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ABSTRACT

Spent nuclear fuel and control assemblies from the RA-3 Research and Test Reactor experienced corrosion while stored at the Ezeiza Central Storage Facility (Ezeiza CSF) in Argentina. These aluminum-clad assemblies were fabricated in the United States of America and were, by agreement, to be returned to the USA for disposition. Remote, camera-aided, visual inspection of the fuel and control assemblies in October 1999, revealed that significant corrosion had occurred during the extended (12 to 26 years) storage at the Ezeiza CSF. The inspected assemblies remained in wet storage in the Ezeiza CSF until the December 2000 transfer to shielded, shipping casks. The assemblies were vacuum-dried in the casks and shipped to the USA Department of Energy's Savannah River Site. After receipt at SRS the assemblies were returned to wet storage. The visual inspection was then repeated on selected assemblies to assess the impact of the additional wet storage and the dry shipment on the corrosion-induced damage. Comparison of the results of the visual inspections demonstrated that neither the additional wet storage nor the dry shipment significantly altered the condition of the assemblies.

This paper summarizes the inspections and inspection results in conjunction with the corrosion experience of aluminum-clad SNF in basin storage.

INTRODUCTION

Interim storage of many research and test reactor fuels worldwide includes water basin storage. Aluminum-clad spent nuclear fuel stored in water basins will be subject to corrosion attack if the water quality and storage conditions are aggressive to aluminum. Aluminum-clad spent fuel from the RA-3 Research and Test Reactor at the Comision Nacional de Energia Atomica CNEA Ezeiza Atomic Center near Buenos Aires, Argentina was subject to conditions conducive to aggressive corrosion during storage at the Central Storage Facility (CSF) and suffered corrosion and mechanical damage. A team of personnel from Westinghouse Savannah River Company (WSRC) performed intensive inspections of 207 fuel assemblies at the CSF in November 1999 [1, 2]. The fuel assemblies were similarly examined following receipt at the Savannah River Site in January 2001. The corrosion and mechanical damage to the assemblies was characterized to provide information to evaluate the corrosion mechanisms and rate of continued corrosion damage.

The condition of the fuel was documented with photographs and video stills from the inspection. The expected impact of the corrosion and mechanical damage on transportion and continued basin storage is evaluated in a companion paper [3].

FUEL STORAGE HISTORY

The irradiated assemblies had been stored in the CSF for times ranging from twelve to twenty six years prior to their inspection at the CSF in October 1999. The wet storage facility consists of a system of water filled interconnected pits that are 13.7 centimeters in diameter (inside) and 2.1 meters deep. There are 198 of these pits with stainless-steel-lined tubes that can hold up to two standard MTR assemblies or one control rod assembly.

The tubes are filled with water that was not deionized or filtered in over 10 years. The water was not circulated and remained stagnant. The source of the original water is unknown. The water level was monitored and water is added when the level was too low to cover the assemblies.

Key characteristics of the basin water (Table 1) suggested that pitting of the stored fuel cladding was likely in the CSF if the irradiation induced oxide films had been damaged or not adequately developed on the fuel cladding.

Table 1 Characteristics of the SRS L-Basin and the Ezeiza CSF Water Chemistry

	L-Basin (1996 to Present)	**Ezeiza CSF (1998)**
Conductivity (μS/cm)	1-3	80-169
Chloride Ion Concentration (ppm)	< 0.1	4-16
Sulfate Ion Concentration (ppm)	< 0.1	3
Nitrate Ion Concentration (ppm)	< 0.1	
pH	6.5-6.6	7.5-8.0
Temperature (deg C)	20	15-20
Gamma Activity, Cs Bq/l	Less than 800	Less than 120,000
Water	Continuous mixed-bed deionization, sludge removal	Stagnant; no sludge removal

INSPECTION AT CSF

Detailed examination of the fuel surfaces was performed at CSF using several video imaging systems. The video systems included an array of three above ground cameras, borescopes, and long video probes. The above ground systems at the CSF were equipped with video cameras, zoom lenses, pan & tilts, and components to control the systems from a remote location over a single coaxial cable.

