FUEL PERFORMANCE IN WATER STORAGE

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INTRODUCTION

Westinghouse Idaho Nuclear Company operates the Idaho Chemical Processing Plant (ICPP) at the Idaho National Engineering Laboratory (INEL) for the Department of Energy (DOE). A variety of different types of fuels have been stored there since the 1950's prior to reprocessing for uranium recovery. In April of 1992, the DOE decided to end fuel reprocessing, changing the mission at ICPP. Fuel integrity in storage is now viewed as long term until final disposition is defined and implemented. Thus, the condition of fuel and storage equipment is being closely monitored and evaluated to ensure continued safe storage.

There are four main areas of fuel storage at ICPP: an original underwater storage facility (CPP-603), a modern underwater storage facility (CPP-666), and two dry fuel storage facilities. The fuels in storage are from the US Navy, DOE (and its predecessors the Energy Research and Development Administration and the Atomic Energy Commission), and other research programs. Fuel matrices include uranium oxide, hydride, carbide, metal, and alloy fuels. In the underwater storage basins, fuels are clad with stainless steel, zirconium, and aluminum. Also included in the basin inventory is canned scrap material. The dry fuel storage contains primarily graphite and aluminum type fuels. A total of 55 different fuel types are currently stored at the Idaho Chemical Processing Plant.

The corrosion resistance of the barrier material is of primary concern in evaluating the integrity of the fuel in long term water storage. The barrier material is either the fuel cladding (if not canned) or the can material. Table I lists the combinations of cladding and can material of the fuels in the basins at ICPP.

ORIGINAL STORAGE BASIN

Facility Description:

The original underwater fuel storage basin (CPP-603) is an unlined concrete structure with three connecting pools (Figure 1). Two pools have fuel suspended directly or in buckets or cans from a monorail system (Figure 2). Carbon steel was the original monorail and hanger construction material, but is being replaced with stainless steel. The buckets and cans are made of carbon steel, aluminum, and stainless steel. Galvanic couples of carbon steel-aluminum, carbon steel-stainless steel, and stainless steel-aluminum are present in this system. The third pool holds fuel in aluminum and stainless steel storage racks.

Originally, water flowed through the basin and was then disposed of on site. In 1966, this was changed to a closed recirculating system, which prevented discharge of radionuclides to the ground but allowed contaminants to accumulate in the basin water. At about the same time, an algae growth problem prompted the use of several algicides including calcium hypochlorite, chlorine, and iodine.⁽¹⁾ The result was high levels of chloride accumulating in the basin water, reaching almost 800 parts per million (ppm), which accelerated the corrosion of many materials in the basin.

In the 1970's, treatment of the CPP-603 basin water began. A reverse osmosis (RO) unit was installed to remove chloride from the water and has been operated intermittently. Personnel radiation

exposures during disposal of the waste products has limited its use. Nitrate was added to reduce the corrosive effects of chloride on aluminum, keeping a nitrate to chloride ratio between 3:1 and 5:1. Water is occasionally removed from the basin and replaced with low chloride water. Finally, ultraviolet lights were added to the inlet water stream to help prevent the buildup of algae in the basin. The positive effects of these treatments can be seen in Figure 3, where the levels of chloride have been reduced to their current level of about 50 ppm.

Monitoring Program:

An inspection program is in place at CPP-603 to evaluate the condition of the fuel and the storage equipment. Binoculars and underwater lights allow some direct observation. Periodic examinations are made of the concrete structure, the monorail, hangers, buckets and cans, and a predetermined sample of fuel. Recently, the addition of underwater cameras has increased the capabilities of in-situ monitoring and virtually all fuels suspended on hangers have been video taped. Some hangers and buckets have been removed so physical measurements could be taken. Corrosion coupons of stainless steel (Figure 4) and aluminum (Figure 5) simulating the storage rack joints have been placed in the basin. Every six months they are removed, visually inspected, and ultrasonic thickness measurements are made. A liquid dye penetrant examination is also made on the stainless steel coupons. Four hangers have been removed from the basin, sectioned, and mounted for metallurgical examination.

Material Condition:

Four materials have been evaluated in the visual inspections made of fuel and storage equipment at CPP-603; stainless steel, zirconium alloys, aluminum, and carbon steel. Hastelloy is very similar to stainless steel and is expected to be at least as corrosion resistant. Zirconium alloys are not included in the 'official' inspection program since they are known to be very corrosion resistant to ambient water environments. However, their condition has been observed during the various basin inspections and no degradation has been detected. No appreciable corrosion has been found on any stainless steel components, either. Aluminum, however, has shown preferential attack in the form of pitting and crevice corrosion. The amount of attack is dependent on the time of exposure in the basin water. The corrosion products on the aluminum coupon in Figure 6 are examples of the preferential corrosion seen with aluminum.(2)

The corrosion is increased where galvanic couples exist (aluminum in contact with zirconium or stainless steel). The less noble aluminum becomes an anode and is corroded preferentially to the more noble stainless steel or zirconium, which acts as a cathode. Efforts have been made to reduce the number of galvanic couples by adding ceramic insulators between the two materials and thus electrically isolating them. Carbon steel, which is used only as handling equipment, has corroded extensively. It is currently either being replaced with stainless steel or additional stainless steel supports are being added.(3)

