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Augmented Monitoring and Condition Assessment Program (AMCAP) Material Test Reactor (MTR) Fuel Inspection Program Report

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EXECUTIVE SUMMARY

Summary Statement

The AMCAP MTR Fuel Inspection Program, a special inspection program comprised of four inspection campaigns, examined a total of ten (10) pre-selected aluminum-clad, aluminum-based fuel core spent nuclear fuel assemblies (ASNF) stored in the L Area Disassembly Basin (L Basin) at the Savannah River Site. A full description of the inspections and the results are reported. The fuel had been stored in bundled-tube storage (Vertical Tube Storage) for periods of 18 to 21 years. The prior service experience of the individual 10 assemblies varies, but all included irradiation followed by wet storage at international research reactor sites prior to shipment to the US and storage in L Basin. The 10 assemblies were expected to be among the "worst" in terms of prior corrosion damage of the entire inventory of the direct-bundle-stored ASNF in L Basin. The inventory of MTR ASNF in L Basin will continue to be stored in the bundled-tube configuration or in slug-storage buckets with inserts pending retrieval for ultimate disposition.

The MTR fuel inspections focused on collecting information for characterization of the material condition of the ASNF considering various types of aluminum fuel corrosion degradation of its assembled materials in water storage. A custom-designed Fuel Inspection Table was used to stage the fuel for remote, enhanced visual examination (close-up video imaging & recording) with controlled lighting and positioning that enables reproducibility of imaging conditions.

The inspections were conducted by fuel subject matter expert staff from Spent Fuel Project Engineering (SFPE) and the Savannah River National Laboratory (SRNL). Stills captured from the video records were used to compare the corrosion evolution from previous records, as available.

This evaluation of the inspection results including the comparison to the previous inspection results demonstrate that the water quality and the storage configuration of ASNF in L Basin do not cause aggressive corrosion degradation of the fuel; mitigation of the prior corrosion degradation of the fuel also appears to have been achieved with the good water quality conditions of L Basin.

Recommendations are made for future inspection of the fuel to trend corrosion degradation and demonstrate continued safe wet storage of the ASNF in L Basin. The next fuel examination is recommended to be performed in 5 years.

Preparation for the ASNF Inspection Campaigns - Overview

The AMCAP MTR Fuel Inspection Table was designed and fabricated in 2014-2015 and placed in L Basin in 2018. A dummy (mock) MTR fuel assembly was examined to dry run the implementation of the inspection table and the inspection procedure prior to the special inspection campaign of the ASNF. This dry run inspection demonstrated fuel handling by Spent Fuel Operations staff, including the fidelity of the Spent Fuel Program (SFP) Operations Procedure, the SRNL Inspection Procedure, and the general fuel examination capabilities for fuel staged on the inspection table.

The 10 ASNF inspection assemblies were selected based on parameters of prior corrosion degradation, burn-up, and fuel design. Nine of the ten assemblies were of the of Materials Test Reactor (MTR) plate fuel, box design, and the tenth was of an involute, round design. The order was based on criticality potential stemming from End of Life (EOL) U-235 content from fuel receipt Appendix A data available for each of the fuel assemblies.

There were no acceptance criteria prescribed for fuel condition for the inspections. Fuel with cladding breaches is acceptable for storage in L Basin due to the very low, manageable radionuclide release in conjunction with the present water filter-deionizer system on-line for L Basin water quality and activity maintenance.

Summary of the Four Inspection Campaigns

The first of the four inspection campaigns involved the examination of the first of the ten MTR assemblies. The intent was to learn from the first fuel inspection and adjust as necessary either or both SFP Operations Procedure and the SRNL Inspection Procedure (*used as a guide*). The ability to capture video to observe corrosion damage features of small size (1/32-inch resolution) and at repeatable locations was a requirement for the inspection. The ability to vary the intensity of the fixed-position LED lighting on the inspection table with supplemental lighting provided by the basin underwater camera lighting helped improve the quality of the images to better identify features of interest as found.

Video recordings while each bundle was retrieved from storage and staged for debundling was implemented after the first fuel inspection. Other video recordings showing the face views of debundled assemblies at the saw row debundling station, and ad hoc staging of the abandoned bundle for video imaging were also implemented during the inspections.

A new bundle with a removable lid was used to replace the original bundle for each inspection. The fuel was placed in the new bundle in the same loading order as the original bundle.

The second through fourth inspection campaigns were in groups of three assemblies. Each assembly was in a different bundle so that nine separate debundling operations were used.

Nine of the assemblies were MTR design and required four rotations on the inspection table. The third campaign included a round assembly of the involute design (HIFAR fuel) which was rotated three times equally apart to gain good video coverage of the side areas to perform a complete inspection.

Most fuel assemblies had both ends cropped. The cropping of fuel was noted at the inception of this program. Cropping had caused an incidence of irregularly shaped and bent exterior fuel plate ends.

The fourth and final inspection campaign consisted of three assemblies that were unique amongst the ten selected assemblies. Generally, these assemblies had considerably higher burnup than those in previous inspections. Additionally, one bundle has a history of extensive cobweb formation; an assembly from this bundle was interrogated for potential incidence of microbial corrosion attack. Collectively, these three assemblies represented the highest U-235 content of the inspection assemblies and were therefore reserved for the final inspection campaign.

The complete set of video recordings from the inspections are stored as inspection records on the SFPdata server on WG10 SRS server.

Summary of the Inspection Results

Corrosion damage to the fuel was readily observed. The inspection results were captured in video recordings and stills from the recordings. The types of corrosion were localized corrosion and included crevice, pitting, galvanic-induced, and end-grain attack. The corrosion, and the extent of the corrosion damage, with the possible exception of the end-grain attack, is attributable to damage caused in poor water quality storage conditions prior to receipt in L Basin. Furthermore, the level of corrosion damage did not interfere with the ready handling of the fuel assembly in unloading/reloading into a bundle, and in movement as the assembly was picked up and manipulated on an individual assembly basis.

The first fuel assembly inspected was an aluminum-clad Argentine RA-3 box type control assembly with very low burnup. The control assembly had cropped ends, no bail present, and easily seen, from either assembly end, two pairs of stainless steel control plate guide inserts running through the assembly body. The assembly had edge corrosion on side plates, crevice corrosion at the interface of the side plates and exterior fuel plates, a cluster of raised nodules and singular patches of pits over the fuel meat region of fuel plates, some evidence of partial discolorations on the edges of fuel meat regions, and minor incidence of pit discolorations. One of the debundled assemblies within the inspection bundle had a darker discoloration over the complete face of an exterior fuel plate, within the fuel meat region.

An RA-3 inspection assembly was included in each of the three campaigns that followed. In general, similar corrosion features were observed for all four RA-3 inspection assemblies. However, the RA-3 fuel assembly inspected in the final campaign had a significantly higher burnup than the previous three assemblies, and distinct areas of oxide spalling/exfoliation with nodules around the periphery were observed at the corners of the fuel meat region. This feature was not observed for the lower burnup RA-3 inspection assemblies.

The two Italian Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA) Galileo fuel assemblies, inspected from separately stored bundles, had minimal corrosion features over exterior fuel plate fuel meat regions and had no evidence of side plate crevice corrosion anomalies noted on the ends of the fuel. However, ENEA stored ISPRA Reactor fuel had moderate side plate edge and crevice corrosion with persistent colonies of end-grain corrosion and corrosion products on the ends of the assemblies of greater severity than most inspected assemblies.

The High Flux Australian Reactor (HIFAR) Fuel from Australia has a cylindrical tube as the outer component of the assembly. The tube was inspected along with the edge of the fuel plates, which were only viewable from one end. The outer tube was composed entirely of a single aluminum alloy and displayed pitting evenly distributed across the entire surface. Numerous small pits covered most of the surface with large, and in some cases through-clad, pits being present with less density but still common.

The Netherlands High Flux Reactor (HFR) Petten inspection assembly was inspected with only a minor number of anomalies of smaller surface area pits and nodules over the fuel meat regions.

A Brazilian Instituto de Energia Atomica (IEA-R1) reactor fuel was examined in the second inspection. Like RA-3 fuel, the IEA-R1 fuel had moderate to advanced corrosion attack including severe side plate edge corrosion; moderate crevice corrosion; exterior fuel plate, fuel meat region pitting including raised nodule colonies and pronounced pitting that included decladding and discolorations in some of those pits.

Comparison pictures and/or field sketches were developed from previous field inspections archives for the RA-3, IEA-R1, HIFAR, ENEA Galileo and ENEA ISPRA fuel which included most of the ten assemblies inspected. In all these comparisons between facility and L Basin inspections, the comparisons between the original storage facility and L Basin inspections showed no progression of corrosion due to L Basin bundled storage.

A table that summarizes the inspection observations and results for the 10 ASNF inspected in the four inspection campaigns is in the Analysis section of this report.

Still images from the current AMCAP MTR Fuel inspection videos and video and photographs of previous facility inspections were collected to make comparative judgements on the progression of corrosion attack for each inspection assembly. These images have been archived in Appendix 3 of this report.

Recommendations and Considerations

The special inspection program to inspect 10 assemblies in 4 separate inspection campaigns was successfully completed. The results of corrosion damage were compared to the results of inspections made at the basin of origin, or upon initial receipt in L Basin, as available. It is concluded that the water quality and the bundled storage configuration for ASNF in L Basin do not cause aggressive corrosion degradation of the fuel. It is further suggested that mitigation of the prior corrosion damage of the fuel also appears to have been achieved with the good water quality conditions of L Basin.

The original target of the AMCAP MTR Fuel Inspection Program was to perform this special inspection as a baseline inspection and then reinspect the 10 assemblies after a 5-year additional storage period to evaluate changes in the level of corrosion. The investigation of past inspections enabled an adjustment in program planning. The AMCAP inspection team reviewed the original inspection video from previous facility inspections and records to enable comparisons to the present inspection results, which amounted to approximately 20 additional years of L Basin storage. The following summarizes the recommendations for assembly inspection in 5 years. Inspection of these assemblies would strengthen the posture that the types of localized corrosion are not progressing under L Basin storage conditions.

Two of the fuel assemblies in the present inspection are not recommended for reinspection due to the minor amount of corrosion damage observed. This includes one of the two ENEA Galileo fuel assemblies and the HFR Petten Assembly.

For the RA-3 fuel, two of the four assemblies are recommended to be reinspected in 5 years. This includes S-113, the first RA-3 inspection assembly, which was a control assembly with stainless steel components that could serve as galvanic couples and the final RA-3 assembly, 236, which was a standard assembly with significantly higher burnup, stainless steel components, and corrosion features unique to the RA-3 assemblies inspected. All RA-3 assemblies showed similar corrosion features in the same places for edge corrosion, crevice corrosion, fuel meat corrosion both pits and nodules and end-grain corrosion on the ends of the assemblies. Additionally, there was a standard assembly, 138, within the first inspection assembly bundle, that had complete dark discolorations over one face of the fuel meat region of an exterior fuel plate that is also recommended for inspection. Three RA-3 assemblies are recommended for future fuel inspections.

ENEA ISPRA Reactor fuel assembly 3-9-IX is also recommended for reinspection. Extensive crevice corrosion and corrosion of the side plates was observed, in addition to end-grain corrosion observed on the ends of the assembly. Because of these extensive, identifiable corrosion features, this assembly is a valuable candidate for reinspection to determine if the good water quality conditions of L-Basin are effectively mitigating additional corrosion attack in areas where accelerated attack has occurred. In addition, a higher burnup assembly is recommended within the same bundle. Assembly 3-51-VI is selected for inspection during future inspection campaigns. This assembly has a 60% burnup compared to 3-9-IX with a burnup of only 30%. A comparison of the recommended inspections could elucidate the impact, or lack thereof, of burnup on the extent or type of corrosion.

The two inspections associated with the Italian ENEA Storage Facilities' Galileo fuel showed minimal corrosion. The moderate corrosion profiles associated with this MTR fuel are bounded by other inspections of other AMCAP MTR Fuel inspections. However, unique corrosion characteristics were observed on the second Galileo fuel assembly 71-GA67 that warrant a repeat inspection to monitor the condition of the assembly over L Basin storage time. This second Galileo inspected fuel is recommended for reinspection.

The IEA-R1 reactor assembly IEA-79 is also recommended for reinspection. This assembly contained pits in the fuel meat region that appeared to indicate decladding and fuel failures, in addition to a number of other corrosion phenomena, which in many cases were some of the most severe of the ten assemblies inspected. As IEA-79 was a relatively low burnup assembly, a high burnup assembly IEA-77 (in an adjacent stored fuel bundle, same rack) is also recommended for the next fuel inspection. This higher burnup fuel selection for inspection is contingent on the availability of previous facility inspection data that can be used for comparisons.

The inspected Australian Mark III fuel UED 1567 had limitations for inspecting fuel plates. Since the outer tube was constructed of a single aluminum alloy, and one of the ends had a fuel ID plate installed cover the ability to view one end of the fuel plate ends, the only useful fuel inspection information observed was on one end of the fuel assembly. Although the HIFAR assembly has limited fuel inspection value, a reinspection of the assembly would provide a check on regular aluminum corrosion rates within a stored bundle, focusing on the exterior aluminum tube condition over storage time.

Summary Table of Inspection Assemblies for Next 5-Year MTR Fuel Inspection				
Country of Origin	**AMCAP MTR Fuel Inspected**	**Reinspect in 5 years? (Y or N)**	**New Fuel to Inspect**	**New Fuel Attributes**
Argentina RA-3	S-113 (C)	Y	138	Fuel Meat Discoloration
Argentina RA-3	30	N		
Argentina RA-3	160	N		
Argentina RA-3	236	Y		
Australia HIFAR	UED 1567	Y		
Brazil IEA-R1	IEA-79	Y	IEA-77	Higher Burnup IEA-R1 Fuel
Italy Galileo	71-GA67	N		
Italy Galileo	GA-84 X (C)	Y		
Italy ISPRA	3-9-IX	Y	3-51-VI	Higher Burnup ISPRA Fuel
Netherlands HFR Petten	F950	N		

It is also suggested that emptied bundles be more thoroughly inspected after debundling to identify any signs of corrosion. Only six of the ten bundles pulled for this inspection received the benefit of a cursory inspection to look for gross debris (e.g. detached fuel plates), but smaller debris, corrosion product, or signs of corrosion attack of the bundle at contact points with the stored fuel may still be observed with a closer inspection.