Most (204) of the assemblies were removed from the storage tubes and basin before inspection. The remaining three assemblies were inspected using a submergible video probe. These camera-aided visual inspections found no evidence of corrosion on sixty-seven assemblies and evidence of limited corrosion on the other one hundred forty assemblies. There were no apparent differences in corrosion that could be attributed to uranium loading or enrichment, cladding thickness and/or fabrication differences among the fuel and control assemblies.

Sites of localized corrosion on the stored assemblies were readily apparent because a white, flocculent corrosion product covered the corrosion site. This was consistent with the SRS experience and is characteristic of localized attack on aluminum alloys exposed to aggressive water environments [4-6]. The majority of the corrosion was at or near the end of the stored assemblies as illustrated by the photograph of assembly #219 (Figure 1A). The examinations also showed that most of the corrosion was on the structural plates although some corrosion was apparent on the outer fuel plates. The increased tendency for corrosion on the structural plates may be attributed to two factors:

1) the difference in heat flux across the fuel plates relative to the structural plates improved the protective characteristics of the oxide film on the fuel plates, and/or
2) the Type 1100 aluminum fuel plate cladding is more resistant to localized corrosion in semi-stagnant water than the Type 6061 aluminum used for the structural plates.

Experience at SRS has demonstrated that the Type 1100 aluminum is more resistant to pitting during exposure in semi-stagnant water than Type 8001 aluminum [4-7].

The fluffy, flocculent nature of the corrosion product hid much of the underlying, corroded metal. However, the corrosion product appears concentrated in three locations:

1) along the crevice formed by the junction between the outer fuel plate and the structural plate,
2) near the screws that connect the structural plate to the lifting rod, and
3) at the cut ends of the structural plate.

In the extreme, the crevice corrosion at the fuel plate/structural plate junction was sufficient to cause separation between the two plates (Figure 2A). Nevertheless the assembly was successfully lifted and transported by the lifting rod attached to the corroded end of the assembly. Most of the assemblies that showed corrosion showed limited attack that was generally confined to the outer fuel plate/structural plate crevices and the corners and edges of the structural plates.

Numerous assemblies showed some corrosion in the regions adjacent to the stainless steel screws that connected the lifting rod to the structural plate while other assemblies showed no evidence of accelerated corrosion in that area. The lack of attack at this rather obvious site for potential galvanic corrosion is consistent with the importance of anode to cathode ratio in galvanic corrosion processes. The lack of corrosion also suggests that galvanic corrosion was generally avoided because of the large amount of aluminum surface exposed. Although the use of stainless steel screws (cathodic to aluminum) to connect aluminum components was successful for these components, prudent engineering design would avoid such coupling whenever practical. Reasons to avoid such coupling were apparent in assembly 219 (Figure 1A) where the preferential attack of the aluminum at the aluminum to stainless steel interface was apparent in the 2001 inspection (Figure 1B). However, as is also apparent in comparing Figure 2A with 2B, corrosion product buildup over the galvanic couple tended to exaggerate the extent of corrosion.

To better quantify the severity of corrosion the total area of corrosion product nodules over fuel meat and on outer fuel plates was measured for each fuel assembly. No nodules were observed on sixty-seven of the assemblies and only nineteen assemblies had more than one and a half square centimeters of nodules on the outer fuel plate surfaces.

The October 1999 examination of the Ezeiza fuel and control assemblies demonstrated that:

1) the assemblies experienced localized corrosion during basin storage,
2) the corrosion observed was consistent with the SRS observations the water storage in basins with a water conductivity's >50 μS/cm may to cause localized corrosion of aluminum [7] depending on the protective qualities of surface oxides,
3) crevice corrosion at the structural plate/fuel plate junction was severe in a limited number of cases,
4) the corrosion, even in extreme cases, did not impair the ability of the assemblies to be handled by the lifting rods even when there was significant attack of the structural plate at the lifting rod end of the assembly,
5) galvanic attack from the stainless steel screws in aluminum structural plates occurred in many of the assemblies, and
6) filiform corrosion was observed near the end regions of the fuel plates in several assemblies. The corrosion appeared to initiate at the structural plate/fuel plate junction.

These observations were consistent with the SRS experience and demonstrated the suitability of the assemblies for transfer to the Savannah River Site.

