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ENGINEERING DESIGN FILE

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Formal analyses and calculations require engineering management approval.

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6. Summary:

This Engineering Design File (EDF) evaluates loss of material from corrosion of the Fuel Storage Container (FSC) and Support Stool (SS) at the Fort St. Vrain (FSV) Independent Spent Fuel Storage Installation (ISFSI). Revision 1 of this EDF incorporates recommendations received from the Department of Energy - Headquarters (DOE-HQ) and the Department of Energy - Idaho (DOE-ID), resolves comments received from the ISFSI Safety Review Committee (SRC) and removes reference to Time Limited Aging Analysis (TLAA) which is no longer required for the current 20 year license renewal period.

This EDF concludes that the remaining wall thicknesses of the FSCs under potential interior corrosion attack mechanisms are greater than the specified minimum required thickness of 0.0135 inch described in the Acceptance Criteria Section of this EDF and that the exterior aluminum coating is adequate to protect the exterior surface of FSCs and SSs from corrosion for more than 40 years. After 40 years 9% of the protective aluminum coating would be lost. The FSCs and SSs are satisfactory for continued service throughout the proposed license renewal period.

7. Signatures: (See instructions for significance of signatures. Add or delete signatories as needed.)

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9. Will document be externally distributed? ☒ Yes ☐ No

10. Registered Professional Engineer's Stamp (if required) ☒ N/A

Registered Professional Engineer Stamp		This Engineering Design File was prepared under the direction of the Registered Professional Engineer as indicated by the stamp and signature provided on this page. The Professional Engineer is registered in the State of Idaho to practice __________ Engineering.

* Not required for commercial level calculations.

ACRONYMS

AMR	Aging Management Review
ASME	American Society of Mechanical Engineers
AWS	American Welding Society
CLB	current license basis
DOE-HQ	Department of Energy - Head Quarters
DOE-ID	Department of Energy - Idaho
EDF	Engineering Design File
FSC	Fuel Storage Container
FSV	Fort St. Vrain
FWEA	Foster Wheeler Energy Application
ISFSI	Independent Spent Fuel Storage Installation
NRC	Nuclear Regulatory Commission
MVDS	Modular Vault Dry Store
QA	Quality Assurance
SAR	Safety Analysis Report
SCC	Stress-corrosion cracking
SERs	Safety Evaluation Reports
SR	Surveillance Requirement
SRC	Safety Review Committee
SS	Support Stool
SSC	System, structure, and component
SSW	Standby Storage Well
TS	Technical Specification
U.S.	United States

Title:	FSV ISFSI MVDS Fuel Storage Container and Support Stool Time Limited Aging Analysis (TLAA)	Revision:	Revision 1
Author:	J. S. Hu and J.L. Stalnaker	Date:	5/10/2010

PURPOSE

The Fort St. Vrain (FSV) Independent Spent Fuel Storage Installation (ISFSI) was built in 1991 and a 20 year license for storage of spent nuclear fuel was issued by the U. S. Nuclear Regulatory Commission (NRC) in November 1991. This license expires in November 2011. The proposed license renewal period is for an additional 20 years beyond November 2011. The effects of corrosion on the Fuel Storage Container (FSC) and Support Stool (SS) were originally evaluated over a period of 40 years. The original license period of 20 years and the proposed license renewal period of 20 years is within the 40 year design life over which the FSC and SS were evaluated. Also an aging management review (EDF-8612, 2010) was performed and concluded that the FSCs and SSs are capable of performing their intended function during the license renewal period. This Engineering Design File (EDF) serves as an independent corrosion analysis of the FSC and SS at the FSV ISFSI.

SCOPE

Perform a corrosion analysis of current configuration of the FSCs and SSs at the FSV ISFSI for a period of 40 years.

ASSUMPTIONS

FSC water content by weight is a maximum of 0.01% of the fuel weight increased by a factor of ten for conservatism (FSV SAR-II-9 CH 4, Ref. 19). This is approximately 1.7 pounds of water (775.6 grams) based on wet fuel blocks being placed in each fuel FSC (see following sections titled "Interior Corrosion Environment of FSC" and "Corrosion of Interior Surfaces of FSC"). The maximum allowed FSC lid seal leakage is 1×10^{-3} cc/sec (SNM-2504, Amendment No. 9). Since atmospheric pressure changes would drive the leakage into or out of the FSC, assume leakage into the FSC occurs 50 percent of the time. The volume of air to enter the FSC over 40 years ($V_{40\ air}$) would then be 0.631 cubic meters or 22.3 cubic feet.