In addition, it is suggested that the opportunity to inspect other assemblies in the target assembly's bundle is seized. While it is not recommended that each assembly be moved to the inspection table, a less extensive inspection with a pole mounted underwater camera between debundling and placement in the isolation bucket would be of programmatic value.

For consideration are improved tools for the inspection of inner fuel plates to include the use of video scopes and /or Non-Destructive Evaluation (NDE) techniques. Additionally, lighting changes should be thought out and prescribed for the ends to allow and facilitate better viewing between fuel plates, as a minimum recommendation for consideration.

1.0 INTRODUCTION

Originally, the L Basin facility was slated to terminate its fuel receipt and fuel storage mission in 2019. It was evident by the 2010 decade that the Spent Fuel management mission would extend well beyond 2030. Aluminum fuel inspection was part of a recommendation to allow for extended fuel management in L Basin [1].

A program plan for a special inspection of aluminum fuel using a remote, underwater visual examination method was prepared [2], and a set of ten fuel assemblies was selected for the inspection [3]. The fuel selected was the Material Test Reactor (MTR) design (fuel plates), the predominantly aluminum fuel in L Basin, and one involute design. All the fuel was of Foreign Research Reactor (FRR) origin with a history of storage in their associated native storage facilities post reactor discharge. Most of these selected assemblies have been stored in L Basin for approximately 20 years and at least that long in the original storage facilities.

The fuel selected for inspection was intentionally chosen for its corroded condition, as it had an incidence of corrosion as found during storage facility field inspections prior to shipment to the Savannah River Site (SRS). The attributes of the fuel selected also included a full range of fuel burnups and facility storage conditions (good water quality to poor water quality, some with a dry storage history).

The inspection concepts and apparatus (fuel inspection table with its camera and lighting system) for performing the inspection in L Basin were developed in 2014. Subsequently, funding for the Augmented Monitoring and Conditions Assessment Program (AMCAP) was suspended until Fiscal Year 2018. Preparations were made in FY18 to perform the inspections in L Basin.

In calendar year 2019, all ten selected assemblies were inspected over four different inspection campaigns starting with one assembly followed by batches of three assemblies. Spent Fuel Project (SFP) operations performed fuel movements for the AMCAP Inspection Team. The AMCAP Inspection Team included SFP engineering and Savannah River National Laboratory (SRNL) nuclear materials management and corrosion experts.

This report is a comprehensive description of the inspection of the ten assemblies. The information includes the details of fuel handling, fuel examination, and the results of the fuel inspection with its focus on the condition of the fuel in terms of corrosion attack. As available, the storage history at the FRR sites has been assembled. This report also provides recommendations for future inspection of aluminum fuel to support its safe storage in L Basin until retrieval for final disposition.

2.0 TYPES OF CORROSION TYPICALLY FOUND IN SFP'S L BASIN

All the fuel selected for the inspection campaigns had prior incidence of corrosion attack. The potential types of corrosion attack on aluminum materials in reactor and basin water is summarized in an International Atomic Energy Agency (IAEA) good practice guide for nuclear storage facilities [5]. A brief summary of the types of corrosion observed on the inspected fuel is provided in this section as a basic orientation to the factors involved in the corrosion phenomena found in SFP's L Basin.

The types of corrosion presented are limited to corrosion that was observed.

General corrosion is the inevitable process of aluminum corrosion in water. Recent work done by SRNL for the U. S. Nuclear Regulatory Agency (U.S. NRC) [4] suggests that, based on the low temperature and good water quality conditions of L Basin, the general corrosion rate should be bounded by approximately 0.1-0.2 mils per year. This corrosion rate would be further reduced specifically for aluminum spent nuclear fuel (ASNF) placed in the reactor core due to a high-temperature-formed oxide that forms during reactor operation.

The observed types of localized corrosion, typical for ASNF stored in L Basin, are crevice, pitting (on-plate and on-edge), galvanic-induced, and end grain attack (or end grain pitting).

The corrosion of aluminum in basin storage water is an electrochemical process which is impacted by a balanced surface potential between aluminum oxidation and the reduction of oxygen that occurs at the surface. The surface potential is impacted not only by the surface of the aluminum alloy (bulk alloy composition, microstructure, surface condition, oxide(s) present) but also many factors of the environment around it (solution conductivity, chemistry, oxygen availability).

Crevice Corrosion – this form of corrosion occurs on a metal surface at locations where two surfaces are joined together, such as the joint of the side and fuel plates of the MTR fuel or a rivet that holds a lifting bail to a fuel assembly. Under-deposit corrosion, which results from debris that accumulates on a metal surface, is a form of crevice corrosion. The crevice allows a generally stagnant micro-environment to form, which leads to the initiation of corrosion from changes in the crevice chemistry, which will differ significantly from the bulk water chemistry. These changes include oxygen depletion in the crevice, acidification of the crevice solution, and a build-up of aggressive species such as chloride.

The factors that impact the initiation and progression of crevice corrosion include:

- Type of crevice – metal to metal or metal to nonmetal
- Geometry of the crevice – size of the crevice opening (tightness), depth and surface roughness
- Metal composition
- Environment – pH, halide concentration (bulk and in-crevice), temperature and oxygen availability (bulk and localized).

Pitting Corrosion – a localized corrosion of a passive metal surface that initiates in a pin-point, then takes the form of varying sized, drill-like cavities with time. The formed pits may be open and uncovered or covered with a semi-permeable membrane of corrosion products (i.e., nodules). For aluminum, the ready formation of aluminum oxide contributes to both oxide within a pit as well as a nodule over the pit. Factors that impact the initiation and progression of pitting corrosion include:

- Metal composition and surface characteristics – presence of surface defects (second phase/intermetallic particles, grain boundaries, etc.)

- Environment – pH, halide concentration, especially chloride, bulk and in-pit oxygen availability, bulk solution conductivity

Pitting at the edge of a side plate end can be described as "edge corrosion" to highlight the prevalence of pitting at this location. Factors contributing to pitting near an edge may be associated with more surface defects associated with the formation of an edge including the ability to physical passivate an angular structure like an edge of a plate.

Galvanic Corrosion (*or Galvanic-Induced Corrosion*)– results from the electrical contact of two dissimilar metals such as two different aluminum alloys or aluminum and stainless steel, in the presence of a conductive electrolyte. In these couples, the less noble material (i.e., aluminum) will become the anode of this corrosion cell and tend to corrode at a higher or accelerated rate, compared with the uncoupled condition. The more noble material (i.e., stainless steel) will act as the cathode in the corrosion cell. An undesirable condition is to have a minor anode as compared to the cathode or a small anode/cathode ratio. The surface potential of the materials is important in determining which material is the anode. Galvanic-induced corrosion on a microscopic scale can also occur between constituents of multi-phase alloys, impurities, and second phase/intermetallic compounds. The same factors affecting the other forms of localized corrosion also play a role in the occurrence and severity of galvanic corrosion with the most important variables being conductivity of the aggressive solution, the difference in corrosion potential between the galvanically coupled materials and the surface ratio between the electrodes.

End Grain Attack (End Grain Pitting) – another type of edge/pitting corrosion that occurs selectively on the cut surface or cross section that is normal to the rolling or fabrication direction. The presence of impurities (stringers) or second phase/intermetallic particles on this surface enhance the localized corrosion due to differences in surface potential as discussed for galvanic corrosion. If the attack progresses along a grain boundary or flow lines aligned in the rolling or fabrication direction, the attack can occur at a faster rate. The factors impacting the other forms of localized corrosion also affect end grain attack.

3.0 WATER CHEMISTRY IN SRS SPENT FUEL POOLS

Spent fuel from the SRS production reactors was discharged and cooled in large basins with light water (approximately 3-4 million gallons) for up to 18 months to achieve radioactive decay sufficient to enable transportation to the Canyon or Tritium extraction facilities for processing and material reclamation. Historically, there were five reactor spent fuel pools and the Receiving Basin for Offsite Fuel (RBOF). With the de-inventory of RBOF, completed in 2003, all Spent Nuclear Fuel (SNF) at SRS had been consolidated into the spent fuel pool in L Area. The L Area Disassembly Basin (L Basin) mission was changed to new mission work from nuclear non-proliferation programs associated with Foreign Research Reactors (FRR) and Domestic Research Reactors (DRR).

The L Basin went through several upgrades in its water purification systems from portable deionizers to permanent, redundant cation and anion exchange systems. Sand filters were replaced with new sand filters. Sludge on the basin floor was removed by vacuuming. New importance was placed on the target parameters for maintaining an enduring good water chemistry program.

The international community managing spent nuclear fuel from research reactors around the world realized the importance of managing their spent fuel water quality in order to preserve the integrity of their spent fuel and prevent deterioration of the fuel from aspects of corrosion of the fuel stored in water systems. The International Atomic Energy Agency (IAEA) issued a good practice guide in 2011 [5] addressing both reactor systems and spent fuel water quality specifically addressing aluminum clad fuel.

The important water quality parameters for corrosion control for aluminum fuel include:

- Conductivity
- pH
- sediments
- anion and cation impurities (chloride in particular)

Maintaining the conductivity of the water as low as practicable is paramount to minimize corrosion processes. The conductivity of pure water at 25 degrees C is 0.0548 micro Siemens per centimeter (μS/cm) which would be the absolute limit for water conductivity. Anion and cation impurities contribute to the conductivity, and in particular, the chloride ion is aggressive to localized corrosion of aluminum. The Pourbaix diagram for aluminum in water shows that a passive oxide layer is stable between a pH of 4 and 8.5 in the water stability region [6]. The typical pH for open pools of water is typically within this range and would not be aggressive in terms of aluminum general corrosion.

Sediments are not prevalent in the open pool of L Basin. The sand filter effectively removes particulates, and sludge on the basin floor is not suspended to provide a source of its settling on the aluminum fuel that is protected from sediments/debris in some measure by bundled storage configuration.

The L Basin facility prepares and uses deionized water as its make-up water. Water is recirculated in a closed loop, minus evaporative losses. Evaporative losses are higher in the winter months so more of the purer deionized water is added to the spent fuel basin during these months.

The fuel that has been received and stored in L Basin since that time has been stored in water quality typically within operating limits. The operating limits are within the IAEA guidelines for good water chemistry. This preserves both the aluminum fuel cladding and the aluminum structural components over an extended storage period in a spent fuel water storage basin.

The L Basin trends for conductivity for the last calendar year (2019) trended between 0.5 to 2 μS/cm for an average of 1.25 μS/cm. Over the last 20 years, and especially in the early part of those years, trends of conductivity were generally lower at around 0.1 to 1.1 μS/cm or an average of 0.5 μS/cm.

The L Basin trends for pH was typically at a pH centered on 6.0 within a range of 0.5 over the last 20 years including the last calendar year (2019). The pH and conductivity are monitored every week using sampling methods.

Chlorides and metal ions including iron and aluminum ions, were typically less than 0.2 ppm over the last 20 years for the L Basin. Copper and mercury are also closely monitored for L basin. All of these elements and ions are monitored every 6 months using sampling methods.

4.0 AMCAP MTR FUEL INSPECTION

4.1 Selected Fuel Assembly Attributes and Opportunities

Fuel assemblies selected for underwater inspection are summarized in the "Basis for Fuel Selection" document [3]. The fuel assemblies selected all have aluminum cladding with mostly uranium-aluminum fuel cores. Variances in the selected fuel cores extend to an assembly with a blended core that contained uranium oxide and uranium silicide fuel.

The fuel selection basis was limited to foreign or domestic sourced, Material Test Reactor (MTR) assemblies with existing observable corrosion or suspected corrosion pre-cursors. There were 10 assemblies selected from five countries and from a total of six irradiation facility/reactor sites within those countries. Nine of the assemblies selected contained High-Enriched Uranium (HEU) fuel.

Physically most assemblies were of the box-type, mostly square, slightly rectangular cross-sectional shapes. One of the selected assemblies was round with inner and outer inert holding tubes with involute fuel fastened between the tubes. Most of the other fuel assemblies were of the box type and included side plates. The length of each assembly varied but most assemblies inspected had a singly or doubly cropped end(s) resulting in an inspected assembly length of 25 to 30 inches. Nozzle ends had been cropped previously. In most cases stainless steel screws were removed by slight cropping of the inert section of the opposite fuel end to the nozzle. Seventy percent of the selected assemblies had curved fuel plates sandwiched between two side plates. The aluminum alloy used in the materials of construction was mostly 1100 aluminum or alloy of similar composition. There were few variances in side plates towards 6061 aluminum or the international standard near equivalent to it. Most sides plates were 1100 aluminum.

The years of storage include the reactor storage facility and Savanah River Site (SRS) Spent Fuel L Basin storage as of CY2019.

Fuel	Plate Geometry	Cobweb Severity Level	Years of Storage	Burnup (KWd/assy)
IEA-R1	curved	Low	55	0.6
SALUGGIA (ENEA)	flat	Low	39	1.0
RA-3	curved	Medium	32	5.4
RA-3	curved	Medium	44	8.6
SALUGGIA (ENEA)	flat	Low	39	16.7
RA-3	curved	Medium	47	24.4
HIFAR	involute	Low	49	45.6
RA-3	curved	Medium	41	72.3
SALUGGIA (ENEA)	curved	Low	46	77.4
HFR Petten	curved	High	23	211.8

SRNL-TR-2012-00171 [3]

The bundles had nominally four or five assemblies within them. Most of the inspected and bundled assemblies were standard type fuel assemblies. A couple of the bundles had an inspection or other bundled assembly with a control assembly which still had the stainless steel guide plates affixed with it. These control assemblies were also fitted with supplemental ID tags made up to fit through the ends of a control assembly that also had an aluminum 1100 material pedigree.

Some of the standard assemblies had an intact bail on the top end of the assembly which had stainless steel screws holding the bail intact. The stainless steel screws were viewable from each of the two side plates.

The primary consideration which formed the basis for inspected fuel selection was prior knowledge or records of fuel degradation at the time of receipt into the basin. A variation of fuel type and burnup was then emphasized in order to expose what, if any, correlation could be drawn between these parameters and corrosion susceptibility. Older fuels were then prioritized as these would be expected to exhibit the most impact from wet storage, all other things being equal. Lastly, a single outlier assembly was chosen from a bundle featuring a high "cobweb" severity specifically to investigate potential microbial corrosion. Barring any cladding surface effect from these cobwebs, this assembly was otherwise known to have excellent storage history and could serve as a pristine condition.

