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DEVELOPING A PROGRAM TO IDENTIFY AND TRACK CORROSION IN NUCLEAR PLANT RAW WATER SYSTEMS

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Abstract

Findings derived from a comprehensive plant performance survey at Ontario Power Generation's (OPG) nuclear units convinced management that it would be prudent to expand the ongoing power piping Flow Accelerated Corrosion (FAC) induced wall thinning base-lining and tracking program to encompass the raw cooling water systems as well. Such systems are subject to a distinctly different class of pipe wall thinning (PWT) mechanisms than the FAC that degrades high-energy power piping. This paper describes the PWT corrosion assessment and tracking program that has been developed and is currently being implemented by OPG for the raw cooling water (i.e., Service Water) systems within it's nuclear generating stations. Interim databases are used prior to initial inspection rounds to catalogue the prospective locations. For each piping system being surveyed, these interim databases include physical coordinates for the candidate locations, the type and wall thickness of the components comprising each location, ranking indications and recommended NDE methodologies as a function of the anticipated corrosion mechanisms. Rationales for assessing corrosion susceptibility and ranking prospective inspection sites are expounded by way of notations built into the database.

Background

Ontario Hydro Nuclear was renamed Ontario Power Generation (OPG) in 1999 to reflect the company's diverse power resources, reassessment of the company's policies and objectives and rededication of management to a leadership role in the new millennium. OPG operates three nuclear sites in the Province of Ontario. The ages of the units vary between ten and thirty years. Cooling water for the plants' components, including nuclear safety system cooling, is drawn from Lakes Ontario and Huron. As such, water for these plants' once through systems is fresh and relatively unpolluted.

The construction of the twenty heavy water cooled units represented a highly successful commercialization of the CANDU reactor technology. As time passed, management became aware of similar cultural concerns that have occurred in the US commercial nuclear power industry. These concerns posed a threat to OPG maintaining its nuclear units at the high end of the overall safety and performance ratings compared with other nuclear operations in North America. Eight Units (Bruce "A" and Pickering "A") were eventually shutdown due to operability and maintainability problems.

To manifest its commitment to improving the performance of it's nuclear operations, the utility commissioned performance of a three month independent performance assessment early in "97. The scope and administration of the assessment was comparable to an INPO audit. The assessment that was performed included six safety system functionality inspections (SSFI's) congruent with the USNRC's "Vertical Slice" assessment policies.

The assessment concluded that the safety and performance of the twelve operating units was at a level of classification comparable to what in the US would constitute "Watch List" status. These findings constituted a serious challenge to management if OPG nuclear system performance was to be restored to the forefront of the North American nuclear industry. A comprehensive recovery program has been developed. The aim of the program is to upgrade existing corrective action projects and add new programs as required to address deficiencies found with respect to personnel/management/cultural issues and system/hardware concerns.

Information exchanged by the assessment team, which was comprised of specialists from the US and Canada representing a variety of disciplines, supported the initiative of including pipe wall thinning detection and corrective action as one spoke of the technical recovery program. Though not an official finding of the assessment, inadequacies in the ongoing erosion-corrosion programs were apparent. To counter those deficiencies, OPG chartered an aggressive Project Execution Plan (PEP) and initiated an associated fast-track schedule to implement the Pipe Wall Thinning Program (PWTP).

Initially, the PWTP's scope was primarily directed to Flow Accelerated Corrosion (FAC) of power piping. OPG joined the EPRI sponsored CHECWORKS® Users Group (CHUG) and enrolled responsible team engineers in EPRI's CHECWORKS® training program. One of the systems targeted in the SSFI was the "Service Water System" within one of the plants judged to

be essentially representative of all three plants (i.e., the "B" block of four units at the Bruce site on Lake Huron). The term SWS as used within OPG embraces a number of raw water and cooling systems. As with their light water cooled cousins, the SWS in the CANDU units include certain systems which are designed for heat extraction associated with normal operating combined with potential safety system functionality. Other SWS are solely intended for post-accident cooling. The SWS SSFI addressed the six different systems comprising the Bruce B SWS. Among the significant findings with respect to the SWS was the following:

> *"Service Water System deficiencies are not being identified in a timely manner and cause a degradation in material condition."*

