the trending of those measures over several cycles, are used to assess whether conditions have improved or degraded since the integration of PRC solution. These metrics include relevant chemistry, HP and operational measures. All of these measures are tracked at Turkey Point-3,4 to assess impact on source term reduction. The Turkey Point metrics and method identified below, although not all will be discussed in this paper.

Chemistry metrics include:

1) Trend analysis over several cycles of the 7-day decay Co-58 and Co-60 reactor coolant (RCS) concentration, and 14 month steady state averaging and correlation with magnitude of shutdown peaks.

2) The magnitude of Co-58 peak releases following shutdown chemistry in alignment with EPRI water chemistry guidelines, Rev. 5. and
3) Total curies of Co-58 and Co-60 released during shutdown/start-up operations.

Radiation protection and Safety metrics:

1) Measurement of Dose Rates
    a. Stainless steel source term for containment system and components
    b. Inconel source term in containment, Steam Generator Channel Head dose rates
    c. Auxiliary Building component and general area dose rates
2) Outage Effective Dose Rate, defined as RWP exposure incurred divided by RWP hours
    a. Overall several cycle trend analysis
    b. Specific RWP trend analysis for repetitive jobs of identical scope
    c. EDR for inside containment, stainless steel source term (excluding SG ECT and Sludge lance RWPs)
    d. EDR for auxiliary building RWPs
3) Contamination Levels
    a. Measured throughout plant in specific work locations and inside components
        i. Smears valves, pumps, reactor vessel head, etc.
    b. Personnel Contamination Incidents or Events (PCI's or PCE's)
        i. Number Tracked by EPRI Level 1, 2, 3
        ii. Number of hot particle PCE's
        iii. Trend analysis over several RFOs and normalized to number of RWP hours
    c. Number of Hot Particles
4) Hours of Required Containment Heat Stress Zone
5) High Radiation Areas
    a. Tracking of the number of very high radiation areas and high radiation areas, over many cycles of operation.
6) Liquid and Solid Radioactive Waste
    a. Annual discharged Effluents: Quantity in curies, of specific isotopes discharged annually in liquid effluents
    b. Solid waste resin disposal curie content for surcharge controlling isotopes.

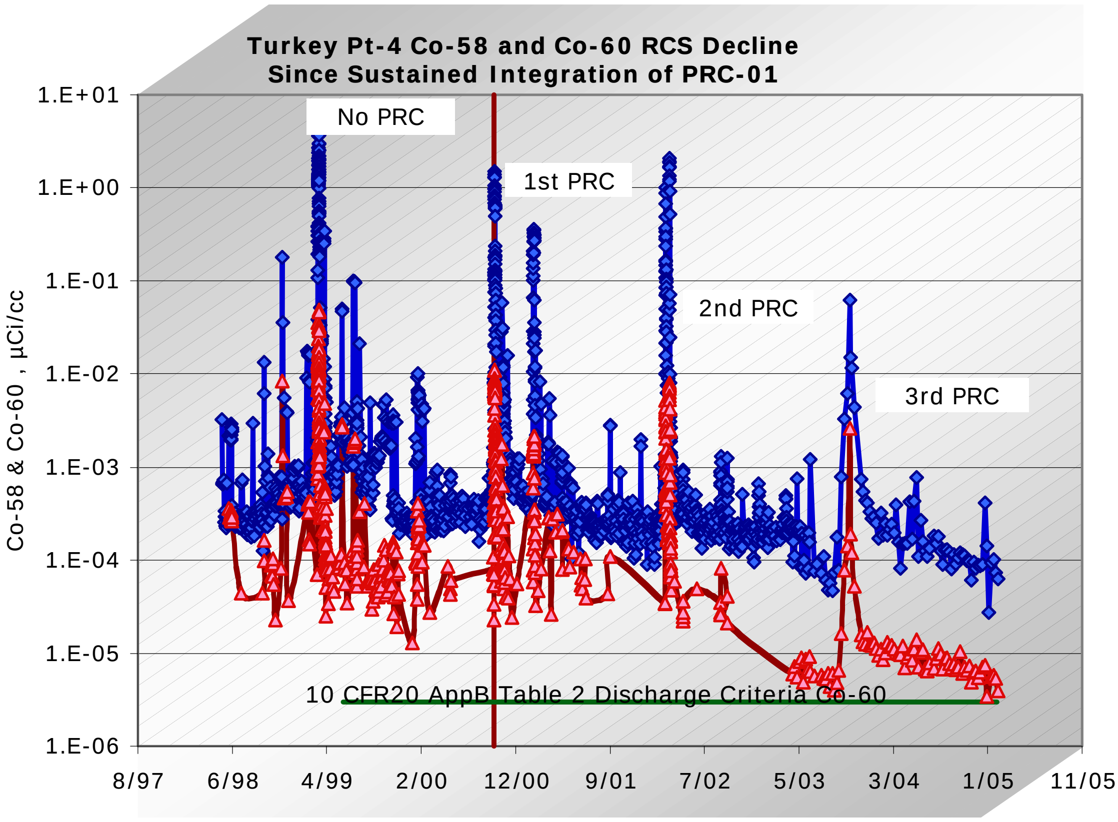
Operations Outage metrics:

1) Certainty in the schedule and how close to critical path schedule activities
    a. Time to peroxide injection and clean-up time to RCS depressurization to 300 psi
    b. Time to EPRI 0.05 µCi/cc clean-up goal
    c. Time to Flood-up
    d. Time to 1st fuel movement
    e. Time for final cavity decon prior to start-up

The first metric of interest is the at power reactor coolant trend analysis for concentration of Co-60 and Co-58. This data is collected on a 7 day decay interval for isotopic accuracy at Turkey Pt. The evidence of a "cleaner" reactor coolant system is confirmed by the RCS activity measurement which reveals a 50-fold reduction in the at power Co-

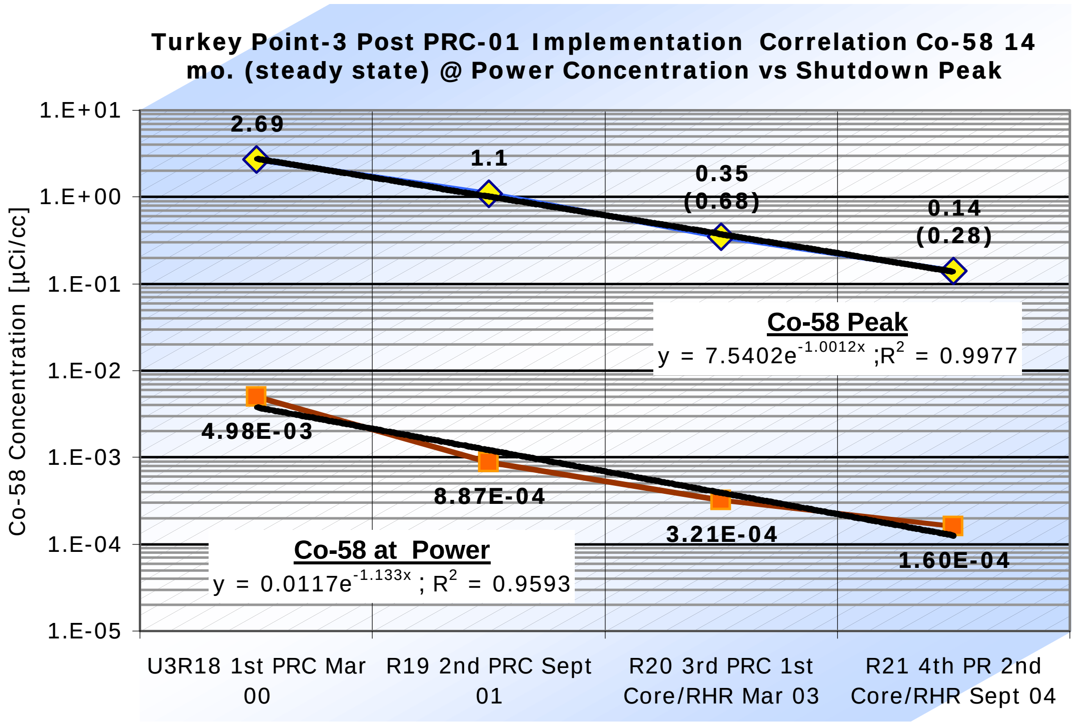
58 and Co-60 concentrations, before and after PRC integration (R17 to R21 comparison). Currently, in Unit 3 the at power Co-58 concentration is 7 E-5 µCi/cc (2.59 Bq/cc) , and the Co-60 5 E-6 µCi/cc (0.185 Bq/cc), extremely low concentrations. The Turkey Point reactor coolant water at power would actually meet the 10CFR20 effluent discharge activity requirements for liquid radwaste for cobalt isotopes. The figure below displays the data for Unit 4. Unit 3 is following the same trend.

Figure : Decline in at Power Co-58 and Co-60 RCS Activity for Turkey Point 4



The Turkey Pt plant chemist developed a trend analysis method to correlate the peak activity Co-58 release at time of forced oxygenation, to the at power last 14 month average of Co-58 reactor coolant concentration based on 7- day decay samples taken twice a week. The data is presented in the figure below. An exponential curve fit was applied to the trend of the Co-58 peak activity normalized for full RCS volume equivalent. Turkey Pt changed sequence from RCPs I/S during forced oxygenation in R18, R19 to RCPs O/S in R20 and R21. For example, the R20 peak Co-58 was 0.7 µCi/cc (25.9 kBq/cc) with RCPs O/S, which is equivalent 0.35 µCi/cc (12.95 kBq/cc) (with RCPs I/S (factor of 2 dilution) R18, R19 full RCS system crud burst, R20 Core/RHR only no RCPs running. The same exponential curve fit was applied to the at power data. The R2 correlation coefficients are extremely close, R2 for peak curve fit equal to 0.9977 and R2 for power data 0.9593. This correlation is used to predict the next Co-58 release during forced oxygenation. It does assume that the forced oxygenation occurs at approximately the same time during each refueling and that there are no short notice outages (SNO) below 400 F RCS temperature. The forecast peak for

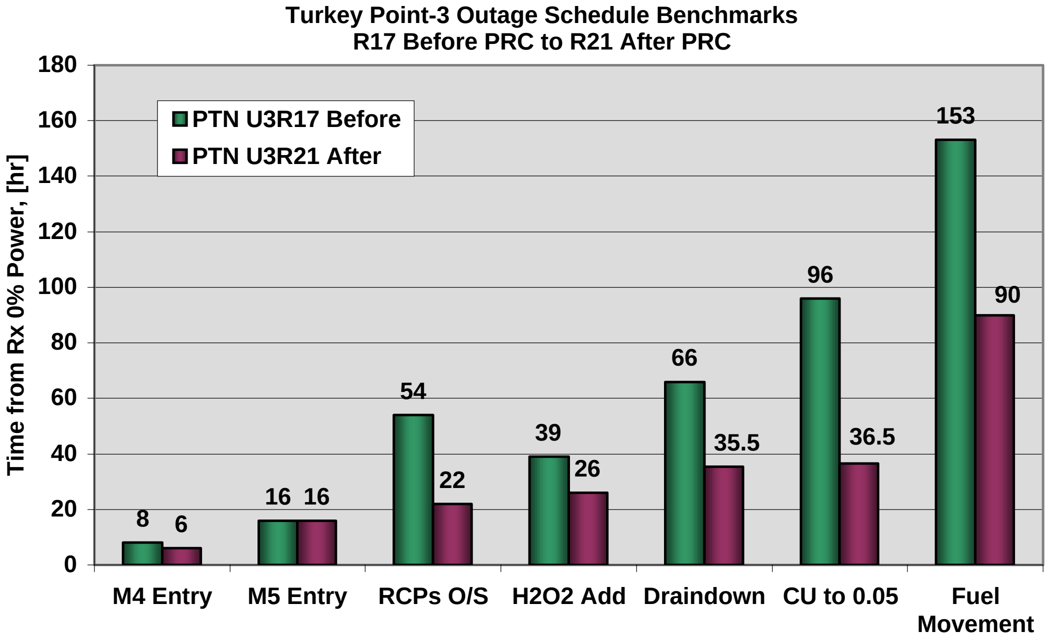
U3R22 under those conditions will be 0.07 µCi/cc (2.59 kBq/cc) Co-58. This is effectively the EPRI guideline clean-up goal. The consequence to schedule will be no required clean-up time in the schedule.



As part of an on-going collaboration with chemistry, radiation protection and outage management, Turkey Pt 3, 4 have worked to revise the outage schedule. The primary change was focusing on removing the last RCP from service as quickly as possible. There are two major reasons for doing this at Turkey Point. First, operating reactor coolant pumps provides tremendous heat load in containment, and controls the length of time that heat stress controls must be in place, for R17 this was 3 days. The second reason was work load management. The outage schedule has restricted work while any RCP is in-service (I/S), so the faster the last RCP is taken out of service (O/S) the more advantage there is to outage schedule. For Turkey Pt 3R21, the last RCP was O/S in 26 hours, as compared to R17 54 hours. This effectively permitted pumps to be O/S 28 hours earlier and more important reduce worker health risk by reducing heat stress control areas from 3 days to 24 hours.

Turkey Pt.- 3,4 injects peroxide in the RCS to complete forced oxygenation after the last RCP is secured, when RCS hydrogen is < 5 cc/kg, SG cool down is complete, and bubble in the PZR is collapsed. This induces the core activity release resulting from oxygenation into the volume of the core and RHR related piping systems ,which is approximately 50% the total RCS volume since SG are essentially no longer in the flow path e.g. dead legs. The figure below shows the impact on outage schedule from U3R17 practice to U3R22 practice. The most significant impact to the outage schedule has been in 2 areas: 1) reducing the time that RCPs must operate from 54 hours to 26 hours, and 2) moving fuel faster, 90 hrs for U3R21 compared to U3R17 153 hours. As it stands today, both units will be prepared to flood up and move fuel earlier than the 90 hours show in U3R21, and reduce critical path time even further.

