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7. Abstract

This document describes the selection of the wire material that will replace the 316 SS wire in the ENRAF level indicators.

8. RELEASE STAMP

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REV. 0

SELECTION OF ENRAF GAUGE WIRE MATERIAL COMPATIBLE WITH THE HANFORD WASTE TANK ENVIRONMENT

R. P. Anantatmula
December 1994

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SELECTION OF ENRAF GAUGE WIRE MATERIAL COMPATIBLE WITH THE HANFORD WASTE TANK ENVIRONMENT

1.0 INTRODUCTION

The measurement of the liquid level is the primary method of early leak detection in underground waste storage tanks at Hanford. The same method is also used for the detection of intrusion of liquids into the tanks. The age of the tanks and the history of the single-shell tanks developing leaks resulted in a high priority being placed on early leak detection. The Food Instrument Corporation (FIC) gauges used for many years for this purpose are no longer available and are rapidly failing. As a result, continued and uninterrupted level detection is a critical activity for monitoring the status of the waste being stored in underground tanks.

After extensive evaluation and testing, the ENRAF, INC. (ENRAF) Series 854 level gauge was selected to replace FIC gauges as the primary instrument for monitoring waste surface levels in waste storage tanks at Hanford. The ENRAF gauge detects the surface level of tank waste by lowering a polyethylene weight suspended at the end of an 8 mil wire. The surface level is recorded when the polyethylene weight touches the waste surface which results in a reduction in the amount of tension in the wire. The material for the wire from which the displacer of the gauge is suspended was selected to be type 316 stainless steel (316) based upon its anticipated excellent corrosion resistance in Hanford tank wastes. Installation of the 316 wire gauges began early in fiscal year (FY) 1994 with a total of 18 gauges scheduled for installation during the fiscal year.

After approximately 10 weeks of service, the displacer attached to the gauge installed in tank 241-S-106 separated from the wire, resulting in an error message on the gauge readout which indicated that the displacer was missing. A task team was assembled which identified the need for short-term actions to re-establish tank waste level monitoring. The failed wire was removed and sent to Pacific Northwest Laboratory for analysis. It was determined that the wire failure was due to chloride ion assisted corrosion of the 316 wire. Radiation-induced breakdown of the polyvinyl chloride (PVC) riser liners is suspected to be the primary source of the chloride ions. Another possible source is the chemical used to clean the waste crusts off the FIC plummets. Certain forms of this chemical used in the tank farms contained hydrochloric acid (HCl), and some of the compounds may still be stuck to the sides of the PVC liners.

As a result of this 316 wire failure, the task team proposed short-term and long-term actions. The short-term actions included confirming the source of the chloride ions while continuing to monitor liquid levels. One of the long-term actions is the selection of a wire material that is compatible with the PVC liner and the tank waste environment. The candidate materials are

Platinum (Pt) -20%iridium (Ir), Pt-10%rhodium (Rh), Pt-20%Rh and Hastelloy®[1] C-22. This document describes the selection of one material, from the list of candidate materials, that is suitable for use in the combined environment of the PVC liner and the tank waste.

2.0 CANDIDATE MATERIALS

2.1 NOBLE METALS AND THEIR ALLOYS

The high resistance of the noble metals to chemical attack is attributed to their thermodynamic stability over a wide range of conditions and the formation of a very thin protective film under oxidizing conditions. A factor that tends to reduce corrosion resistance of noble metals in aqueous solutions is the tendency of these metals to form complexes with some anions.

Platinum is immune to attack at almost all pH levels at 25^0C. Corrosion is found only in very concentrated acid solutions (e.g., aqua regia) under oxidizing conditions. Platinum is attacked by sodium hydroxide to form platinum hydroxide but the reaction occurs only at a temperature higher than 300^0C, which is considerably greater than the Hanford waste tank operating temperatures. Platinum is unaffected by most organic compounds. However, certain organic compounds form complexes with Pt, leading to its corrosion. Such complexing of Pt is not expected in the Hanford tank wastes, especially at the low waste tank operating temperatures. Platinum generally shows very low rates of attack in chlorine and, therefore, Pt anodes can be used for cathodic protection in seawater, and for chlorine production. However, in strongly oxidizing acid solutions, Pt can be attacked at low current densities due to the complexing action of the chloride ion. Such an attack is not probable in the Hanford waste tank environment since the wastes are alkaline.