All assemblies selected were stored in L Basin in Expanded Basin Storage (EBS) Bundles with nearly half of the selected assemblies stored in bundles in L Basin over 20 years. Most of the assemblies inspected have been stored in wet storage between the original facility and Savannah River Site (SRS) L Basin in excess of 30 years. Some of the assemblies have been reactor discharged in excess of 50 years.

4.2 The Developed MTR Fuel Inspection Table

The MTR fuel Inspection features double and adjustable intensity Light-Emitting Diode (LED) light banks on the corner of the inspection table, backstop rest for the inspected fuel, accommodations to receive rectangular box MTR fuel or round fuel, 8 camera slots for optimized basin underwater camera viewing and camera zooming, symmetrical ruler for fuel positioning on the table, accommodations for up to a 36 inch fuel length and adjustable inspection table legs.

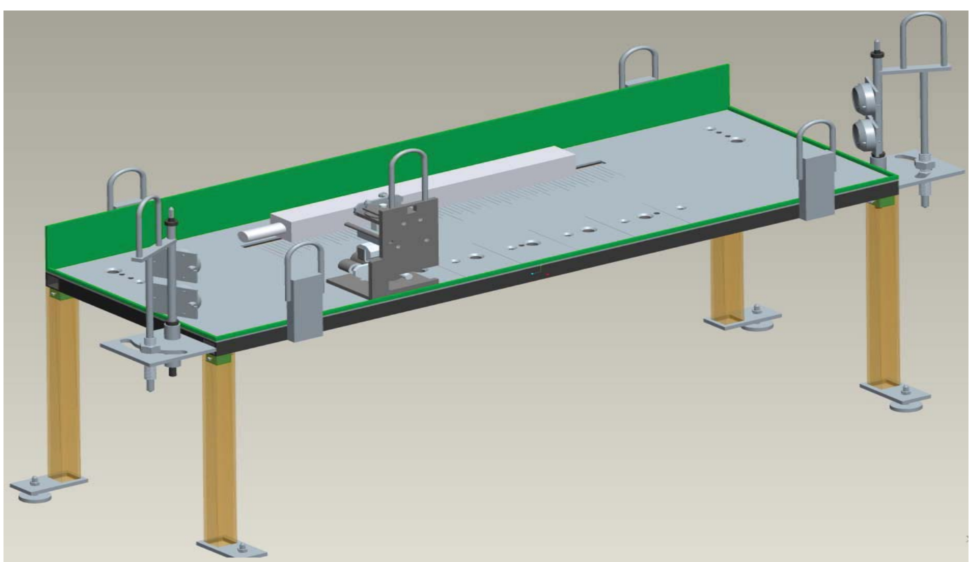

Figure 4-1 L Basin MTR Fuel Inspection Table Isometric

The Inspection Table consists of 8 distinct camera locations designated Slots 1 through 8. Once a slot is occupied, the camera can pan and tilt to investigate anomalies and regions of interest. The camera angle must first be centered following relocation to a new slot in order to provide a full viewed snapshot of each 6" segment of the fuel. The locations are marked by slots in which to drop the camera holding tool.

Remote controlled LED lights are also included in the inspection table design. These lights can be toggled on/off alternately throughout the procedure to provide optimal viewing conditions of certain regions of the fuel. The LED lights are also adjustable individually as two or just one light banks(s) with and without the use of the basin underwater camera lighting.

A visual aid gauge is provided to assist the inspectors in characterizing the surface area of surface flaws such as pits, nodules, and general corrosion. This tool can be placed overtop the target assembly to overlay a calibrated semi-transparent grid on the camera view. The grid line pitch is 2 mm or approximately 1/12". The visual aid gauge was used and placed over the fuel, but there was no attempt to measure the surface area of anomalies, as the focus was capturing observations during inspection of the fuel resting on the inspection table. The visual aid gauge was optionally used as determined by the inspection team.

The assembly staging area of the table features a backstop, fuel trough and engraved ruler markings to assist in consistent placement of assemblies. Rectangular fuels should be pressed against the backstop while cylindrical fuels should rest in the fuel trough. Lateral positioning is achieved using the engraved ruler markings to ensure left/right centering. The fuel is centered when both edges of the assembly fall on the same ruler marking number on either side of the centerline, 0.

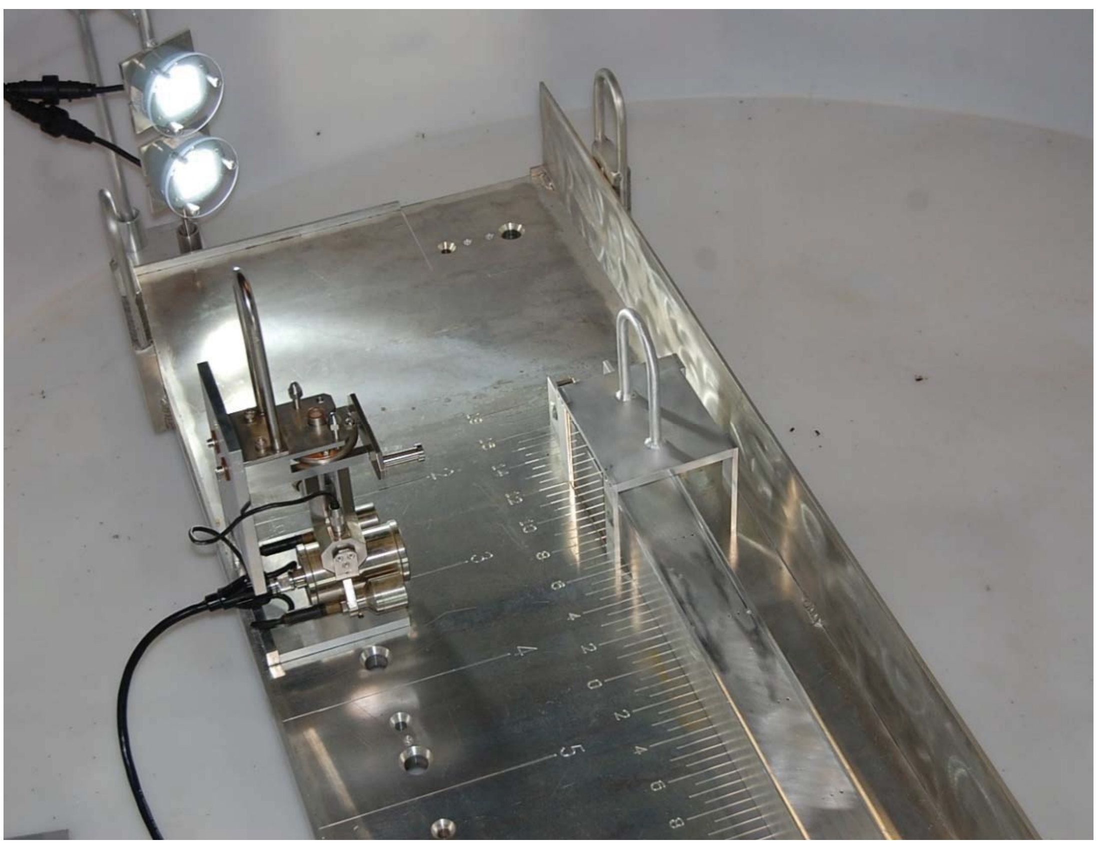

Figure 4-2 Inspection table showing LED light bank on, camera with fixture and fuel assembly area gauge

4.3 Strategy for the AMCAP Fuel Inspections

Two procedures were developed to execute the fuel inspections.

An operations procedure (SOP-DHS-166-L) [7] was developed to facilitate the inspection bundle retrieval and movement to a bundle unloading station. The fuel was to be carefully removed one at a time and placed in a slug bucket with a criticality safe bucket insert. The slug bucket was moved to the area of an inspection table, and the inspection assembly was to be removed and placed horizontally on an inspection table.

Video recording of the bundle movement from the stored position to the debundling station, and as the fuel was individually unloaded at the fuel unloading station and placed into a slug bucket was taken.

During the inspection process, fuel was rotated to get the whole circumference of the fuel. Cameras were also moved by operations from one slotted position to the next. At the completion of the inspection the fuel assembly was removed from the inspection table and loaded back into the slug bucket.

The slug bucket was moved to the tilt table for loading the fuel into a new bundle. After the fuel was loaded into the new bundle, a removable lid was secured onto the bundle. The fuel loaded into the new bundle was loaded in the same order that it was debundled from the original bundle prior to the inspection. The bundle was then moved back to its stored position.

The old bundle was held for a later camera inspection of the empty bundle without procedure.

An SRNL inspection procedure [Appendix 6] (*used as an inspection guide*) was also developed as work instructions for the inspection team to use to ensure a consistent fuel inspection was performed. The inspection team consisted of an SRNL nuclear fuel storage expert, an SRNL corrosion expert and an SFP fuel inspection cognizant process engineer. The inspection procedure had the means of performing the inspection within its work instructions. These instructions included prescriptive direction on fuel rotations, camera placements, varying lighting between the LED light banks and the camera light to obtain various contrasts to perform a comprehensive inspection. The stationed camera has a zoom-in feature to gain localized video positioning to capture the breadth of corrosion features. The inspection team worked at their own pace to gain the comprehensive inspection of the inspection assemblies.

Opportunities arose after the first inspection debundling to gain more video of the other assemblies as they were being debundled and raised to place debundled fuel into a facility slug bucket insert. These opportunities publicized and optimized obtaining video for both fuel plate faces while the fuel was handled vertically, although lighting was adjusted during these operations, but it was not consistently optimized. Other opportunities included obtaining video of the fuel bundle travel paths from retrieving the bundle to lid removal and fuel debundling. Fuel debundling video was limited by camera lighting and basin underwater lighting which casted shadows and suspect discolorations of the fuel during debundling operations. Video of the interior of the empty bundle was grossly achieved to check for unexpected anomalies or crud at the bottom of the bundles. This empty bundle video was a bonus for defining basin general corrosion of the L Bundles in underwater storage over an extended period.

The inspections of the ten targeted fuel assemblies, from ten separate fuel bundles, were performed in four campaigns. The first campaign had only one bundle. Succeeding fuel inspection campaigns were performed in three sequential campaigns each containing three bundles of fuel with and three separate fuel inspections, using the inspection table. A separate operations procedure was used for each fuel inspection, having a code of inspection record for each MTR fuel inspection.

Lessons learned gained from fuel inspections notably were included from the first fuel inspection and thus operations procedure improvements were made. The second fuel inspection campaign validated the first fuel inspection and lesser operations procedure improvements were made after that campaign.

Of the ten assemblies selected, there were seven assemblies from two different countries. Where there is more than one inspection from a specific country, this inspection report numbers each of the inspections sequentially in the order that the inspections occurred.

<u>For reference the following was the inspection order for the inspected 10 MTR aluminum -clad fuel assemblies:</u>

<u>Campaign 1- Inspection 1</u> (*Conducted January 2019*)

Argentine RA-3 Bundle L-RA3-0817 with Inspection Control Assembly S-113 bundled with 2 Standard Assemblies 138 and 195.

<u>Campaign 2</u> (*Conducted June 2019*)

<u>Inspection 2</u> Brazilian IEA-R1 Bundle L-IEA-R1-0625 with Inspection Standard Assembly IEA-79 bundled with 4 Standard Assemblies IEA-59, IEA-61, IEA-66 and IEA-72.

<u>Inspection 3</u> Argentine RA-3 Bundle L-RA3-0822 with Inspection Standard Assembly 160 bundled with 3 Standard Assemblies 110, 139 and Commission Nacional de Energia Atomica (CNEA)-301.

<u>Inspection 4</u> Italian ENEA Galileo Bundle L-ENEA-0024 with Inspection Control Assembly GA 84X bundled with 4 Standard Assemblies CMN 7, GA 12, GA 16 and GA 45.

<u>Campaign 3</u> (*Conducted August 2019*)

<u>Inspection 5</u> Argentine RA-3 Bundle L-RA3-0794 with Inspection Standard Assembly 30 bundled with 2 Standard Assemblies 153 and CNEA-257 and a Control Assembly CNEA S-121.

<u>Inspection 6</u> Italian ENEA Galileo Bundle L-ENEA-0352 with Inspection Standard Assembly 71-GA67 bundles with 4 Standard Assemblies 71-GA69, 71-GA72, 71-GA76 and 71-GA77.

<u>Inspection 7</u> Australian HIFAR Bundle L-HIFAR-1918 with Inspection Mark III E Assembly UED 1567 bundled with 4 Mark III E Assemblies ED 513, UED 1553, UED 1556 and UED 1561.

<u>Campaign 4</u> (*Conducted December 2019*)

<u>Inspection 8</u> Argentine RA-3 Bundle L-RA3-0787 with Inspection Standard Assembly 236 bundles with 3 Standard Assemblies CNEA-270, CNEA-271 and CNEA-272. in the bundle.

<u>Inspection 9</u> Italian ENEA ISPRA Bundle L-ENEA-0356 with Inspection Standard Assembly 3-9-IX bundled with 4 Standard Assemblies 3-1-IX, 3-5-IX, 3-12-IX and 3-51-VI.

<u>Inspection 10</u> Amsterdam HFR Petten Bundle L-HFR-1435 with Inspection Standard Assembly F950 bundled with 3 Standard Assemblies F976, F987 and F1130.

APPENDICES list video still pictures for debundling and the fuel inspection, comparisons of both debundling and inspection (limited) pictures with previous facility fuel inspections, and a video catalog guide. The video for this inspection effort is part of the record of the inspection.

Other assemblies' debundling pictures and fuel inspections comparisons are shown in Appendix 1, Inspection Assembly Bundle Debundling Photos.

Additional pictures are noted in Appendix 2, Inspection Assembly Photos.

Comparison pictures from previous facility inspection sheets and/or pictures to the inspection debundling or inspection table pictures are listed in Appendix 3, Inspection Assembly Bundle Debundling/Inspection Pictures with Previous Facility Inspections.

Appendix 4 lists MTR Fuel Inspection Campaigns Digital Media Catalog for all the video taken from moving the bundle from storage to debundling, debundling operations, and inspection of the selected fuel inspection at the inspection table for each of the ten selected fuel inspections with bundled information.