Figure Turkey Point Refueling Outage Schedule Reductions of Benchmark Activities

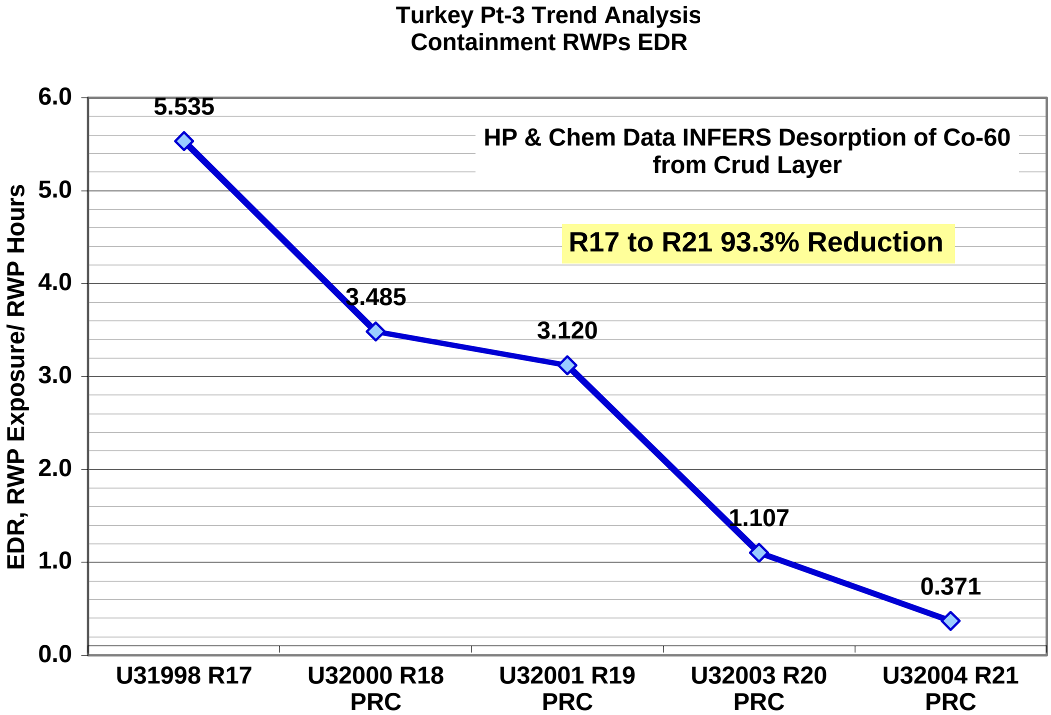


The aggregate clean-up of activity using PRC-01 and combined optimized shutdown sequence has resulted in critical path reductions, for refueling controlled outages, typically 24 to 48 hours. More importantly, both units now have new reactor vessel head with the integrated head package. This will permit the head to be lifted 24 to 36 hours earlier than in U3R21. They have also revised the technical specification to permit 1st fuel movement in 72 hours. If the peak activity, and aggregate core clean-up, had not occurred and the units peaked at above 2 µCi/cc (74 kBq/cc) Co-58, the shutdown chemistry clean-up would have delayed critical.

If source term has indeed declined in a power plant, we would expect evidence of that not only in chemistry data but more importantly in the occupational radiation exposure received during refueling (RFO) outages. The examination of effective dose rate (EDR), defined by RWP exposure divided by RWP hours, component dose rates and contamination levels throughout the plant reveals the source term change. EDR is an effective tool at Turkey Pt since they have not substantially modified shielding and HP practices, and require all radiation workers to log out on electronic dosimeters when leaving the RCA. The data was examined for EDR from R17 where PRC was not integrated through R22 where PRC was integrated for the past 4 RFOs. Overall there has been a 93.3% decline in EDR at Turkey Point U3. It is particularly relevant to note that the major decline in EDR correlated with the major decline in at power Co-60 and Co-58 RCS concentration data. This suggests that after the second use of PRC, the plant was placed in a new, lower, equilibrium condition for these dose controlling isotopes. While it cannot be confirmed without direct GeLi measurements, the data suggests that Co-60 is desorbing from stainless steel systems.

This is supported in the examination of containment RWPs, excluding Inconel SG ECT and sludge lance RWP data, showing a decline greater than the Co-60 decay of 18% per 18 month PWR cycle.

Figure: EDR for Turkey Pt-3 Trend Analysis for Containment RWPs



Note: SG ECT & Sludge Lance removed from EDR calculations since they are Inconel Source Terms
No shield package changes for U3 for All outages to impact EDR values.

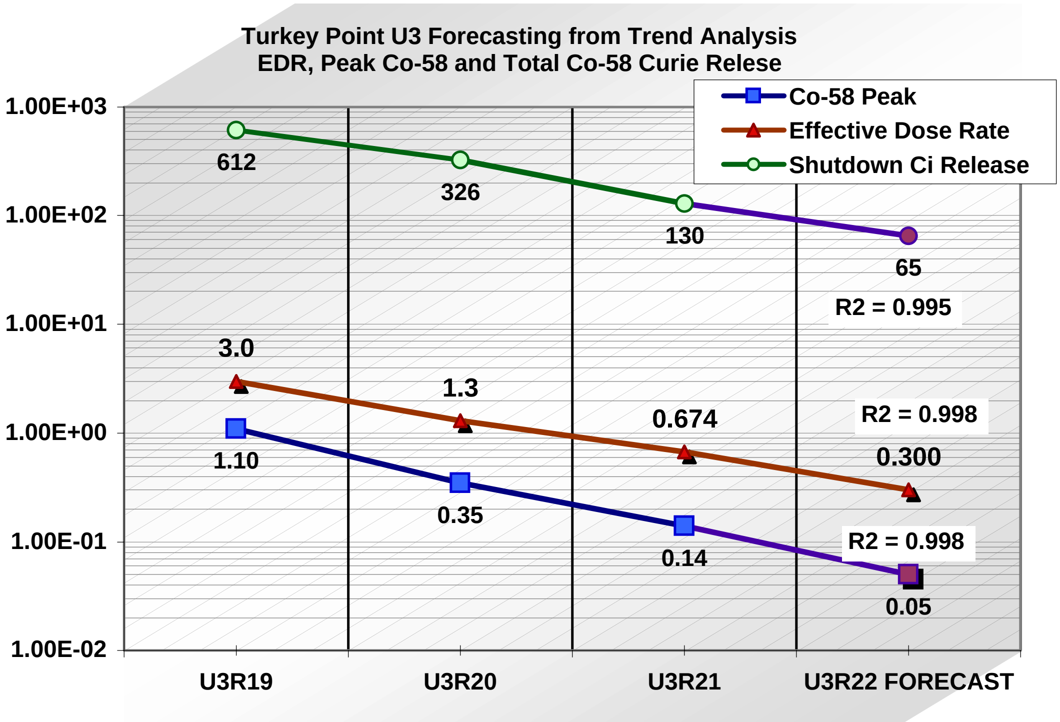
The EDR data shows that during the 1st RFO use of PRC, the decline in effective dose rate was 37%, dropping from 5.535 mR/ RWP-Hr to 3.485 mR/ RWP-hr. There was only a 10%, from 3.485 mR/RWP-hr to 3.120 mR (0.031 mSv)/ RWP-hr. However, it was not until the third use of PRC that the EDR decline really accelerates to 64.5 % for R20, and 66.4% in R21, both exceeding the Co-60 decay curve of 18% per 18 month cycle. This trend is also consistent in Turkey Point U4. The only plausible explanation for these changes is desorption of Co-60 out of the crud layer in stainless steel materials.

The effective dose rate for specific RWPs was also evaluated before and after PRC-01 integration. The table below shows the EDR decline for U3 and U4 for ISI, reactor work, motor operated valves. There was a 65% to 69% drop in the EDR for reactor work which includes the reactor head disassembly and reassembly. There was some evidence that extremely small particles were partitioning up into the CRDM area during shutdown, which elevated dose rates. Occasionally, the dose rates would decline slight, when the vessel head was vented. Once these particles were mitigated with PRC, there was a significant drop in reactor vessel head dose rates and no change when the RV head was vented. Turkey Pt U3 set a world record for the low dose RVH replacement outage in September 2004 with 5.923 REM (59.23 mSv) as confirmed by the ISOE/North American Technical Center (NATC).

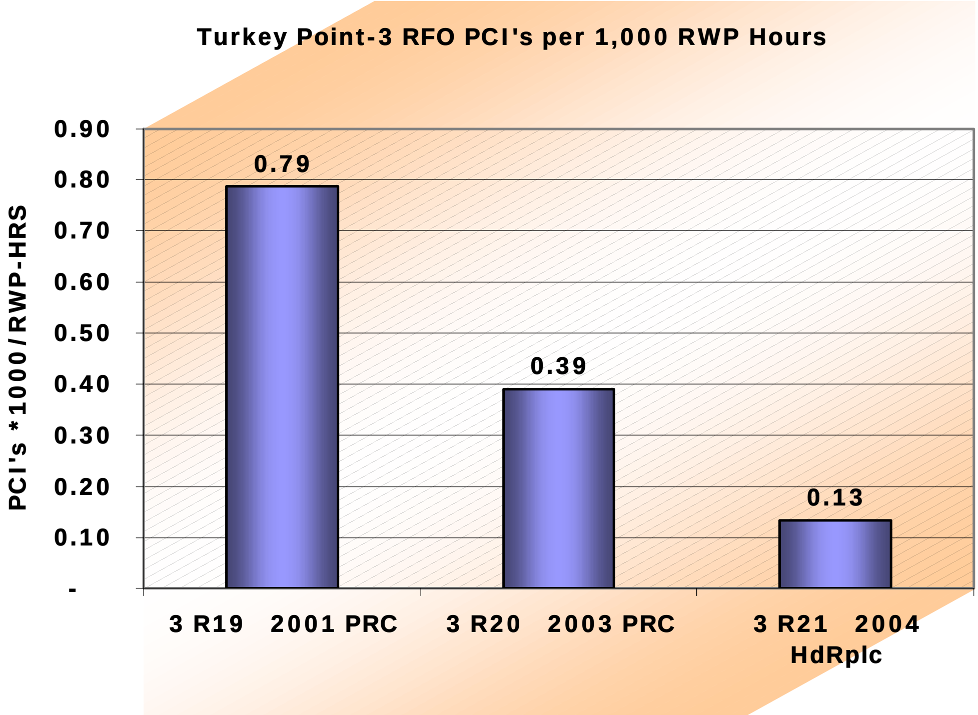
Table EDR for Specific Turkey Pt. U3 and U4 RWPs

RWP	Before PRC-01	After PRC-01	% Change
ISI (U3)	6.25	2.97	-52%
ISI (U4)	7.74	3.77	-51%
RX (U3)	11.88	4.11	-65%
RX (U4)	13.10	4.05	-69%
MOV (U3)	2.18	1.41	-35%
MOV (U4)	2.31	1.40	-39%

When you combine the chemistry metrics for trend analysis with the radiation protection metrics for trend analysis, there is an observed relationship between the magnitude of the Co-58, shutdown Co-58 curie release, and the overall outage effective dose rate. This adds further confirmation that the source term is being very successful reduced by use of PRC-01 technology. The figure below shows the close correlation of outage effective dose rate (EDR), Co-58 peak at time of forced oxygenation and total shutdown curies of Co-58. The data forecasts that in R22 the outage EDR will be 0.300 mR (0.003 mSv)/RWP-hr, peak Co-58 at 0.05 µCi/cc and total Co-58 shutdown curies at 65 Ci (2.4TBq).

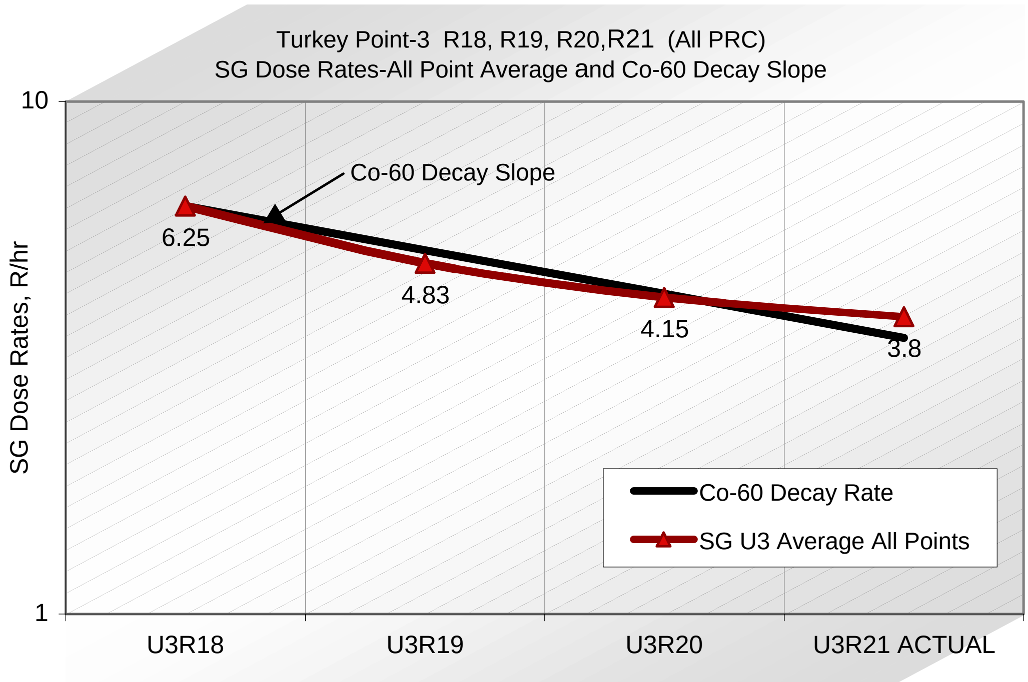


At the same time that effective dose rates dropped, so did contamination levels inside the RCS. There are two benchmarks used here. The first is the decline in PCI's and the second is the contamination measurement data in specific locations in the plant. The figure below shows the decline in PCI's during RFOs using PRC.