The inspected assemblies were returned to wet storage in stainless steel tubes in the Ezeiza basin and remained in the basin for approximately one year. The re-stored assemblies were then packaged for transfer to SRS. The nozzles were cropped from the assemblies as part of the packaging process. Forty-two assemblies were packaged in each of five shipping casks (one cask held only thirty nine actual assemblies and three dummy assemblies). The placement of the assemblies in the cask provides a mechanism for rubbing against the cask grids and thereby removing some of the corrosion nodules. The loaded casks were vacuum dried and sealed before shipment. The standard casks arrived at SRS in December 2000 and were transferred to wet storage in the SRS L-basin. Approximately fifty assemblies were subsequently removed from the L-basin for enhanced visual inspection. These assemblies were inspected using technologies similar to those used in Ezeiza and were returned to the L-basin when the inspection was complete. The L-basin inspections were made during the time period from January 30 through February 7, 2001.

EXAMINATION AT SRS L-BASIN

The second detailed examination showed little or no change in the condition of the Ezeiza assemblies as shown in Figures 1-3. This examination was made after the assemblies had experienced

a) additional (approximately a year) wet storage in the Ezeiza basins,
b) transfer to a shipping cask,
c) vacuum drying,
d) dry shipment from Ezeiza to Savannah River,
e) removal from the cask,
f) transfer to wet storage in the SRS L-basin, and
g) removal from the L-basin for examination.

The operations outlined above removed some of the corrosion product from the assembly surfaces and allowed the actual extent of corrosion to be more readily observed. The presence of flocculent corrosion product exaggerates the size of the corroded region.

There is no evidence of new corrosion sites developing during the additional storage in either the Ezeiza basin or the dry storage environment. This is in spite of the fact that the chemistry of the Ezeiza basin water was conducive to corrosion and that no special care was taken to assure that the dry storage environment was as dry as practical. The lack of additional corrosion during the 1999 to 2001 period was apparent in several others areas and no evidence of new corrosion sites was found by the inspections.

The corrosion observed on the Ezeiza assemblies was concentrated along the corners and edges of the structural plates. Clearly, corrosion was observed in other regions such as the crevices between the structural plate and the fuel plates, near the screws connecting the lifting rods to the structural plates and in isolated regions on both structural plates and fuel plates. The cause of the isolated localized, pitting corrosion on the fuel plates and the structural plates was not established however, experience suggests that such corrosion is most likely at the site of mechanical damage introduced during the handling and transfer of the assemblies.

The propagation of corrosion damage, even in the high conductivity Ezeiza basin waters, is slow. There was no obvious increase in corrosion-induced damage after an additional year of exposure to the Ezeiza basin water and dry transfer to the Savannah River Site. These observations are consistent with SRS experience and with the established durability of aluminum-clad spent nuclear fuel in both wet and dry storage environments.

Slow propagation of corrosion damage after long term exposure is expected if the damage is following normal pit growth kinetics. Under many pitting condition, the pit depth, d, increases with time, t, according to the relationship

$$d = at^n$$

where a and n are empirical constants and n normally has the value of approximately 0.3 to 0.5 [8]. Therefore these observations suggest that the durability of aluminum in wet (and dry) interim storage environments is controlled by its susceptibility to pitting and that, after the initiation of stable pits, the rate of attack may decrease with increasing exposure time.

CONCLUSIONS

Camera aided visual inspections of aluminum-clad spent nuclear fuel stored in the Ezeiza (Argentina) water basins showed that corrosion induced damage was significant and consistent with SRS experience with aluminum-clad SNF. The inspections, made in Ezeiza in 1999 and at SRS in 2001, demonstrate that aluminum-clad SNF is durable in both wet and dry environments. Corrosion product accumulations on the surfaces of aluminum cladding exaggerate the extent of actual corrosion.

The storage conditions present in the CSF basins promoted the corrosion of the aluminum fuel and caused galvanic corrosion, crevice corrosion, pitting corrosion, and filiform corrosion . No significant changes in the corrosion damage were seen due to the additional year of storage under these condtions plus the drying and shipment in standard fuel shipment casks.