$V_{40\ air} = (1 \times 10^{-3}$ cc/sec)(cubic meter / 1×10^{6} cc)(3.1536×10^{7} sec/year)(40 year)(0.5) = 0.631 cubic meter

$V_{40\ air}$ = (0.631 cubic meter) (35.315 cubic foot / cubic meter) = 22.3 cubic feet

Estimate 40 year water content ($V_{40\ water}$). Conservatively assume a temperature of 90 degrees F and a relative humidity of 95%. The Grosvenor psychrometric chart, figure 12-2b (Perry's 2008) shows the moisture content (H) = 0.03 pounds water per lb dry air and the specific volume (v) = 14.6 cubic feet per lb dry air. The 40 year water content ($V_{40\ water}$) would then be 0.046 pounds water.

$V_{40\ water} = (H / v)\ V_{40\ air}$ = [(0.03 pounds water / lb dry air) / (14.6 cubic feet / lb dry air)] (22.3 cubic feet)
$V_{40\ water}$ = 0.046 pounds water

The additional water introduced by the 40 year water content (0.046 pounds) through the potential seal leakage of 0.631 cubic meters of outside air is only a small fraction of the above water content (1.7 pounds) because of the small volume of air. This potential additional moisture is well enveloped by the factor of ten already used for conservatism and is therefore negligible.

The FSC water content based on 0.01% of the fuel weight increased by a factor of ten for conservatism (FSV SAR-II-9 CH 4, Ref. 19) is adequate for evaluation of FSC internal corrosion for a period of 40 years.

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ACCEPTANCE CRITERIA

FSC Boundary Design Calculations (FSV SAR-II-9, Calculation A4-2.3.4, No. 4) establish that the FSC design is in accordance with ASME III Division 1 Subsection ND Class 3 Components. This evaluation will use the same acceptance criteria used in the FSC Corrosion Allowance Design Calculation (FSV SAR-II-9, Calculation A4-2.3.4, No. 6). This calculation uses the American Society of Mechanical Engineers (ASME) design standard to determine that the minimum required FSC wall thickness is 0.0135 inch. The external surfaces of the carbon steel FSC and SS are protected from atmospheric corrosion with a flame sprayed aluminum coating applied to the FSC and SS external surfaces (Drawing 362A0067, 1991, Drawing 362A0082, 1991 and Document 1742901). Evaluation of aluminum coat to provide adequate protection shall be for the 40 year design life of the components.

CORROSION CALCULATIONS

Corrosion Basis

Corrosion is a chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties. Therefore, corrosion is an interaction between a material and an environment. The corrosion resistance of a metal is strongly dependent on the environment to which it is exposed. For a given corrosion resistance of the material, as the corrosivity of the environment increases, the rate of corrosion increases. For a given corrosivity of the environment, as the corrosion resistance of the material increases, the rate of corrosion decreases.

The environment is the entire surroundings in contact with the material. The primary factors used to describe the environment are: (a) physical state – gas, liquid, or solid; (b) chemical composition – constituent and concentrations (which effect such factors as conductivity, pH, etc.); and (c) temperature.

There are five methods to control corrosion: (a) material selection; (b) coating including metallic coating (sacrificing and noble metal coatings) and organic coating; (c) modification of environment – inhibitors; (d) modification of the potential – cathodic and anodic protection; and (e) rational design. (Doffelaar and Atkinson, 1995)

Classification by appearance of the corrosion is particularly useful in failure analysis. Eight forms of corrosion can be identified based on appearance of the corroded metal (Doffelaar and Atkinson, 1995):

1. Uniform corrosion – a general dissolution of the metal, resulting in a fairly uniform penetration over the entire exposed metal surface. Uniform corrosion is the most common corrosion in that it accounts for the greatest weight loss of metals by corrosion process. Steel is particularly susceptible to uniform corrosion. Uniform corrosion is also the most predictable form of corrosion.

2. Pitting – one of the localized forms of corrosion. In the pitting process, the anodic area is well defined and remains in the same localized area for long times. Surfaces adjacent to this highly attacked region show little or no signs of corrosion. The passive metals that depend on a protective film for their corrosion resistance (including aluminum, stainless steel, and titanium alloys) are particularly susceptible to pitting attack in areas where the passive film has broken down.

3. Crevice corrosion– a specific form of concentration-cell corrosion. The formation of a crevice, either by a design with constricted geometry or by formation of a deposit on the metal surface, can lead to changes in the environment in the constricted area. Crevice corrosion can occur inside crevices and under shielded areas on the metal surface where a stagnant solution exists.