Contamination levels in the cavity are reported to be < 100K dpm/ 100 cm^2, significant lower than the mrad smearable levels prior to mitigation of colloids. The accumulator check valves are notorious for being highly contaminated in PWRs. Turkey Pt-3 data showed a reduction from 200 mrad/100 cm^2 smearable to 20K dpm/100 cm^2. This is a DF of 500 (assuming 1 mrad = 50,000 dpm/100 cm^2). The ALARA supervisor has reported that over all contamination levels are down significantly everywhere in the plant, except low point drains. For example, the reactor vessel head, under the flange on the O-ring, has dropped from U3R17 maximum contamination level of 350K smearable to < 15K dpm/100 cm^2, a DF of 23.

The improvement in source term is evident in the data showing the decline in Steam Generator (SG) dose rates. Turkey Point-3,4 changed steam generators in 1981 and 1982 to Westinghouse Model 44F, Inconel 600 thermally treated. They show an overall decline of 35 % for all points averaged in the SG channel head from R18 to R22. The decline as measured by the average of all channel head cold leg and hot leg measurements in all 3 SG, closely matches toe Co-60 decay curve. This indicates that there is no new deposition occurring over the cycles.



The following graph is the specific cold leg and hot leg averages, before and after PRC-01 integration, for each of the channel head measurement points. Variability in this data may be the result of the use of teletectors, which tend to be angularly sensitive in response and over response. AMP-100 instruments are preferred for accuracy.

Figure : Change in Turkey Pt 3 SG Hot Leg Dose Rates from R17 to R21, PRC was Integrated in R18

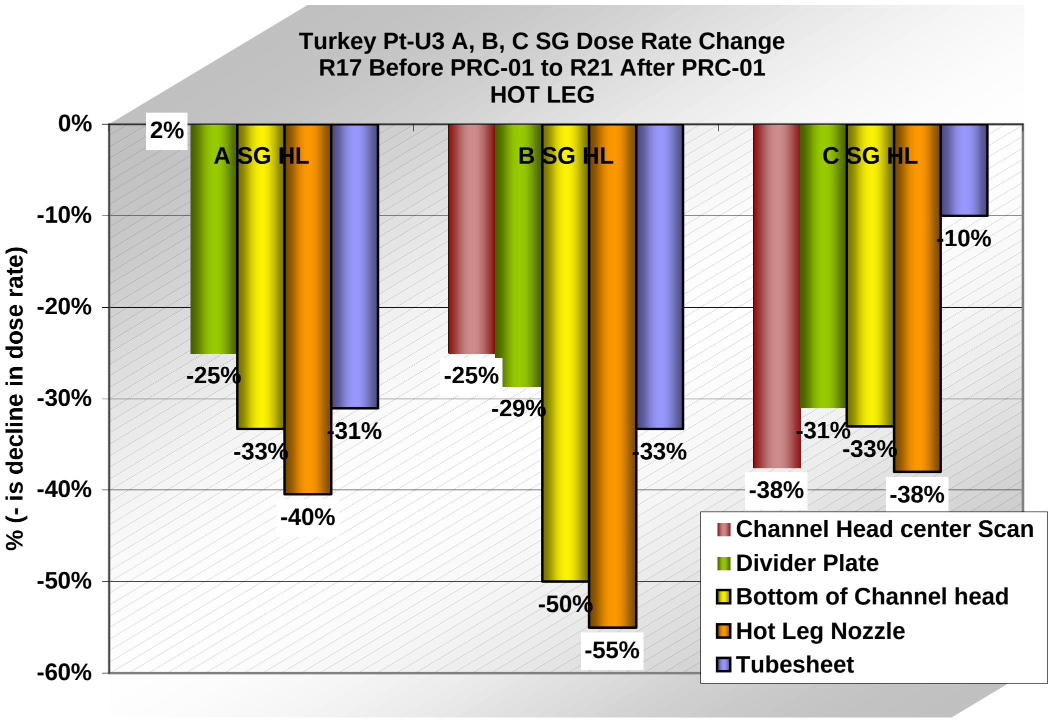
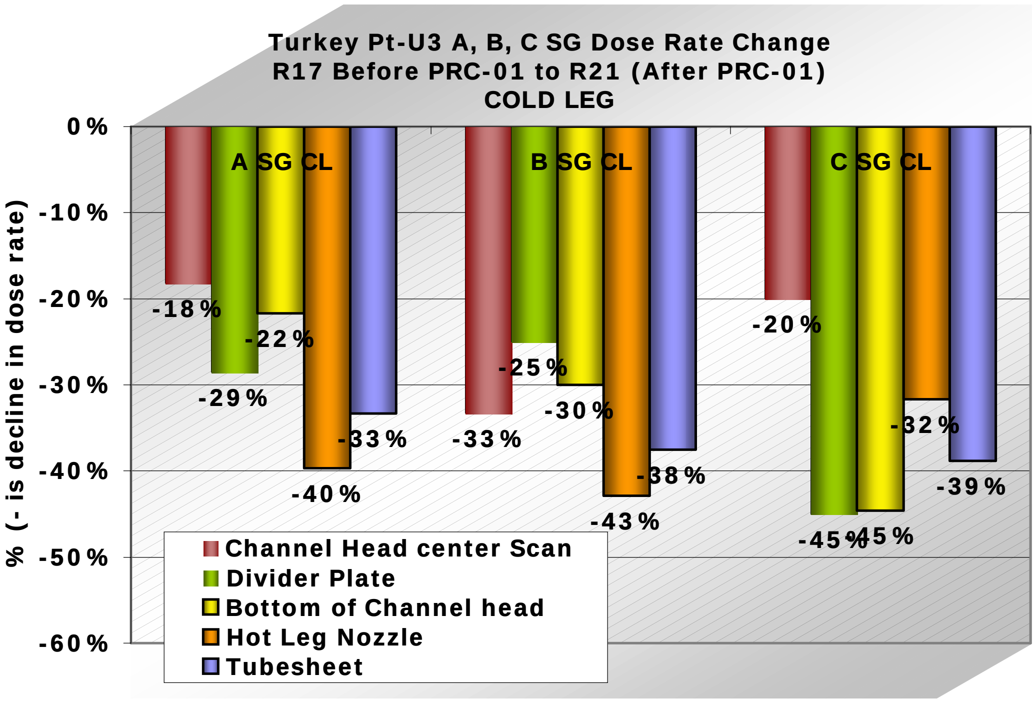


Figure : Change in Turkey Pt 3 SG Cold Leg Dose Rates from R17 to R21, PRC was Integrated in R18



As the production of corrosion product curies are reduced, and no new source term is added to RC system, the decay of activity effects the number of high radiation areas (HRA's) requiring added RP control. Turkey Pt RP tracks the number of HRA's on a monthly basis. Since the integration of PRC-01 in 2000, the total number of HRA's has declined by approximately 50% for Unit 3 and 4. They also track and trend on a monthly basis the number of hot spots. The below 2 tables display the decline in these measures.

Table : Trending of Turkey Pt 3, 4 Number of High Radiation Areas

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
U3U4 Total HRAs CY 2000	13	13	12	10	10	12	12	9	9	10	10	9
U3U4 Total HRAs CY 2001	9	10	10	10	9	9	9	9	9	11	11	10
U3U4 Total HRAs CY 2002	10	9	7	7	7	9	8	8	7	5	5	5
U3U4 Total HRAs CY 2003	5	5	4	7	7	7	6	6	6	6	6	6
Total Decrease Post PRC-01	**-8**	**-8**	**-8**	**-3**	**-3**	**-5**	**-6**	**-3**	**-3**	**-4**	**-4**	**-3**

Table : Trending of Turkey Pt 3, 4 Number of Hot Spots

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CY 2000 Hot Spots 2 RFOs	21	21	18	16	14	5	5	5	5	5	5	5
CY 2003 Hot Spots- 2 RFOs	5	5	5	5	5	5	3	3	3	3	3	3
Total Decrease Post PRC-01	**-16**	**-16**	**-13**	**-11**	**-9**	**0**	**-2**	**-2**	**-2**	**-2**	**-2**	**-2**

The combined data of the at power trends and the decrease in dose rates and contamination levels are indicative of an aggregate cleaning of the core inventory of corrosion products. The cleaner RCS system has rippled benefits not just in dose reduction but in the cost and operation of LRW and effluent discharges. The reactor now generates substantially less Co-60 curies, a reduction from 200 Curies released during RF 17 shutdown cleanup to less than 5 Ci for U3 R21 shutdown cleanup. Consequently, the cost for disposal of primary resin liners has substantially decreased since in Florida, they are controlled by the quantity of Co-60 curies in a shipment.

The aggregate cycle to cycle clean-up has also manifested in reducing the annual quantity of specific isotope curies discharged and reported to the NRC. The isotopes that are affected are those that are known to behave as colloids or particulates, Co-58, Fe-55, Ni-63, Fe-59, Co-60 and Ag-110m. PRC-01 has no effect on tritium or isotopes that are known anions, Sb-125, I-131, etc. Turkey Pt 3,4 has not modified their liquid radwaste processing technology in over 10 years. There liquid radwaste system uses activated carbon, and sequential vessels of mixed bed gel ion exchange resin. They specifically do not use ultra-filtration or reverse osmosis membrane technology. The figure below depicts the declining in liquid radwaste effluent releases for Co-58 and Co-60. A similar trend is indicated in the data for Ag-110m.

