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# Hanford Double Shell Tank Corrosion Monitoring Instrument Trees

Prepared for the U.S. Department of Energy
Office of Environmental Restoration and
Waste Management

Westinghouse
Hanford Company Richland, Washington

Hanford Operations and Engineering Contractor for the
U.S. Department of Energy under Contract DE-AC06-87RL10930

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# HANFORD DOUBLE SHELL TANK

# CORROSION MONITORING INSTRUMENT TREES

J. L. Nelson
Westinghouse Hanford Company
P. O. Box 1970
Richland, WA 99352

## ABSTRACT

High-level nuclear wastes at the Hanford site are stored underground in carbon steel double-shell and single-shell tanks (DSTs and SSTs). Westinghouse Hanford Company is considering installation of a prototype corrosion monitoring instrument tree in at least one DST in the summer of 1995. The instrument tree will have the ability to detect and discriminate between uniform corrosion, stress corrosion cracking (SCC), and pitting. Additional instrument trees will follow in later years. Proof-of-technology testing is currently underway for the use of commercially available electric field pattern (EFP) analysis and electrochemical noise (EN) corrosion monitoring equipment. Creative use and combinations of other existing technologies is also being considered. Successful demonstration of these technologies will be followed by the development of a Hanford specific instrument tree. The first instrument tree will incorporate one of these technologies. Subsequent trees may include both technologies, as well as a more standard assembly of corrosion coupons. Successful development of these trees will allow their application to single shell tanks and the transfer of technology to other U.S. Department of Energy (DOE) sites.

Keywords: Hanford, radioactive waste, high-level waste tanks, electrochemical noise, electric field pattern, probes, double-shell tanks, single-shell tanks, corrosion

## INTRODUCTION

The DOE Hanford Site nuclear reservation, located in Southeastern Washington State, maintains 231 million liters of radioactive waste stored in 177 large underground storage tanks. Both DSTs and SSTs are constructed of reinforced concrete with carbon steel liners. They primarily store caustic wastes from defense reprocessing of spent nuclear fuels. Some of the SSTs have leaked radioactive liquid waste to the soil. These leaks are possibly caused by nitrate-induced SCC. Efforts to avoid nitrate-induced SCC in newer DST designs appear successful. These efforts include a post weld stress relief at the time of construction and more rigorous control of hydroxide and nitrite waste chemistry. A potential for pitting and crevice corrosion in the carbon steel liners exists, particularly at the vapor/liquid interface and in the vapor zone. There is no evidence of significant uniform corrosion of the carbon steel liners.

In spite of careful control of waste chemistry, one DST has operated with low hydroxide levels for several years, and four additional DSTs have recently been discovered to have below normal hydroxide levels. It appears that the highly complicated waste chemistries contained in the tanks may be consuming hydroxide at a slow rate. Such problems in controlling waste chemistry have accentuated the need for in-tank corrosion monitoring.

## BACKGROUND

Hanford DST liners are fabricated from A516 and A537 carbon steels. The stored wastes are principally aqueous solutions of nitrates, nitrites, hydroxides, and aluminates. Lesser quantities of fluorides, chlorides, and organic chelating agents are also present. Radiation levels in the solutions can be as high as 1,000 Rad/hr, with some tanks containing sufficient quantities of heat producing radioisotopes that the wastes would boil spontaneously if not cooled. Chemistry controls for the DSTs specify that pH is to be maintained at greater than 11.5. Numerous laboratory studies of waste tank corrosion have demonstrated that carbon steel passivates under oxidizing conditions with pH between 8 and 14[1]. Uniform corrosion under these conditions can be controlled to less than 0.5 mil per year (mpy)[2].

The presence of significant quantities of nitrates in the waste raises the concern of nitrate induced SCC. It is this mechanism that is believed to be the cause of many of the SST failures at Hanford. Stress corrosion cracking in DSTs is controlled chemically by the use of hydroxide[3] and nitrite, but maintaining adequate hydroxide concentrations in the waste is difficult. The slow consumption of hydroxide by the waste and the occasional addition of low hydroxide (uninhibited) water to the tanks tend to lower hydroxide levels to undesirable ranges. Moreover, the vapor above the waste is low in hydroxide and tends to condense on the tank walls. This condensate runs down into the waste, lowering the hydroxide concentration at the vapor/liquid interface near the tank wall. This relatively dilute, uninhibited waste in the vapor space and at the vapor/liquid interface is a serious concern for inducing SCC and pitting in these regions. It is these corrosion mechanisms that will be monitored by the planned instrument tree.