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This is due to the limitation of oxygen or chemical diffusion in or out of the area. The difference in chemical composition results in potential shifts in the metal surface. The more negative area on the surface will be anodic, and corrosion damage will occur in this area. The more positive area on the metal surface will be cathodic and will not corrode.

4. Galvanic corrosion – it occurs when a metal or alloy is electrically coupled to another metal or conducting non-metal in a common electrolyte. The three essential components of galvanic corrosion are: a) materials possessing different surface potentials; (b) a common electrolyte; and (c) a common electrical path.

5. Stress-corrosion cracking (SCC) – it is a localized corrosion and observed when there is simultaneous presence of a susceptible metal, tensile stresses at the metal surface, and a specific environment containing an aggressive species that promotes stress-corrosion cracking. Five controlling parameters have been identified for the SCC process: (a) tensile stress, (b) composition and microstructure of the metal, (c) specific species of the environment, (d) electrochemical potential, and (e) temperature.

6. Erosion-corrosion – the acceleration in the rate of deterioration on a metal because of the combination of mechanical wear and electrochemical corrosion. The combination of wear and corrosion results in more severe attack than that would be realized with either mechanical or chemical corrosive action alone.

7. Inter-granular corrosion – a localized attack at grain boundaries with relatively little corrosion of the grains. As corrosion proceeds, the grains fall out and the metal or alloy disintegrates. One class of material that is particularly susceptible to inter-granular corrosion is the austenitic stainless steels when it is sensitized so the chromium is effectively removed or lowered in content.

8. De-alloying – the selective corrosion of one or more components from a solid-solution alloy. A very common example of de-alloying is dezincification, which is the process of selectively removing zinc from the copper-zinc alloy, brass.

Following the guideline of corrosion basis, the fuel storage container and support stool corrosion analysis will be performed through three steps: (a) an evaluation of the material and design of the FSC and SS; (b) an evaluation of the corrosion environments of the FSCs and SSs; and (c) an estimation of the corrosion of the FSCs and SSs as a combined effect of the material and environment. Because the exterior and interior corrosion environments of the FSCs are different, they will be discussed separately.

Material and Design of FSC and SS

The FSCs are high integrity containment vessels designed to ASME section III requirements. They were proof pressure tested during manufacture and leak tested after being loaded with spent fuel (FSV SAR-II-9 CH 4 2009). A FSC is a cylindrical carbon steel container approximately 16 ft. long and 18 inches in diameter with a 0.5-inch thick shell, a 2.0-inch thick bottom plate and a 1.5-inch thick lid. The lid is sealed with double metal O-rings and bolted to the body of the container with 24 one-half inch steel bolts. The intended function and material group of the subcomponents of the FSCs and SSs are also given in the The FSC and SS AMR (EDF-8612, 2010) Table 2 and Table 3, respectively. Details of the FSC is shown on the FSC Assembly drawing (Drawing 362A0066, 1991) the FSC Fabrication drawing (Drawing 362A0067, 1991) and the FSC Lid Fabrication drawing (Drawing 362A0068, 1991). Details of the SS are shown on the Miscellaneous Details drawing (Drawing 362A0082, 1991)

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There is a groove along the circumference of the bottom plate at the junction with the shell. The depth of the groove is 0.5 inch. The weld joining the bottom and shell is above the groove (Drawing 362A0067, 1991).

The exterior carbon steel body of the FSC and exterior of the SS is protected from atmospheric corrosion by application, during manufacture, of a flame sprayed coating of aluminum to the outside surface. The aluminum coating specification (Document 1742901, 1991) shows the thickness of the coating to be 6 to 8 mils.

Six graphite fuel blocks are stacked and stored in each FSC in an air environment at approximately atmospheric pressure. FSV SAR figure 1.1-4 (FSV SAR-II-9 CH 1 2009) shows the cross section of a standard fuel element to be a hexagon and the distance across the flats to be 14.172 inches. The cross sectional area is 173.9 in^2. The weight of each graphite fuel element is 285 pounds (FSV SAR-II-9 CH 3 2009).

Exterior Corrosion Environment of FSC and SS

FSCs are stored in the FSV Modular Vault Dry Store (MVDS). Each FSC is supported with one SS within the vault (Drawing 362A0300, 1991). Both the FSC and SS are located in the vault making their exterior surfaces subject to the same corrosion environment.

The MVDS was designed such that the cooling air enters through a protective wire mesh intake, flows though a concrete labyrinth, and enters the vault through concrete distribution louvers. The air picks up heat from the vault before passing through the exit louvers, up the concrete duct, and out to the atmosphere through protected outlet ducts (FSV SAR-II-9 CH 1 2009).

