Quad Cities Source Term Challenges and Lessons Learned

Authors: Kenneth Ohr (Radiological Engineering Manager – Quad Cities Station)
Don Barker (Radiation Protection Manager – Quad Cities Station)

Exelon Generation Company, Quad Cities Generating Station
22710 206th Avenue North, Cordova, IL 61242-9740

Executive Summary

In October 2000, Quad Cities Generating Station entered its sixteenth Refueling outage on Unit 1 and discovered dramatically different radiological conditions in the Drywell as well as Turbine Building steam-affected areas. The root cause behind the unexpected radiological conditions was determined to be a reaction between recently-injected Noble Metals (chemical compounds containing Platinum and Rhodium) and Depleted Zinc Oxide passively injected through the Feedwater system. This reaction, coupled with the historically high inventory of Cobalt-60 on in-core components, resulted in a loosely-bound corrosion layer on the fuel that was readily transported rather than the desired tightly-bound layer anticipated from Zinc (DZO) injection.

This excursion was previously unidentified in the industry as the practice of Noble Metals Chemical Addition was new to the domestic-Boiling Water Reactor (BWR) industry and has resulted in industry guidance on both Zinc Injection and Noble Metals Chemical Addition. Extent of condition of this issue has extended beyond Quad Cities Unit 1 and includes, to a lesser extent, Quad Cities Unit 2 and several other domestic BWRs.

Upon shutdown for Q1R17 in November of 2002, Drywell surveys indicated that the Recirc System dose rates had stabilized. However, the Main Steam System dose rates had increased by 25-100%. A steam dryer modification was performed during the outage that reduced the moisture carryover by 94% upon start-up. With conditions somewhat stabilized the Station is no longer in a reactive mode but is moving to a proactive mode for the long-term recovery of the Quad Cities units.

Background

As an older Boiling Water-type Reactor (BWR), Quad Cities has been engaged in evaluating chemical remedies to both mitigate Inter-Granular Stress Corrosion Cracking (IGSCC), and reduce Source Term creation and transport. This quest for Optimal Water Chemistry has included Hydrogen Addition (HWC), Depleted Zinc Oxide (DZO) Injection, and Noble Metals Chemical Addition (NMCA).

The primary purpose of HWC is the protection of stainless steel components by scavenging oxygen, ultimately decreasing corrosion on the piping surfaces. Several negative side-effects exist in conjunction with HWC, namely the increase in N-16 production and resultant high energy gamma dose rates during power operation and the costs associated with the high injection rates needed to maintain the required hydrogen concentration throughout the entire volume of water passing though Recirculation piping. At Quad Cities, HWC effectively protects core internals from IGSCC but only marginally protects Recirculation Piping while resulting in increases in dose rates in Steam-Affected areas five to seven times.

Depleted Zinc Oxide (DZO) is injected to reduce the amount of Co-60 incorporated into the primary system corrosion films and thereby reduce dose rates on primary system piping. The Zinc competes with cobalt for sites in corrosion films and inhibits corrosion on stainless steel surfaces. DZO also suppresses the release of established Co-60 from fuel cladding and in core cobalt-bearing materials. Implementation of DZO injection at Quad Cities Unit 2 was effective in reducing build-up of dose rates on Recirculation Piping and resulted in the lowest dose outage in Quad Cities history at 149 rem (1.49 Sv).

Noble Metals Chemical Addition (NMCA) consists of Platinum and Rhodium injected into the primary system where they deposit on the piping and other vessel surfaces. Recirculation System piping and vessel internals are further protected from inter-granular stress corrosion cracking (IGSCC) and less hydrogen (HWC) is required to be injected due to the catalytic effect of Noble Metals on the piping surfaces. In terms of HWC consumption, NMCA is highly effective and reduces the required Hydrogen injection flow rates to one-fifth of former flow rates.