In 1992, a carbon steel double hook hanger failed under static load (Figure 7). Therefore, metallography was performed on all three types of hangers to better define their condition. The first hanger evaluated, a single hook made entirely of 304 stainless steel, was found to be in good condition with low corrosion rates. (The exact value could not be determined since no initial measurements were made and the remaining material was within the design requirements). Areas of lack of fusion were found where the cross member was welded to the hanger (Figure 8). Corrosion

products and impurities in the water accumulated in the solution trapped in this gap, becoming more corrosive than the free flowing solution, and resulting in a small amount of crevice corrosion (Figure 9). No other signs of localized attack were detected.(4) This type of hanger is acceptable for interim storage of fuels.

Two carbon steel/304 stainless steel single hooks were then metallographically examined (Figure 10). Although the amount of general corrosion on the carbon steel sections appears extensive, a sufficient amount of sound metal remains intact beneath the corrosion products. Galvanic attack was detected on the carbon steel where it is welded to the stainless steel. No general corrosion was detected on the stainless steel, but, localized attack was found. Crevices were formed between the carbon steel and stainless steel where the welds were not full penetration welds. As seen in the previous example, corrosion products and water impurities accumulated in the trapped solution creating a more corrosive environment. Intergranular stress corrosion cracks were found in the heat affected zone (HAZ) of the stainless steel due to the aggressive solution in the crevice. (HAZ is an area which is heated during welding to a sensitization temperature, which produces a grain structure more susceptible to corrosion.) Figure 11 shows a cross section of the hanger where each type of corrosion has occurred. This type of hanger could fail and thus additional supports (redundant rigging) have been installed.(5)

The third type of hanger, the double hook assembly, was the type that failed (Figure 7). Metallography showed similar results as with the single hook carbon steel hanger. A general corrosion rate of 0.002 inches per year is estimated based on design dimensions and actual remaining material. Some accelerated attack due to the galvanic couple was found where the stainless steel cross plate is welded to the hooks. However, general corrosion of the small carbon steel to carbon steel weld is where the failure actually occurred. This is where the hanger necks down in width and the weld material is small (Figure 12). Figure 13 shows where one side of the weld has corroded completely through. Small intergranular stress corrosion cracks in the HAZ were also found. As with the single hook assembly, these were caused by the aggressive solution in the crevice created during welding.(6) These hangers are also susceptible to failure and additional supports are being installed.

The stainless steel "tie-plate" corrosion coupon (Figure 4) has been in the CPP-603 basin since 1978. The material and weld configuration simulate the structural joints of the stainless steel fuel storage racks. A visual inspection and liquid dye penetrant inspection indicated no general or localized corrosion. Ultrasonic thickness measurements indicated a negligible loss of material. (The largest measured loss was 0.012 inches with a ± 0.014 tolerance on the original dimension.)(7)

Two aluminum corrosion coupons (Figure 5) simulate the weakest area of the aluminum fuel storage racks; the expanded metal and wire mesh bottoms. Pitting has been the primary mode of corrosion for both coupons (Figure 6). The amount of pitting observed has been worse with each subsequent six-month examination. Crevice corrosion was found on both the expanded metal mesh and wire mesh material. In fact, the wire mesh was missing in the most recent inspection.(2)

Current plans are to discontinue fuel storage at the CPP-603 facility by the year 2000. Several projects have been initiated in support of this effort. A video camera has been used to record the condition of most of the fuels in storage at CPP-603. As expected, the stainless and zirconium type fuels are in good condition, but the aluminum is corroded (pitted). The extent of pitting depends on how long it has been in the basin. Studies are under way to evaluate methods of recanning the corroded aluminum to prevent further degradation. Current plans are to move most of the fuels to the

new underwater storage facility, but dry fuel storage is also being investigated as a possibility.

MODERN STORAGE BASIN

Facility Description:

In 1984 a new water storage facility for fuel began operation (CPP-666). It consists of six pools with stainless steel and aluminum storage racks in recirculating water (Figure 14). Improvements over the old facility are chillers to keep the water temperature down, ultraviolet lights to prevent algae growth, a 304L stainless steel liner on the concrete structure, and anion and cation exchangers to remove impurities from the water. These systems have effectively maintained high purity water.

Monitoring Program:

An inspection program similar to that used at CPP-603 is in place at CPP-666. The program includes periodic examinations of the stainless steel liner, aluminum and stainless steel "tie-plate" coupons representing the storage racks (Figure 15), and simulated aluminum storage cans. Inspection of the liner is by visual examination only using binoculars and under water lighting. The "tie-plate" coupons are removed once per year for a visual examination and ultrasonic thickness measurements. Liquid dye penetrant tests are performed on the stainless steel coupons.