Appendix 5 presents Opportunity Inspection Pictures of Interest that includes pictures of debundling, at the inspections table and inspection of emptied bundles. A brief narrative follows each picture.

Appendix 6 is the SRNL MTR Fuel Inspection Guide used by the inspection team to accomplish a comprehensive fuel inspection.

The following lists a subsection presented for each inspection fuel assembly's reactor, storage facility, fuel receipt inspections and L Basin fuel inspections along with a short historical brief on the inspection fuel assembly characteristics.

4.4 The Brazilian IEA-R1 Reactor

4.4.1 IEA-R1 Reactor and Fuel Irradiation History

The IEA-R1 research reactor was a light water reactor built by Babcox and Wilcox (B&W) patterned after the research reactor at the University of Michigan in the mid-50s. It was a nominal 5 KW reactor with a 5 by 5 or 5 by 6 assembly configuration array, with 3 separate positions within the reactor building. The reactor was installed in an explosion proof facility.

The reactor went critical in September 1957. It was used for research and for isotope production. The reactor ran at only 2 MW until 1980 with HEU Fuel, then 4 MW with low-enriched uranium (LEU) fuel to 2011 and *is still operating* at 5 MW. The reactor housed control and standard fuel rods.

The inspection assembly and other assemblies were made for the second reactor charge load. The inspection assembly was only in the reactor 7.5 days with only 14 MWh reactor exposure. The other standard assemblies had moderate reactor exposure between 520 and 660 MWh, and the fuel was placed in the reactor about one year.

4.4.2 IEA-R1 Fuel Assembly Construction

The first IEA-R1 fuel was fabricated by Babcock and Wilcox (B&W) in 1957. The fuel elements contained cast uranium-aluminum alloy fuel with 20% U-235 enrichment. The fuel plates were made by hot rolling and brazed to aluminum side plates of the assembly. A high chloride/fluoride flux was used for brazing. Soon after startup, a high activity level was detected in the reactor pool. The B&W fuel fabricators were notified, but they were unable to solve a persistent corrosion and pitting problem of the aluminum clad fuel. After a short period of irradiation, the assemblies were discharged to a wet storage basin.

The inspection assembly and the four other assemblies in the inspection assembly bundle were standard box-type MTR assemblies with curved fuel plates. They were made for the second load of the IEA-R1

Reactor. The fuel was fabricated and inspected in December 1958. The inspection assembly had 9 inner most fuel plates sandwiched between 2 sets of 4 inner aluminum alloy non-fuel plates and an exterior non-fuel plate. The other assemblies in the bundle each had 17 inner curved fuel plates and 2 outer fuel plates.

Fuel cladding was 0.015 inch thickness made-up of Al 1100. The reinforcing lugs were also Al 1100. The side plates and aluminum non-fuel plates were made up of Al 6061-T6 along with the handle and the pins (Al 6061-T913Al).

The IEA-R1 fuel was the only LEU fuel inspected, as all other inspected fuel was HEU fuel.

4.4.3 IEA-R1 Fuel Storage History

The IEA-R1 is an MTR open pool research reactor (RR) of B&W design located at the Instituto de Pesquisas Energeticas e Nucleares (IPEN), within the campus of São Paulo University, in São Paulo city. It reached initial criticality on September 16th of 1957. Although designed to operate at 5 MW, from 1957 until 1997 the power level was maintained between 200 kW and 2 MW. Since 1997 the reactor has included operation at 5 MW power.

The MTR fuel used in the IEA-R1 reactor can be binned into four design categories. The first category is U-Al alloy fuel with 20% enrichment and 19 curved plates. This initial fuel run in 1957 failed in-core due to pitting corrosion at the fuel plate/support plate junction caused by brazing flux used to attach the fuel plates. This fuel (40 total assemblies), was wrapped in polyethylene bags, and was placed into the dry storage that consisted of horizontal pipes of carbon steel in a concrete vault as shown in the figure below. The fuel of the same design but with swaged-in attachment of the fuel plates to the support plate was run starting in 1958.

Figure 4-3 Dry Storage Facility for IEA-R1 Fuel

The second design category of fuel is U-Al alloy with 93% enrichment and 18 flat fuel plates. The third design category of fuel is UAlx-Al dispersion fuel with 20% enrichment and 18 flat plates. The fourth design category is U3O8-Al dispersion fuel with 20% enrichment and 18 flat plates, identical to the third design category.

The inspection assembly IEA-79 and the other four (4) assemblies in the inspection bundle were all LEU assemblies from the first design category that were in wet storage at the IEA-R1 storage facilities.

4.4.3.1 *Water Chemistry at IEA-R1 Storage Facilities*

The water quality at the IEA-R1 reactor, with a common water between the reactor and the fuel in storage racks, was reported to have been excellent throughout the history of operation and storage. The pH had been kept at 5.5 to 6.5, the conductivity was below 2 μS/cm, and the chloride ion concentration was below 0.5 ppm. The facility reported that the pitting attack (large nodular-capped pits, readily visually seen) was caused by galvanic corrosion between the stainless steel racks and the aluminum fuel while in storage. Other anecdotal statements given to the SRS inspection team in the July 1996 site visit was that a control assembly failure containing noble metal (silver) occurred. The opinion of one member of the SRS team (R.L. Sindelar) at that time suggested that the pitting attack was likely induced by deposits of silver and not the galvanic attack of the stainless steel racks.

4.4.4 IEA-R1 Fuel Packaging, Handling and Transportation to SRS

All the fuel assemblies mentioned in the preceding storage section was shipped to SRS prior to 2000 and placed in L Basin storage. Additional fuel was shipped and stored in 2008. This additional fuel was LEU fuel that was dry stored only.

Standard IEA-R1 assemblies were cropped on both ends prior to cask loading. The control assemblies were cropped on one end prior to cask loading.

127 fuel assemblies were shipped to SRS prior to 2000. Four casks were used for the fuel shipment from IEA-R1 facility to SRS. Two GNS-16 were loaded with 33 assemblies per cask. And two GNS-11 casks were used loaded with slightly less than 33 assemblies per cask. Based on fuel inspection reports, the fuel casks housing IEA-R1 fuel were sip tested.

4.4.5 IEA-R1 Storage Facility Fuel Inspections

Team members completed independent sip testing in wet storage area along with visual assessments. Visual inspections were recorded with a camcorder, still photos, and underwater video [8].

The individual assemblies were manually raised using hook and overhead crane from the stainless steel storage racks on the basin floor to within 6-7 feet of the basin water surface. The assemblies were photographed using a 35mm still camera with 200mm lens and an 8mm video camcorder. Detailed observations on selected assemblies were made using an underwater video probe and 8mm camcorder system. This probe was used to examine the side plates, outer fuel plates and the top portion of the fuel assemblies from 1-3 inches.

The visual examination conducted on the Brazilian fuel was the most extensive examination on any spent nuclear fuel in water storage in the world. The underwater video probe showed that this system can detect corrosion that is not readily visible. When the typical white, lighter corrosion product is present, it is usually readily visible from a distance. Based on the size of the nodules compared to known reference marks on the fuel, a judgment can usually be made on the size of the pit beneath this product. As the cladding thickness on these type fuels is relatively thin compared to the diameter of the aluminum oxide nodules, the pits generated on the surface of the fuel plates have a high probability of penetrating into the U-Al fuel core if the nodule is over the core region.

A total of 66 high-enriched uranium (HEU) and low-enriched uranium (LEU) fuel assemblies that were stored in wet storage were visually inspected. The results showed that 25 assemblies did not contain corrosion pits into the fuel meat region. The Cs-137 release rates from all 66 of the assemblies were well-within the SRS interim criteria of 13.57 μCi/hr per cask shipment which is equivalent to 35.9 pCi/ml/hr based on the volume of water used in sip tests. A maximum release rate of approximately 0.32 pCi/ml/hr was recorded in sip tests of the IEA-R1 fuels. There was no significant difference between the results before, and after removal of the deposits over the pits which, for some pits, exposed fuel meat directly to the water.

A total of 4 out of 40 Low-Enriched Uranium (LEU) fuel assemblies were visually inspected. Visual examination showed that corrosion attack at the brazed joints and pitting corrosion on the fuel plates had occurred. These conditions are attributed to corrosion mechanisms during water storage. No additional degradation due to dry storage was apparent.

4.4.6 IEA-R1 Fuel Inspection

One inspection assembly of the ten selected was IEA-R1 fuel from Brazil. The fuel selected was LEU fuel formed into a standard assembly with extremely low burnup (less than 1%). The IEA-R1 inspection assembly was bundled with four other LEU standard assemblies each having a moderate (17 to 21%) burnup. The inspection assembly was in the middle of the bundle.

Sip tests through the bundle lid conducted in 2018 were over 60% lower than those conducted in 2012 for Cesium 137. This recent cesium result was slightly lower than the bulk water average for all of 2018. Alpha, conductivity, Total Inorganic Carbon (TIC) and Total Organic Carbon (TOC) sample analyses were also significantly lower in 2018 versus 2012.

4.4.6.1 *IEA-R1 Fuel Retrieval and Debundling*

The bundle was retrieved from its storage position and moved to the debundling station inside of the saw row. There were no anomalies noted during the retrieval and movement of the bundle.

At the debundling station in the saw row, there were five assemblies debundled. All assemblies showed signs of intermittent random sets of crevice corrosion within the outer edge of exterior fuel plates at the side plate interface. Assemblies showed random intermittent clusters of pronounced nodules/prominent pits over the fuel meat region. Both types of corrosion occurred on each of the two outer fuel plates. The corrosion observed during debundling closely followed the previous facility inspection. See below picture for debundled assembly IEA-59. Observations from debundling showed no increase in the extent or severity of corrosion degradation for any of the five (5) debundled assemblies from the IEA-R1 inspection bundle. For other debundled fuel comparisons refer to Appendix 3.

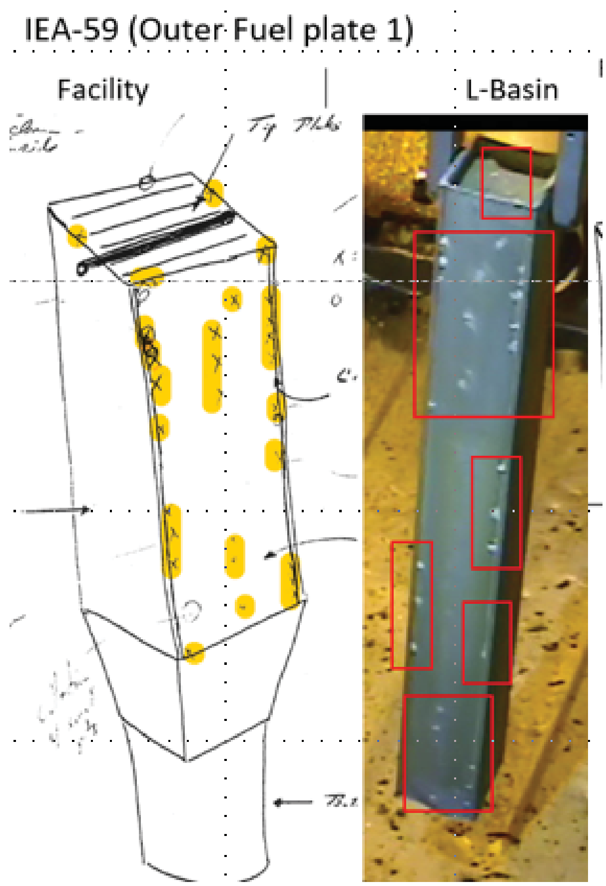

Figure 4-4 IEA-59 Previous Facility Inspection versus L Basin Debundling of IEA-59

The previous facility fuel inspection examined uncropped fuel for IEA-59. At one end of the cropped fuel assembly, end-grain corrosion was noted.

All the IEA-R1 assemblies in the selected bundle were standard assemblies with both ends cropped and curved fuel plates. There were five total assemblies debundled. The inspection assembly had only 9 inner fuel plates and the other assemblies had 17 inner fuel plates with 2 outer fuel plates.

The burnup of the inspection assembly was low at less than 1 percent. The other debundled assemblies had a moderate burnup in the range from 17 to 21 percent.

4.4.6.2 IEA-R1 Fuel Inspection Table

IEA-79 was the inspection assembly.

From the previous Brazilian facility inspection, potential through-cladding penetrations and sub-surface pitting corrosion were noted on both sides on the outer fuel plates. There was no corrosion noted on the side plates.

What is interesting to note about IEA-79 is that, per Appendix A (DOESRAAF-97-016, No. 11, Revision 1), although the assembly looks like it has 17 inner plates and 2 outer plates, as is typical of the other standard assemblies in the bundle, in reality ten of the outermost plates, 5 on one side and 5 on the other side, are just aluminum metal with the inner most 9 plates containing fuel.

Detailed inspection of the outer aluminum plates, which were determined not to be outer fuel plates, showed concentrated clusters of densely populated pitting corrosion nodules. These clusters were in a dense pattern on the concave side of the assembly but sparser on the convex side. Also, some end grain irregular shaped and sporadically populated, end-grain corrosion pockets forming on the edge of cropped fuel plates.