Therefor, early in the PEP development process, the program was expanded to capture pipe wall thinning in raw water systems. While raw water system operability had not yet degraded significantly due to flow-related mechanisms, the utility has experienced signs of significant internal corrosion in some sections of service water and fire protection piping. As finalized then, the PEP's scope addresses potential wall loss in both high energy, fire protection and service water systems. The SWS aspect of the PEP, assessing wall thinning from types of corrosion other than that caused by power piping FAC, was doubtlessly motivated in large part by the need for monitoring SWS performance identified in the United States Nuclear Regulatory Commission (USNRC) Generic Letter 89-13$_{(1)}$.

Although flow-related corrosion mechanisms are certainly a factor in localized portions of power plant raw water piping systems, much of the corrosion in raw water is a result of other than the oxide layer dissolution mechanism primarily associated with FAC. For this reason, the term "Non-FAC" as it's usage evolved at OPG became synonymous with corrosion in cooling water systems.

Development of the Non-FAC Program

The OPG Non-FAC program borrows significantly from the concepts upon which CHECWORKS® is founded. In fact, EPRI was in the process of developing a formal Non-FAC version simultaneous with the OPG's efforts to create its Non-FAC PWTP. The EPRI work product known as the "Cooling Water Application" component of CHECWORKS®, became available in June of "99.

CHECWORKS® FAC program contains predictive subroutines and is driven by a logic that selects sites for NDE as a function of deterministic evaluation of susceptibility to chemical dissolution of the oxide layer. While the OPG Non-FAC program does not include quantified corrosion prediction, it does reflect many of the key concepts found in the CHECWORKS® FAC and the new Non-FAC models. The results of NDE output generated by the Non-FAC program will ultimately be entered into a CHECWORKS ® database for effective, consistent data management.

In addition to administrative controls, the PEP for the PWTP called for preparation of technical procedures to implement the program. The key procedure to be developed was entitled "Selection of Systems and Components for Inspection". As the name implies, it was the objective of this procedure to detail the rationale that was intended to be applied to the process of selecting the particular pipe and pipe system components (elbows, reducers, tees etc.) to be subject to examination. Though both FAC and Non-FAC site selection protocols are established in the site selection procedure, only the Non-FAC site selection rationales are discussed in this paper. The processes and methodologies for selecting systems and components for inclusion in the Non-FAC program described below are essentially in accordance with the strategies recommended in EPRI TR-102063[2] and TR- 109633[3].

The scope of the Non-FAC PWTP includes pipe ≥ 2½”Ø in the following six raw water systems:

- Common
- Low Pressure
- High Pressure
- Closed Loop Demineralized Water
- Emergency
- Fire Protection

Each of OPG’s three nuclear sites has slightly different nomenclature for these systems; some plants have additional raw water systems. Most of the cooling water pipe in the OPG nuclear plants is welded.

To ensure that OPG uses a common approach to the PWTP from plant-to-plant, representatives of each plant meet regularly to coordinate the engineering issues emerging as each plant implements the program.

While Ultrasonic Testing (UT) is the predominant means for quantifying the scour-type wall thinning encountered in FAC, the Non-FAC mechanisms include pitting that is associated with under deposit corrosion and /or MIC. During the inception of the PWTP, UT was perceived as being a not particularly effective or efficient means of detecting pitting. It was recognized from the outset that both radiography (RT) and UT would be necessary tools in the Non-FAC inspection process. Tangent Technique radiography (TT-RT) was thought to be the preferred method. RT produces results that are inherently more quantifiable than UT, particularly with regard to the pitting type corrosion common to SWS. Pits in or near the pipe wall arc tangent to the incident radiation are revealed on the TT-RT film at a scale that is in direct proportion to the magnification defined by the object-to-source/film geometry. Pipe wall deposits including corrosion tubercules and certain types of macrofouling biota (shells) can be profiled with TT-RT. In many instances, RT can be performed without dewatering the system or removing insulation. UT is more applicable for the scour type wall thinning associated with FAC in high-energy piping.