Each of these components affects the oxide layer on the fuel and other metal surfaces in and outside the core. Changes to any of these components affect both the composition of the oxide layer, and how tightly or loosely it is bound to the metal surfaces. This, in turn, affects the concentration of various isotopes (namely Co-60) in reactor water.

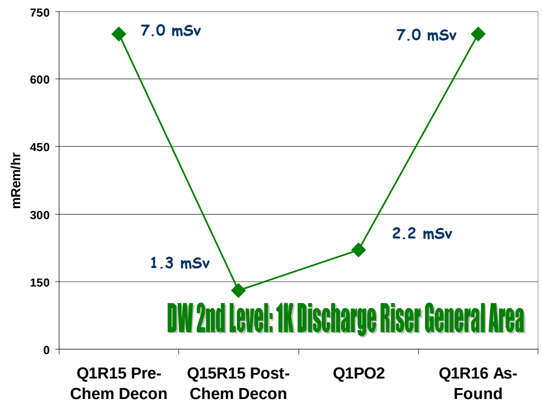
Unit 1 Shutdown Radiological Conditions

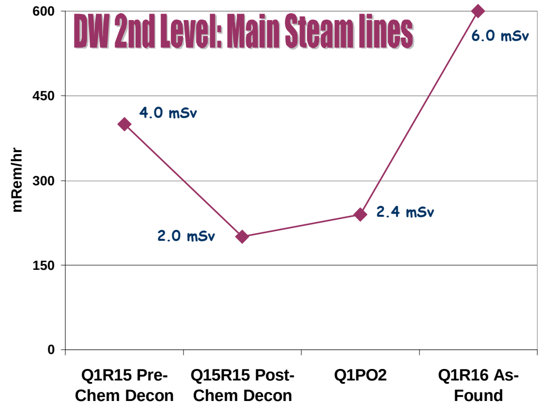
Unit 1 commenced its sixteenth Refueling outage (Q1R16) on 14 October 2000 with radiological conditions in the Drywell expected to mirror those of Unit 2 seen during its fifteenth Refueling outage (Q2R15) on February 2000. The radiological conditions on Unit 2 reflected the best Drywell conditions seen without the use of Chemical Decontamination of Recirculation piping in plant history. Injection of DZO on Unit 1 was planned to result in equally beneficial conditions during the Q1R16 outage.

The actual As-Found radiological conditions included the following anomalies:

- Reactor Water Chemistry spikes in activity at shutdown including increases in Co-60 activity approximately 15 times normal eventually increasing by a factor of 1000 early in the outage;
- Drywell dose rates elevated by three to five times expected values (similar to what was historically seen pre-Chemical Decon in past outages); and,
- Secondary (Steam Side) dose rates elevated two to five times normal with the Moisture Separator elevated ten times normal.

The most dramatic impact was seen on the second elevation of the Drywell where the largest scope of inspection and maintenance activities were to be performed.





Radiological Response

The increased dose rates identified did not match any known model at that time. This led to several major actions to allow both for exposure reduction and for the need to complete the required Refuel outage activities.

- Installation of additional lead shielding (including shielding of the Main Steam Lines - now a significant source);
- Deferral of high dose work scope where prudent;
- Re-evaluation of all ALARA planning packages and respiratory requirement evaluations;
- Increased radiological job coverage with augmented technician and management staffing utilizing resources from other Exelon nuclear stations; and,
- Implementation of daily Station ALARA Committee meetings.

In parallel with outage exposure control activities, an expert team was formed to determine the root cause of the unexpectedly high dose rates. This team was comprised of personnel from the Quad Cities Generating Station, other Exelon Station and Corporate RP/Chemistry experts, General Electric, and Electric Power Research Institute (EPRI). Three additional teams were formed to begin evaluation of other long-term consequences of the conditions and likely remedies.