An atmospheric corrosion environment can be classified as industrial, marine, rural, and indoor (industrial, commercial, and residential) in descending order of corrosivity (Doffelaar and Atkinson, 1995).

The FSV ISFSI is located on part of the original FSV Nuclear Generating Station site which is about three and one-half miles northwest of Platteville, CO. Platteville is located in Weld County and is about 35 miles north of Denver. DOE owns the 3.83 acres of land on which the ISFSI is located and has easements for access and control of the immediate area. The ISFSI is located approximately 1500 feet northeast of the Xcel Energy fossil-fueled, power plant building. Population density in the rural area surrounding the site is relatively low. The nearest town is Platteville which had a 2000 Census population of 2,370. The nearest population centers with populations greater than 25,000 (based on the 2000 census) are Longmont (population 71,093), Greeley (population 76,930), and Loveland (population 50,608). The nearest boundaries of Longmont, Greeley and Loveland are all about 14 miles from the ISFSI location. The majority of the land within five miles of the site is agricultural. The area within a few miles of the site is characterized by irrigated farm land and pasture land with gently rolling hills. (FSV SAR-II-9 CH 1 2009)

Empty and new FSCs are stored in the MVDS vacant vault positions (FSV SAR-II-9 CH 1 2009). The spent fuel stored within the FSCs in the MVDS is cooled by a passive, self-regulating natural convection cooling system. This system induces buoyancy driven ambient air to flow across the exterior of the FSC (FSV SAR-II-9 CH 3 2009) Based on the above descriptions, the exterior corrosion environment at the FSC and SS can be classified as between rural and indoor atmospheric.

In summary, the environment could be described as:

1. Physical state – air at atmospheric pressure;

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2. Chemical composition – No chemicals, such as salt, in the atmosphere. Furthermore, the cooling air is constantly flowing through the vaults such as to prevent condensate formation on the exterior surfaces from atmospheric moisture.

3. Temperature – ambient. The vaults where the FSCs and SSs are located are continuously cooled by the system. Temperature is critical to corrosion. The rule of thumb is that the corrosion rate will double for every 10 °F increase (Droffekaar and Atkinson, 1995). Hence, keeping temperature low in the vault helps the corrosion control.

Interior Corrosion Environment of FSC

There are six graphite fuel blocks stored in each FSC. Experiments conducted by Great Lakes Carbon Corporation and documented in the PSCo Engineering Evaluation (FSV SAR-II-9 CH 4, Ref 19) indicated:

1. When graphite is saturated with water, its water content would be 0.01% by weight.

2. The water absorbed by the graphite would evaporate quickly in the atmosphere.

The weight of one graphite fuel block is 285 pounds (FSV SAR-II-9 CH 3 2009). A moisture level of 0.01% would result in 0.0285 lbs of water for each block. For six blocks, the total amount of water would be 0.171 lbs (77.56 cc). The 0.01% moisture level is based on the following assumptions (FSV SAR-II-9 CH 4, Ref 31).

1. The fuel and the reactor primary coolant system were dry when the FSV reactor was permanently shut down on August 18, 1989.

2. Reactor operations personnel do not recall any incident resulting in water ingress between the final reactor shut down and the completion of fuel loading at the ISFSI in June, 1992.

3. The fuel blocks were maintained in a dry helium environment throughout their storage period in the Reactor Building, either in the reactor vessel or in the fuel storage wells.

4. The fuel blocks did not come into contact with air until they were loaded into the FSCs for transfer to the ISFSI.

Corrosion of FSC and SS Exterior Surfaces

Among the eight forms of corrosion previously discussed, uniform corrosion is the most likely to occur on the exterior surface of FSC and SS because it is the most common form of corrosion (Fontana 1967). Crevice corrosion and pitting attack are also possible in the area where the graphite blocks are in contact with the carbon steel due to the large potential difference in the galvanic series.

The carbon steel body of the FSC is protected from atmospheric corrosion by application of a flame sprayed coating of aluminum on the outside surface. The protection of steel by aluminum coating depends partly on cathodic protection and partly on the inert barrier layer of oxide film that forms on the metal surface.