The Site Selection Procedure

The procedure provides a stepwise rationale for determining what to inspect and how to prioritize the inspection process. The specific NDE procedures required to implement the inspections are identified. Finally, a methodology for assimilating collected inspection data and refining subsequent inspection priorities base on that information is described.

The reader familiar with the FAC aspects of CHECWORKS® would recognize clear parallels in the thrust of the site selection procedure for assessing raw water system PWT. However, in addition to the flow-related mechanisms that predominate in FAC, other important factors which are often more influential participate in raw water system PWT. These include solid particle erosion, MIC and under deposit corrosion. While erosion and cavitation types of corrosion can also be a factor in limited portions of SWS's, FAC per se is not. Thus, the corrosion affecting SWS can be summarized as representing two general categories; flow-related and several non flow-related mechanisms.

The site selection procedure first directs the user to assess the "susceptibility" of a location (or a component within the location) to wall thinning. Once this is done, the selected locations are prioritized for the purpose of determining the order in which inspections should be performed. An engineering specialist experienced in piping system corrosion assessment performs these analyses. Susceptibility is essentially a function of component geometry and location within the system. System geometry is weighed along with assessment of velocities derived from flow diagrams. These factors, tempered by the specialists' experience, determine locations considered most susceptible to a family of corrosion mechanisms know to degrade carbon steel piping internals. The OPG PWTP procedure includes the following guidance for assessing susceptibility with respect to certain of the flow-related and other mechanisms:

Erosion Corrosion ("EC")

Definition- A corrosion process that leads to metal loss of steel piping, when exposed to flowing water. Metal loss occurs by mechanical stripping of oxide and corrosion product layers away from pipe wall, which can be enhanced by particles suspended in flow.

Recommended Inspection Methods- Damage is usually in the form of scallop shaped or smooth gouges. Use a scanning method to detect damage and RT or UT to quantify damage.

Susceptible Locations- Areas where the flow velocity is the highest especially where the flow changes direction, and where localized high velocities occur such as downstream of orifices and control valves.

Cavitation-Erosion ("CE")

Definition- A mechanical erosion process caused by high velocity, liquid, micro-jet impact into pipe wall, which results in local high shear stress damage to pipe. The micro-jets are formed by water accelerating into voids from collapsing fluid bubbles.

Recommended Inspection Methods- Damage may be pitting, or local area wall loss characterized by rough scalloped or gouged appearance. Use a scanning method to detect damage in piping. Use RT to quantify damage in valves and orifices, and UT to quantify damage in piping.

Susceptible Locations- Inside or downstream of pressure reducing components.

Microbiologically Influenced Corrosion ("MIC")

Definition- Localized corrosion influenced by the presence of microbial life (bacteria) on pipe surface. The presence and metabolic processes of the bacteria form deposits that initiate under-deposit corrosion, and excrete enzymes and other digestive waste products that are corrosive.

Recommended Inspection Methods- Damage is usually in the form of pitting. Use a scanning method to detect damage. Use VT, when systems are opened, and on line monitors to detect the presence of MIC. Use RT to detect MIC in welds, and RT or UT to quantify damage in piping.

Susceptible Location- Stagnant or low flow areas, and/or areas with Silting such as horizontal runs and system low points.

Under-deposit Corrosion ("UC")

Definition- Localized corrosion that causes metal loss under deposits by the migration of electrons from the deposit covered metal to the surrounding deposit free areas. The deposit covered area becomes oxygen depleted causing electrons to migrate to the relatively oxygen rich surrounding areas to support the cathodic reduction of the dissolved oxygen.

Recommended Inspection Methods- Damage is usually in the form of pitting under corrosion products or deposits. Use a scanning method to detect damage. Use VT, when systems are opened, to detect the presence of corrosion products (tubercles). Use RT or UT to quantify damage in piping.

Susceptible Locations- Areas susceptible to silting, MIC, or tubercle formation, such as straight pipes with low flow velocity, areas with flow velocity reductions, such as downstream of reducers, and vertical bends.