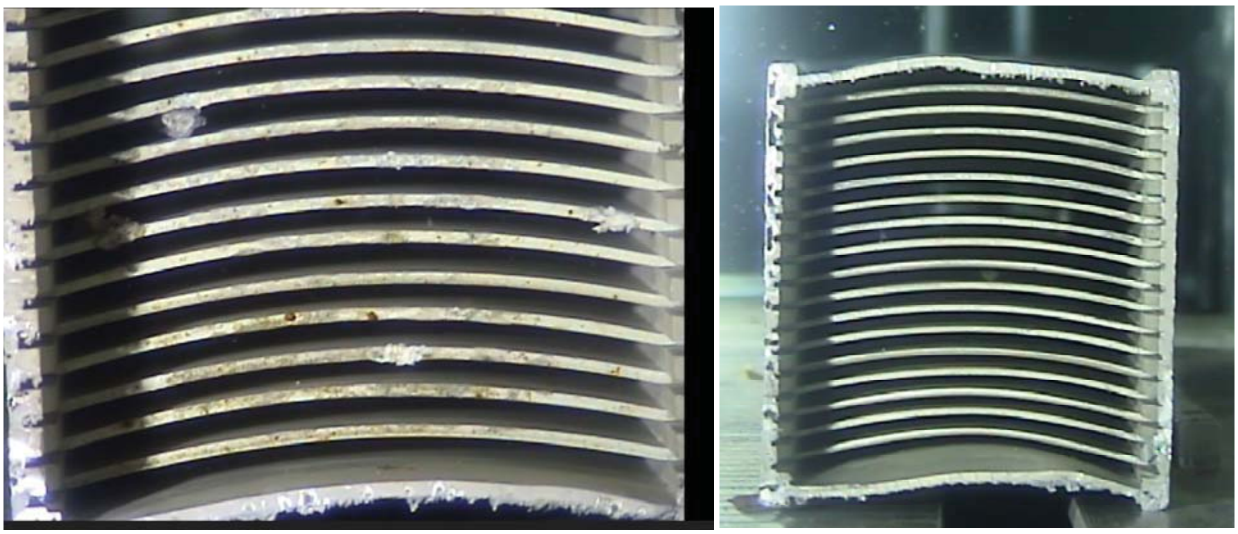

Figure 4-5 Top End View of IEA-79 (left) and Bottom End View (right), for comparison

Figure 4-6 Exterior Fuel Plate IEA-79 showing cropping damage on edge of fuel plate (left) and crevice corrosion nodule with Side plate damage/pit (right)

Figure 4-7 Exterior Fuel Plate IEA-79 showing a population of raised nodules and pits (left) and (separate image) side plate pitting (right)

Detailed inspection table inspection of the outer aluminum plates, which are determined to not be outer fuel plates, showed concentrated clusters of densely populated pitting corrosion nodules, some in a dense pattern on one side and some in sparse patterns on the other side.

Detailed inspection table inspection of side plates noted random pits sparsely populated on both side plates without the raised nodule formations.

There was also noted discolorations in nodule clusters and in what appears to be holes without nodules. The discolorations are likely fuel cladding breaches as was noted for several of the IEA-R1 assemblies during previous facility fuel inspections.

4.5 Argentine RA-3 Fuel

4.5.1 RA-3 Reactor and Fuel Irradiation History

The RA-3 Research Reactor is located at the Ezeiza Atomic Center close to Buenos Aires. The Ezeiza Atomic Center is a Commission Nacional de Energia Atomica (CNEA) atomic energy research and development site.

The RA-3 reactor began operations in 1967. It is a 5 MW (10 MW capable) light water cooled and moderated, graphite reflected reactor. In the early years of operation, the reactor was operated at 3 MW power.

The reactor uses 25 MTR box type fuel with curved fuel plates in a square matrix. Originally and prior to 1989, HEU fuel was used in the reactor. The reactor ran 5 days a week for 46 weeks on average.

The inspection assemblies selected for inspection and other assemblies in the inspection assembly bundle were placed in the reactor from 1967 to 1987 with the reactor operating at 3 MW.

There were four RA-3 inspection assemblies over a wide range from 130 to 1700 MWh per inspection assembly regarding reactor service time. Other assemblies in the inspection assembly bundle fell also in the middle of this range of reactor exposure.

4.5.2 RA-3 Fuel Assembly Construction

There was one control assembly and 3 standard inspection assemblies. All of the inspection assemblies were box-type MTR fuel with curved fuel plates. All of the RA-3 fuel was HEU fuel.

The fuel plates were swaged and pinned into the side plate comb grooves, fastened by aluminum rivets. The control assembly was originally a much longer assembly than the standard assembly at 63 inches versus 35 inches for the standard assembly. Both assemblies were cropped to around 28 inches, slightly more or slightly less, after receipt at SRS.

The control assemblies had 15 fuel plates and the standard assemblies had 19 fuel plates. Thus, the fuel loading was about 30 % less for the control assemblies as opposed to the standard assemblies.

The aluminum alloy used for most of the assembly was Al 99.5 analogous to Al 1050. The fuel meat is a uranium-aluminum alloy (30-35% Uranium, outer to inner fuel plates).

The bail screws for the standard assemblies used 304 stainless steel. The control rod guide on the control assemblies used 316 stainless steel. The fuel plates used Al 99.7 (Al 1070) and they are roll swaged. Originally the control assembly side plates used 304 stainless steel screws, but these were cropped off when both ends of the control assemblies were cropped.

4.5.3 RA-3 Fuel Storage History

The Central Storage Facility (CSF) is adjacent to the RA-3 Research Reactor at the Ezeiza Atomic Center. There are two storage areas within the Central Storage Facility. Each storage area had six sets of underground storage tubes. The storage facility had concrete tubes in the ground lined with stainless steel and filled with water. Two standard or one control assemblies could be stored in the tubes. Originally conductivity was controlled. In 1990 the water deionizer stopped, and the conductivity slowly increased throughout the 1990s [9].

4.5.3.1 *Water Chemistry at Ezeiza Storage facilities for RA-3 Fuel*

In the 1990s, the Ezeiza CSF experienced high exposure rates associated with the fuel since the water storage system remained shut down since 1990. Records from the facility prior to shipment to SRS (1998) indicate the water chemistry results for two different underground storage tube water systems read a high conductivity of 81 and 160 μS/cm. The pH was at 7.5 and 8.0 for each sector. Chloride levels were elevated at 3.4 and 16 micrograms per milliliter. Sulfates were at or between 1.1 and 2.5 micrograms per milliliter. Dose rates were as high as 11 R/hr at the floor level and 1.9 R/hr at 1-meter distance from an open tube.

Some brownish coating of the fuel was found during a late 1970s inspection. It was later determined that it was hematite particles (iron oxide) determined to originate from the corrosion of painted carbon steel channel caps in the storage system. The hematite particles with the water quality degradation together contributed significantly to the corrosion process for the RA-3 fuel.

4.5.4 RA-3 Packaging, Handling and Transportation to SRS

Comprehensive fuel inspections were conducted in June 1999 at the Central Storage Facility for RA-3 Spent fuel assemblies destined for SRS. Video with three different views from three different cameras exists for each fuel assembly. The fuel showed severe crevice corrosion at the side plate to outer fuel plate intersections, so the fuel was essentially pressure washed before it was loaded into casks and shipped to SRS. The water chemistry was elevated between 81 and 160 μS/cm and pH was slightly elevated between 7.5 and 8.0.

Documentation shows inspection of over 200 assemblies that were loaded in five shipping casks. The Nuclear Assurance Corporation – Legal Weight Truck (NAC LWT) cask was used with a basket of 42 assemblies per cask at capacity.

4.5.5 RA-3 Central Storage Facility Fuel Inspections

The Ezeiza Central Storage facility (CSF) had two storage buildings with six columns of stainless steel lined concrete storage tubes filled with water. Fuel was placed vertically either 2 to the tube (standard assembly) or one to the tube (control assembly).

Inspection was completed in fall of 1999. There were 208 assemblies inspected. These included assemblies with RA-3 HEU and LEU fuel. Most assemblies (90%) were inspected with above ground cameras system set-ups and about five percent were inspected using either a video probe or manually with a digital camera.

The types of corrosion noted was primarily along the crevice regions where the side plates and the outer fuel plates intersect and meet. Random pitting corrosion nodules were found on the surfaces of many fuel plates.

Three sets of tapes have been electronically converted to digital media and are available for viewing for each stored RA-3 assembly. Additionally, there are short field notes for each of the two outer fuel plate sides documented.

4.5.6 RA-3 Fuel Inspections

Four of the ten assemblies selected for inspection were RA-3. This fuel was chosen for its known anomalies over the fuel meat region of the fuel over a wide range of burnups. The last RA-3 bundle selected for Campaign 4 had an inspection assembly with other bundled assemblies over 40% burnup.

The fuel is curved MTR -type fuel and side plates and exterior fuel plates were viewable from the sides of the assemblies. Material of construction were similar for the side plates and fuel cladding and other components, either 1050 or 1070 equivalent which are very similar in composition.

Each of the four AMCAP fuel inspection campaigns included one RA-3 inspection assembly and the accompanying bundle.

None of the four RA-3 bundles showed any trailing debris as the bundle was lifted in VTS and moved to the unloading station in the Machine Basin Saw Row.

4.5.6.1 *RA-3 Fuel Retrieval and Debundling 1*

The first bundle selected had three assemblies stored within it. The inspection assembly was a control assembly, while the two remaining assemblies were standard assemblies.

The inspection control assembly S-113 had a supplemental tag that was attached at the ends. The tag went through the assembly and the fuel ID was viewable from the top end and the opposite, bottom end was bent over helping the tag to stay in-place. Pitting corrosion was noted on the top end tag. The fuel ID number was faint and faded but readable. Dark discoloration over the fuel meat region was noticed in patches and the patches were not over the whole fuel meat surface. Side plate rivets were viewable during debundling. The inspection assembly had low fuel burnup.

Standard assemblies 138 and 195 were debundled with the inspection control assembly. One of the two standard assemblies in the bundle had a pronounced dark discoloration over the whole fuel meat region. The other standard assembly in the bundle had the same patchy dark discolorations over the fuel meat region as the debundled inspection assembly. Both standard debundled assemblies showed edge corrosion on the side plates.

Figure 4-8 RA-3 debundled Standard Assembly 138 showing pronounced dark discolorations over the fuel meat region of an exterior fuel plate

4.5.6.2 RA-3 Fuel Inspection Table 1

Control assembly S-113 was the inspection assembly. The assembly was placed on the inspection table, where both ends, both side plates and both exterior fuel plates were comprehensively inspected. Since this was the first bundle and first fuel inspection, a vast amount of video was taken.

The two control rod guides are easily viewable from either end of the inspection assembly. One control rod guide serves as a channel for installation of the tagging system which uses the guide for installation of the tag. The control rod guide is stainless steel. The inner fuel plates do not touch the control rod guides. Galvanic induced crevice corrosion is evident on the upper right and lower left control rod guides, noting in the upper right guide (see below, left picture) is a dark corrosion crevice pocket.

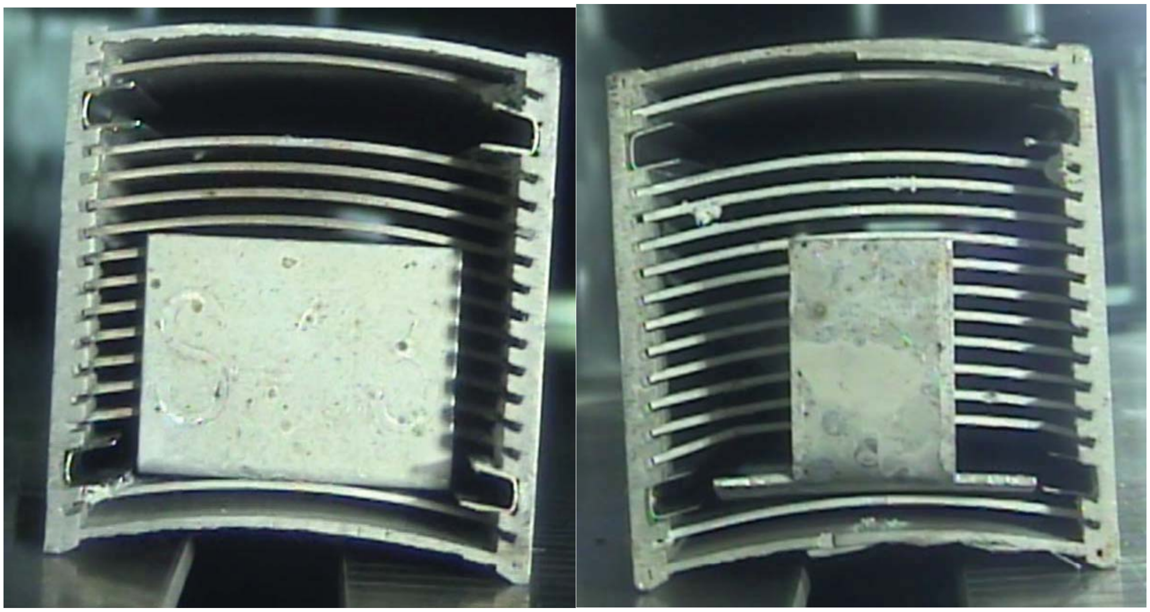

Figure 4-9 Top End View of S-113 Control Assembly (left) and Bottom End View (right) with inserted tag

Slight pitting corrosion and discoloration are readily evident on the bottom end of the tag. On the top end, the pitting looks somewhat different with no discoloration noted. The corrosion on the top end of the tag could have been caused by sediment. Similar morphology has been observed on the upward facing surfaces of aluminum alloy coupons exposed in the basin as part of L Basin Corrosion Surveillance Program. This phenomenon has been attributed to sediment deposited on the upward facing surfaces. Sparse pockets of end-grain corrosion with accompanying white, flocculent corrosion product are evident on both ends of the inspection assembly.

For the side plates, edge corrosion had prominent pitting along the edges and few instances of brownish discoloration in the pits. Formations of pitting corrosion nodules with a foaming appearance are apparent in prominent gouges or scratches along the edges of both side plates. There was a similar white, lighter colored formation on the side plate hole groove of one rivet. Marking and grooving of the side plate faces are evident from the use of parallel grippers on the assemblies. Reevaluation of these mechanical defects resulting from fuel handling operations if this assembly is to be reinspected during a later campaign could provide valuable information on the extent of corrosion, or lack thereof, in L Basin wet storage.

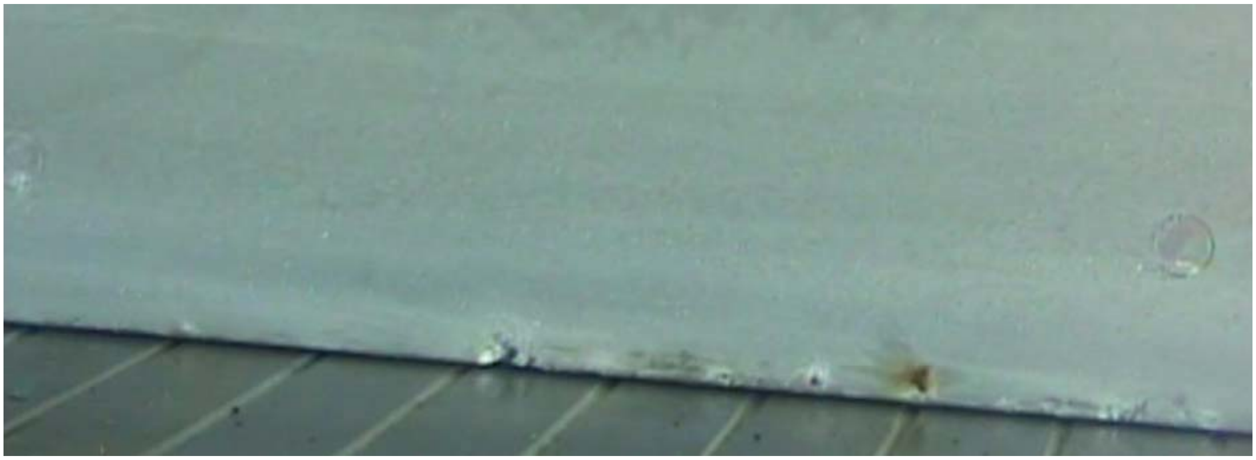

Figure 4-10 S-113 Side plate edge corrosion with pitting and discoloration

Edge pitting corrosion on the side plates is readily seen for each side plate edge. Crevice corrosion at the interface of the side plates and exterior fuel plates was not readily apparent.