There are two types of aluminum coating. A typical type I coating contains 9% Si, 87.5% Al, and 3.5% Fe. A typical type II coating contains 97.5% Al, 2% Fe, and 0.5% Si. In 1969, type I and type II aluminized steels were evaluated at three atmospheric-testing sites. The results of the testing were documented by the Inland Steel Company in a Research Report (Legault and Pearson, 1980). The weight loss data obtained from specimens for six years were fitted to the following equation:

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$\Delta W = \kappa t^{n}$ (Equation 1)

Where

- ΔW = weight loss, g/m^2
- k, n = coefficients
- t = exposure duration, years

Review of the Appendix A certificate of conformance for the aluminum material indicates it would be a Type II. The coefficients of *k* and *n* (Legault and Pearson, 1980) from the curve fitting for the type II aluminum coatings are shown in Table 1. The corrosion losses, including weight losses (g/m^2), thickness reductions (mil) and percentages of thickness reduction (%), for an exposure duration of 40 years are given in Table 2. The percentages of thickness reduction were calculated based on the minimum thickness of the aluminum coating, 6 mils. The thickness of the aluminum coating is between 6 and 8 mils (Document 1742901).

Table 1. The coefficients of *k* and *n* from the curve fitting for type II aluminum coatings (Legault and Pearson, 1980)

Location	Environment	k	n	Correlation Coefficient
Porter County, IN	semi-industrial	1.13	0.88	0.942
East Chicago, IN	semi-industrial	4.06	0.41	0.957
Kure Beach, NC	marine	1.77	0.82	0.978

Table 2. The corrosion losses, including weight losses (g/m^2), thickness reductions (mil), and percentages of thickness reduction (%), for an exposure duration of 40 years for Type II aluminum coatings

Location	Environment	**ΔW** (g/m^2)	**Mils** $_{1,2}$	%
Porter County, IN	semi-industrial	29.0	0.43	7.2%
East Chicago, IN	semi-industrial	18.4	0.27	4.5%
Kure Beach, NC	marine	36.4	0.54	9.0%

(1) density (**d**) = 2.66 g/cm3
(2) **Mils = (ΔW/d)x 39370**

The results in Table 2 indicate that in the worst case (Type II aluminum coating at Kure Beach, NC, marine atmospheric corrosion environment), the thickness reduction of the aluminum coating over 40 years is 0.54 mils, which is 9.0% of the minimum thickness of 6 mils. The results above are for atmospheric environments that are more corrosive than the rural and indoor environment at FSV.

For crevice corrosion to occur between the base of a FSC and the SS beneath it, electrolyte (such as condensate) is needed. This is unlikely because of the drain feature incorporated into the SS geometry (Drawing 362A0082, 1991). This feature would drain any condensate running down the sides of the FSC and into the SS to the vault floor. Also the MVDS cooling air ventilation system reduces the chance of condensate formation. In the worst case, if crevice corrosion did occur, the cathodic protection coating of aluminum would sacrifice itself to protect the carbon steel substrate of FSCs and SSs (ASM Handbook 2006).

In summary, the aluminum coating would protect the exterior surface of FSCs and SSs from corrosion for more than 40 years. After 40 years 9% of the aluminum coating would be lost. This conclusion is derived from the above calculations and supported by the following items as well:

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1. The FSV SAR (FSV SAR-II-9 CH 1, 2009) states that the method of spray aluminum coating protection of FSCs has been used for many years in Europe, and the technique was validated by the American Welding Society (AWS C2.14-74) following a 19 year duration test program. The Foster Wheeler Energy Application (FWEA) MVDS Topical SAR (FSV SAR-II-9 CH 1, Ref. 1) referred to this experience, and NRC letter approval (FSV SAR-II-9 CH 1, Ref. 2) was given for the use of carbon steel containers in MVDS where so protected.

2. Video inspection of FSC and SS exterior surfaces documented in the FSV FSC and SS AMR (EDF 8612 2010) indicated that after almost 20 years of exposure, no corrosion evidence was observed on the aluminum coated surfaces.

3. ASM (ASM Handbook 2006) reports the following:

> Another, well-known study of thermal spray coatings was initiated slightly later in the 1950s by the American Welding Society (AWS C2.14-74). The AWS study included aluminum and zinc wire-flame-spray coated steel specimens with coating thicknesses of 0.08, 0.15, 0.23, 0.30, and 0.40 mm (3, 6, 9, 12, and 15 mils). Field exposures were conducted at a variety of atmospheric exposure sites and two seawater immersion sites. The study was scheduled to last 12 years, but because the coatings were doing so well, the exposure period was extended to 19 years. Results of this 19 year study are presented in a 1974 report (AWS C2.14-74). After 19 years of marine atmospheric exposure, the flame sprayed aluminum coated steel panels showed no rusting of the steel substrates. Over 4000 specimens were included in this study, which found that 0.08 to 0.15 mm (3 to 6 mils)-thick thermal sprayed aluminum coatings (either sealed or unsealed) provided complete protection to steel substrates in seawater, severe marine atmospheric and industrial atmospheres. Some blistering and rust staining of the aluminum coating on unsealed panels were noted. Thermal sprayed zinc coatings were also capable of providing 19 years of protection to steel substrates, but a minimum of 0.30 mm (12 mils) was required for seawater exposures and 0.23 mm (9 mils) of unsealed zinc or 0.08 to 0.15 mm (3 to 6 mils) of sealed zinc for marine and industrial atmospheres.

