Title of Innovation:
Hanford Site Nuclear Waste Tank Corrosion Monitoring System

Nominee(s)
Glenn Edgemon and Megan Dahl, ARES Corporation
Kayle Boomer, Mark Brown, and Jim Castleberry, Washington River Protection Solutions, LLC.

Category:
Corrosion Monitoring

Dates of Innovation Development:
May 2008 to September 2013

Web site:
N/A

Summary Description:
The Hanford Site is a 560 square mile complex originally established by the U.S. government in 1943 to produce plutonium for the first nuclear weapons, ultimately bringing an end to World War II. Plutonium production activities continued at the Site through 1991. Production activities resulted in a broad range of contaminated materials and facilities, including approximately 53 million gallons of high level (i.e., highly-radioactive) nuclear waste in liquid, sludge, and solid forms. The high-level waste was stored as it was created in underground single-shell and double-shell carbon steel tanks built between 1943 and 1986.

Corrosion monitoring and control in the double-shell tanks (DSTs) has historically been provided through a waste chemistry sampling and analysis program. In this program, waste tank corrosion is inferred by comparing waste chemistry samples from the tanks with the results of laboratory tests on carbon steel specimens immersed in a range of waste chemistries. This method has been mostly effective, but is expensive, time consuming, and does not yield real-time data.

In 1996, the Site launched an effort to improve their DST corrosion monitoring strategy. Since that time, Mr. Edgemon has led a team of ARES and Hanford Site design and engineering personnel in developing systems capable of meeting the Site’s corrosion monitoring needs and withstanding the harsh DST
environment. Two primary operational systems have recently emerged from these efforts: the Multi-Probe Corrosion Monitoring System (MPCMS), installed in five DSTs between 2008 and 2010; and a new Retractable Corrosion Monitoring Probe (RCMP), the first of which was installed September 2013. These systems provide critical information on waste corrosivity, helping to ensure the continued integrity of the Site’s waste transfer and storage systems. Prior to this work, no large scale corrosion monitoring systems had ever been developed for nuclear waste tanks.
Full Description:

How does the innovation work?

Because the history and potentially extreme environmental and health hazards associated with the radioactive waste stored at the Hanford Site are largely unknown to the general public, some background information has been provided here to provide context for the DST corrosion monitoring systems described in this nomination.

Following the end of World War II and throughout the Cold War Era, the Hanford Site played a critical role in the nation’s defense. Plutonium production for the manufacture of nuclear weapons was the Site’s principal goal. Between 1944 and 1987, the Site constructed and operated nine graphite-moderated, light-water, production reactors (to irradiate fuel and produce plutonium), six large chemical separations plants (to extract plutonium from the fuel), and a variety of laboratories, support facilities, and related infrastructure. Of all the steps involved in the production of plutonium at Hanford, the chemical separations plants produced some of the most complex and contaminated waste streams.

The enormous volume and extreme health and environmental hazards posed by high-level wastes made waste management a high priority immediately after the start of plutonium production. Between 1943 and 1964, 149 underground single-shell tanks (SSTs) were constructed at the Site to store high-level waste produced by the chemical separation plants. The SSTs were fabricated onsite from welded carbon steel plates and range from approximately 55,000 gallons to 1,000,000 gallons in volume. No stress-relief annealing was performed on the SST primary tank steel following fabrication. To date, 67 of the 149 SSTs are known or assumed to have leaked waste to the surrounding soil. Nitrate-induced stress corrosion cracking (SCC) is now accepted as the most likely mode of failure for the Hanford SSTs.

SST Fabrication Showing Roof Construction

By the mid-1960s, SST storage capacity was nearly exhausted due to continuous plutonium production operations at the Site. Between 1968 and 1986, 28 additional tanks of a double-shell design were
constructed. Each DST consists of a primary steel tank (bottom, walls, and dome) that sits inside a secondary steel liner surrounded by a reinforced-concrete shell.