Plant piping drawings are first assembled for systems that included open and closed service water and fire protection systems. Using the procedure's susceptibility guidance, such as that outlined above, the engineer proposes prospective inspection sites. The candidate sites are cataloged and then the prioritization process commences. Industry and OPG operating experience with respect to cooling water system corrosion was reviewed including EPRI SWSRI documentation and SWAP forums. The systems were then walked-down in order to get firsthand appreciation of the degree of difficulty in accessing the prospective inspection locations and to confirm the piping isometrics. Field notes documented evident interferences that would

challenge NDE such as cable trays and adjacent walls and pipes. Most lines have been noted to be insulated with the exception of the Fire Protection and Emergency Water systems.

At this juncture, a first cut of the interim database was prepared. The prospective sites and the data obtained from walk-downs were reviewed with the Systems Engineers. Their observations concerning the proposed inspection locations and their experience with respect to system configurations and operating experience were then distilled and factored along with safety-relatedness considerations in the subsequent prioritization process.

The Site Selection Data Matrix

(**Note:** Implementation of OPG's Non-FAC Pipe Wall Thinning Program proceeded essentially concurrently at each of the utilities three nuclear plants. Therefor, there are some differences in the form of the details used to track inspection sites but not in the substance. The matrices discussed in this section are used at the Bruce Facility.)

One of the first steps in the site selection process was development of separate Excel-formatted data matrixes, which serve as an interim database for the prospective inspection sites selected for each of the six systems. Specific physical characteristics of the selected pipe or component, their locations, and conditions affecting their accessibility are displayed and the attributes factored into the inspection prioritization process are included among the data arrayed in the interim database.

The consensus of each plant's PWTP representative participating in the coordinating team was that the selection data must ultimately be capable of being collected in the CHECWORKS® data format.

Plant piping drawings are first assembled and reviewed by the project specialists. Based on the review, an initial draft of the selection matrix is issued. This draft constitutes compilation of candidate locations for performing NDT inspections.

Column "B" of the potential inspection location matrix uses the abbreviations noted on pages 5 and 6 above to record the rationale for judging a particular location to be susceptible to corrosion. Additional parenthetical abbreviations indicate component-specific geometry factors that influence the susceptibility assessment. For example:

"XEL" = Extrados of Elbows
"TIN" = Side of Header Opposite Tee Inlet

Accompanying "Notes" on the backside of each data matrix serve as a ready reference, reminding the engineer of the bases for the susceptibility judgements to be made and the applicable abbreviations to be used in documenting those decisions.

The PWTP procedure calls for the inspection location selection process to integrate the impact of the following four criterion in the prioritization process:

1. Nuclear Safety Consequences
2. Economic Consequences (Power generation reliability, confidence/reliability of operability, etc.)
3. Susceptibility
4. Inspection Accessibility

The first two criterion are captured in a quantifiable way in Column "Q" of the matrix. The numerical value indicated generally reflects a weighted combination of (1) Nuclear Safety and (2) Economic Consequence criteria. The range of "Category" values assignable is from "1" (highest) to "3". Note that this numerical ranking practice of equating relatively high ranking point values with high numeric value is the opposite of common nuclear industry practice of ranking safety consequence in descending order of importance. With respect to the Common Water System cited in Tables 1 & 2 below, this SWS has moderate nuclear safety consequence (e.g., fuel pool cooling). The highest Category assigned to the Common SWS is "2", reflecting a location that is considered to have moderate nuclear safety and significant economic consequences. Certain of the Common SWS lines service equipment was judged to be sufficiently critical to operation to warrant assigning the "2" value. The corresponding lines on the discharge portion of the system downstream of the various heat exchangers are usually assigned lower values since their importance to nuclear safety and operability is less. The nuclear safety and economic consequence criteria reflected in the "Category" column become apparent during the initial susceptibility assessment. Thus, these values are usually assigned relatively early in the location selection process.

Column "S" of the inspection location data matrix, "Priority" assimilates the criterion indicated as "3" and "4" above, i.e., "Susceptibility" and "Inspection Accessibility". "Priority" cannot be assessed with complete accuracy until after the completion of the system walk-down and the System Engineers interview.