After aluminum spraying the FSC and SS exterior surfaces were sealed with aluminum pigmented silicone resin sealer (Document 1742901, 1991).

Corrosion of Interior Surfaces of FSC

Referring to the previous discussions, among the eight corrosion forms, uniform corrosion, galvanic corrosion, and crevice corrosion are the corrosion forms that could occur inside the FSCs:

1. Steel is a metal particularly susceptible to uniform corrosion especially in wet atmospheric environments.

2. Crevice formed between the bottom of the graphite fuel block and the base of FSV may cause crevice corrosion of the FSV base.

3. Graphite is one of the noblest materials (by gold and platinum) in the galvanic (electromotive force) series table. On the other hand, iron is a relative active metal positioned between cadmium and chromium. Galvanic corrosion would occur when steel and graphite contact each other and water condensates are present at their interface. In this case graphite would act as the cathode and be protected while steel would act as the anode and corrode more rapidly.

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The most likely location for galvanic corrosion to occur is the interior surface of the FSC bottom where the graphite fuel blocks are sitting. The internal diameter of a FSC is 16.63 inches. The diameter of the circumscribed circle of the hexagonal graphite fuel blocks is 16.367 inches. So there is a gap of 0.132 inches between the edge of the block and the FSC internal wall surface if the blocks were perfectly centered. This means that there would be little contact between the blocks and the walls.

There are four components in each electrochemical corrosion cell (Droffelaar and Atkinson, 1995): an anode (electron donators), a cathode (site where electrons are consumed), a metallic path connecting the anode and cathode, and an electrolyte. For the interior environment of a FSC, the iron provides both anodic and cathodic locations on the surface due to differences in composition from one area to the next and the metallic path. Water serves as the electrolyte. With these elements present the iron is able to corrode by reacting with the water and oxygen present inside the FSC. Getting rid of any one of the above elements will cause the corrosion process to stop. Hence, corrosion will only occur in the FSC until the water is consumed. The electrochemical cell would be disrupted and the corrosion would stop. The corrosion reactions for FSC interior uniform corrosion and galvanic corrosion could be described as follows:

Anode reaction: $2\ Fe \rightarrow 2\ Fe^{++} + 4\ e^-$

Cathode reaction: $O_2 + 2\ Fe^{++} + 2\ H_2O + 4\ e^- \rightarrow 2\ Fe(OH)_2$

Precipitation: $2\ Fe(OH)_2 + \tfrac{1}{2}O_2 + H_2O \rightarrow 2\ Fe(OH)_3$

Overall reaction $2\ Fe + 1\tfrac{1}{2}O_2 + 3\ H_2O \rightarrow 2\ Fe(OH)_3$

The overall reaction indicates that every two moles of iron react with one and half moles of oxygen and three moles of water. A similar set of equations could be written for the corrosion of iron with water in the absence of oxygen that would produce hydrogen as a byproduct. However these equations would consume less iron with the available water inside the FSC than with the aerobic corrosion equations listed above. Therefore, even though the oxygen may be quickly consumed inside the FSC the aerobic equations will still be used to give an estimate of metal loss.

As discussed above, an estimation of saturated graphite moisture level of 0.01% would result in a total of 77.56 grams of water in each FSC. Considering off-normal and accident conditions, a safety factor of 10 is used in this analysis. A safety factor of 10 will raise the total water inside a FSV to 775.6 grams (43 moles), which will consume 1,604 grams (28.7 moles) of iron. The carbon steel density is 128.7 grams per cubic inch. The volume associated with the loss of 1,604 grams of carbon steel is 12.5 cubic inches.

Uniform corrosion would affect the entire interior surface of a FSC, including the shell, the bottom, and the lid. The total interior surface area of a FSC is 9,221 square inches (Table 3). Therefore the thickness reduction would be 0.0014 inches and the remaining thickness of the shell would be 0.4986 inches, the remaining thickness of the bottom plate would be 1.9986 inches, and the remaining thickness of the lid would be 1.4986 inches (Table 4).