DST Fabrication Showing Concrete Wall Construction

Because of the SCC problem in the SSTs, the DSTs were stress relief annealed after fabrication. Based on age and leakage of waste from some SSTs, all SSTs were removed from service by 1980, and by 2004, all remaining drainable liquid had been pumped from SSTs into newer DSTs. Approximately 27 million gallons of high-level waste are currently stored in DSTs. Waste is in both supernatant (liquid) and solid forms. Solid forms of waste include sludge, saltcake, and interstitial liquids. Waste stratification, mixing, bulk reduction operations, radioactive decay, isotope recovery operations, chemical treatments, and thermal mixing have also complicated the makeup of wastes contained in the DSTs.

High-Level Nuclear Waste, Surface at Tank Dome/Wall Interface
Corrosion monitoring and control in the DSTs has historically been provided through a waste chemistry sampling and analysis program. In this program, waste tank corrosion was inferred by comparing waste chemistry samples taken periodically from the DSTs with the results from a series of laboratory tests on carbon steel specimens immersed in a wide range of normal and off-normal waste chemistries. This method has been mostly effective, but is expensive, time consuming, and does not yield real-time data.

The DST operations and maintenance activities are guided by a comprehensive DST Integrity Program. As part of this program, laboratory testing has been performed to identify chemistries and the range of corrosion potentials capable of inducing SCC in the various DSTs. Localized forms of corrosion such as pitting and SCC are the only credible failure modes for the DSTs. In conjunction with the laboratory test program, DST corrosion monitoring systems (the systems being nominated herein) have been developed to monitor the corrosion rate and corrosion potential of the DST.

Two major DST corrosion monitoring system designs have evolved in this effort – the MPCMS and the RCMP. The MPCMS is a “fixed” system containing several in-tank probes each with a variety of metallic coupons, electrical resistance sensors, and reference electrodes. These are multi-probe systems approximately 60 feet long that allow corrosion rate and corrosion potential measurements to be made at a variety of elevations in an instrumented tank. The RCMP is a simpler and more efficient system. The RCMP also facilitates corrosion potential measurements, but uses a retractable head that can be raised and lowered in the DST. With the laboratory SCC data as reference, the Site can now determine if a given DST is suffering higher than expected rates of uniform corrosion, or more importantly, is at a corrosion potential capable of inducing SCC.
When and how was the innovation developed?
In 1996, the Hanford Site launched an effort to improve Hanford’s DST corrosion control strategy and to help address questions concerning the remaining useful life of the DSTs. Mr. Edgemon led the initial team that evaluated available corrosion monitoring techniques, conducted proof of principle testing, and installed the initial prototype and operating systems between 1996 and 2006. This work led to the development of the DST corrosion monitoring system designs presently in use at the Hanford Site (the MPCMS and RCMP). Five MPCMSs were designed, fabricated, tested, and installed in DSTs between 2008 and 2010. These systems are still in operation. The first RCMP was installed in September 2013. Each of these systems required the development of a variety of radiation and chemical resistant reference electrodes, sensors, shielding, wiring, and other components.

How or why is the innovation unique?
The use of ER sensors and reference electrodes to measure corrosion rate and corrosion potential is of course not new or unique. However, prior to this work, these monitoring techniques and associated systems had never been developed or applied to a nuclear waste tank environment at Hanford or anywhere else in the world. The design challenges for these systems are extreme. All components must withstand high temperatures (up to 160°F), concentrated caustic (pH 12+), and high radiation fields (up to 200 Rads/hr). In addition, these systems must withstand all physical and environmental forces in and above the tank.

What type of corrosion problem does the innovation address?
Both the MPCMS and RCMP systems facilitate the monitoring of DST waste corrosivity. Prior to the installation of these systems, DST corrosion could only be inferred from comparing periodic waste chemistry samples to a set of lab test results. No real-time information could be gathered from the DSTs prior to the installation of the MPCMS and RCMP systems. With these systems installed, Site engineering personnel can determine if a tank is suffering high rates of uniform corrosion due to changes in tank conditions (e.g., mixer pump operation, chemistry adjustment, waste/water additions, etc.). More importantly, Site engineering personnel can determine if a tank is at a corrosion potential capable of inducing SCC and take steps to chemically adjust the waste to bring the tank out of this dangerous regime.