Figure Co-58 and Co-50 Effluent Discharged Activity

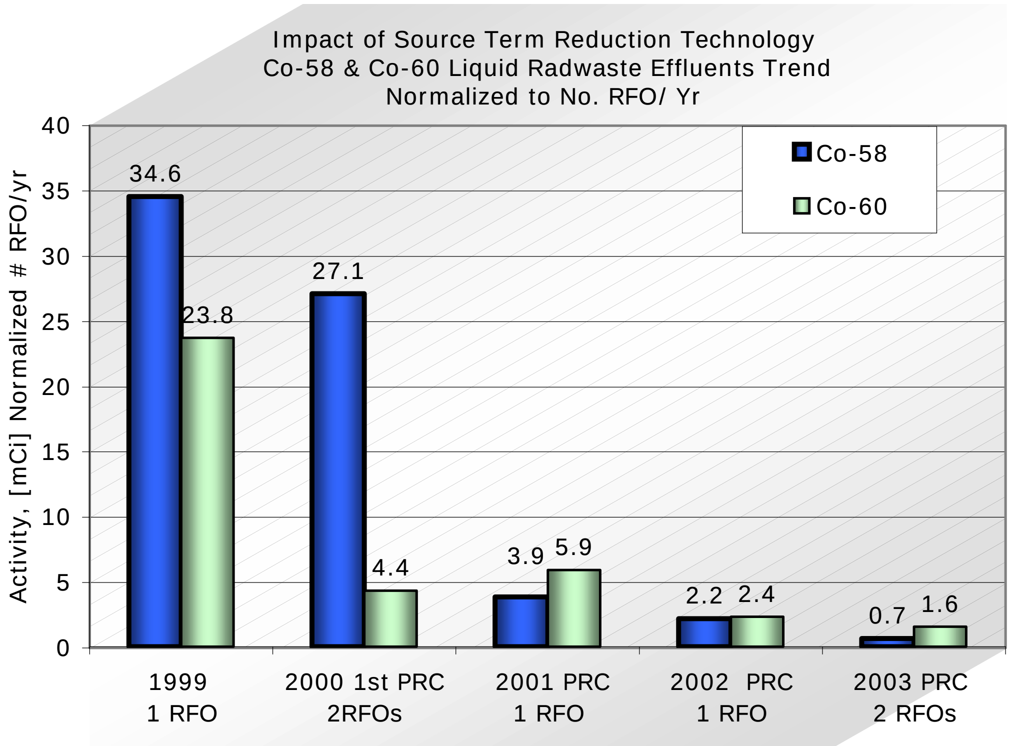


Figure Ag-110m Effluent Discharged Activity

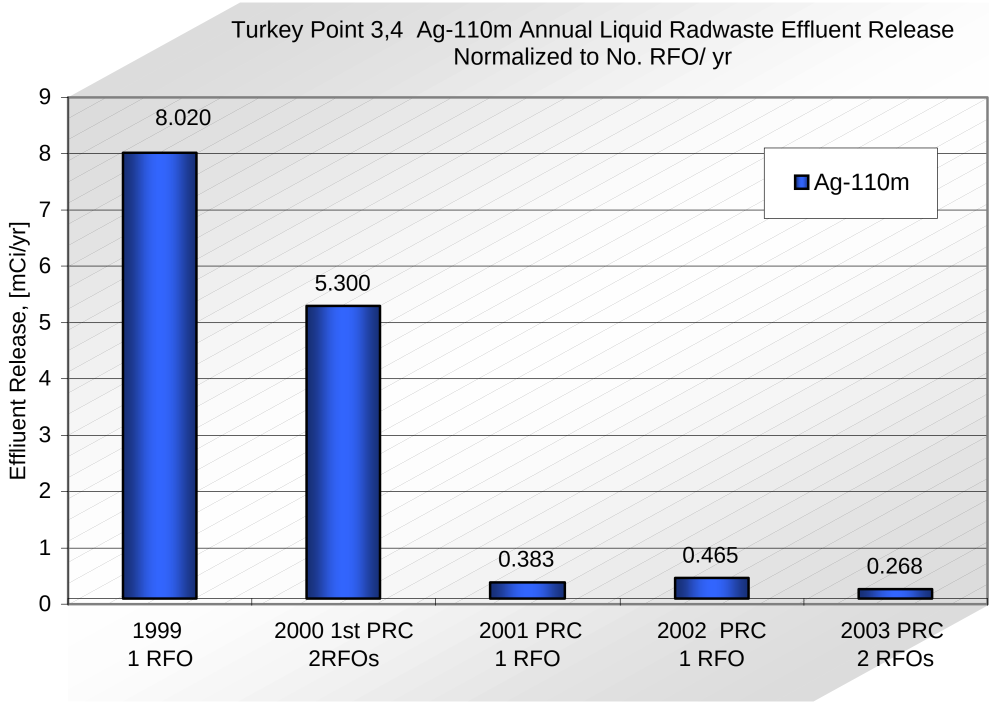
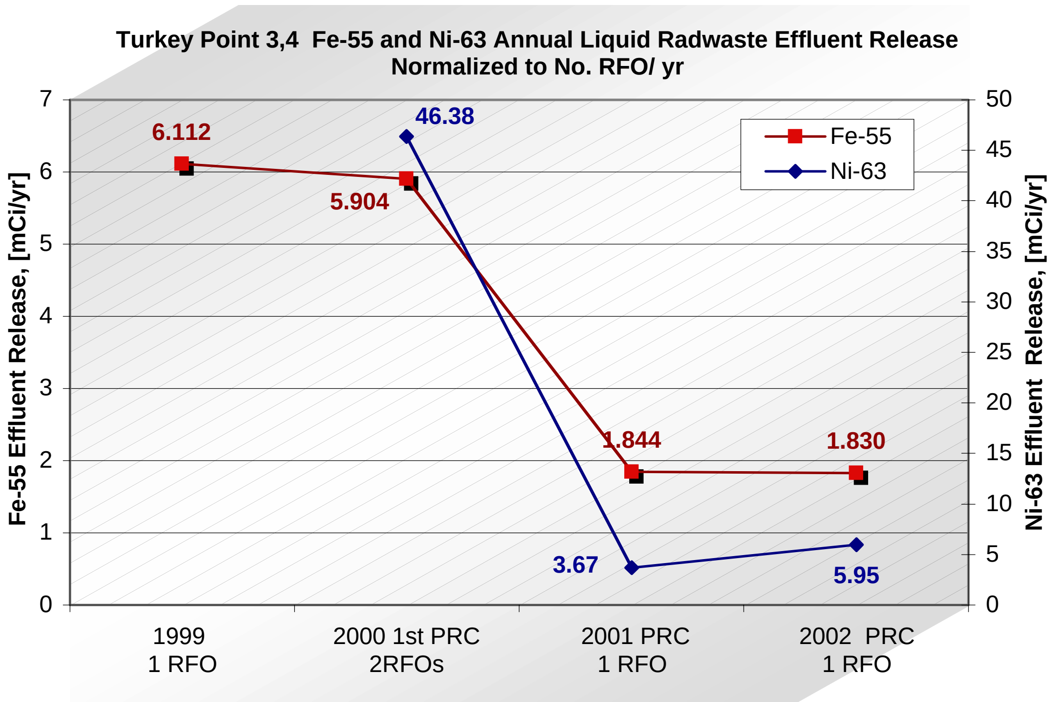


Figure : Turkey Point 3,4 Fe-55 and Ni-63 Discharged Annual Effluent Activity



The decrease in effluent activity of Co-58, Co-60 and Ag-110m is attributed to simply less curies being produced in the reactor as a consequence of PRC-01 technology cleaning the RC system. The difficult to measure, beta emitting radioisotopes of Fe-55 and Ni-63 have also been reduced with sustained use of PRC-01. That leaves Sb-125 as the largest effluent contribution at Turkey Point for removal by LRW system, which is caused by a stored antinomy beryllium start-up source in the spent fuel pool. New polymers developed by Los Alamos for the selective binding of antimony preferred over chloride, sulfate and borate have been bench tested at Turkey Point. The results are promising for a new solution for selective Sb-125 removal.

Lead Plant OE: SCANA VC Summer

While the Turkey Point-3,4 OE is significant and compelling, the question remained on how other plants would respond to PRC technology with a wider range of factors affecting crud transport and behavior including core design and fuel duty, operating pH, materials of construction, age of SG, and shutdown sequence. VC Summer is an interesting unit to look examine in this aspect.

VC Summer started commercial operation Jan 15th 1984. Plant power is rated for an electrical output of 952 Mwe and has operated for some 20 years. During R9, new Inconel 690 TT SG were installed. VC Summer also operates the highest duty core for 3 Loop PWRs with an exist temperature of 617 F (325 C), as compared to Turkey Points 557 F (292 C). The plant has often believed that operating all 3 RCPS during shutdown forced oxygenation (FO2) was important for source term mitigation, and yet Turkey Pt executes the FO2 of the reactor coolant with all RCPs off. What is common between the units is that all 3 units, VC Summer and Turkey Pt 3,4 have all integrated PRC-01 and used consistently for the past 4 RFOs.

VC Summer has used a metric of the weighted average of 8 benchmark dose data points consistently measured throughout containment to assess changes in radiological conditions during the outage for the past 7 RFOs. In addition, the EPRI SRMP in SG channel head are also used to assess radiological conditions. The data for VC Summer is presented in the graph below. The dose rates on average approximately equal the Co-60 decay over the 5 year period of 48%. The change in average SG dose rates for VC Summer is within 10% of the change for Turkey Pt 3 and 4. The current VC Summer R15 outage was forecasted to incur 120 REM of occupational radiation exposure based on dose rates measured during R14. The outage is current in the final stages and the plant outage exposure is targeted to come in <65 REM TLD. This is a direct result of decreased dose rates throughout the plant experienced during R15.

Figure : VC Summer R12 to R15 Decline in Channel Head SG Dose Rates (All Pt. Average)

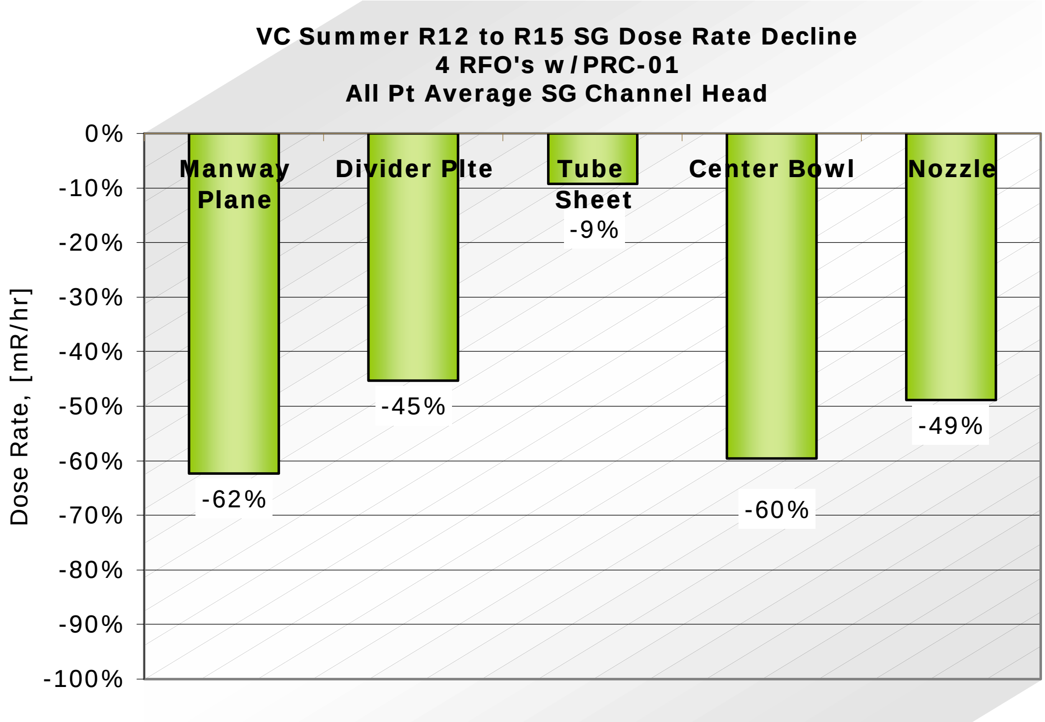


Figure Comparison of All Channel Head Dose Rate Averages VC Summer and Turkey Pt-3

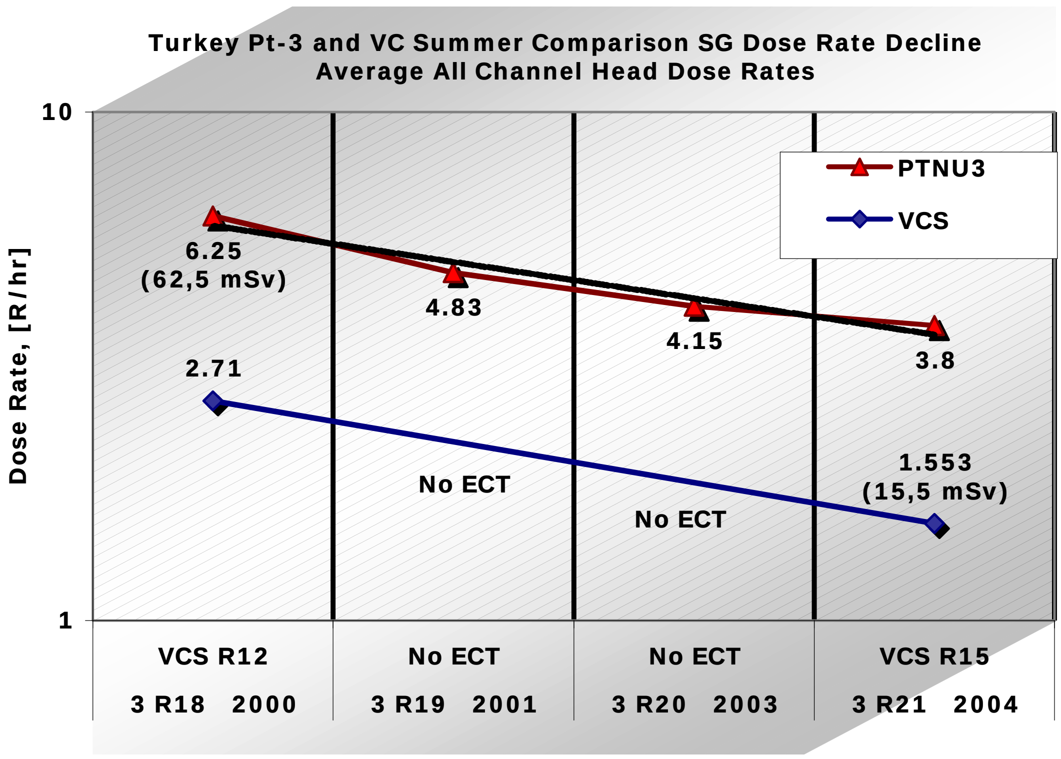
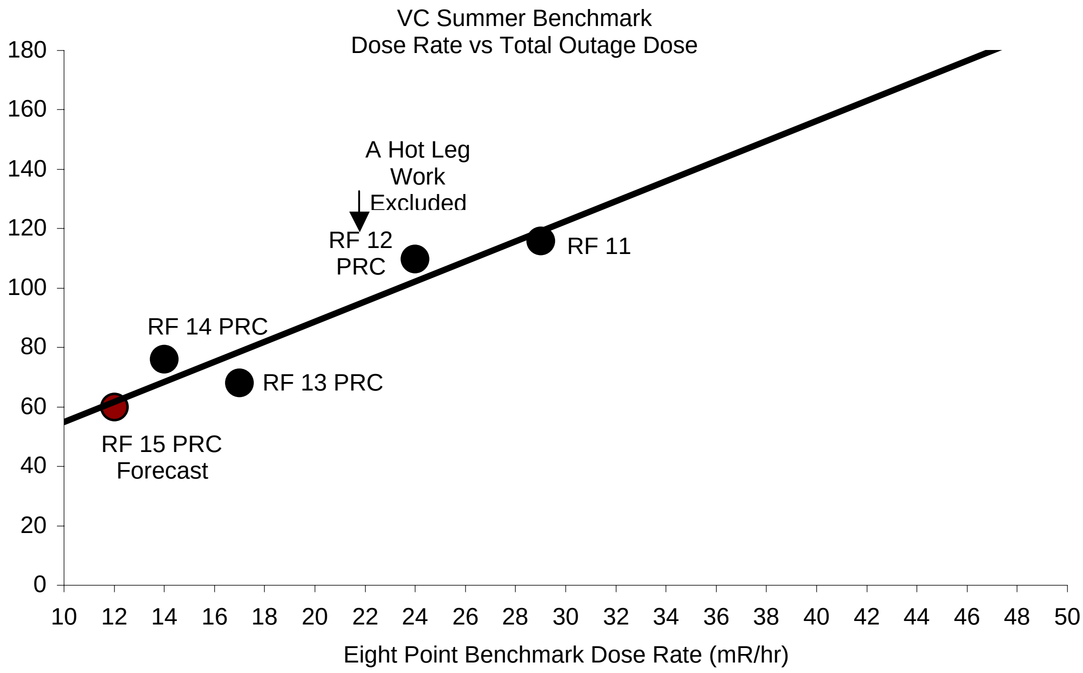
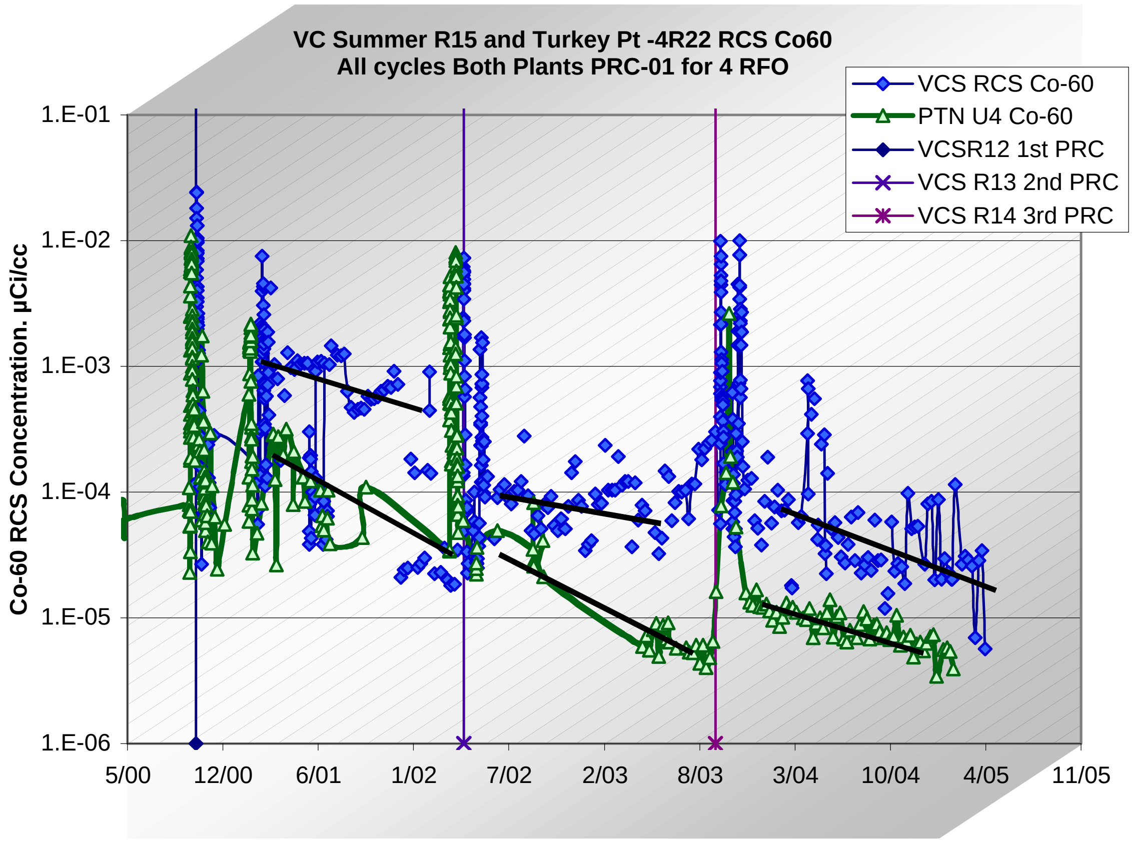