Crevice and galvanic corrosion would only affect the bottom plate with a surface area of 217 square inches (Table 3). The thickness reduction would be 0.0576 inches (3%) and the remaining thickness of the bottom plate would be 1.9426 inches (Table 4).

The thinnest remaining thickness after all the water is consumed is in the shell, affected by the uniform corrosion, which would be 0.4986 inch, much thicker than the required minimum thickness of 0.0135 inch.

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Table 3. The interior surface area of a FSC

Height, in,	Diameter, in.	Surface Area, in.^{2}			
		Shell	Bottom	Lid	Total
168.19	16.63	8787	217	217	9221

Table 4. Estimation of the thickness reductions from interior uniform and crevice/galvanic corrosion

Corrosion Form	Corrosion Loss			Thickness, in.					
	Volume, in.^{3}	Affected Area, in.^{2}	Thickness Reduction in.	Shell		Bottom		Lid	
				Starting	Remaining	Starting	Remaining	Starting	Remaining
Uniform	12.5	9221	0.0014	0.5000	0.4986	2.0000	1.9986	1.5000	1.4986
Crevice/ Galvanic	12.5	217	0.0574	NA		2.0000	1.9426	NA	

CONCLUSIONS AND RECOMMENDATIONS

The remaining wall thicknesses of the FSC after all water has been consumed by potential corrosion reactions are much thicker than the specified minimum required thickness of 0.0135 inch described in the Acceptance Criteria Section of this EDF. The FSCs thus are satisfactory for continued service throughout the proposed license renewal period.

The aluminum coating will protect the exterior surface of FSCs and SSs from corrosion for more than 40 years. After 40 years a maximum of 9% of the aluminum coating would be lost.

Consistent with the FSV FSC and SS AMR (EDF 8612 2010) it is recommended that vault external visual inspections be performed periodically (once every 10 years) to examine accessible FSC and SS exterior surfaces for signs of degradation to assure continued acceptable performance during the license period. Tracking and trending of the inspection results should also be performed.

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Appendix A - Aluminum Coating Composition

FWEA PURCHASE ORDER 71231
FWEA CONTRACT 8·2711·5284

DELTA

LOCATION

DELTA ENFIELD WIRES LTD.
MILLMARSH LANE
BRIMSDOWN
ENFIELD
MIDDLESEX EN3 7QB
TELEPHONE: 081-804-1255
TELEX: 264852 DEM G
FAX No: 081-804-5206

CERTIFICATE OF CONFORMITY

IT IS CERTIFIED THAT THE GOODS DETAILED HEREIN HAVE BEEN INSPECTED AND TESTED & CONFORM TO THE FOLLOWING SPECIFICATION

signed [signature] date 27-8-91

Position .... E.R.M. 40

INVOICE TO
The Chief Inspector
Universal Metal Sprayers Ltd
Thorncliffe Works
Thorncliffe Park Estate
Chapeltown
Sheffield
S30 4ZE

RECEIVED 5 SEP 1991

DESPATCH NOTE No.	ACCOUNT No.	DATE OF DESPATCH	CARRIER
11/01271 11/01294 11/01301			

ORDER No.	SIZE AND DESCRIPTION	ORDER STATUS	CUSTOMER ORDER No.	WEIGHT KG	LENGTH METRES
Z99828-1 XXXXXXXX	'Alspray' 99.5% Aluminium Spraying Wire generally to BS1475, 1050A 1972.M		3631	500	20 coils
Z99853-2	4.76mm Dia			250	10 coils
	Batch No. 2178			150	6 coils
	Control No. 29958-28				

Analysis

Silicon:	0.070%
Iron:	0.120%
Copper:	<0.01%
Manganese:	<0.01%
Zinc:	<0.01%
Ti+V:	<0.003%
Chromium:	<0.01%
Boron:	0.004%
Gallium:	<0.01%
Aluminium:	99.75% min

Despatch to

NETT WEIGHT (KG)
TARE WEIGHT (KG)
GROSS WEIGHT (KG)

10 CFR PART 72 SCREEN

Screen # 10-024

Facility Name: FSV ISFSI Change No.: EDF-9166, rev 1

Activity Description: Engineering Design File (EDF)-9166, revision 1, "FSV ISFSI MVDS Fuel Storage Container (FSC) and Support Stool (SS) Corrosion Analysis," evaluates loss of material from corrosion of the Fuel Storage Container (FSC) and Support Stool (SS) at the Fort St. Vrain (FSV) Independent Spent Fuel Storage Installation (ISFSI). Revision 1 of this EDF incorporates recommendations received from the Department of Energy - Headquarters (DOE-HQ) and the Department of Energy - Idaho (DOE-ID), resolves comments received from the ISFSI Safety Review Committee (SRC) and removes reference to Time Limited Aging Analysis (TLAA) which is no longer required for the current 20 year license renewal period.