The resistances of Ir and Rh to chemical attack surpass that of Pt. Their domain of stability is extremely wide, and in the absence of complexing agents they are stable in aqueous solutions of all pH values. In bulk form, Ir and Rh are unattacked by alkalies, acids, and oxidizing agents including aqua regia. In finely divided form, Rh is attacked by concentrated sulfuric acid and aqua regia. A fused mixture of caustic potash and potassium nitrate will attack Ir. Additions of Ir and Rh to Pt considerably raise the corrosion resistance of Pt in a wide variety of reagents. For example, a 10% addition of Rh to Pt reduces the corrosion rate in 36% HCl at 100^0 C (212^0 F) from 0.2 mm/yr (8 mils per year) to 0 mm/yr, and the attack of 100g/L ferric chloride ($FeCl_3$) at 100^0 C (212^0 F) from 16.7 to 0.2 mm/yr (660 to 8 mils per year). Iridium additions to Pt result in corrosion resistances similar to that obtained through Rh additions.

[1]Hastelloy is a registered trademark of Haynes International, Inc.

In spite of their high initial cost, the noble metals and their alloys offer substantial advantages over other materials used in the industry. They avoid the frequent and expensive replacement of plant components due to corrosion, they protect the product from contamination resulting in a higher quality of the product, and they frequently permit the carrying out of operations which would not otherwise be possible. For the ENRAF gauge application, the cost of the noble metal alloy wire is estimated to be only $400 per gauge.

2.2 HASTELLOY C-22

Nickel and nickel-based alloys are widely used in the industry because of their ability to withstand a wide variety of corrosive environments at high temperatures and stresses. Pure nickel is ductile and tough and resists corrosion by fresh waters and deaerated non-oxidizing acids. It has excellent resistance to corrosion by alkalies. Nickel and its alloys are readily fabricable and are free from the ductile-to-brittle behavior of most body-centered cubic and noncubic materials. Nickel forms unique intermetallic phases which enable the formulation of high strength alloys for both low-and high-temperature service.

Several high strength nickel alloys have been used in the industry over the last three decades. In the mid 1980s, Hastelloy C-22, a corrosion resistant nickel alloy was designed on the basis of a critical balance between the alloying elements chromium, molybdenum, and tungsten (see Section 7.1). The alloy is nominally 59Ni-22Cr-13Mo-3W-3Fe and offers the best resistance to oxidizing and reducing environments without compromising the metallurgical stability. In addition, the material outperformed other nickel alloys, e.g., Hastelloy C-276, Hastelloy C-4 and Alloy 625, in resisting localized corrosion and also when tested in the as-welded condition.

3.0 ASSESSMENT OF CORROSION IN TANK ENVIRONMENT

The ENRAF gauge wire resides above the liquid waste in the tank dome space. As such, the wire is routinely exposed to the vapor inside the dome space which is normally more dilute with respect to the waste constituents, e.g., OH, NO_3, NO_2, etc. Thus, any condensed vapor droplets are expected to be much more benign compared to the waste as far as degradation of wire material of the candidate alloys is concerned.

There is, however, the possibility of the ENRAF gauge wire accidentally coming into contact with the high level liquid radioactive waste below and PVC liner (and chemicals containing HCl that may be attached to the PVC liner) above the waste that could potentially degrade the ENRAF gauge wire material. Table 1 (see Section 7.2) lists the ranges of concentrations of major ions present in the tank waste.

TABLE 1. COMPOSITION OF IONS IN HANFORD TANK WASTE

ION	CONCENTRATION
Na^+	0.1 to 10M
K^+	0.05 to 0.3M
NO_3^-	0.05 to 3M
NO_2^-	0.05 to 3M
$CO_3^=$	0.01 to 0.5M
$PO_4^{\equiv}$	0.01 to 0.05M
NH_3/NH_4^+	0 to 0.5M
TOC	0 to 15 g/l
OH^-	0 to 3M
$SO_4^=$	0 to 0.1M
pH	9 to 13+

The noble metal alloys resist corrosion by solutions containing caustic. Hastelloy C-22 also is expected to resist corrosion by caustic at Hanford waste tank temperatures. The PVC liners (and possibly the chemical containing HCl) above the waste, on the other hand, create an environment of HCl. Although the noble metal alloys resist degradation by HCl, Hastelloy C-22, however, is not expected to be immune to attack by HCl. Therefore, the life expectancy of Hastelloy C-22 in the HCl environment is not anticipated to be as long as that for the noble metal alloys.

4.0 ASSESSMENT OF MECHANICAL PROPERTIES OF CANDIDATE MATERIALS

The polyethylene displacer weighs approximately 220 g, which puts the wire under a stress of 9.6 ksi. The motor turning the drum (which releases the wire into the tank) shuts off if the load to pull the wire exceeds 350 g. There is also an override for the motor shutoff and the gauge can be used with the override until the load reaches approximately 1.4 kg (3 lbs), at which time the magnetic coupling between the drum and the motor drive slips. The motor is then automatically turned off.