Figure : VC Summer R12 to R15 Benchmark Dose Rates Inside Containment



Examination of the at power data comparing VC Summer and Turkey Point U3 also reveals a parallel effect of needing a minimum of 3 RFOs of sequential PRC use to effect the reduction in at power Co-60 concentrations. That data is show below. Based on the aggregate impact of PRC-01 in the mitigation of colloids, an accurate predication can now be made for both units on the peak Co-58 in subsequent RFO. VC Summer R12 through R14 trend analysis predicted a 0.7 µCi/cc peak for R15, the actual peak was 0.603 µCi/cc. Turkey Pt-3 peak predication was 0.25 µCI/cc the actual was 0.28, which is equivalent to 0.14 µCi/cc when normalized to full RCS volume. Turkey Pt 3, 4 reduce the active volume by 50% for FO2 by injecting peroxide after all RCPs are O/S. This data is also shown below.

Figure   Comparison of VC Summer and Turkey Pt-4 At Power Co-60 RC Activity



VC Summer R12 did have a Co-58 release in acid reducing, 2.46 µC/cc and another 3.32 µCi/cc peak with forced oxygenation. A few plants have experienced unexpected peaks in acid reducing. While not confirmed, the assumption is that the high duty core will produce more nickel oxide, which is reported to have a lower brittle fracture strength, making it more subject to shear forces. As the reactor is cooled under 400 F in acid reducing chemistry iron starts to dissolve into coolant, which tends to weaken the non-homogenous crud layer on the fuel, and results in a crud more susceptible to fluid velocity shear forces in acid reducing chemistry. The VCS R15 AR and AO peak were totaled to approximate total curies, 5.7 µCi/cc. VC Summer did replace SG in R9, and experience a 32 µCI/cc peak in R10, 2nd cycle post SGR. There is no longer any significant release of Co-58 during acid reducing at VC Summer. The comparison of shutdown Co-58 for R12 and R15 is presented below. The data is normalized to the time of FO2. The second graph shows the decline and correlation of total shutdown Co-58 curies released at FO2 and an exponential curve fit and correlation coefficient.

Figure : VC Summer R12 and R15 Shutdown Co-58, Normalized to Time of Peroxide

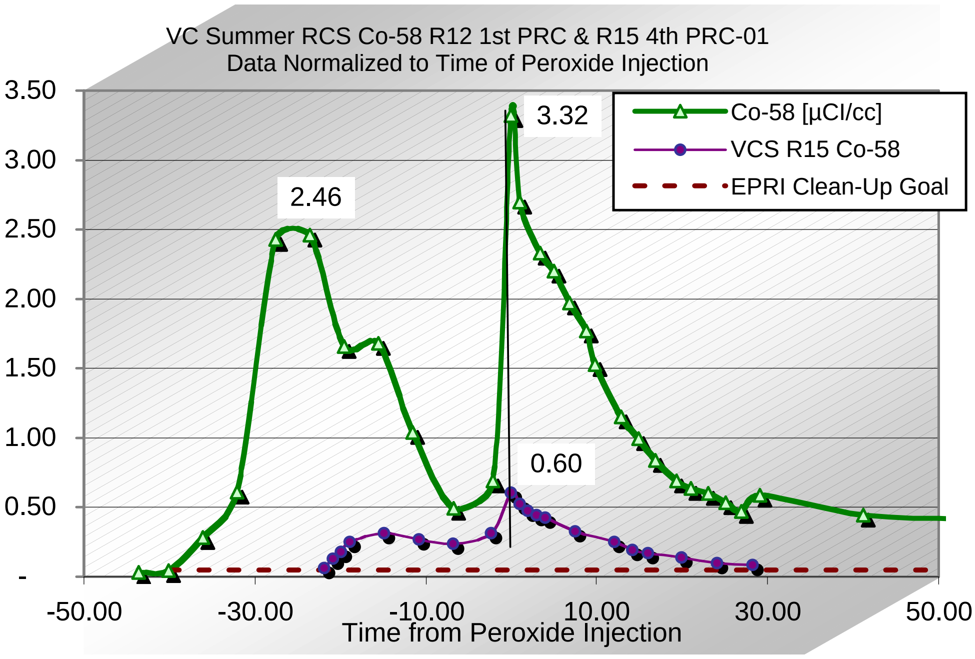
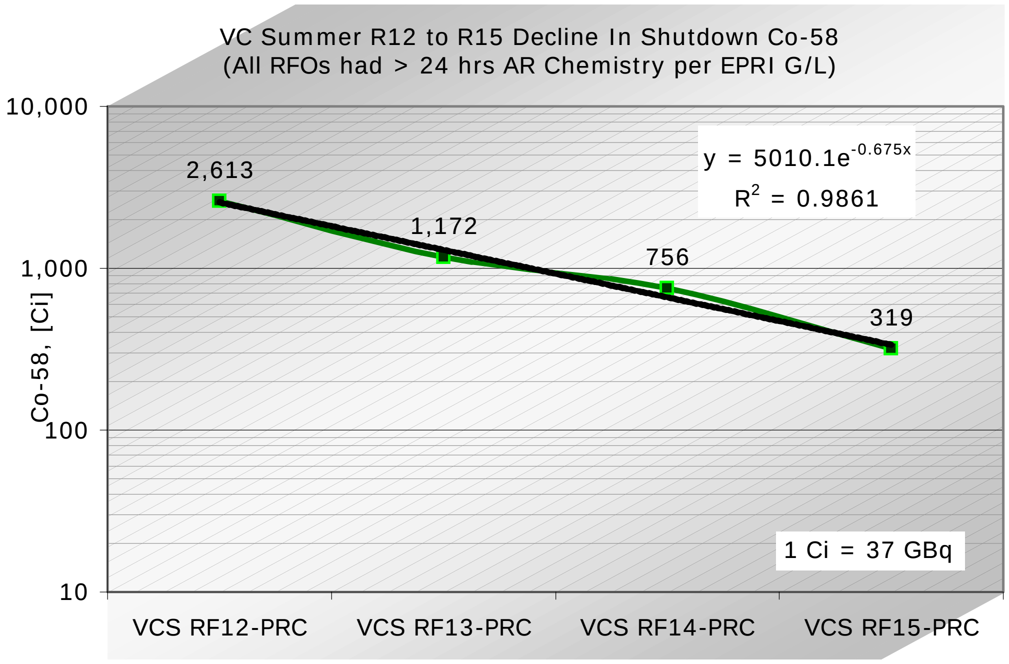


Figure VC Summer R12 to R15 Shutdown Co-58 Curies Released



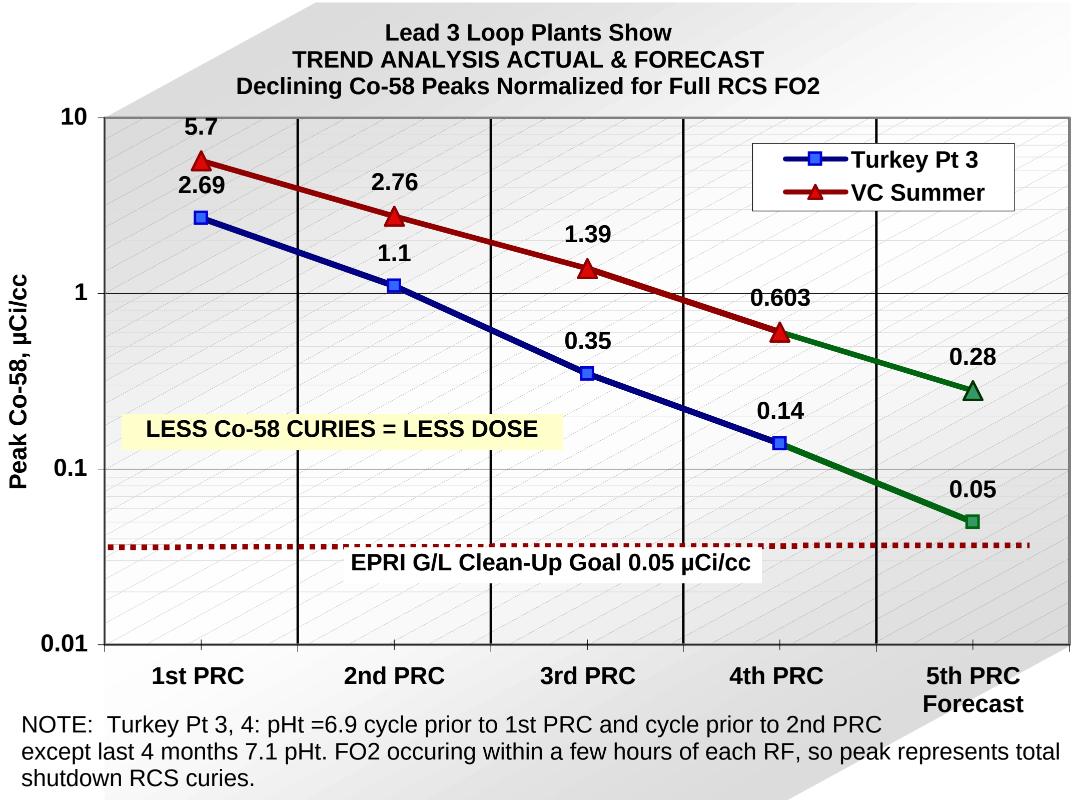
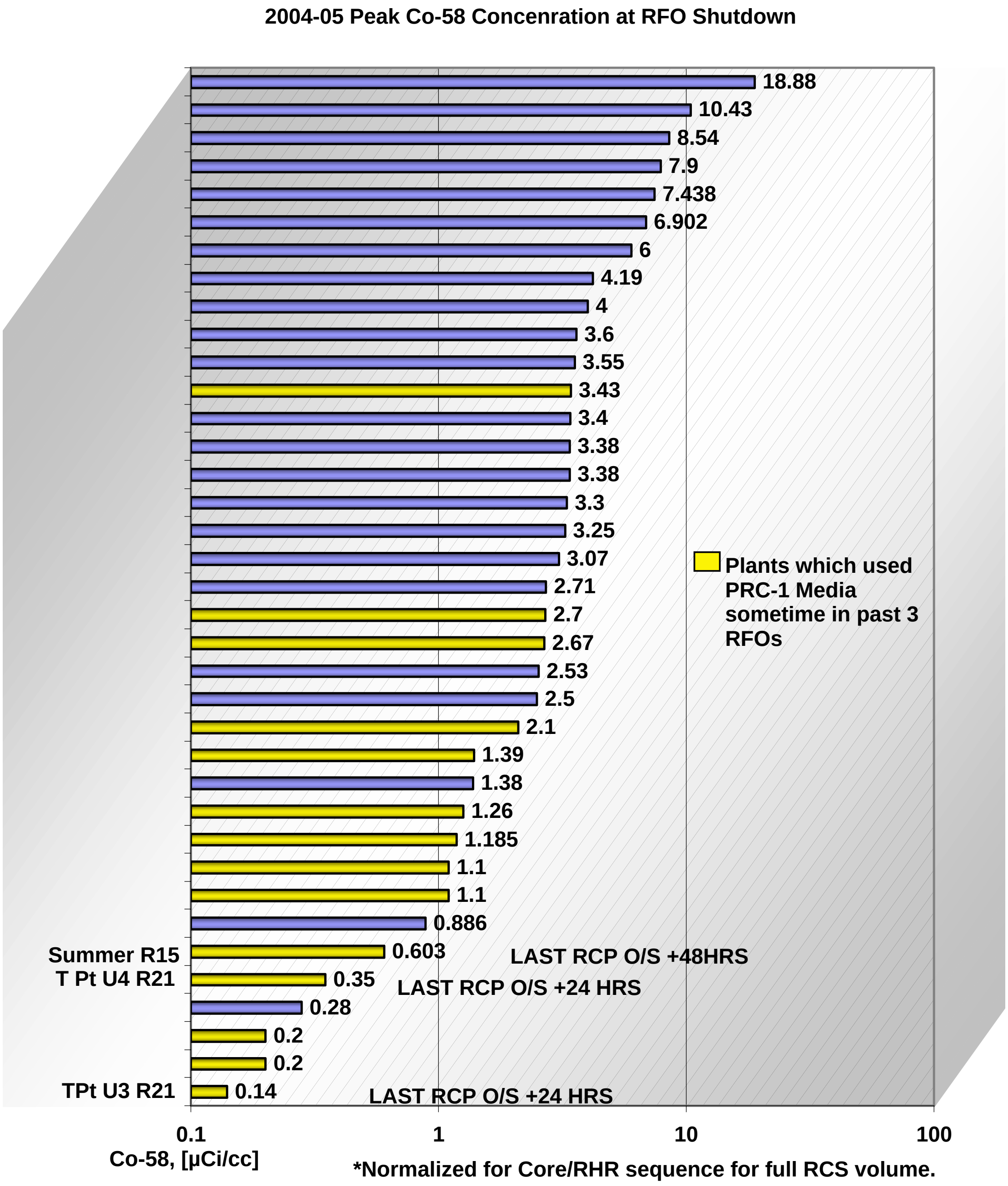


Figure Comparison of VC Summer and Turkey Pt-3 Peak Co-58 and Forecast

The correlation coefficients for an exponential curve fit are extremely tight, with an R2 of 0.9861. This provides the certainty from which subsequent RFO peak releases and total curie releases of shutdown Co-58 can be predicted, and consequently, provide better outage schedule information for required time to clean-up, RCPs O/S and 1st fuel movement. It is important to note that these relationships can be disrupted by any Mode 3 short notice outage (SNO) and dependent on how the shutdown chemistry of that outage is managed.