Two types of simulated aluminum storage cans are inspected. The dummy fuel cans are weighted, sealed aluminum cans used for evaluating corrosion of the outer surface in the basin environment. They are removed and weighed once per year; a weight gain would indicate water leakage into the can. The mockup fuel cans were designed to evaluate potential galvanic and crevice corrosion. An inner aluminum can with zirconium and 100 ml water is sealed inside an outer aluminum can (Figure 16). Every two years, they are removed, a liquid penetrant test is performed, and they are cut open to visually inspect the interior of both cans.

Material Condition:

Periodic inspections of about 60% of the stainless steel basin liner have shown both the base metal and welds to be sound with no indications of corrosion.(8) A green film of algae has been found on the surface, however. The water pretreatment system of ultraviolet lights was out of service for some time (about two years) which apparently allowed the algae growth to form.

The stainless steel coupons removed from the basin after eight years of exposure have shown no localized corrosion and a low general corrosion rate of 0.13 mpy.(9,10) Some pitting has been identified on the aluminum coupons after seven years of exposure. None of the white corrosion product buildup, as in CPP-603, was found.(11) In the most recent inspection of the dummy fuel storage cans, pit initiation was detected. The mockup fuel storage can was also removed this year. Pitting was seen on the outside of the cans and water was found on the inside, indicating perforation of the can. As with the other aluminum coupons, no buildup of corrosion products was seen. Since the algae film was found on these coupons, the possibility of microbiologically influenced corrosion (MIC) is being investigated.(12) Samples of the water and the microbes found in the basin were sent to Montana State University. The samples are being cultured, evaluated for the type of microbes, and

then placed in contact with metal samples to evaluate corrosivity. Possible methods of eradicating the algae, without increasing the corrosiveness of the basin water, are also being investigated.

It is assumed from these observations that all stainless steel and zirconium type fuels in this basin are in good condition. Although MIC is under investigation, it is possible that the high radiation fields of the actual fuel would kill the organisms. Based on this assumption (still under investigation), the aluminum should also be in fairly good condition. Examination of the actual fuel requires removing it from the racks and performing some type of specialized remote nondestructive examination. The methodology is currently being developed to perform these inspections.

Studies are also currently under way at the Chemical Processing Plant to evaluate alternative methods for storing aluminum type fuels. Possible changes in the storage basin, such as increasing water flow, are being investigated. Another possibility is to transfer the fuel to dry storage.

CONCLUSIONS

Due to the change of mission the Idaho Chemical Processing Plant, storage of government owned fuels will continue for a longer period of time. Thus, careful evaluation of current material integrity and prediction of future conditions are required. The original storage facility has experienced a variety of corrosion problems and is planned to be out of service by the year 2000. The newer facility has a number of very effective controls to prevent excessive corrosion of fuels and storage equipment. Generally, stainless steel and zirconium clad fuels are in good condition in both water storage basins and their continued storage should not be a problem. Aluminum, however, is not as resistant to a water environment. Aluminum alloys have corroded extensively in the older facility and are beginning to corrode in the newer basin. Research is currently underway either to mitigate the corrosive effects of aluminum in water storage or to find an alternative storage method, such as dry storage.

TABLE I
FUEL CONTAINMENT MATERIALS

<u>Cladding Material</u>	<u>Can Material</u>	<u>Storage Area</u>
Stainless Steel	Aluminum	CPP-603
Stainless Steel	Stainless Steel	CPP-603
Stainless Steel	None	CPP-603
Hastelloy	Stainless Steel	CPP-603
Aluminum	None	CPP-603
Zircaloy-2	Stainless Steel	CPP-603
Zircaloy-4	Stainless Steel	CPP-603
None	Stainless Steel	CPP-603
None	Aluminum	CPP-603
Stainless Steel	Stainless Steel	CPP-666
Aluminum	None	CPP-666
Zirconium	Aluminum	CPP-666
Zircaloy-2	None	CPP-666
Zircaloy-4	None	CPP-666

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Figure 1. CPP-603 Fuel Storage Basin

Figure 2. CPP-603 Monorail and Single Hook Hanger

Figure 3. Chloride Concentration Versus Time at CPP-603

Figure 4. Tie-Plate Coupon Representing Stainless Steel Fuel Storage Racks at CPP-603

Figure 5. Aluminum Coupons at CPP-603 Representing Fuel Storage Racks, Expanded Metal Mesh and Wire Mesh

Figure 6. Expanded Metal Mesh Aluminum Coupon After 10 Years

Figure 7. CPP-603 Double Hook Hanger

Figure 8. Cross Section of CPP-603 Stainless Steel Hanger

Figure 9. Crevice Attack at Base of Weld Lack of Fusion Area (375X)

Figure 10. CPP-603 Carbon Steel Single Hook Hanger

Figure 11. Cross Section of Single Hook Hanger

Actual Weld Joint

Figure 12. Carbon Steel Weld Joint of Double Hook Hanger

Figure 13. Double Hook Weld, Corroded Through One Side

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Figure 14. CPP-666 Fuel Storage Basin

Figure 15. CPP-666 Stainless Steel and Aluminum "Tie-Plate" Coupons

Figure 16. CPP-666 Aluminum Mockup Fuel Can

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