## PROBE DEVELOPMENT

Development of the first corrosion monitoring instrument tree is focusing on two promising probe technologies: EFP analysis and EN analysis. Both of these techniques offer the ability to identify uniform corrosion, SCC, and pitting as they occur. Other monitoring methods such as electrical resistance probes, polarization resistance probes, or the more standard array of corrosion coupons are also under evaluation. Resistance probes do not have the ability to distinguish between uniform corrosion, SCC, and pitting. Polarization resistance probes have been used in waste tanks with generally unreliable results. Corrosion coupons will not provide timely information owing to the extended exposure times required and the difficulty of examining radiologically contaminated specimens. Neither EFP nor EN analysis has been demonstrated under the rigors of the high-level nuclear waste tank environment, so a modest demonstration and development program is in progress.

Westinghouse Hanford Company is sponsoring work at Pacific Northwest Laboratory (PNL) for the development of EFP and other existing probe technologies. A commercially available EFP instrument is being used to evaluate the corrosion of tank liner steels in a variety of waste simulants. Other existing probe configurations are being tested as well. The equipment response is being evaluated as the steel is held in the passive, pitting, and cracking potential ranges. The probe materials will be examined after completion of the study to physically confirm the indications of the monitoring equipment. An array of weight loss, U-bend, and Wedge-Opening Loaded specimens is being tested concurrently with the probe testing to provide verification to the probe response.

Westinghouse Hanford Company is sponsoring development of EN technology at Oak Ridge National Laboratory. This work being conducted on simplified hydroxide/nitrate/nitrite waste simulants. As with the EFP studies, the chemistry of the waste simulant is being adjusted to produce electrochemical potentials capable of inducing uniform corrosion, SCC, and pitting in specimens of tank liner steels. As a precursor to the EN studies, potentiodynamic scans, linear polarization resistance, electrochemical impedance spectroscopy, and Tafel plots have been completed on tank liner steels in simulated waste. After completion of the EN studies, the corrosion specimens will be metallographically examined to verify the response of the EN equipment.

Completion of this development work will provide the basis on which to select the one probe type to be used in the first instrument tree. Subsequent instrument trees will include additional instrumentation and may utilize both EFP, EN, and other probes. The results of the demonstration studies will be published after the data analysis has been completed.

## PROBE DESCRIPTION

### Electric Field Pattern

The EFP analysis is based on inducing an electrical current into a structure and monitoring the changes that appear in the electric field pattern. The pattern changes have characteristic forms for uniform corrosion, SCC, and pitting. To monitor these changes, small sensing pins are attached to the area to be studied. Multiple pins are arrayed in this area, approximately 2 cm apart. Each pin is connected to a lead which then runs to a control unit. The control unit sequentially applies a potential difference between two pins and measures voltage drop. This measurement is compared to a measurement between a pair of reference electrodes and the initial voltage drop values when the monitoring started. A sequential interrogation of pin pairs yields a complex array of voltage drop data which is converted to corrosion characteristics using proprietary software. The software uses an empirical model to analyze the voltage drop data as a specific corrosion mechanism and to pinpoint the location of a nonuniform attack, such as a pit or crack[4].