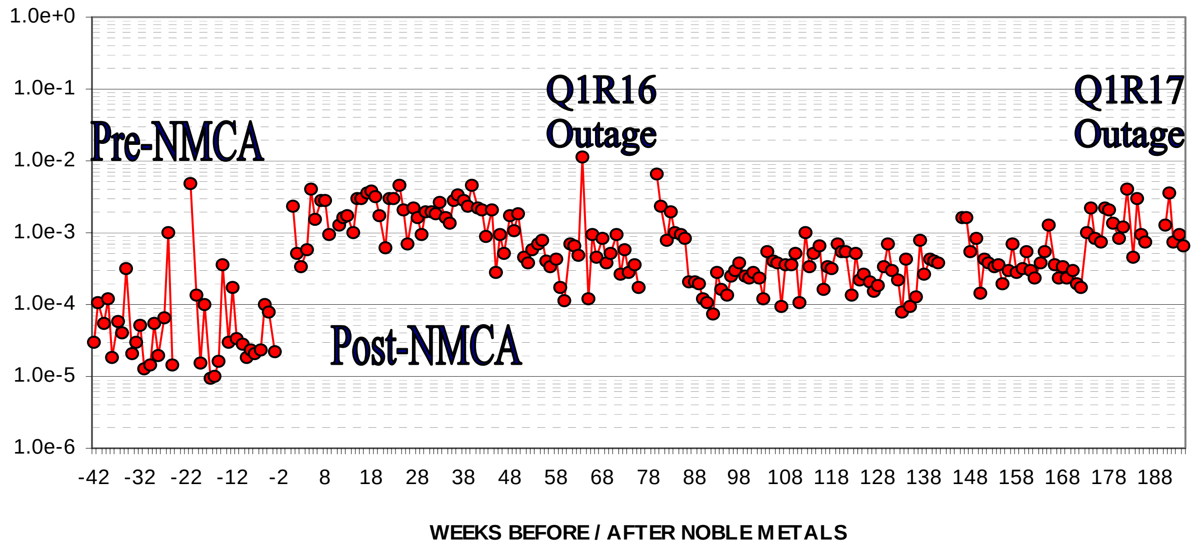
Root Cause

The root cause of the Q1R16 High Shutdown Drywell Dose Rates was determined to be a combination of the Fuel Crud Corrosion Layer Not Being Optimally Stabilized and the High Initial Co-60 Inventory in the Primary Coolant. Other contributing causes were determined to be application of NMCA during a mid-cycle outage (with no immediate fuel removal) and excessive Hydrogen (HWC) cycling.

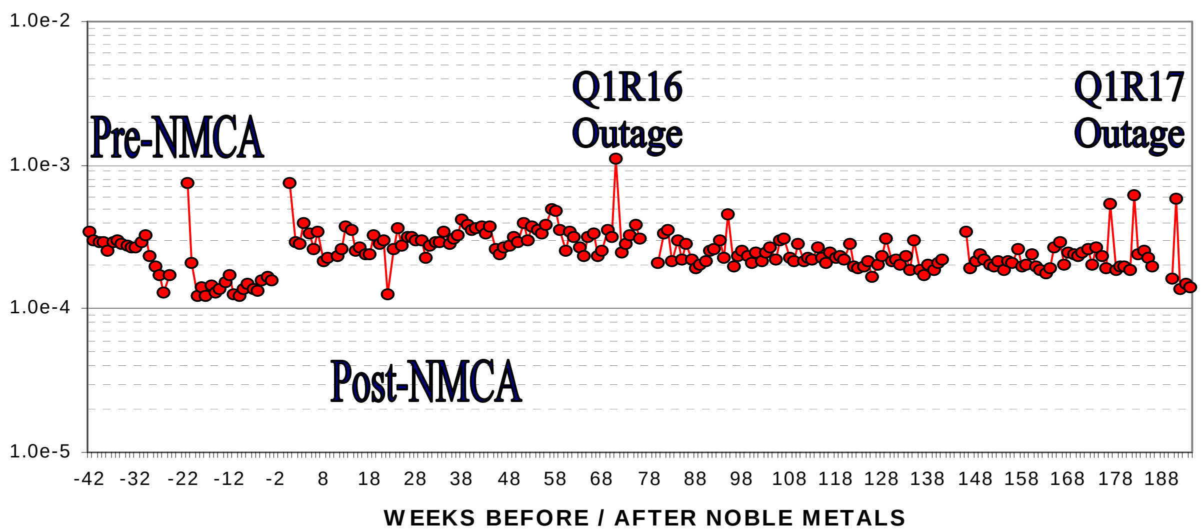
Simply stated, historically high Co-60 levels at Quad Cities Unit 1 were disturbed when NMCA was implemented on a system where DZO was not applied for a long enough interval thereby not allow the fuel deposit DZO-affected corrosion films to stabilize. This condition was further exacerbated when DZO was not injected at a high enough concentrations to effectively stabilize the fuel deposits.