The "Susceptibility" component is largely influenced by considerations reflected in Column "B", i.e., degradation probabilities generally attributable to particular portions of systems as a function of geometries. Criterion "4" is a distillation of observations made during the system walk-down. Column "M" asks the surveyor to record whether the inspection site will require scaffolding for access. The status of the pipe with respect to whether or not insulation is present is recorded in Column "N". This information is then considered in conjunction with the question of schedule. Whether or not the particular site to be inspected is within an area requiring a plant or Unit outage is an important aspect of the overall accessibility issue. Again, the combination presented in the "Priority" column is quantified by assigning a value of from "1" (highest) to "4". A "Priority" value of "4" can be assigned as a contingency. It is used to compensate for having erroneously ascribed susceptibility to flow related degradation when later evidence indicates infrequent flow.

Table 1: Common Water System
Prospective Locations For Non-Destructive Examination

A	B	C	D	E	F	G	H
LOCATION NO.	**LOCATION SELECTION BASIS**	**COORDINATES**			**DRAWING**		
	Acronyms Ref. Loc'n. Selection Criteria Per Appx.B of Std. N-STM-04916-10001 ***See "Notes" on Back***	**Unit or Bldg.**	**Col Lines**	**Elevation**			
7111-01	EC,GC & SPE	WT	**27**(-13)	564	NK-29-DDH-71119-0001-06		
7111-02	MIC & UC	WT	**27**(-4.5) WH(+7)	587-6	NK-29-DIH-71119-0002-09		
7111-03	MIC & UC	WT	**24**(+3 to 5-6) **WH**(-4)	568	NK-29-DIH-71119-0002-09		
7111-04	EC,GC & SPE	WT	**24**(+12-9) **WH**(+3)	571-3	NK-29-DIH-71119-0002-09		
7111-05	GC	WT	**27**(-5-6) **WB**(+12 +- 1)	565-6	NK-29-DIH-71119-0003-05		
7111-06	EC (TIN) & CE	0	**12**(-4-6) **SB**(+7&11)	585	NK-29-DIH-71119-0007-12		
7111-07	EC (XEL)	0	**12**(-3) **SH**(-1-6)	586-9	NK-29-DIH-71119-0007-12		
7111-08	MIC & UC	0	**4**(+10-6 + - 2) **SJ**(-11)	594-6	NK-29-DIH-71119-0008-12		

Table 2: Common Water System Prospective Locations For Non-Destructive Examination									
A	**I**	**J**	**K**	**L**	**M**	**N**	**Q**	**R**	**S**
Location No.	**Physical Attributes**				**Accessibility**		**Cat. See "Notes" On Back**	**NDE**	**Priority See "Notes" On Back**
	B.O.M. #	**Mat'l.**	**Diam. / Component**	**Wall**	**Scaffold? (feet above floor)**	**Insulated?**			
7111-01	523A5036	Cr-Mo	24-14 Red	.375"	No (2)	Yes	2	UT	4 *
7111-02	52320345	CS	6	.280"	Yes (16-3)	Yes	3	RT or ET	2
7111-03	5101115	CS	4	.237" (A)	No (5)	Yes	3	RT or ET	3
7111-04	51010211	CS	12	.375"	Yes (9-3)*	Yes	2	UT or ET	3
7111-05	5101115	CS	4	.237" (A)	No (3-6)	Yes	2	UT	2
7111-06	51011191	CS	24	.375"	No (6)	Yes	2	UT	3
	523G5050		24 Tee	.375"				UT	
	523G1753		36-24 Red	.375"				UT	
7111-07	51011156	CS	4	.237"	Yes (7-9)	Yes	2	UT	3
7111-08	51011191	CS	24	.375"	Yes (15-6)	Yes	2	UT	3

The assessments distilled in the two numeric values established in Columns "Q" and "S", which in turn are a quantification of the four site selection criterion, are ultimately represented by a single numeric value referred to as "Rank". The site selection procedure calls for an overall rank assignment for inspections to be in accordance with a hierarchy of numbers from "1" to "8" (highest). Note that this reverses the protocol used in Columns "Q" and "S" wherein the lower the assigned value the higher the priority. An empirical formula was devised to effectively merge Columns "Q" and "S" and to quantify rank according to ascending numerical order. The Rank values assigned based on the respective "Category" and "Priority values are as follows:

Cat. & Priority = Rank			Cat. & Priority = Rank			Cat. & Priority = Rank		
1	1	8	2	1	7	3	1	4
1	2	7	2	2	5	3	2	3
1	3	6	2	3	4	3	3	2
1	4	5	2	4	3	3	4	1

For the examples of the Common SWS inspection sites contained in the Tables 1 & 2 above, the assigned "Rank" values are as shown in Table 3 (next page).