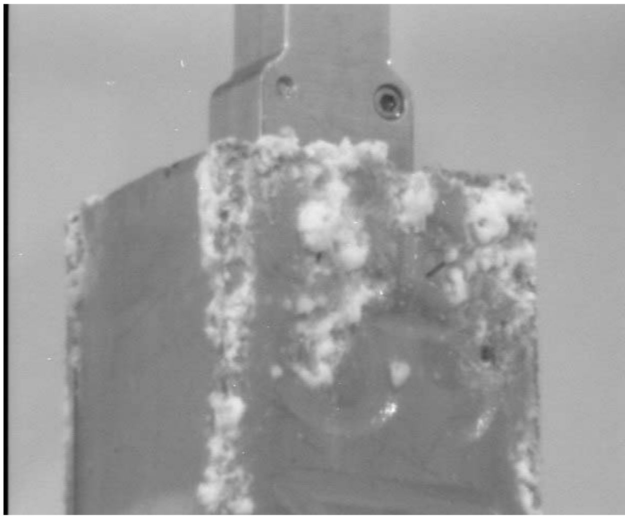

Figure 1A. RA-3 Assembly #219 Examined at the EzeizaCSF Shows Increased Corrosion Attack on the Structural Plate (center) Compared to the Fuel Plate (left) and Increased Attack at the Location of the Stainless Steel Screws

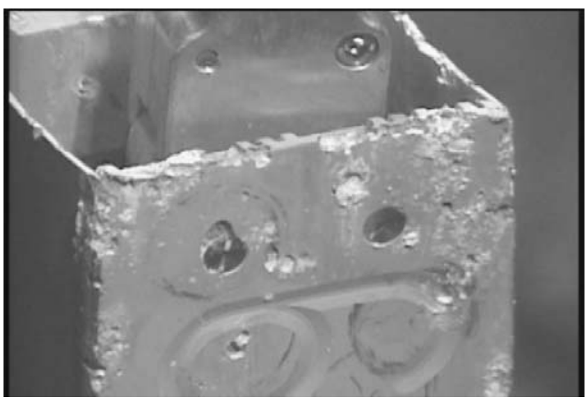

Figure 1B. RA-3 Assembly #219 Examined Underwater in SRS L-Basin Shows Loss of Corrosion Nodules and No Evidence of Additional Corrosion Attack. The Stainless Steel Screws Have Been Removed.

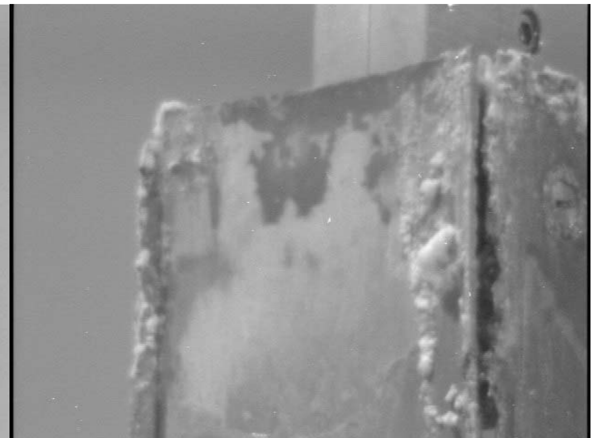

Figure 2A. RA-3 Assembly #243 Examined at the Ezeiza CSF Shows Crevice Corrosion Attack at the Side Plate (right) Connection to the Fuel Plate (center)

Figure 2B. RA-3 Assembly #243 Examined at SRS L-Basin Show No Significant Change Except for Loss of Corrosion Product Nodules

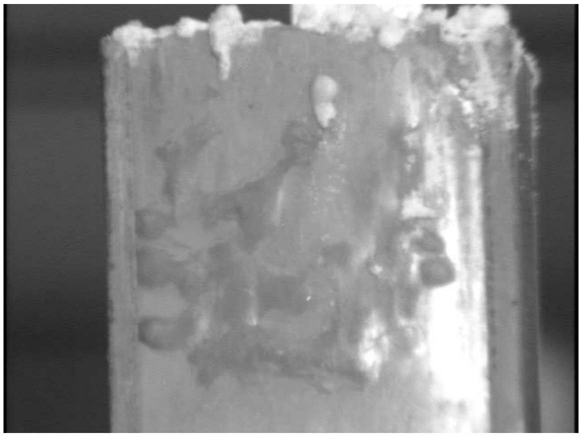

Figure 3A. RA-3 Assembly #112 Examined at the Ezeiza CSF Shows Apparent Filiform Corrosion

Figure 3B. RA-3 Assembly #112 Examined Underwater in SRS L-Basin

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