Chemistry Parameters

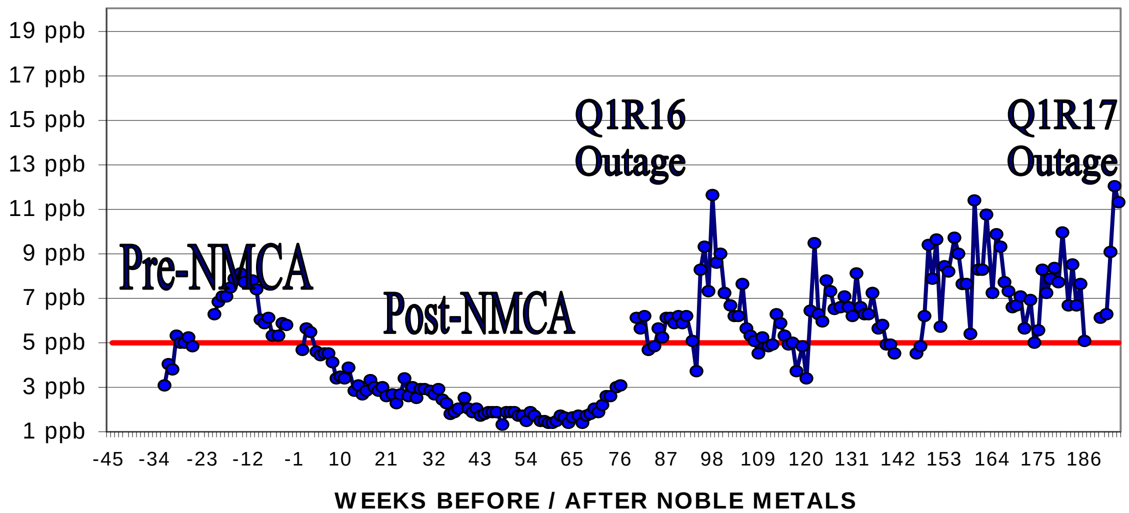
In retrospect, several trends become readily apparent. Insoluble Co-60 concentrations in reactor water increase by a factor of fifty after the application of NMCA as shown below. Currently, the insoluble Co-60 has decreased slightly from pre-Q1R16 levels but continues to hover around the 1.0e-03 uCi/ml level.



Similarly, soluble Co-60 concentrations were also seen to increase by a factor of two following NMCA application. Currently, soluble Co-60 has begun to steadily decrease as the combination of DZO/hydrogen management and increasing RWCU flow-rate take effect.



Finally, prior to Q1R16, DZO concentration in reactor water steadily decreased to 2 ppb despite no significant change to the input rate. DZO concentration has been maintained between 5 and 10 ppb following Q1R16.



During cycle 17, DZO has been maintained in the 5-10 ppb range. Additionally, hydrogen cycling has been minimized. The soluble and insoluble Co-60 levels have stabilized and even begun to decrease, particularly in the case of the soluble form.