White-washing lighter discoloration patches are prevalent on both sides of the exterior fuel plate. Generally, a change in lighter or darker silver color is apparent over the fuel meat region, clearly distinguishing its boundaries. One side of an exterior fuel plate had noticeable dark discolorations isolated and along one fuel meat edge in two spots, on one side and in one spot of the opposite exterior fuel plate. Dense formations of very small surface area pitting corrosion nodules are evident over the fuel meat region of the assembly.

Figure 4-11 White-washing lighter discolorations over fuel meat area of S-113

4.5.6.3 RA-3 Fuel Retrieval and Debundling 2

Campaign 2 included an RA-3 bundle with 4 standard assemblies. One standard assembly of the 4 (Assembly ID 160) was the inspection assembly.

At the debundling station, video was taken of all four debundled assemblies. Inspection assembly 160 showed minor side plate edge pitting corrosion. Assembly 110 showed darker fuel meat region discolorations with abundant patches of raised nodules (sparsely populated) over one exterior fuel plate and somewhat less on the opposite side. Also, one end of assembly 110 had rough, jagged cropped edges. This was also observed with assembly 139. This assembly also displayed pitting corrosion to the side plate edge and crevice corrosion at the interface of the fuel and side plates. CNEA-301 assembly had only blotchy white patchy discolorations shown over the fuel meat area.

Figure 4-12 Debundling of Assembly 110 showing exterior fuel plate pronounced, dark discoloration over the fuel meat area and a population of heavy pitting corrosion nodules also over the fuel meat region

4.5.6.4 RA-3 Fuel Inspection Table 2

Inspection assembly 160 was a standard assembly. The first RA-3 inspected assembly from Campaign 1 was a control assembly.

Both ends of inspection assembly 160 showed minor end-grain corrosion formations on the edge of interior fuel plate ends. Crevice corrosion was found in the slotted fuel comb pockets, where the fuel plates adjoin into the side plates. The bail on the top end view showed moderate pitting and raised nodule corrosion. The bail was fabricated of the same material as the side plates, Aluminum 1050.

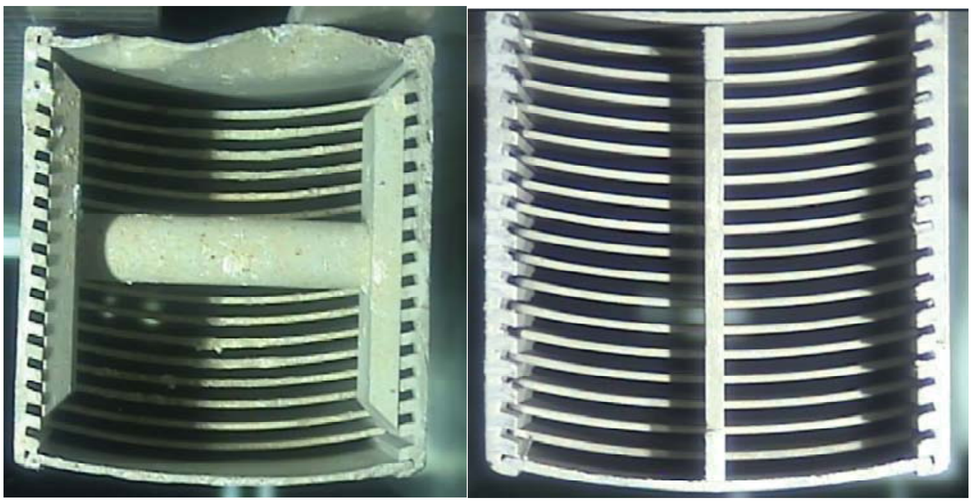

Figure 4-13 Top End (left) and Bottom End (right) of Inspection Assembly 160

External fuel plates were in overall good condition with little or no formations of nodules or evidence of pitting. Some light discolorations were observed over fuel meat region.

Pitting corrosion was observed in many places along the edges of the side plates and near those edges. Some pitting corrosion was also present on the interior of the side plates away from the edges.

There was no galvanic-induced corrosion evident adjacent to the stainless steel screws mounted into the aluminum side plates for the bail.

Figure 4-14 RA-3 Inspection Assembly 160 Exterior Fuel Plates (two different exterior fuel plates shown) showing substantial pitting edge corrosion on side plate edges.
Note the RA-3 fuel was pressure washed prior to being loaded into casks for SRS Shipment.
No new white, lighter corrosion clusters were found during its inspection.

4.5.6.5 RA-3 Fuel Retrieval and Debundling 3

There were four assemblies in Campaign 3's RA-3 bundle. The bundle contained 3 standard assemblies and one control assembly. The control assembly had the supplemental fuel tag as in Campaign 1's control inspection assembly. Standard assembly 30 was the inspection assembly for the RA-3 inspection for Campaign 3.

Standard assemblies 30 and CNEA 257 were in very good condition. The only corrosion characteristic found was a characteristic white hazing over the fuel meat with occasional darker blotchy patches. Standard assembly 153 had exceptionally clean side plates and exterior fuel plates.

Control assembly S-121 had some internal pitting corrosion on the side plates and crevice corrosion along the side plate to fuel plate interfaces.

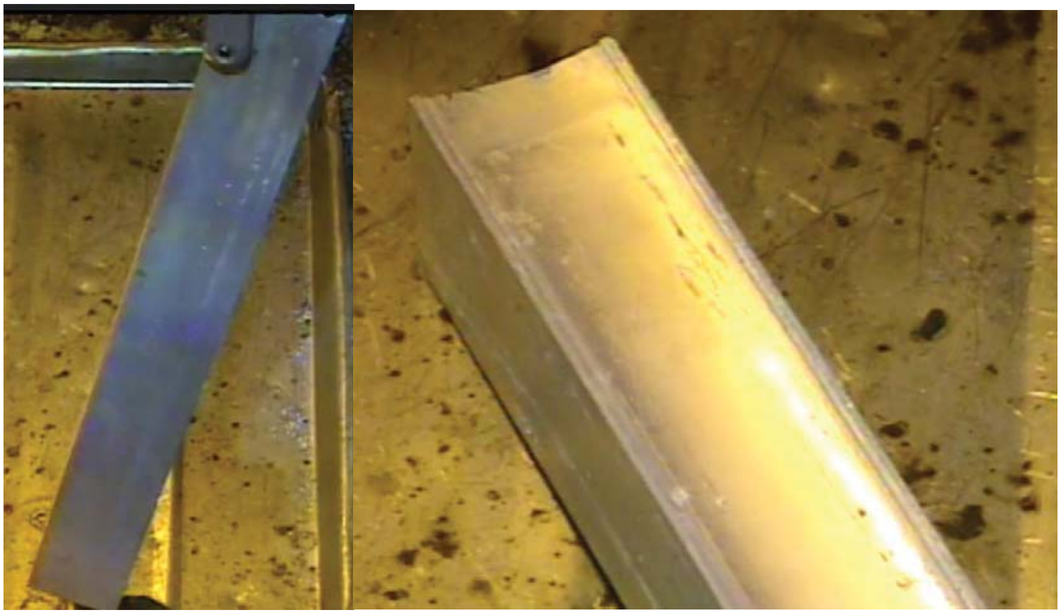

Figure 4-15 Debundled Control Assembly S-121 External Fuel Plates showing pitting corrosion (left) Close-up of concave curved exterior fuel plate (right)

4.5.6.6 RA-3 Fuel Inspection Table 3

The ends of the inspection assembly 30 showed cropping fragment frays on one end, and on the top bail end there was one isolated spot of crevice corrosion in the side plate slots.

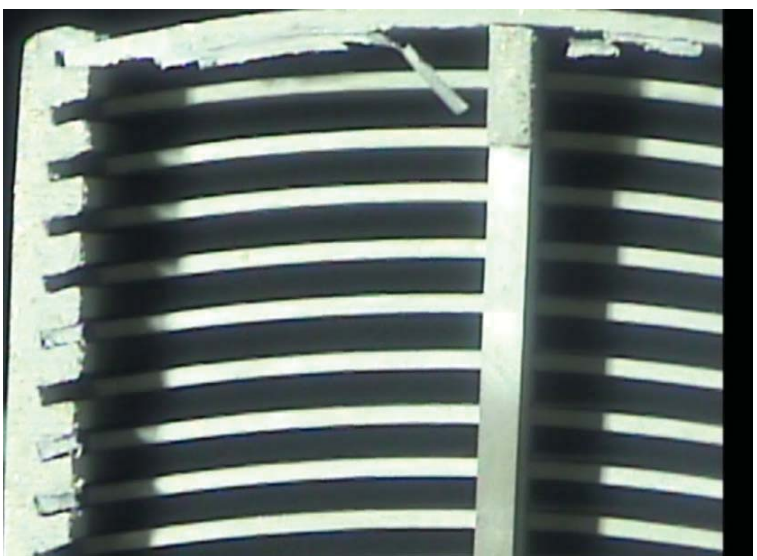

Figure 4-16 Crevice corrosion in three of the fuel plates in side plate comb slots which could be cropping fragments. Note cropping fragments in the top part of the picture.

The exterior fuel plate was relatively clean in appearance with one location of a group of prominent pits showing no evidence of discoloration. The side plates were also relatively clean. Both the external fuel plates and the side plates had several scratches, but corrosion was minimal.

There was no galvanic-induced corrosion evident adjacent to the stainless steel screws mounted into the aluminum side plates for the bail.

4.5.6.7 RA-3 Fuel Retrieval and Debundling 4

The bundle containing the final RA-3 assembly to be inspected was debundled as part of Campaign 4. The bundle housed 4 standard assemblies.

At the debundling station, inspection assembly 263 appeared spotted with one location of fuel meat edge dark discoloration. The side plates appeared clean of anomalies.

Debundled standard assemblies were clean of defects and anomalies on all four sides with some discoloration spotting noted.

CNEA 272 has obvious crevice corrosion nodules noted at the side plate and exterior fuel plate interfaces. A few, sparsely populated indistinguishable anomalies appeared over the fuel meat region.

4.5.6.8 RA-3 Fuel Inspection Table 4

At the inspection table, the end views of assembly 236 displayed edge corrosion to the end of the side plates as well as on the end of several fuel plates. Crevice corrosion was also evident at the fuel plate grooves in the side plates.

Figure 4-17 Top end of inspection assembly 236

The edges of the side plates had noticeable pitting throughout the assembly, with some of that attack being extensive. Galvanic-assisted crevice corrosion was noted on one of the bail screw heads (shown in Figure 4-18) with nodules protruding from the surface of the adjacent side plate.

The exterior fuel plates of the RA-3 assemblies had corrosion product nodules of various sizes. A separate, distinct corrosion feature was observed at the ends of the exterior fuel plate of RA3-0787, near the boundary of the fuel core region of the plate. The feature appeared to be a region of exfoliated/spalled oxide. The cause of the exfoliated/spalled oxide could be due to the greater thickness of oxide that would be expected to form over the higher temperature and higher heat flux region of the growing oxide in reactor service.

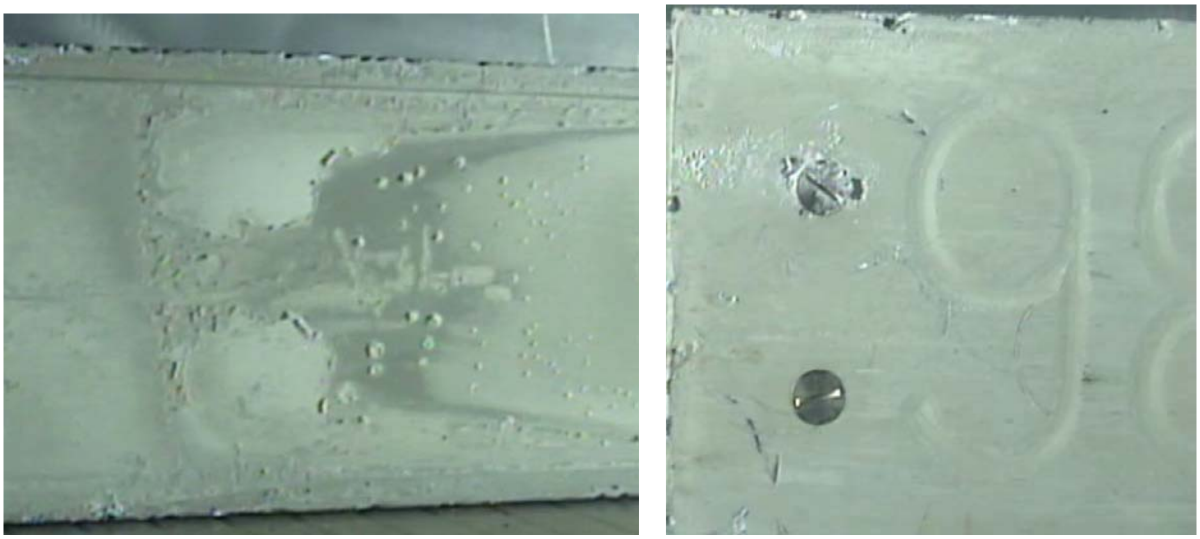

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Figure 4-18 Region of exfoliated/spalled oxide with surrounding pitting corrosion nodules (left) and galvanic corrosion action on a stainless steel bail screw (right)

4.6 <u>Italian ENEA Galileo and ISPRA Fuel</u>

4.6.1 <u>Galileo Fuel RTS-1 and ISPRA Fuel ISPRA-1 Reactors and Fuel Irradiation History</u>

There are two types of reactors associated with ENEA fuel from Italy. A third of the fuel selected for inspection is covered by these types of fuel. Both reactors operate at 5 MW power. Both fuel types use an aluminum alloy. Both reactors were used for nuclear materials research. Galileo RTS-1 also produced isotopes.