When PRC plants are compared the rest of the industry for peak Co-58, there is a trend that indicates that plants using PRC have predictable lower Co-58 peaks. The data presented below is a summary of peak data reported at the 2004 EPRI meeting. Turkey Pt 3,4 and VC Summer had a minimum of 16 hours of acid reducing time. The plants showing yellow bars have all used PRC at sometime during the past 3 RFOs. Those plants with the lowest peaks have consistent used PRC for 3 to 4 RFOs. Other plants shown in blue have used conventional gel resins or conventional macroporous resins. The advantages of lower Co-58 peak release is the time that RCPs can be taken out of service very early accelerating the outage schedule. In addition, less curies are generated and costs for LLW disposal of primary resins is substantially decreased. The data demonstrates that the longer the consistent use of PRC-01 solution, including correctly executed shutdown sequence and management of short notice outages, the lower the peak. This is indicative of a continuing process of cleaning up the core and reactor coolant system. It should be noted that when shutdown sequence was not followed properly, or a short notice outage (SNO) occurred close to the scheduled RFO the peak predication would vary more than the expected +-20% forecast.

Figure : 2004 Reported Co-58 Peak Activity for 39 US Nuclear Power Plants



Cost/Benefit Assessment

There are several elements of the value proposition to be considered when evaluating the NPE engineered solution and the technology of PRC-01. The table below identifies some of those impacts which are easily monetized and those which are difficult to monetize but have value.

TABLE : Value Proposition for Sustained Integration of PRC Technology

PRC-01 Impact Areas	**Eliminated or Reduced Operating Impact**
Lower Co-58 Peaks during forced oxygenation crud burst release during RFO shutdown	Outage crews beginning work sooner with higher dose. Elimination of exclusion zones.
Reduced to Time to Clean-Up Activity	• Critical path and related outage jobs get early start Acceleration of schedule to move fuel
Reduced CRUD on fuel	Avoid down power from AOA problem ; Minimize crud induced fuel failures; heat transfer improvements
Outage Effective Dose Reduction, Aggregately RFO to RFO	Lower Outage Exposure, RFO to RFO INPO Ranking Improvement over NON-PRC Plants
Reduced Curie Generation and Release from Core (200 Ci Co-60 to 5 Ci Co-60)	Decrease in LLW Curie Surcharge for Disposal
Substantially Lower Contamination Levels (200 mrad to 50K dpm reduction)	Reduction in Contract SR. HP Staff/ RFO Labor Cost Reductions, elimination of pre-job decon, HP oversight and post job decon Critical Path gain for Final Cavity Decon Health physics jobs are easier – reduction in contaminated areas
Reduce filter change-outs on purification system	Avoids loss purification time – Eliminates generation of high dose and high disposal costs of RCS filters (e.g.$30,000/filter)
Cleaner LRW drained from systems	Reduced Discharge Inventory, annual RHETS report More high level radwaste liquid processing - more resin usage
Dose reduced for each maintenance job	Contamination levels in valves/piping is much lower
Dose reduced for refueling crew	Refueling cavity is clarity excellent- Previous loss of clarity resulted in – slower refueling/core verification more dose
Lower contamination levels	S/G reduced smearable contaminations - mitigation of hot particles for ECT and nozzle dam work BWR Lower Turbine Contamination Levels BWR/PWR Lower Cavity Levels for Final Decon- CP Savings
Reduced Personnel Contamination Events (PCE)	Labor Savings from Reporting INPO Assessment of HP Program
SG ECT Probe Use	Increase number of tubes/ probe, less deposited crud in SG tubes

FPL and NPE worked on a post integration impact assessment for Turkey Point 3, 4 to estimate the value proposition of the integrated solution and PRC-01 technology. The analysis considered only 3 areas of impact since they were deemed the most significant for Turkey Pt: 1) reduction in critical path time due to lower generation and release of curies from core during shutdown refueling; 2) monetization of avoid radiation exposure derived from the decrease in effective dose rate and actual outage labor hours, 3) reduction in LLW costs for disposal as it relates to shipment of liners full of primary and other ion exchange resins where costs are controlled by curie surcharge.

The table below is a calculation estimating the avoided occupational exposure, based on the change in outage effective dose rate. There is a generous assumption that good HP and shielding practices could have reduced the EDR 20% each subsequent RFO without any other source term reduction efforts. This is reflected in the adjusted EDR column noted for HP practices. For example, the EDR 3 RFO average prior to PRC was 3.15 mR/RWP-hr. It was assumed that a 20% decline would have occurred due to good HP practices to yield an EDR of 2.52 in R18, 2.02 in R19 and so on. The difference between the actual RFO EDR, and the adjusted EDR from HP practices, yields an adjusted EDR which is attributed to source term reduction. In R21 the actual EDR was 0.61 mR/RWP-hr, if only HP practices are considered at a 20% decline aggregate before PRC integration, the EDR should have been 1.29 mR/RWP-hr, the difference 0.67 mR/RWP hour is assigned to impact of source term reduction efforts. Multiplication of the actual RFO RWP-hours, derives the avoided exposure, of 127.28 REM for R21. The total aggregate calculated avoided exposure for Unit 3 is 325 REM over 4 RFOs. The impacts are essentially the same for U4.

Table: Estimate of Avoided Occupational Radiation Exposure for Turkey Pt-3

RFO	PRC-01 Use	FINAL OUTAGE CRE, [REM}	FINAL RWP-HRS, [HRS]	OUTAGE EDR, [mR/RWP-hr]	*ASSUMED IMPACT ON EDR FROM HP PRACTICES	EDR ACTUAL LESS HP PRACTICES IMPACT ADJUST	CALCULATED AVOIDED EXPOSURE, [REM]
PTN U3R21, Oct 2004 RVH REPL	4th	117.402	189,641	0.62	1.29	(0.67)	**(127.28)**
PTN U3R20, April 2003	3rd	106.947	82,056	1.30	1.61	(0.31)	**(25.39)**
PTN U3R19, Sept 2001	2nd	94.218	72,732	1.30	2.02	(0.72)	**(52.41)**
PTNU3R18 March 2000	1st	144.443	105,103	1.37	2.52	(1.15)	**(120.42)**
Avg. EDR Previous U3 Non PRC 3 RFOs	MB	---	---	3.15	3.15	---	

If the avoided exposure is summed, the total is 325 REM for 4 RFOs, or about 81.25 REM/ RFO avoided. If we use the industry average assigned value of $12,500 per person-REM avoided (Ref: www.natcisoe.org), this would monetize to $4.06 Million for unit 3, twice that if you include Unit 4 or $8.13 Million. While these dollars exist in no HP outage budget explicitly, they are used for decision criteria for evaluation plant changes and used by INPO for ranking plant performance. Costs that are in plant O&M budgets are the cost of contract staff and disposal of low level radioactive waste and critical path time. Turkey Pt decreased the contract HP staff by 35%, at a recurring cost savings of $425,000 per RFO after the 1st Use of PRC in U3 and U4. The decrease was due primarily to the decrease in contamination levels and the decrease in the number of high radiation areas, which drive the procedures for HP job preparation, oversight and clean-up. The curie surcharge cost for disposal of a disposal liner containing primary and other plant resins prior to PRC was $250,000 charge of on average 200 Ci of Co-60. The recent U3 RFO released only 10 curies during shutdown and start-up of Co-60. Adjusting for 5 year decay, this will be 5 Ci of Co-60 for disposal which has a minimal curie surcharge for disposal. In the future, the resins are expected to be sufficient low in activity to be diverted to a volume reduction facility.

The final economic impact assessed was reduction in critical path time for refueling outages. Turkey Pt has credited 24 hours/ RFO of critical path savings to shorter required clean-up time driven by the continuing decline in peak Co-58 release. Prior to PRC integration shutdown clean-up of Co-58 activity was on critical path for as long as 60 hours. Now shutdown chemistry is never on critical path. The new RV head with the installed integrated head package for U3 and U4, the revised technical specifications to move fuel in 70 hours, and back-fit of SFP coolers will now enable the movement of fuel not in 100 hours but in 70 hours from shutdown. Any peak greater than 1.2 µCi/cc would place post FO2 shutdown clean-up back on critical path. The cost per critical path hour in replacement power only, is $30,000/ CP-hr, or a savings of $720,000 every outage controlled by refueling critical path schedule.

BWR Lead Plant OE

On the heels of the demonstrated success in the PWRs, NPE re-engineered the technology for lower cost materials and application in BWRs. There has been confusion in the industry that the macroporous substrate was dominating the PRC function and not the Los Alamos developed polymers. This is incorrect. Many power plants have used macroporous resins and not duplicated the OE of PRC-01 solution. The technology was converted from a high cost macroporous bead structure to a lower cost strong acid cation gel powdered ion exchange resin substrate available from any NPP supplier supporting the BWRs, Graver, Epicor, US Filter, etc.

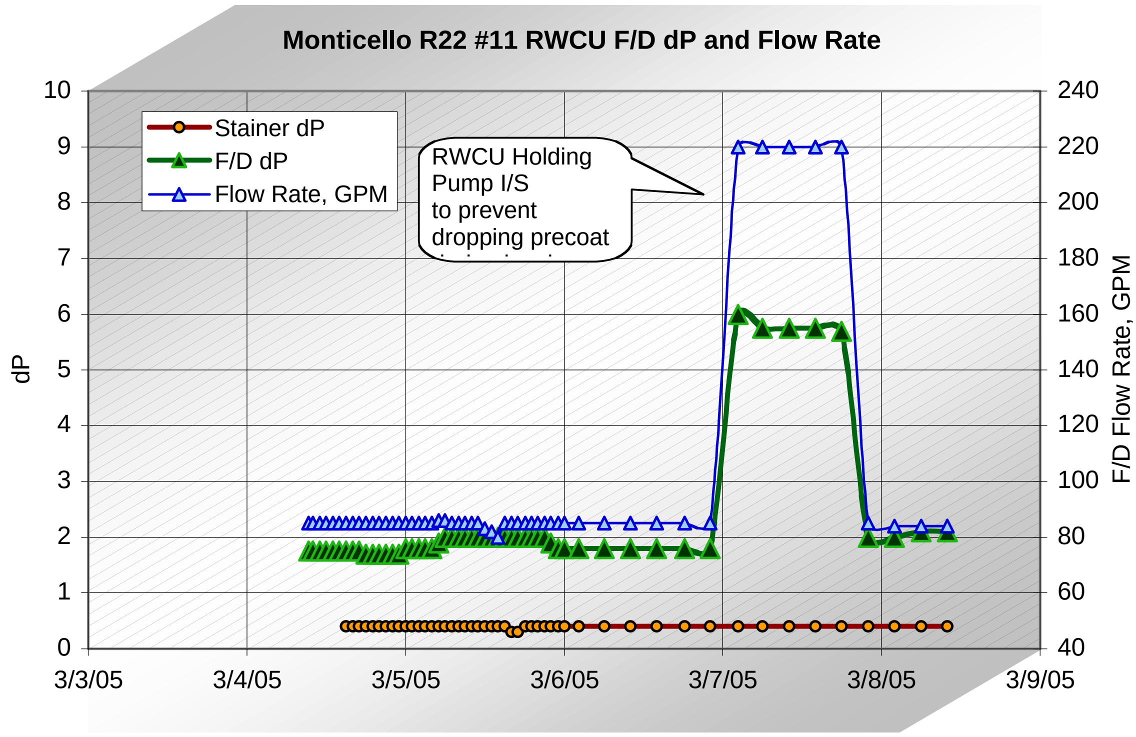
Table: PWR and BWR Solutions for PRC Technology-Substrate Function

Product ID	Form	Substrate
PRC-01	Deep Bed	Cation Macroporous
PRC-01M	Deep Bed	Cation Gel
PRC-2	Powdered Epicor or Graver	Cation Gel

This work was first supported by PSE&G Hope Creek during RFO9. NPE conducted benchtop screening tests of powdered PRC-2, and small on-line columns for PRC-01 deep bed media. Benchmark data was performed on Hope Creek corrosion product behavior at shutdown using conventional mixed bed powdered ion exchange resin precoated on filter/demineralizers (F/D) in RWCU system. This data was used to provide a benchmark between 2 different BWR units.