<u>Lessons Learned</u>

Many technical and management Lessons have been Learned as a result of the Unit 1 high dose rates. Initially, the Quad Cities experience was communicated to the industry with recommendations by General Electric as part of Service Information Letter (SIL) 631 (subsequently revised once). This letter documented their initial position regarding DZO injection rates (5-10 ppb) and other chemistry parameters.

Beyond the technical recommendations, this event also served to reinforce the need for open communication between departments and to differentiate between laboratory (test) results and real-world results. When discrepancies are noted between hypothesized responses and actual results, actions must be developed and the differences investigated immediately.

<u>Actions Taken during Cycle 17</u>

The site is maintaining the DZO concentration between 5 and 10 ppb. Additionally, the cycling of hydrogen has been minimized. Reactor Water Cleanup (RWCU) flow-rate has been increased on both units and the remaining stellite bearing control rod blades continue to be removed. The steam dryers on both units have been modified to reduce the moisture carryover in order to reduce steam side dose rates. The Station planned on performing a Recirc System chemical decon during Q1R17 (November 2002), however, data showed that the noble metals would not redistribute from core surfaces to the Recirc piping. The decision was made to not take the risk of running an entire cycle without IGSCC protection of the Recirc piping and the chem decon was deferred until Q1R18.

To help offset the impact of decon deferral, a scope reduction team was formed to look at reducing the scope of Q1R17. The team consisted of Site and Corporate Engineering, Operations, Chemistry and Radiation Protection personnel. A total of 260 rem of work was removed from the outage.

Q1R17 As-Found Conditions

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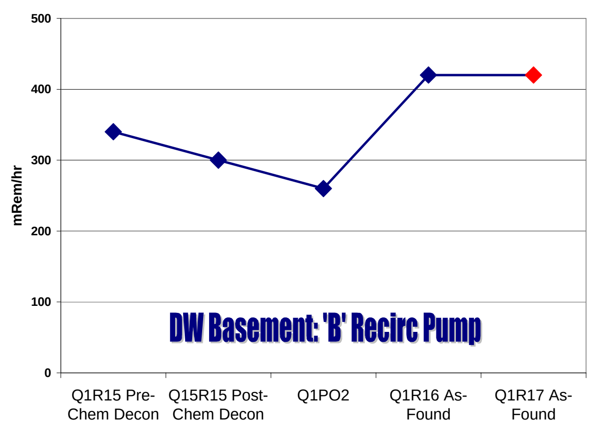

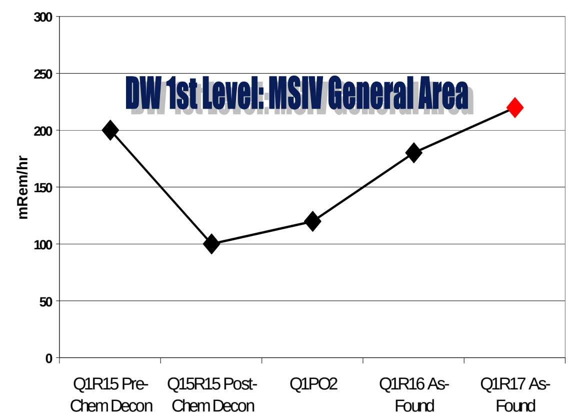

Looking Forward: The Exposure Reduction Charter

A comprehensive action plan has been put in place to move Quad Cities from fourth quartile to first quartile exposure performance. Six teams were formed to attack the source term issues. Each team consists of Quad Cities, Corporate and Industry personnel. The teams address the following areas:

- Exposure Reduction
- Chemistry Optimization
- Cobalt Transport
- Cobalt Reduction
- RWCU Capacity Increase
- Fuel Cleaning

The first steps have been taken to return Quad Cities to low dose performance. However, there is still a lot to be done. This Exposure Reduction Charter is the detailed plan that will drive the Station forward in exposure reduction.