As the implementation phase of the PWTP progresses, it is expected that inspection results will yield insights, particularly with respect to the rationale used to predict susceptibility, which could necessitate "tweaking" ofthe assigned "Category" and "Priority" values. Thus, experience is expected to produce refinements of the initially assigned ranking.

Implementing The Program

Actual performance of NDE inspections commenced in earnest this year. The first system to be extensively evaluated to date is the fire protection system at Pickering "A", one of the four unit plants that is indefinitely shutdown. Fire protection remains an essential safeguard notwithstanding the plant's shutdown status.

Table 3: Common Water System
Prospective Locations For Non-Destructive Examination

A	T
Location No.	**Rank**
7111-01	3
7111-02	3
7111-03	2
7111-04	4
7111-05	5
7111-06	4
7111-07	4
7111-08	4

As was anticipated, UT was determined to be impractical for locating the discrete pitting typically encountered in systems like fire protection, which are essentially in a perpetually wet lay-up mode. Radiography has proven the most practical tool for evaluating pitting and for perceiving the macro-fouling that generally fosters the under-deposit pitting and MIC commonly associated with raw water piping.

OPG has done some preliminary evaluation of one real time NDT method known generically as Low Frequency Electro Magnetic Technique (LFEMT), including a feasibility demonstration. The concept uses an array of sensors mounted on a unit that contacts the pipe OD and requires insulation removal (a disadvantage compared with radiographic real time methods(4)). However, the array of sensors currently commercially available which are suitable for the contour of elbows and reducers/expanders is limited. This factor has, to date, precluded implementation of a pilot program to assess LFEMT. Likewise, other available emerging real time technologies(4), while of interest, have not yet been pursued.

One interesting observation has been that fouling and pitting are less sever in the stagnant fire protection lines than in those adjacent to headers that see flow. The fire lines were believed to be stagnant. However, observations during the system walk-down and follow-up interviews with plant personnel revealed that isolation valving at inter-ties between the fire protection headers and a service water line were in fact open. The extensive internal corrosion evident in the following radiograph represents the worst cases.

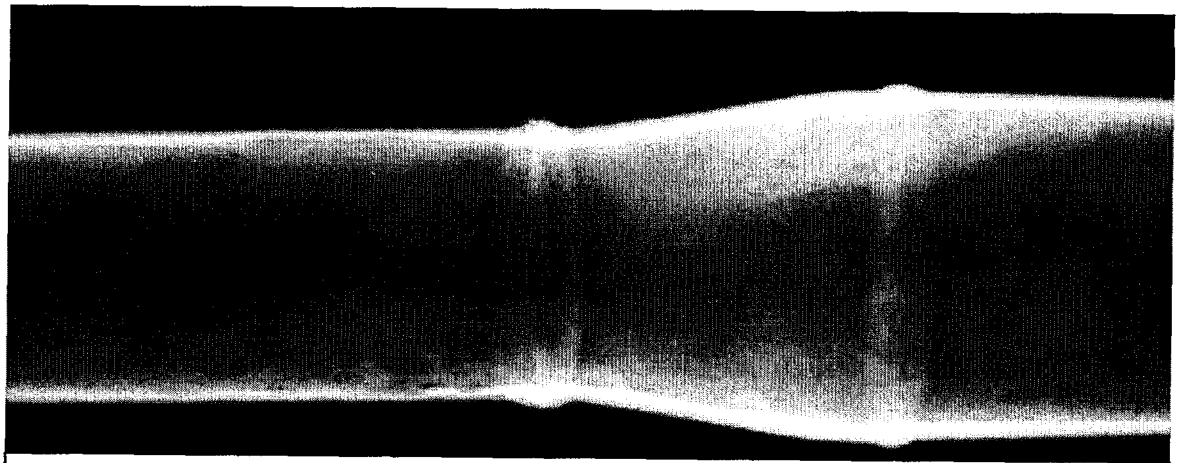

Figure 1: Shadows indicate extent of heavy corrosion tuberculation in this horizontally oriented pipe. Wall reduction at deeper pits is about 33%.