The most common industrial use of EFP analysis is to monitor the corrosion of an in-service pipeline by instrumenting the exterior of the pipe itself. In this way it is possible to monitor the actual corrosion of the inside wall of the pipe rather than monitor the secondary behavior of an independent probe or corrosion coupon. Radiation exposure and limited physical access preclude the instrumentation of the external surface of an in-service waste tank liner. Using this technology for waste tank corrosion monitoring involves attaching the sensing pins to the interior of a sealed standpipe and then inserting it through a tank riser to contact the waste. Data leads from the sensing pins would extend upward through the interior of the pipe to connect with the control unit outside of the tank. Additional discussion of this concept is provided in the next section. The advantages of this design include a nearly trouble free assembly in contact with the tank contents and continuous monitoring over a relatively large instrumented section. The only exposed surface is the exterior of the instrumented pipe. This pipe will have corrosion characteristics (and thus service life) similar to the tank itself. In comparison to more complicated assemblies, the instrumented pipe will be easy to insert, remove, decontaminate, and examine after exposure. The disadvantage of this design is that it precludes direct EFP monitoring of the tank liner itself. By instrumenting a pipe, there will be unresolved concerns that the pipe alloy, mechanical stresses, or chemical environment may not adequately represent tank liner conditions. Although these concerns are no greater for this assembly than for any other type of probe, such an arrangement eliminates this capability of the technology.

### Electrochemical Noise

Electrochemical noise analysis is based on the measurement of currents and potentials resulting from micro-electrochemical events averaged over time. These randomly occurring individual events adhere to the Poisson distribution when evaluated over a large number of occurrences, so they are subject to interpretation by statistical analysis. Noise analysis is particularly useful for monitoring local corrosion such as pitting and SCC. These mechanisms have distinctly different current-potential signatures from each other or that of uniform corrosion.

Raw EN data are composed of records of potential and current taken simultaneously. Potential and current are measured between three electrodes of the same material as the tank liner. One electrode serves as a reference electrode. To detect SCC, one electrode will be stressed[5]. Analysis of the raw data is accomplished by examination of the time record, statistical analysis, and either a Fast Fourier Transform analysis or Maximum Entropy Spectral analysis. The result of these analyses is the ability to uniquely identify such local corrosion mechanisms as pitting, SCC, and crevice corrosion.

The advantage of EN monitoring is the direct interpretation of the corrosion process from standard mathematical techniques. This is contrasted to EFP data analysis where interpretation of the data is based on an empirical model. The real-time operation of the EN system facilitates identification of the precise time when a corrosion process begins and the correlation of this change with changes in the waste tank environment. The disadvantages of the EN technology include a relatively complex probe system and comparatively difficult data analysis requiring specialized knowledge. Data analysis difficulties can largely be circumvented through the use of proprietary software packages.

## INSTRUMENT TREE DEVELOPMENT

The Hanford corrosion monitoring instrument tree is in conceptual design. The final configuration of the first tree is contingent upon successful demonstration of a probe technology. The system will be capable of operation under the following service conditions:

- Temperature range from 10°C to 100°C
- Liquid phase pH range from 7 to 14
- Vapor phase relative humidity to 100%
- Liquid phase radiation levels to 1,000 Rad/hr
- Vapor phase radiation levels to 200 Rad/hr
- Liquid phase chemistry as described previously
- Tank liquid levels fluctuating from 15 cm to 11 m
- Liquid phase flow rates of up to 1 m/s
- Vapor phase displacements of up to 14 standard cubic meters per minute

The following design goals have been established for the instrument tree:

- Design service life shall be a minimum of two years. Data cables will be isolated from the service environment.
- Instrument assembly will fit through a maximum size circular tank dome opening of 15 cm.
- Data acquisition and instrument control will require a minimum of "on location" operation in order to reduce operator exposure to hazardous conditions. Remote data acquisition and control via modem, hard-wire, or radio frequency link is planned.
- Minimum services provided at the tank opening are 110 volt a.c. (single phase, 20 amp, 60 hertz) power, phone (data) connection, and weather tight service box. Additional service requirements such as purge gasses, environmental (heating/cooling) controls, or water supply are not planned.
- Instrumentation will extend to within 1 m of the tank bottom. The approximate total distance from grade level to tank bottom is 16 m.
- Instrumentation will be designed to facilitate ease of decontamination by minimizing features where liquids could be retained. Straight pipe runs, flush surfaces, and wire rather than multi-strand cable will be used.

The first instrument tree is scheduled for deployment into a DST by September 1995. The plan is to "piggyback" an a prototype probe assembly onto a Hanford standard thermocouple tree already scheduled for insertion in this time period. Data acquisition and control will be provided by modifying the existing local radio frequency link used for other instrumentation at the tank. In addition to providing actual in-tank corrosion monitoring, the goal of the first assembly is to demonstrate the technology under actual service conditions and to identify areas for design improvement for future assemblies. The choice of probes is contingent upon successful completion of the proof-of-technology studies discussed above. All instrument trees will include an array of thermocouples for establishing temperature profiles.