Monticello stepped forward as the lead BWR plant during RFO22 in Spring of 2005. Monticello is a BWR that has been in commercial operation for 31 years, since start-up June 17, 1971. This plant has used hydrogen water chemistry (HWC) and depleted zinc injection (DZO) for over 10 cycles. In the past 8 years, there has been no change in BRAC dose rates. There was a need for a new, non-invasive, source term solution. Monticello reviewed the PWR data and operational experience on PRC and decided to proceed with integration.

NPE integrated PRC-2 as a precoat on the Monticello 2 RWCU filter/demineralizers and 2 spent fuel pool filter demineralizers 3 days prior to shutdown. The F/D were operated throughout the reactor shutdown and clean-up process until RWCU was taken O/S for normal maintenance. The F/D performed operationally the same with PRC-2 precoat, as compared to the 205H precoat practice for RWCU. The figure below displays the pressure drop data record for the RWCU F/D and in-line strainer as a function of flow rate through the filter. It should be noted that the holding pump was placed in-service during a period where operators were concerned that the precoat would drop due to system pressure and valve manipulations at that time.



NPE conducted the 3 different assessments of PRC-2 and Monticello specific crud behavior through the shutdown operations. The first were laboratory screening tests of different precoat overlay and underlay loadings which matched the engineering parameters of RWCU F/D. This was used to screen the difference over small volume through put, 1.5 Liters, differences in DF. There were several tests conducted to evaluate PRC-2 precoat used as an overlay on 205H and compared isotopic DFs to typical precoat used by Monticello for shutdown refueling, 205H only. The results below are interesting. The effluent concentrations for Cr-51, Fe-59 remain at MDA's for both precoat loading configurations. However the effluent quality for Mn-54, Co-58, Zn-65 and Co-60 all show an improved level of effluent quality, and higher DFs. These tests only provide an early indication of a precoat efficiency. Clearly, if the precoat configuration doesn't work well on 1 liter throughput, it won't work well in full system integration and could be eliminated by this screening test. The PRC-2 overlay/205H underlay precoat composition has provided data indicating an opportunity efficiency improvement for dose controlling isotopes.

Table: Precoat Screening Test Results

Precoat Test #1: Monticello R22 PRC-2 Overlay/205H Underlay					Run Date:	3/5/05	
Precoat Sample	**Cr-51**	**Mn-54**	**Co-58**	**Fe-59**	**Co-60**	**Zn-65**	**Tc-99m**
Inf PRC-2/205H R22 RFO	5.29E-03	1.95E-03	1.18E-03	8.50E-04	2.62E-03	9.99E-04	7.26E-04
Eff PRC-2/205H R22 RFO	4.14E-06	5.20E-07	7.02E-07	1.13E-06	6.07E-07	7.88E-07	1.75E-06
DFs	**1277**	**3750**	**1678**	**753**	**4320**	**1268**	**415**
*MDA’s in yellow							
Precoat Test #3: Normal Precoat RWCU 205H					Run Date:	3/6/05	
Precoat Sample	**Cr-51**	**Mn-54**	**Co-58**	**Fe-59**	**Co-60**	**Zn-65**	**Tc-99m**
Inf 205H Normal RWCU	1.89E-03	9.92E-04	9.40E-04	2.98E-04	1.85E-03	7.77E-04	5.28E-05
Eff 205H Normal RWCU	4.14E-06	8.66E-06	1.23E-05	1.13E-06	2.27E-05	9.18E-06	1.00E-06
DFs	457	115	77	263	81	85	53

A second test was conducted using cascading filters to “bin” insoluble isotope behavior. The test procedure involves taking RC sample and filter through a 0.45 µm filter, counting RC and filtrate, to determine percent retained by the filter. Second, taking the 0.45 µm filtrate remaining sample, and cascading into a second filter of 100,000 MWCO UF, ~ 0.0162 µm and determining percent retained by smaller filter and so on. Examination into the size binning data of each isotopic revealed that the Fe-59 was easily filterable by 0.45 µm filter, 100%, but the other corrosion products had a significant fraction that was not filtered until 100,000 MWCO UF (~0.0162 µm) filter was employed. This provides some insight for the differences in observed removal efficiencies on the precoat screening tests, with PRC-2 demonstrating a higher efficiency for small particle corrosion products of Co-58 and Co-60. The MDA’s in the particle size speciation, or binning tests, were high due to the limited availability of a small volume counting geometry and the small volume of sample.

Figure: Co-60 Speciation Cascade through 0.45 µm and 100K MWCO UF

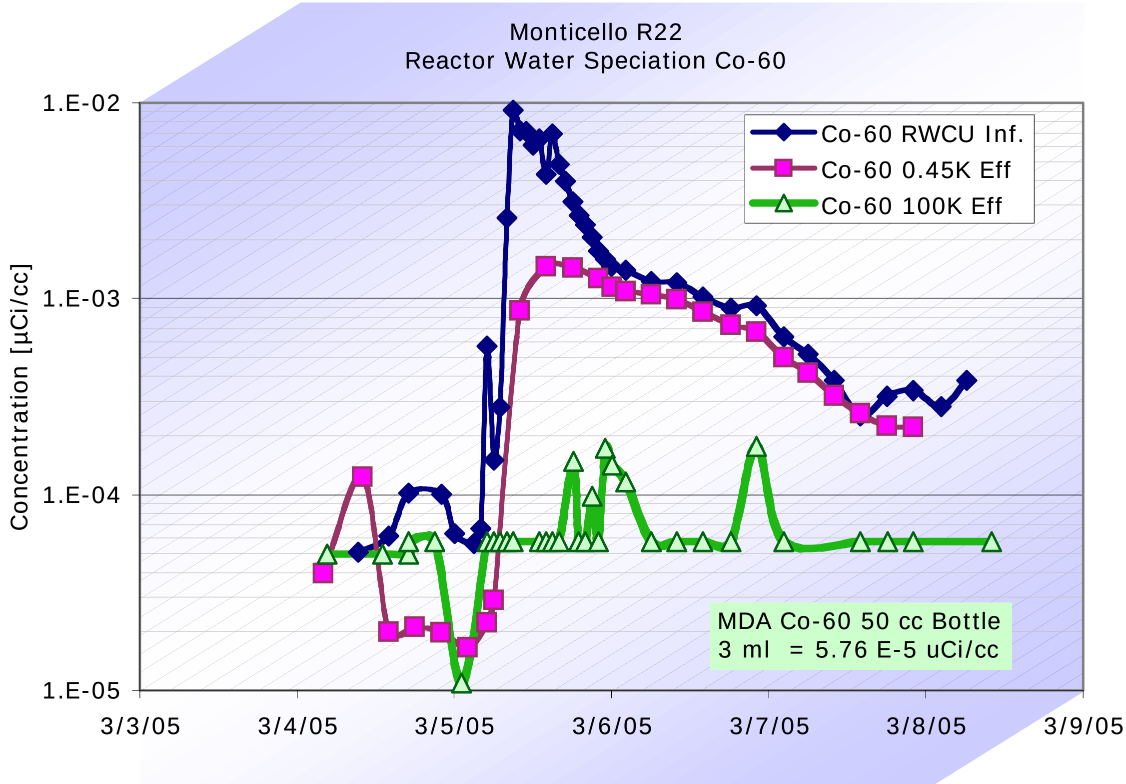


Figure: Co-58 Speciation Cascade through 0.45 µm and 100K MWCO UF

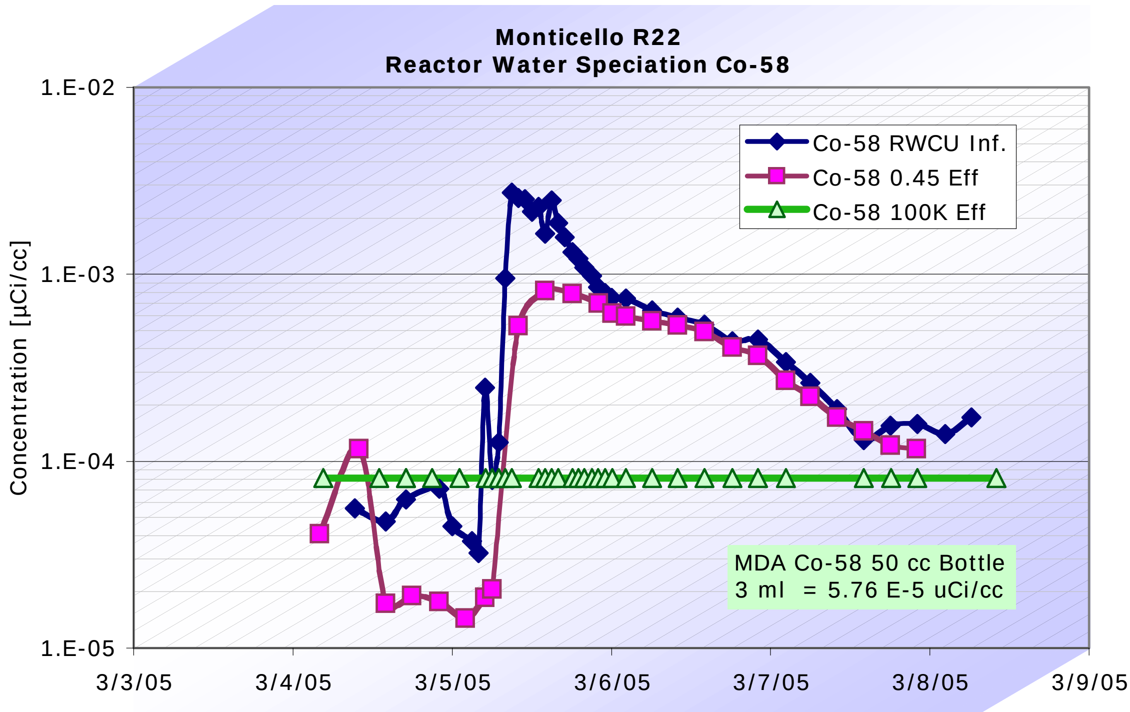
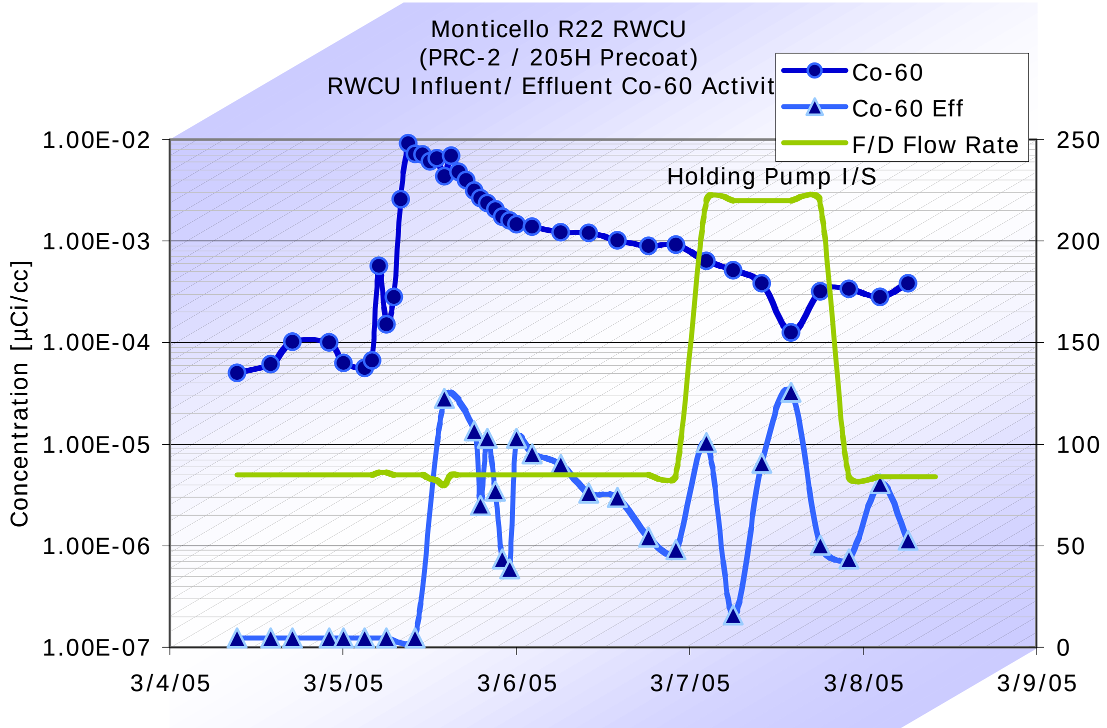
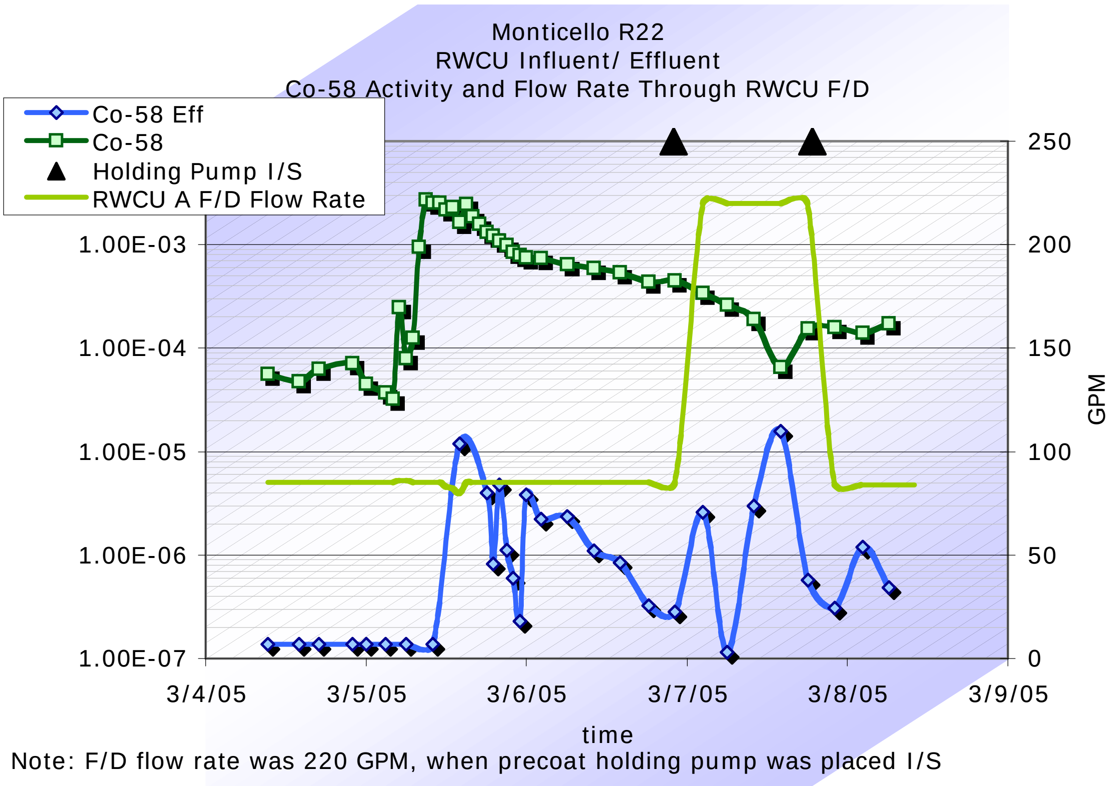