What is the need that sparked the development of the innovation?
The realization that the DSTs were going to be required to function beyond their design life sparked the need to improve the Site’s DST corrosion monitoring strategy. The technology involved in the MPCMS and RCMP systems has evoked interest at other U.S. Department of Energy (DOE) nuclear waste cleanup sites including Oak Ridge National Laboratory, Idaho National Environmental and Engineering Laboratory, and the Savannah River Site.

Are there technological challenges or limitations that the innovation overcomes?
As you can imagine, the inside of a high-level nuclear waste tank is a harsh environment. No commercially-available components were available for such an application. Each in-tank component of the MPCMS and RCMP systems was selected by a design team of Materials, Metallurgical, and Corrosion Engineers, then in most cases, subjected to a variety of laboratory tests prior to being accepted for use
on these systems. In many cases, no laboratory tests were available that could duplicate the
combination of chemical and radiological conditions inside the nuclear waste tanks. In such cases, field
trials were performed on early prototype systems to establish the survivability of reference electrodes,
wiring, and other sensors.

**What are the potential applications of the innovation?**

Though nuclear waste management is a relatively small industry in terms of people employed, number
of employers, etc., the material that must be managed poses a potentially extreme hazard to people and
the environment. The Hanford Site is one of several DOE Sites that must manage, process, and
ultimately dispose of high-level nuclear waste generated as a result of plutonium production during the
Cold War era. Other key sites include the Savannah River Site, Oak Ridge National Laboratory, Los
Alamos National Laboratory, and Idaho National Environmental and Engineering Laboratory. Corrosion
monitoring systems similar to those developed at Hanford have been developed for applications at Oak
Ridge and Savannah River. In addition to existing storage facilities, both the Hanford Site and Savannah
River Site are constructing and/or operating large scale nuclear waste treatment facilities. The corrosion
monitoring technologies developed for the DSTs at Hanford could be readily adapted to these and other
treatment facilities. Depending on how the huge amount of spent commercial nuclear reactor fuels are
processed, the technology deployed at the Hanford Site may also have application in commercial
nuclear power industry.

**How does the innovation provide an improvement over existing methods, techniques, and
technologies?**

Prior to the development of the MPCMS and RCMP systems, DST corrosion control was managed
through a waste sampling and chemical analyses program as described above. In a few instances at
Hanford and other DOE sites, small sets of corrosion coupons had also been deployed in waste tanks.
The waste sampling and analyses program provides chemistry data and corrosion of the tank must be
inferred by comparing the chemical analyses information with laboratory test data done, in most cases,
on non-radiological waste simulants of similar composition. In some cases, waste chemistries in the
tanks do not precisely match any one of the set number of test results. In addition, waste chemistries
expected during waste processing and removal operations are expected to be outside the bounds of the
current chemistry test bases. Coupons, when they are used provide information on what has happened,
in terms of corrosion, in a tank. In short, they do not provide real-time data on tank waste corrosivity.
The MPCMS and RCMP corrosion monitoring systems allow for the collection of real-time corrosion data
and immediate detection of off-normal corrosion conditions in the event they occur. Waste sampling
and coupon programs do not allow these capabilities.

**What type of impact does the innovation have on the industry/industries it serves?**

The deployment and operation of the MPCMS and RCMP systems at Hanford provides near real-time
information on tank waste corrosivity, allowing for timely decision making regarding corrosion control.
The ability to immediately detect and correct off-normal corrosion conditions should increase the
service life of the DSTs. Better yet, as long-term trends in data are studied, the systems should allow
corrosion engineering personnel to model and predict when off-normal corrosion conditions will occur,
allowing preventative waste chemistry adjustments to preclude such conditions from ever arising. The
systems may also ultimately reduce or eliminate the need for periodic tank waste sampling operations which expose personnel to potentially hazardous material and increase the amount of radiological waste that must ultimately be disposed of at the Site.