This EDF concludes that the remaining wall thicknesses of the FSCs under potential interior corrosion attack mechanisms are greater than the specified minimum required thickness of 0.0135 inch described in the Acceptance Criteria Section of the EDF and that the exterior aluminum coating is adequate to protect the exterior surface of FSCs and SSs from corrosion for more than 40 years. After 40 years 9% of the protective aluminum coating would be lost. The FSCs and SSs are satisfactory for continued service throughout the proposed license renewal period.

Use of this form must be in accordance with MCP-2925. Sufficient activity description, justifications, and documents reviewed must be provided to permit an independent reviewer to reach the same conclusions. The discussions in Appendix A should be used to develop any justifications documented below.

1. License Condition or Technical Specification: (Complete this section for all Part 72 screens.)

1a.	Does the activity require any change, even editorial, to the license or technical specifications?	☐ Yes	☒ No
1b.	Does the activity require an exemption to any NRC regulations?	☐ Yes	☒ No
1c.	Is the activity a change to or require a change to FSV SAR Section 7.7, 9.3, or Chapter 11 or TMI-2 SAR Section 7.6, 9.3, or Chapter 11?	☐ Yes	☒ No

Justification: EDF-9166 is only an evaluation of the effects of corrosion to FSC and SS materials. This activity does not require any change to the license or technical specification or require an exemption to any NRC regulations. Also SAR sections above do not need revision based on this EDF.

Documents Reviewed: FSV ISFSI SAR, FSV ISFSI Technical Specifications.

If the answer to 1a or 1b is "Yes" the activity may not be implemented until NRC approval is obtained. If the answer to 1c is "Yes" a ***72.44 Evaluation*** in accordance with MCP-2925 is required before the activity may be completed.

2. Facility Change: If the activity is a physical change (addition, modification, or removal) within a facility or to any equipment or structure, or to any design document (drawing, calculation, analysis, specification, design input or assumption, etc.), then complete this section. Also complete this section for changes to the SAR. Otherwise indicate **N/A** at the end of this section.

2a.	Does the activity adversely affect a design function of equipment or structures described in the SAR or TS Bases?	☐ Yes	☒ No
2b.	Does the activity adversely affect a method of performing or controlling a design function of equipment or structures described in the SAR or TS Bases?	☐ Yes	☒ No
2c.	Does the activity adversely affect an evaluation which demonstrates the design functions of equipment or structures described in the SAR or TS Bases?	☐ Yes	☒ No
2d.	Does the activity result in a change to the Technical Specification Bases?	☐ Yes	☒ No

Justification (include effects that are not adverse): EDF-9166 is only an evaluation of the effects of corrosion to FSC and SS materials. This activity does not have an adverse affect on the design function, method of controlling a design function, evaluation which demonstrates the design functions of the equipment described in the SAR or TS Bases.

10 CFR PART 72 SCREEN

Documents Reviewed: FSV ISFSI SAR, FSV ISFSI Technical Specifications.

If any answer in Section 2 is "Yes" then a ***72.48 Evaluation*** in accordance with MCP-2925 is required before the activity may be completed.

3. Procedure Change: If the activity is a change to facility operation, maintenance, transport, test, or experiment procedures, then complete this section. Also complete this section for changes to the SAR. Otherwise indicate **N/A** at the end of this section.

Is the activity a modification to, addition to, or removal from any procedure that adversely affects the operation and control of equipment or structures as described in the SAR or TS Bases? ☐ Yes ☐ No

Justification (include effects that are not adverse): NA.

Documents Reviewed: NA

If this answer is "Yes" then a ***72.48 Evaluation*** in accordance with MCP-2925 is required before the activity can be completed.

Conclusion:

If all the questions on this form are answered NO, then the signatures on this form will complete the 10 CFR Part 72 regulatory screen and the activity may proceed.

Assumptions & Limitations:

None

APPROVALS

Print/Type Name	Signature	Date
J. L. Stalnaker Complete By Trained Screener Print/Type Name	[signature] Trained Screener Signature	5-10-2010 Date
H. L. Lord Independent Review By Qualified 72.48 Screener Print/Type Name	Harry L. Lord Qualified Screener Signature	10 May 2010 Date