Figure: RWCU Co-60 DF with F/D Flow Rate

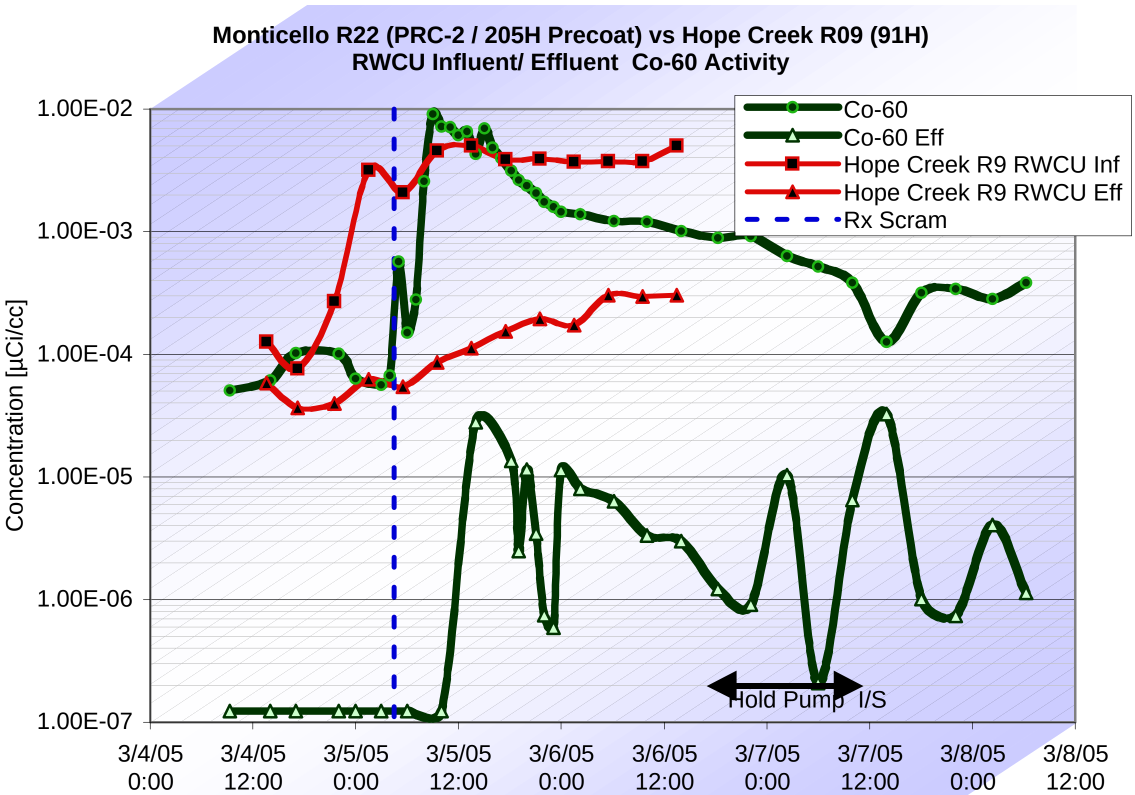




Note: F/D flow rate was 220 GPM, when precoat holding pump was placed I/S

RWCU removal efficiencies were also evaluated for plant integrated PRC-2 precoat overlay. There was no Monticello historical DF data on RWCU F/D during shutdown. However, Hope Creek R09 data provided this benchmark of performance for RWCU precoat F/D. The figure below shows the improvement in the effluent quality with a PRC-2 overlay. Recall, that there was an operational period during Monticello RFO where the hold pump was placed I/S with normal RWCU flow rate. This of course effected the efficiency for that shortened period of precoat residence time, velocity increase through the precoat, and subsequently degraded the effluent quality during that period.

Figure: RWCU Benchmark Comparison Monticello R22 and Hope Creek RO9



Note: HC R9 scram time/date correlated to Monticello R22 Scram. Both Units new precoats RFO.

The preliminary results at Monticello have indicated a decrease in the defueling/refueling radiation exposure, and a 50% decrease in the turbine side contamination levels. There is a preliminary indication that the dose rates decreased in the 16 point average of survey points in the drywell by 14% in R22, where they did not decrease in R21. Monticello will now evaluate the potential application of the technology at power on CPS to affect over at power deposition, with the hopes that drywell dose rates will be reduced.

Figure : Monticello R18 to R22 Refueling Floor Effective Dose Rate

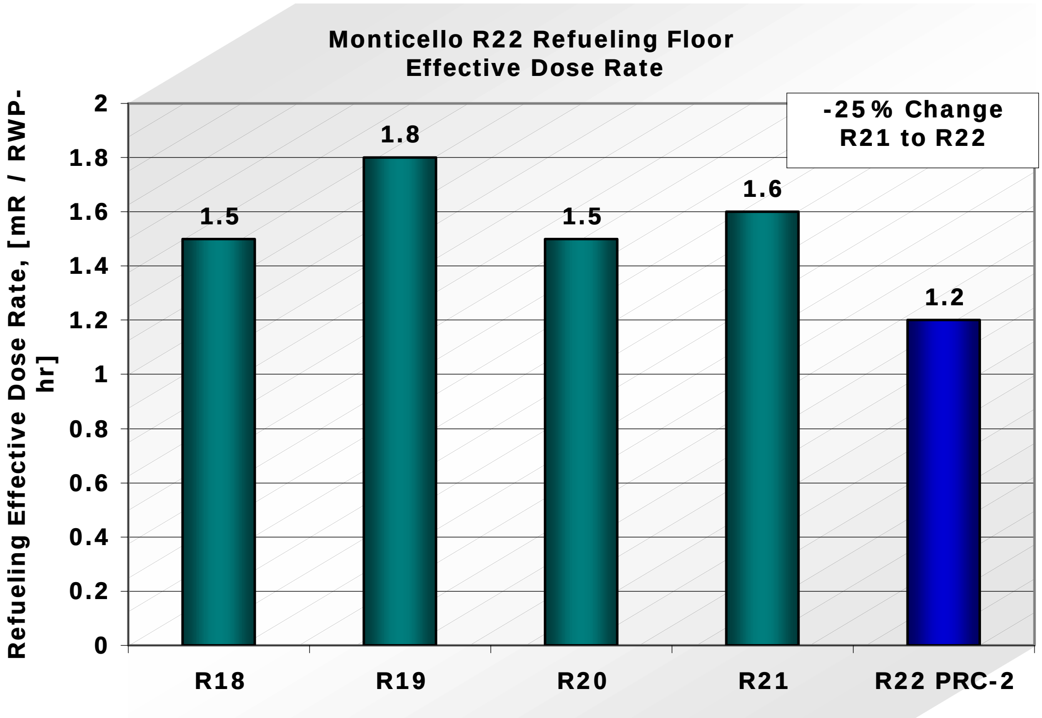


Table : 16 Point Area Dose Rate Survey and Overall Change for R21 and R22 (PRC-2)

Survey Location	**R20 to R21**	**R21 to R22 (PRC-2)**		**R21**	**R22**
B Disch 933' (3ft)	-7%	7%	B Suct 951' (3ft)	+14%	0%
A Suct 933' (3ft)	-16%	-4%	E Riser (3ft)	0%	+9%
A Disch 933' (3ft)	-13%	-9%	D Riser (3ft)	-15%	-6%
B Suct 933' (3ft)	+4%	-4%	C Riser (3ft)	-8%	-17%
RHR-9 951' (3ft)	10%	+9%	B Riser (3ft)	-8%	-9%
K Riser (3ft)	-5%	-16%	A Riser (3ft)	+6%	-58%
J Riser (3ft)	+6%	+18%			
H Riser (3ft)	0%	0%			
G Riser (3ft)	+33%	-17%			
F Riser (3ft)	+38%	-36%	**Overall Average=**	**0.4%**	**-14%**

What is common between the PWR and BWR crud characterization studies, is that in all of the 20 PWRs and 2 BWRS characterized, there is a significant fraction of Co-58 and Co-60 which is much smaller than 0.45 µm, and in the range of 0.0162 µm to 0.002 µm. This is an important factor since the mechanical filtering and trapping ability of deep bed gel and macroporous ion exchange resins, and powdered gel ion exchange resins are limited and cannot sustain effective removal colloids in the 0.0162 µm or smaller range for much over 200-400 bed volumes.

SUMMARY

In summary, the PRC technology has demonstrated efficacy for improved removal of activity in both PWRs and BWRs which if applied correctly, is sustained in use, aggregately affects the overall plant source term in PWRs, and holds the opportunity to impact BWRs. The technology is easily and safely integrated into existing plant systems. The results in source term reduction provide a significant cost benefit to the utility.

Turkey Point 3,4 aggregate impact of PRC-01 engineered solution:

- 325 REM estimated of avoided occupational exposure for Turkey Pt U3
- 50 fold reduction in Peak Co-58 during shutdown forced oxygenation
- 30 fold Reduction in at Power Co-58 14 month average concentration in Reactor Coolant
- 24 hours of critical path time reduction per RFO, estimated $720,000 every RFO, assigned directly to results of engineered solution; as much as 48 hours of critical path reduction per RFO in the future with new RVH
- 26 hours earlier for last RCPs to be taken O/S
- 93.3% Reduction in effective dose rate for Containment RWPS
- 90% reduction in EDR for all RWPs
- 100% reduction in RCS shutdown Filters Usage
- $250,000 avoided per RFO in primary resin curie surcharge for LLW disposal
- 89.4 % Reduction in Co-58 Curies released at shutdown
- 91.8% Reduction in Co-60 Curies released at shutdown
- 4 hours of activity clean time required for U3R21, reduced from 60 hours U3R17
- 83.5% reduction in number of PCI's per 1,000 RWP hours, from 3R19 to 3R21
- 39.2% average reduction in SG channel head dose Rate from U3R18 to U3R21
- 61.5% reduction in number of High Radiation Areas
- 35% Reduction in contract HP staff, $400,000 avoided costs every RFO.
- 76% Reduction in Hot Spots
- 49 fold Reduction in annual effluent activity discharged for Co-58 and 15 fold for Co-60
- 87.7 % Reduction in Ni-63 annual effluent activity discharge, and 70% for Fe-55
- 500 fold reduction in contamination levels for accumulator check valves
- 50 fold reduction in cavity contamination levels
- 5.923 REM (59.23 mSv) Collective Occupational Radiation Exposure for U3 Reactor Vessel Head Replacement 1st World Record Low Dose Performance.

- 5.407 REM (54.07 mSv) Collective Occupational Radiation Exposure for U4 Reactor Vessel Head Replacement and 2nd World Record Low Dose Performance.

ACKNOWLEDGEMENTS:

The author would like to acknowledge the significant contribution that Dr. Sallie A. Fisher, President of Puricons, Inc., made to the testing and development of PRC-01 technology, and the science of ion exchange in the nuclear power industry. Dr. Fisher passed away April 18th, 2005, after a one year battle with cancer at the age of 81.

I first met Dr. Fisher in 1985 when I joined the Electric Power Research Institute. She became at that first meeting my long time mentor in the science of ion exchange, for which I am both privileged and grateful. Dr. Fisher started her career in 1949 when she graduated from University of Wisconsin, at Madison, with a PhD in Inorganic and Physical Chemistry. She was a professor of chemistry early in her career, a research scientist, inventor, and eventually her body of scientific work brought her recognition from her colleagues around the world. She was most proud of the science achievement award presented in 2002 by the British Chemical Society. I recall the conversation where she expressed a child like excitement of the pending award, and that it prompted her to consider the purchase of new dress for the special event. On her return from England, she told me she had instead found a suitable 20 year old dress in her closet. Perhaps my favorite story was about the post meeting day social trips to the bar with her colleagues attending the International Water Conference in Pittsburgh, as she did for almost 30 years. Little did her colleagues know that she was the last chemist standing and drinking every evening, due to her discrete ingestion of a teaspoon of ion exchange resin to absorb the alcohol, washed down with alcohol of course.

She has long held relationships with her Alma Mater, where she generously endowed the University of Wisconsin to fund a Chair in the Chemistry Department for the polymer separation science. It is through her brilliance, her teaching, and her gift, that her life-long contribution will be extended and sustained by the next generation of young scientists.