The second instrument tree is planned for deployment into the same tank within six months of the of the first. It is expected that this will be an independent unit, rather than an add on to an existing design. Both EFP and EN will be used in this tree, as will as other viable probe technologies. The performance of the technologies will be compared to each other and to the data coming from the first instrument tree. It is considered highly desirable to deploy the EN technology into this same first tank so that the unique benefit of immediate response to changing electrochemical conditions can be obtained. The particular tank under consideration will have a mixer pump installed in this time frame and may go through several fill and drain cycles. Immediate feedback on the changes in the corrosivity of the waste due to these changes in the tank environment will provide increased confidence that the tank is being operated safely. The second instrument tree is considered permanent in the tank and will be operated to failure. After six months or more of successful operation of the second tree, the first tree will be removed from the tank for post exposure examination. This physical examination will be used to verify the on-line data received from the probe.

A third instrument tree is planned for deployment in late calendar year 1996. It will be placed into a different tank than the first two trees. Depending on the level of success from the first two trees, either one or both of EFP and EN monitoring will be used. In addition, the third and later trees will be instrumented with a more complete set of corrosion monitoring tools. The expected configuration of these trees is shown in Table 1. This final design for the instrument tree will be considered the standard design for use in subsequent DSTs. As many as half of the 28 DSTs and a small number of the SSTs at Hanford may be instrumented with this tree design.

## SUMMARY

Westinghouse Hanford Company is initiating an ambitious program of installing corrosion monitoring equipment into high-level nuclear waste storage tanks at Hanford. Success of this program depends heavily on the application of real time, in-line corrosion monitoring technologies such as EFP and EN analysis. These technologies are currently undergoing

proof-of-technology testing in laboratory studies. The first prototype corrosion monitoring instrument tree is targeted for insertion into a DST in September of 1995. Additional trees of increasing complexity will be installed in multiple tanks after successful demonstration of the first two prototype trees. The goal of the tank corrosion monitoring effort is to instrument a sufficient number of tanks to provide high confidence that the tanks are being operated safely.

TABLE 1
FINAL DST INSTRUMENT TREE CONFIGURATION

| Instrumentation | Vapor (suspended) | Interface (floating) | Liquid (submerged) |
|---|---|---|---|
| Uniform attack probe (electrical resistance) with crevice | X | | X |
| Uniform attack probe (electrical resistance) without crevice | X | | X |
| Pitting probe (EFP and/or EN plus polarization resistance) | X | X | X |
| SCC probe (EFP and/or EN plus polarization resistance) | X | X | X |
| Coupon rack: | | | |
| pitting/uniform attack | X | X | X |
| U-bends (creviced at bolt) | X | X | X |
| Wedge-Opening Loaded tension specimens for SCC | X | X | X |
| Thermocouple(s) | X | X | X |
| Electrochemical potential | | X | X |
| pH | | X | X |

## REFERENCES


1. Metals Handbook, Ninth Edition, 1987, Vol. 13, Corrosion, American Society for Metals, Metals Park, Ohio.

2. Divine, J. R., W. M. Bowen, D. R. Mackey, D. J. Bates, and K. H. Pool, 1985, "Prediction Equations for Corrosion Rates of A-537 and A-516 Steels in Double Shell Slurry, Future Purex, and Hanford Facilities Wastes," PNL-5488, Pacific Northwest Laboratory, Richland, Washington.

3. Ondrejcin, R. S., 1984, "Prevention of Stress Corrosion Cracking in Nuclear Waste Storage Tanks," Corrosion/84, paper no. 258, (Houston, TX: NACE International 1984).

4. Strommen, R. D., H. Horn, and K. R. Wold, "New Technique Monitors Pipeline Corrosion, Cracking," Oil & Gas Journal, December 27, 1993.

5. Report to the ASTM Subcommittee G01.11.04 and New Standard Guide for Electrochemical Noise Measurement.