**Does the innovation fill a technology gap? If so, please explain the technological need and how it was addressed prior to the development of the innovation.**

Prior to the development of the MPCMS and RCMP, no comprehensive corrosion monitoring systems had ever been developed for nuclear waste tanks. In terms of technology, no systems had been developed capable of withstanding the in-tank environment of the DSTs. Without corrosion monitoring systems, tank corrosion rate and tank corrosion potential could not be directly measured and instead, had to be inferred from waste chemistry testing.

**Has the innovation been tested in the laboratory or in the field? If so, please describe any tests or field demonstrations and the results that support the capability and feasibility of the innovation.**

Multiple laboratory studies have been performed to develop the electrodes and other components on the prototype and other early corrosion monitoring systems. Additional laboratory studies were performed to validate the performance of specific components used on the MPCMS and RCMP. The first prototype system was installed in a DST in 1996. Six additional systems based on this prototype design were installed and operated in DSTs between 1997 and 2006. Five MPCMSs were installed in DSTs between 2008 and 2010. These systems are currently in operation. The first RCMP system was installed in September 2013. Numerous papers documenting the laboratory and field application of these systems and the associated laboratory work have been published. A list of selected publications is attached to the end of this nomination form.

**Is the innovation commercially available? If yes, how long has it been utilized? If not, what is the next step in making the innovation commercially available?**

The innovation is commercially available, although as described above, commercial applications are relatively limited. The novelty of the MPCMS and RCMP systems is in their ability to survive highly caustic and highly radioactive environments, and their ability to provide corrosion information in an industry where previously, very little had existed.

**Are you aware of other organizations that have introduced similar innovations? If so, how is this innovation different?**

Throughout the development of the Hanford Site DST corrosion monitoring systems, the technology was openly shared with other DOE waste management sites. Each year, the DOE sites have collaborated in an annual information exchange related to waste corrosivity, corrosion monitoring, and control. A full scale system similar to the RCMP was actually developed, tested, and fabricated for installation and operation at the Savannah River Site in the late 1990s, but funding for installation was cut shortly before the system was deployed. A smaller version of the DST corrosion monitoring systems developed for Hanford between 1997 and 2006 was tested and deployed at Oak Ridge National Laboratory.
The application and acceptance of new waste tank corrosion monitoring technologies has been more successful at Hanford than at other DOE sites in part due to the sheer volume of high-level nuclear waste than must be safely contained and managed at Hanford. Approximately 58% of all of the weapons grade plutonium produced in the U.S. was produced at Hanford. By the termination of production operations in 1991, the chemical separations plants and other facilities at Hanford had produced 26 different waste streams resulting in approximately 245 million gallons of waste. This total was reduced by 197 million gallons, through waste concentration in evaporators, and discharges of low-level water and waste to trenches, cribs, and ponds. Several million gallons of high-level waste have been generated as a result of cleanup activities conducted since the end of plutonium production activities. Today, approximately 53 million gallons of high-level waste is stored in 177 underground carbon steel tanks built between 1943 and 1986. Clearly, the scale of the cleanup effort at Hanford drives the development of better corrosion monitoring and control strategies.

Are there any patents related to this work? If yes, please provide the patent title, number, and inventor.

No patents or invention disclosures specific to the Hanford DST corrosion monitoring systems have been filed.

Selected Refereed Publications


Selected Invited Papers


Inhibition of Stress Corrosion Cracking of Carbon Steel Storage Tanks at Hanford, C. Brossia, J. Beavers, C. Scott, M. Brongers, G. Frankel, G. Edgemon, H. Berman, and B. Wiersma, NACE 2007, paper no. 07606 (Houston, TX 2007).