Based on the above, the yield strength (YS) of the wire should be at least 60 ksi to resist stretching from the loads generated by the wire-pulling operations. Such a high YS is necessary in the fully annealed state to preclude stress corrosion cracking (SCC) in an environment corrosive to the material under consideration. The YS and the ultimate tensile strength (UTS) for solution treated Hastelloy C-22 are ≈55 ksi and 115 ksi, respectively (see Section 7.3). The material can be cold-worked and aged to increase both the YS and UTS to >60 ksi and >150 ksi respectively. However, the cold working operation may make the material more susceptible to SCC in HCl environment. Platinum-10%Rhodium and Pt-20%Rh alloys also do not possess adequate YS in the fully annealed state, and cold working is necessary to increase the YS to 60 ksi and above. On the other hand, Pt-20%Ir alloy wire can be fabricated in the fully annealed state with a YS of >60 ksi and UTS of ≈115 ksi (see Section 7.4). Therefore, the tensile properties of Pt-20%Ir wire appear to be adequate for the ENRAF gauge wire application. In the worst case scenario, a 10% cold work is all that may be needed to raise the YS to 60-65 ksi level. Limiting the stresses in the wire this way will result in an improvement in cracking properties, although the material is expected to be fairly immune to the tank environment.

5.0 IMPACT OF GALVANIC COUPLE CREATED BY ENRAF GAUGE 316 COMPONENTS AND NOBLE METAL ALLOY WIRE

The choice of noble metal alloy wire creates a galvanic couple between the 316 material components of the ENRAF gauge and the wire. The 316 components are the ring that is attached to the bottom end of the noble metal alloy wire (resides in the tank above the waste surface) and the drum on which the excess wire is spooled (situated outside the tank on the ground above).

The 316 drum is located outside the tank, and approximately 45' of the noble metal alloy wire will be in contact with the drum during normal operations. Galvanic corrosion of the drum is expected to occur if water vapor from the atmosphere condenses on the drum. The surface area of the drum under consideration is approximately two times that of the wire. Assuming the corrosion of 316 is increased by a factor of 100 by galvanically coupling with the noble metal alloy, the increase could be as high as 50-fold for the present scenario.

The corrosion rate of 316 in a marine environment (see Section 7.5) (which is more aggressive than the arid environment at the Hanford Site) was found to be <0.001 mpy. These data were obtained at 800' from the beach. The same set of data also contained results for wrought iron, which showed an increase by a factor of 12 when the test location was only 80' from the beach. In order to retain conservatism, the corrosion rate of 316 in a marine environment can be assumed to be <0.02 mpy, which is a factor of 20 higher than that recorded in Reference 5 at 800' from the beach. Coupling the 316 drum with the wire can enhance this rate to <1 mpy. This enhancement in corrosion is not considered to be a cause for concern for the 316 drum, since the thickness of the drum is 3/16". However, a concern could be the grooves machined onto the drum for spooling the wire. Therefore, it is important to periodically examine the drum to verify that no appreciable damage of the grooves has taken place.

Galvanic corrosion is also possible if droplets of waste vapor condense on the noble metal alloy wire and drip down to the groove of the 316 ring (see Figure 1). The bottom end of the wire is wrapped onto this groove in order to eliminate kinking of the wire. Since the waste vapors condensing on the wire in the vapor space are quite benign, the corrosion behavior may be assumed to be similar to the corrosion experienced in the atmosphere, viz., <1 mpy for the 316 coupled to the noble metal alloy. The failure of the ring may still occur in a relatively short period of time from a chloride-assisted corrosion mechanism. Thus, once again, the ENRAF gauge assembly should be periodically examined to monitor the degradation of the 316 ring. It should be pointed out, however, that the design of the gauge assembly (see Figure 1) is such that it will preclude dropping of the polyethylene displacer onto the tank waste in case of ring failure.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The presence of both acidic and alkaline environments in the waste tanks at the Hanford Site presents a challenge to choose a suitable material for the wire in the ENRAF surface level gauge. The material choice is also complicated by the requirement of a thin wire (.2 mm diameter) dictated by the design of the gauge. Even a slight amount of corrosion of the wire could create stresses reaching the UTS leading to early failure of the gauges.

Hastelloy C-22 is resistant to corrosion by the alkaline environment of the waste at the Hanford waste tank operating temperatures. However, it is not immune to SCC in a HCl environment that is created by the presence of the PVC liners. The potential for SCC is increased if the material is required to be cold worked to obtain adequate mechanical properties. The Pt-Rh alloys are immune to the HCl as well as the caustic environments. However, the tensile properties in the fully annealed state are not adequate to withstand the loads expected during the ENRAF level gauge operations.