The Galileo fuel reactor is called RTS-1. The reactor was a light water cooled, moderated and reflected pool-type reactor that operated from 1963 to 1980. The Galileo reactor uses flat MTR -type, HEU fuel. In the Galileo reactor, the fuel is positioned in a parallelepiped, rectangular matrix (35 assemblies).

The Galileo control assembly inspected had a very low reactor exposure of 23 MWh. The other inspected Galileo standard assembly had higher exposure at 250 MWh. All other bundled assemblies were standard assemblies and the reactor cycle ranged from 80 to 500 MWh except one had very low exposure at 7 MWh.

The ISPRA-1 Reactor is a heavy water (D2O) moderated, graphite reflected reactor, upward primary coolant flow. The outlet cooling temperature is 51 Celsius. It started operation in 1959. The ISPRA reactor uses curved MTR -type, LEU fuel. In the ISPRA reactor the fuel is place in double concentric circles around an inner centermost assembly.

The inspected ISPRA fuel assembly featured 1850 MWh burnup, and the other assemblies ranged from 1400 to 2200 MWh.

4.6.2 Galileo Fuel Construction

The Galileo fuel are box-type flat plate MTR assemblies. Most of the other AMCAP MTR inspection assemblies are curved plate.

The Galileo fuel control assembly has only 10 fuel plates, missing the interior set of fuel plates; whereas, the standard assemblies have 19 total fuel plates. One of the two Galileo inspection assemblies was a control assembly and the other inspection assembly was a standard assembly. There were 4 standard assemblies in each of the two Galileo inspection assembly bundles.

The control assembly has an inner aluminum box structure separating each set of 5 fuel plates. In both instances, the outer fuel plates are external fuel plates.

Fuel cladding is 0.016 inch thick and composed of Al UNI 4507 (equivalent to Al 99.5/ 1050 or 1050 A). The fuel meat is a uranium-aluminum alloy (15% uranium). The side plates were made up of Al UNI 3571 (equivalent to 6351). Brazing (clad sheet strip brazing alloy) was used at fuel plate side plate junctures.

Both ends appeared to be cropped at the origination facility based on documentation for Galileo Control and Standard assemblies.

4.6.3 ISPRA Fuel Construction

The ISPRA fuel are box-type curved plate MTR assemblies like most of the AMCAP MTR inspection assemblies.

The ISPRA fuel standard assemblies have 19 inner fuel plates and 2 “dummy” non-fuel exterior plates. One standard assembly in the bundle has 17 inner plates and 2 exterior plates.

Fuel cladding is 0.015 inch thickness made up of Al 99.5 (equivalent to 1050 or 1050A). The fuel meat is also made up of the same alloy. The fuel meat is a uranium-aluminum alloy (22.7% uranium). Side plates are Al unspecified material likely to also be Al 99.5. Fuel and exterior Al plates were swaged into the side plates.

Both ends were cropped at the origination facility based on documentation for ISPRA assemblies.

4.6.4 ENEA Galileo and ISPRA Fuel Storage History

The spent fuel from RTS-1 (Galileo) and ISPRA-1 (ISPRA) reactors is assumed to have been stored at the EUREX facility in Saluggia, Italy in wet storage. Historical information on storage pool conditions is limited.

4.6.5 ENEA Galileo and ISPRA Fuel Packaging, Handling and Transportation to SRS

Two IUO4 casks were used to move the ENEA Galileo and ISPRA fuels to SRS. Two different cask baskets were used, the TN-9083 basket and the AA-267 basket. Each cask basket had 36 assemblies loaded in it.

4.6.6 ENEA EUREX Storage Facility Fuel Inspections

Inspections were performed at the storage facility. Hand markup of diagrams were used to document inspection anomalies and corrosion of inspection assemblies, showing both outer fuel plate sides.

There were two RTS-1 Reactor Galileo Fuel and one ISPRA-1 Reactor ISPRA fuel assemblies selected for inspection. The inspection diagrams were available for two of these assemblies including one for the ISPRA fuel and one for one of the two Galileo fuel.

The Galileo fuel inspection diagram showed minor, isolated crevice corrosion on one side of the assembly and an isolated raised nodule on the other fuel plate side. One of the two fuel plate sides had clusters of several grouped nodules found during the inspection.

Review of some of the other Galileo fuel in one of the inspection bundles revealed isolated single pronounced nodules and single strips of intermittent crevice corrosion. On rare occasion, there was a cluster group of nodules over the fuel meat area on one of two sides of a fuel assembly. Some of the isolated nodules appeared to have tails that appeared to look like shooting stars phenomena.

4.6.7 ENEA Galileo and ISPRA Fuel Inspections

The fuel IDs for Galileo assemblies sometimes had a number prefix such as “71-“ or “67-“. Spent Fuel Programs Operation accountability personnel did not always track the fuel prefix for each assembly although debundling pictures noted the prefix on the assembly side plates. Usually the prefix was on one side plate end with the “GA” and the unique number was on the other end of the side plates in many instances on the assemblies in the field.

4.6.7.1 Galileo 1 Fuel Retrieval and Debundling

The first fuel selected from Italy ENEA that was inspected was from the Galileo reactor. The first Galileo bundle retrieved had one control inspection assembly with 4 standard assemblies, for a total of 5 assemblies in the bundle.

The inspection control assembly GA84X had only minor whitish discoloration on the exterior fuel plate fuel meat region. There was no noticeable corrosion on any of the fuel assembly side plate or external fuel plate faces, based on debundling video feed taken.

Standard assembly CMN7 had some metal fabrication anomalies (could be construed as corrosion) on one end and some discoloration noted on the opposite end of the assembly. The two-side plate and two exterior fuel plate faces were clean and free of defects or corrosion. Some pronounced scratching near the top of one side was observed.

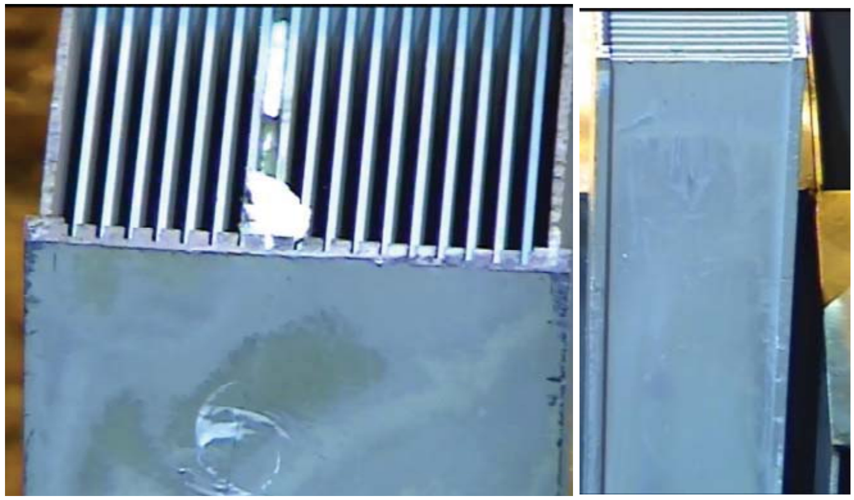


Figure 4-19 CMN7 Assembly (left); GA12 Assembly (right)

Standard assemblies GA12, GA16 and GA45 had relatively clean exterior fuel plates with some whitish discoloration patching noted over the fuel meat region of the fuel plates. Assembly GA12 had side plate end-grain corrosion with raised nodules. Assembly GA16 had some side plate face pitting nodule corrosion. These 3 standard assemblies also had clean top and bottoms with no anomalies noted based on the video taken during debundling.

4.6.7.2 Galileo 1 Fuel Inspection Table

The control inspection assembly GA84X had clean top and bottom ends with no anomalies noted. The exterior fuel plates had only one isolated area of corrosion at the crevice region near the side plate interface. One of the side plates had patches of pitting corrosion nodules. The other side plate had a couple of isolated pronounced pitting corrosion nodules, one of which had a crevice corrosion pit around the middle of the side plate.

Figure 4-20 GA-84X external fuel plate crevice corrosion (left) and side plate pitting (right)

4.6.7.3 Galileo 2 Fuel Retrieval and Debundling

All five of the debundled standard Galileo fuel assemblies had anomalies present over the fuel meat regions of exterior fuel plates. The prevalent features were sparsely populated raised nodules and/or pits with darker discoloration trailing phenomena or no trailing. Whitish patchy discoloration was also prevalent on these fuel meat areas of the exterior fuel plates.

The side plates and both ends of the fuel assemblies were clean based on video taken during debundling efforts. Inspection Assembly GA67 (noted as 71-GA67); and assemblies GA69, GA72, GA76 and GA77 (also with the 71- prefix) were debundled. All assemblies are standard Galileo assemblies.

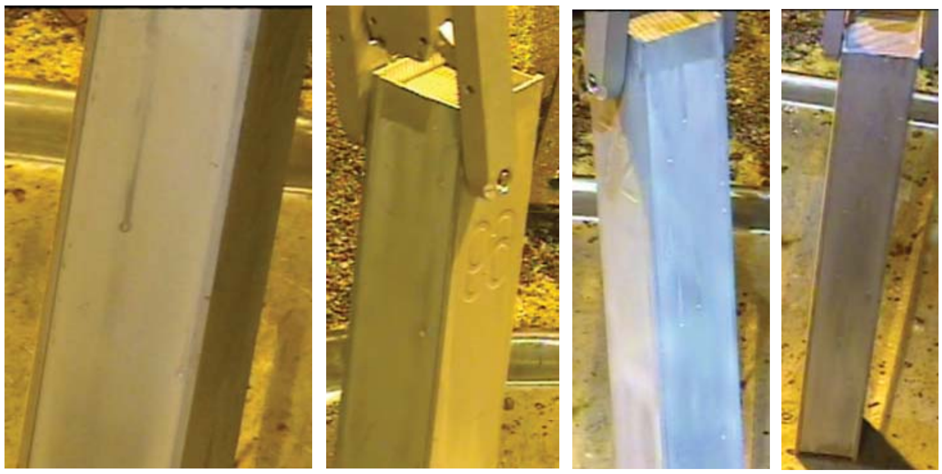


Figure 4-21 Exterior fuel plates of the 2nd Galileo bundle of fuel during the debundling process (various debundled assemblies)

4.6.7.4 Galileo 2 Fuel Inspection Table

The top and bottom end of inspection assembly GA67 was relatively free of corrosion. Isolated areas of edge or end-grain corrosion with buildup of corrosion products were observed on one end of the inspection assembly.

Figure 4-22 Bottom End of Inspection Assembly GA67 on the MTR Fuel Inspection Table. Note crevice corrosion product on one fuel plate (next to the exterior fuel plate).

On the exterior fuel plates, discoloration and nodules with the darker trailer were better seen on the inspection table. The inspection also revealed several prominent pits within the fuel meat region of the exterior fuel plates, but there was no evidence of discoloration around those pits. The inspection table also revealed some groups of pitting corrosion nodules on the edge of the fuel plates near the side plates with pitting at the edge of the crevices.

The side plates had scratches and isolated locations of smaller surface area pits. One side had some brown staining which could have been a paint rub.

Figure 4-23 Singular nodules/pits with trailing "shooting stars" phenomenon (both pictures) over the fuel meat region of an exterior fuel plate. Note characteristic pit (left) and crevice corrosion (right)

4.6.7.5 ISPRA Fuel Retrieval and Debundling

The Italian ENEA ISPRA fuel has curved plates in contrast to the other ENEA Galileo fuel which have flat plates.

There were 5 standard assemblies debundled from this Campaign 4 last ENEA bundle selected for inspection. Video was taken for 4 of the 5 assemblies, unintentionally omitting assembly 3-12-IX.

Both assemblies 3-1-IX and 3-5-IX had clean side plate faces, but there were several intermittent chains of crevice corrosion noted at the edge of the outer dummy fuel plates at these side plates. Assembly 3-5-IX also had fuel meat discoloration (streaking) on outer dummy fuel plate faces.

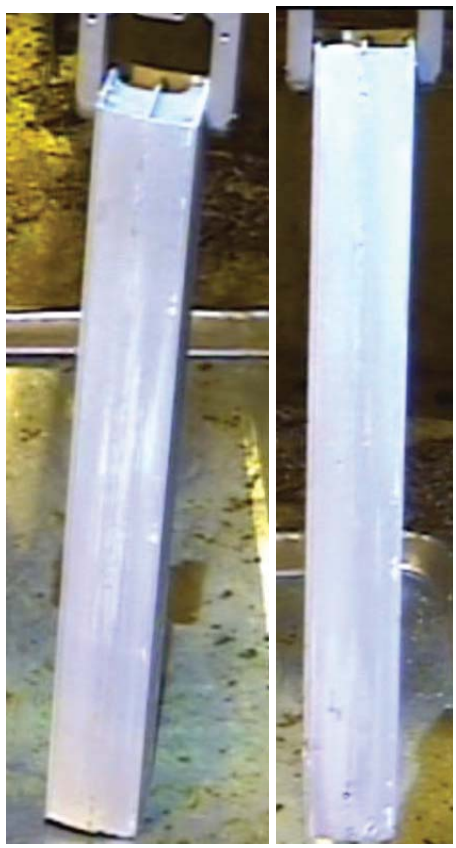


Figure 4-24 ISPRA Debundled assembly 3-5-1X showing crevice corrosion on concave dummy fuel plate (left); Crevice corrosion concave outer dummy fuel plate 3-51-VI (right)

Assembly 3-51-VI had general pitting on side plates and side plate edge corrosion. Significant corrosion attack was noted throughout the outer dummy fuel plate on one side of the assembly.

Inspection assembly 3-9-IX had concave side crevice corrosion on the side plate and side plate edge corrosion noted from the debundling video.

4.6.7.6 ISPRA Fuel Inspection Table

Inspection assembly 3-9-IX had crevice corrosion on both ends of the assembly concentrated in the side plate groove areas. Some edge corrosion was also noted. One side had a pocket of end-grain corrosion formed on one end of a fuel plate with no discoloration found. The edges of the tops and bottoms of the assemblies seemed frayed on both side plate and dummy fuel plate edge, namely due to cropping of the fuel.