These were encountered in laterals branching off the fire protection line headers. The worst tuberculation was within the branch lines proximate to the headers. It is evident that the sporadic flow is probably the root cause of the extensive internal corrosion that has been found. This is consistent with the following observation cited in Reference 3:

> *"...if the system is subject to cyclic use, expect thru-wall failure and general occlusion with significant flow blockage in small diameter piping"*

Corrosion product buildup on pipe system walls reduces the cross-section of the pipe and increases the hydraulic drag. SWS pipe designed without due consideration of the impact of corrosion on flow volume may actually deliver half or less of the design "Q". The effective diameter can be determined so that the design assumptions with respect to a given spool's hydraulic through-put can be validated. A practical way of accomplishing this is to cut a section out of the line as seen in Figure 2. Orienting the spool piece vertically, pot the bottom end in waterproof sealant. Then fill the spool with a measured amount of water. That volume is then compared with the volume that would represent the as-built pipe to compute the effective ID.

A limited amount of MIC assays have been done. Not surprisingly, elevated levels of aerobic heterotrophic bacteria and some anaerobes have been found. . MIC colonization at a particular site on a pipe wall usually originates with aerobes in/on biofilms. As the biomass accumulates, incorporation of anaerobes or facultatively anaerobic microbes deep within the accumulated mass is facilitated. However, as is often the case in raw water carbon steel piping systems, it is difficult to quantify the relative impact of MIC in the overall corrosion that is occurring.

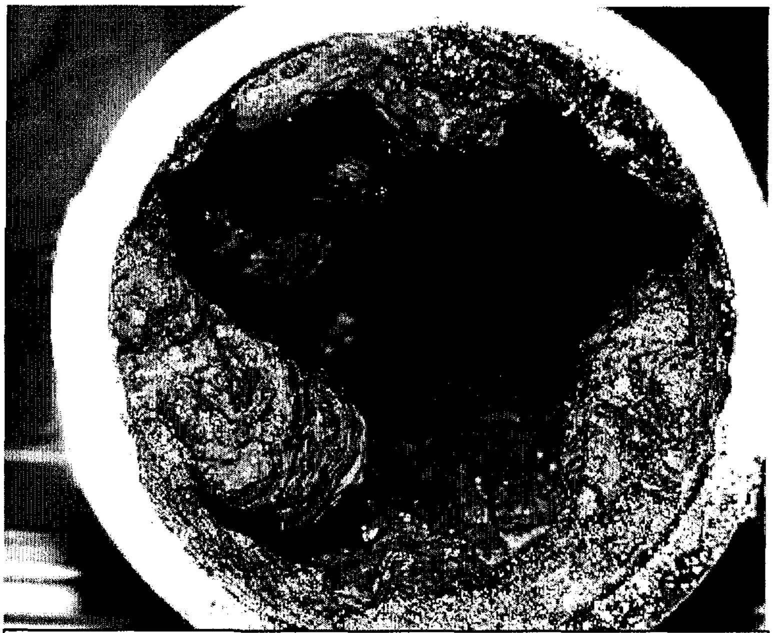

Figure 2: Sectioned 6"Ø Fire Protection lateral reveals a nearly-occluded ID as a result of tuberculation.

Breaching a system to cut spools provides an opportunity to take crud samples for MIC analysis. In power plant raw water systems there may be a tendency to expand the MIC sampling beyond that necessary to obtain the basic bacterial characterization that is actually necessary. Generally, as has been the case so far in the OPG systems, the analysis shows significant populations of aerobic and sometime anaerobic bacteria. While this is interesting information, it doesn't ordinarily impact the issue of whether or not the pipe will be refurbished or replaced. It would be the exception for comprehensive MIC analysis to be warranted in order to help address the question of how quickly corrosion might reach the established minimum wall thickness or when the pipe might perforate.