In addition to displaying immunity toward HCl and caustic environments, the Pt-20%Ir alloy possesses adequate tensile properties in the fully annealed state for operations associated with the ENRAF level gauge.

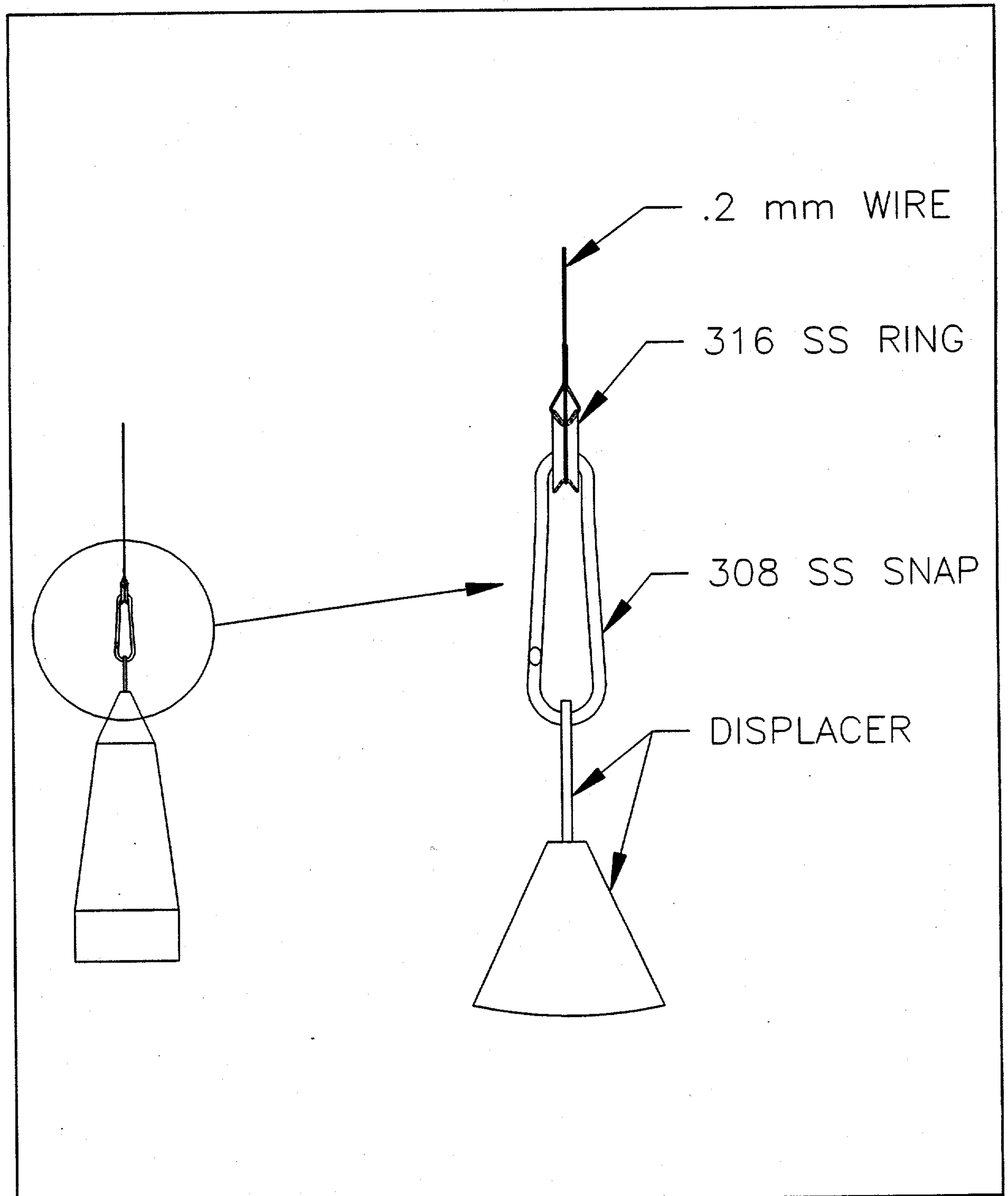

Figure 1. ENRAF Gauge 316 Ring and Displacer Assembly.

Based on the above discussion, the Pt-20%Ir alloy is recommended to be used as the wire material for the ENRAF level detector. Because of the possibility of galvanic corrosion of the 316 components that are in electrical contact with the noble metal alloy wire, a periodic inspection (once every three months) of these 316 components is recommended to verify the integrity of the components.

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