Activities In The Future

The implementation of the NDT phase of the PWTP is just now being actively prosecuted. To date, pipe found to be occluded and/or with near thru-wall pits has been replaced over relatively short lengths. However, initial indications suggest that it is possible that considerable replacement or rehabilitation of Fire Protection Piping and such SWSs as have similar operating characteristics, i.e., infrequent flow, may be necessary in the not to distant future. The program procedure has established the following criterion to establish what constitutes "significant" wall thinning for SWS piping:

$$T_{MIN} = 0.5\ T_{NOM} \text{ Or } T_{HOOP} \text{ (whichever is larger)}$$

Given the relatively low operating temperatures encountered in raw water systems, the 50% of nominal wall thickness criterion effectively governs.

An additional wall thinning criterion that might be considered in addition to pitting could establish some integrated minimum criteria based on "Average Wall Thinning". The "AWT" criteria would utilize an array of sample spools, considered representative of the condition over all locations tested, which would be cut from the line. In order to determine the average wall loss over the test spool length, corrosion products would need to be removed by abrasive blasting and/or acid cleaning and the segments weighed. Comparing the as-corroded weight with the theoretical, as-fabricated weight would allow the average wall loss to be calculated.

Much of the SWS piping within OPG's nuclear plants is encapsulated in anti-sweat insulation (ASI). Cold Lake Huron and Lake Ontario water passing through the pipe can otherwise produce copious condensation, particularly in summer when the air is warmer and more humid. Condensation that puddles on floors is a safety (fall) hazard. The OPG PWTP includes a component that assesses corrosion on pipe OD's. The location selection procedure calls for visual examination and pit depth measurement as a result of corrosion under insulation (CUI). The depth of any pitting will be measured using dial-reading micrometers and recorded in the interim data matrix.. The same criteria cited above with respect to what constitutes significant corrosion for ID's are applied for OD's.

CUI has been determined by NACE International to be a major concern in high-pressure process industry piping. When ambient moisture penetrates jacketing and accumulates against the pipe OD, the insulation's thermal reluctance is compromised and, worse, the soggy insulation serves as a poultice, concentrating airborne pollutants and causing pitting corrosion. NACE has prepared guidance for locating, quantifying and mitigating CUI(5). The NACE effort, however, is directed toward outdoor piping. There is no known guidance for predicating susceptible OD corrosion zones on indoor pipe encased in ASI. Intuitively, susceptible zones under ASI are expected to be at the 6 o'clock position at low spots on horizontal runs, particularly where breech points such as those to accommodate valve bonnets are relatively frequent, and at the base of riser spools. The amount of insulation stripped for inspection of a selected OD location in terms

of diameters is in inverse proportion to the diameter, e.g., as little two diameters (3D) for large diameter piping (≥ 24") and up to 9D for small bore piping (< 2").

The procedure ordains that if wall thinning at a given location is found to be "significant" as defined above, the inspection location sample size will need to be expanded as follows:

- Components (i.e., the pipe spools or appurtenances such as elbows, reducers and tees within a given inspection location) within two diameters downstream of the component found to have "significant" wall thinning

- The next two components in the same train with similar susceptibility based on Rank or similarity of configuration or conditions of flow

- Corresponding locations or components in each other train or a multi-train line

Should it develop that replacement in kind is not feasible due to restricted accessibility, or if improved reliability/availability is deemed necessary, some options that may be considered include:

1. Upgrading to a more corrosion or erosion resistant material (this has been done to a limited extent to solve erosion-corrosion problems at certain "hot spots" such as downstream from flow control valves).

2. "Sleeving" sections with cured-in-place liners.

3. Removing corrosion product with a combination of water and abrasive blasting and lining the pipe with a liquid or paste grade polymeric material.

Item (2) is addressed in References 6 while References 7 and 8 provide information on Item (3).

While it is important to bacterially disinfect the pipe if a lining is to be installed, experience suggests that abrasive blasting mild carbon steel pipe to a gray-metal condition effectively eradicates residual MIC. However, flushing a prepare pipe with brominated water or spraying the abrasive blasted surface with hydrogen peroxide is often done as a precaution to optimize disinfection processes when lining raw water pipe.

References

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5. "A State-of-the-Art Report on Protective Coatings for Carbon Steel and Austenitic Stainless Steel Surfaces Under Thermal Insulation and Cementitious Fireproofing", NACE International Publication 6H189.

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