The side plates of the inspection assembly had numerous scratches, markings and some isolated pits present. Pitting was also observed at some areas of crevice attack that was pronounced and extensive.

The outer dummy fuel plates had some severe pitting near, but slightly below, the crevice region. The outer dummy fuel plates had some brown discoloration patches with no evidence of pitting. A few isolated holes in the outer dummy fuel plate center areas were noted with no discoloration around these pitted holes.

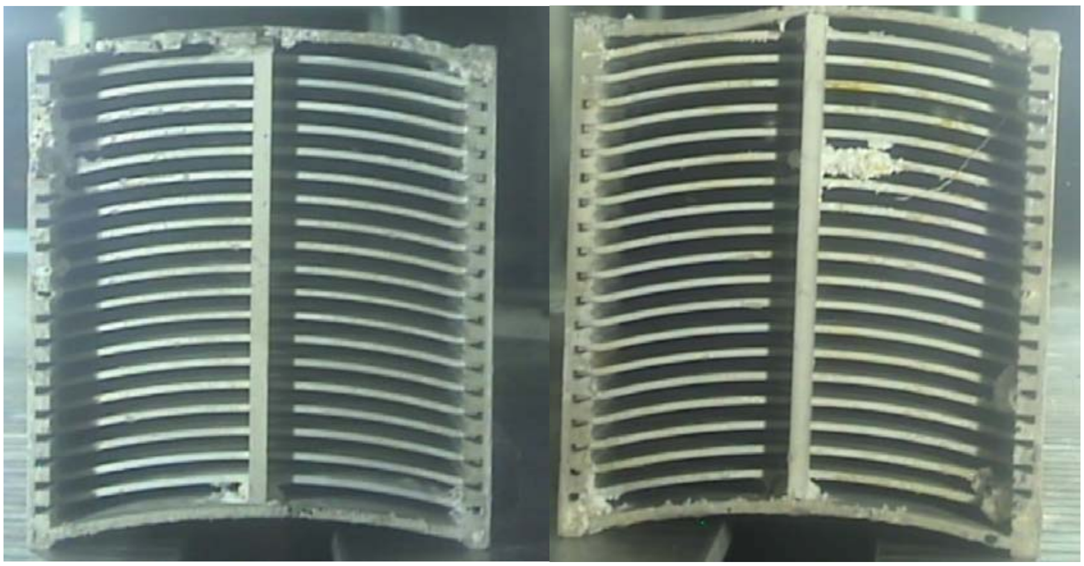


Figure 4-25 Top and Bottom views of the Inspection Assembly 3-9-IX

Figure 4-26 Outer dummy fuel corrosion features of Inspection Assembly 3-9-IX

4.7 ANSTO Australian HIFAR

4.7.1 HIFAR Reactor and Fuel Irradiation History

The Australian Nuclear Science and Technology Organization (ANSTO) High Flux Australian Reactor (HIFAR) was a 10 MW reactor operated by the Australian Nuclear Science and Technology Organization (ANSTO) from 1958 to 2007. The reactor provided materials research and production of radionuclides for wide usage within the country.

The reactor used heavy water for cooling and moderation of enriched uranium fuel. Towards the end of its mission the fuel used progressed towards and eventually used exclusively LEU fuel. Its reactor core was 25 assemblies similar in diameter and length as a washing machine tub. The reactor operated on a 28-day cycle including operation and shutdown for fuel changeouts and maintenance. The last few years the reactor went to a 35-day operating cycle. The reactor operated most of the time throughout its life at the 10 MW full power.

The HIFAR inspection assembly has 38% burnup. Other assemblies within the inspection assembly bundle ranged from 30% to 46% burnup.

4.7.2 HIFAR Fuel Construction

The fuel is arranged between an inner aluminum tube and outer aluminum tube. The fuel is assembled and fastened by brazing from the outside of the inner tube to the inside of the outer tube. The outside diameter of the arranged fuel assembly is 4 inches. The fuel can be seen from either end of the assembly and it resembles a curved, involute pattern. The fuel is a uranium alloy fuel in an aluminum matrix. The fuel is about 25 inches long cropped on both ends and weighs nearly 10 lbs.

There are 10 fuel plates for the Mark IIIE type HIFAR Assemblies pedigree of the inspected fuel. HIFAR fuel cladding is 0.017 inch thickness Aluminum, alloy not specified in facility provided Appendix A data. The fuel plates are traditional roll-bonded. The fuel meat is an aluminum- uranium alloy.

The fuel assembly uses an aluminum inner and outer tube shell. The outer tube is 4 inch outer diameter and 3.9 inch inner diameter and weighs approximately 2.5 lbs. The inner tube is 2.3 inch outer diameter and 2.0 inch inner diameter and weighs approximately 1.0 lb. Aluminum silicon brazing foil is used for attaching fuel plates to inner and outer aluminum tubes.

Most of the materials of constriction including inner and outer tubes and fuel construction are Al 1050 based on review of ANSTO provided documentation for receipt of the fuel.

4.7.3 HIFAR Fuel Storage History

The ANSTO HIFAR spent fuel storage facility had both wet and dry storage for spent fuel assemblies.

The wet storage facility had two ponds each lined with stainless steel liners. One pond had a fuel cropping bay within it. This pond stored 390 fuel elements and the other pond stored 244 fuel elements. The ponds utilized demineralized water, skimmers, particulate filters and ion exchange systems. Conductivity, pH and radioactivity of water was controlled and monitored.

The dry storage facility consisted of 50 sandstone tubes lined with stainless steel tubes.

The fuel was stored in aluminum cans placed two to a stainless steel canister. There were 11 stainless steel canisters per tube (22 fuel elements). Notes from the fuel files indicated that most of the HIFAR Mark III fuel was housed in dry fuel storage. Although we have video showing some wet storage of some of the HIFAR Mark III. These dry storage tubes were monitored for relative humidity, temperature, oxygen and krypton-85 and they were backfilled with dry nitrogen to inhibit corrosion of the fuel cladding.

The fuel examined had a history of dry storage where the corrosion attack to the outer housing was suggested to have occurred.

4.7.4 HIFAR Fuel Packaging, Handling and Transportation to SRS

The earlier HIFAR fuel assemblies were shipped to SRS in the late 90s. This included the HIFAR inspection bundle.

There were three casks used.

One cask was the LHRL-120 with 120 assemblies and two cask baskets. The other two casks were TN7/2 with one basket each of 60 assemblies. Thus, there were 240 assemblies between three casks shipped. All casks were shipped dry.

Later HIFAR assemblies came to SRS in the 2000s using the LWT with a new HIFAR Mark III shipping basket.

4.7.5 ANSTO HIFAR Storage Facility Fuel Inspections

There are several types of Appendix As noted for the HIFAR Mark III and Mark IV fuel. The Mark III Series UED type HIFAR fuel was the fuel we planned on inspecting with others of the same type in the same bundle as the inspection assembly. Review of archived information revealed that most of the UED assemblies had a clean outer tube shell. Severe pitting of one outer tube was noted. Isolated cases noted severe and mild localized pits grouped at either end of the outer tube. One instance of through pits on an outer tube in the bottom region was noted. Many assemblies had individual pits throughout the length of the tube to various degrees of pitting from mild to severe. Some bubbling phenomena(on) was noted during the inspection of one assembly. Ends of the assemblies where the fuel plates could be seen looked relatively clean with few anomalies.

The one inspection assembly UED-1567 was a Mark III type assembly. A Visual Inspection Data Sheet was filled out on this fuel assembly as it was inspected at the facility. It is a round fuel assembly so two inspection sheets were filled out for two side views and an inspection sheet was filled out for both involute end views. Slight damage was noted on 1) two of the ten fuel plates on an end view and 2) a side view end edge which could have been attributed to the fuel being cropped on both ends. No corrosion was noted on the end view. Also noted was an embedded item shown on one fuel assembly end view. Investigation revealed this was a thermocouple holder fitting intentionally placed between two fuel plates. On the side views, varying depth pits were noted.

4.7.6 ANSTO HIFAR Fuel Inspection

HIFAR fuel was inspected on the 3rd Inspection Campaign along with one bundle each of ENEA Galileo and Argentine RA3 fuel.

The view of the ends of the fuel was obstructed by the covering of one end of the fuel with a fuel assembly tag.

4.7.6.1 HIFAR Fuel Retrieval and Debundling

There were 5 Mark III type involute assemblies debundled from one bundle prior to the inspection at the inspection table of one of those assemblies. The exterior of this round involute fuel had an outer shell viewable for all the assemblies. There is no fuel meat in that aluminum outer shell.

Assembly ED 513 had one viewable end that appeared to be in good condition on the ends, including the brazed areas. The outer shell looked relatively clean and free of pits although it had some dents and dings namely due to handling.

Assembly 1553 had some pitting along its outer tube.

Assembly 1556 had a viewable end in good condition with some jagged edges due to cropping. No corrosion was noted on this assembly end.

Assembly 1561 appeared to be in good condition on the sides with no notable pitting or general corrosion based on the video taken. The top of the assembly noted a dent on one side top edge near the fuel plate.

Inspection Assembly 1567 showed numerous various size pits from side views and potentially some denting of the assembly. Some of the pits appeared to be holes penetrating the exterior aluminum shell of the assembly.

Figure 4-27 Assembly 1556 cropped top end sitting in a lug bucket (left) and side view showing minor individual pits – holes with a symmetrical pattern were part of its fabrication (right)

4.7.6.2 HIFAR Fuel Inspection Table

At the inspection table HIFAR Inspection Assembly UED 1567 (Mark III E type assembly) was inspected at the ends then rotated on the sides (twice after initial placement) to complete the inspection of the sides of the assembly. Video showed usage of a couple traditional tooling methods to turn the assembly so that a nearly consistent 120-degree rotation was achieved to produce a comprehensive outer tube inspection of the inspection table. The inspection table is equipped with a trough that enabled the cylindrical fuel assembly to remain stable and in place during the inspection of its sides.

The viewable bottom end showed some end-grain pitting. There was one potential area of end-grain pitting corrosion product and slight discoloration. The top end had a tag installed and this involute fuel end was not viewable. The tag appeared in good condition with no corrosion or sediment present.

The three side views from the inspection table lighting and perspectives of the outer fuel tube revealed numerous, mostly round pits of varying surface areas. The pit density was high on each of the three perspectives throughout the outer fuel tube. Closeup views revealed there were many pits of various diameters throughout the assembly outer tube sides. There was one colony of a cluster of raised nodules. The third view showed some discoloration on its side views but that could have been due to lighting variances, as it was not seen on the other two sides.

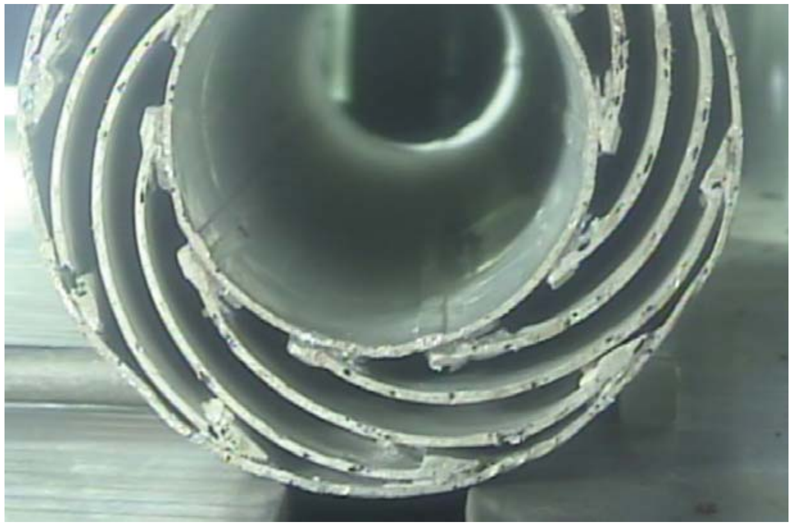


Figure 4-28 Viewable end of the inspection assembly's involute fuel plate. Note the potential end grain corrosion with corrosion product in the bottom middle of the picture.

Figure 4-29 Characteristic pitting of the inspection assembly UED 1567 that was typical for some assemblies, but not all the Mark III E assemblies. The outer tube contains no fuel, but had numerous, varying surface area pitting such as this could provide a corrosion pathway for corrosion to the inner involute fuel plates.

4.8 Netherlands HFR Petten Fuel

4.8.1 HFR Reactor and Fuel Irradiation History

The High Flux Reactor (HFR) Petten fuel was HEU fuel irradiated in a tank in pool, light water moderated and cooled reactor. The HFR initially operated at 20 MW stepping to 45 MW in mid reactor operation life (around 1970).

The reactor operated for about 275 days per year at full power. The reactor was used for isotope production, material testing, nuclear chemistry and boron neutron capture therapy.

The inspection assembly for the HFR Petten fuel had 5100 MWh reactor exposure which was the highest of any inspection assembly. Other assemblies in the inspection assembly bundle saw also high reactor exposure within 10 % of this MWh. All assemblies were in the HFR Petten reactor for 450 days (15 months).

4.8.2 HFR Petten Fuel Construction

Fuel assemblies had curved plates in a traditional MTR Box-type configuration with side plates. The standard assemblies were densely packed with 21 inner fuel plates and two outer fuel plates between the side plates. Both ends of the assemblies were cropped resulting in an overall length of 26.5 inches.

The HFR Petten selected for inspection was Type "F" Petten fuel that had an aluminum uranium alloy with aluminum matrix fuel meat (Uranium 33%). The side plates and fuel spacers were made up of an aluminum magnesium silicide metal (equivalent to Al 6082).

Fuel cladding was slightly thinner for inner fuel plates at 0.015 inch thickness versus outer fuel plate cladding at 0.023 inch thickness. The cladding was fabricated into the fuel by hot and cold rolling. Fuel Cladding is AG2NE, AG3NEor AG5NE which may equate to Al 5754.

All of the HFR Petten fuel was cropped at the origination facility.

4.8.3 HFR Petten Fuel Storage History

HFR has two storage pools in its basin storage system. One storage pool is for storage of in-core components, and experiments and core capsules. The other, slightly smaller storage pool is for storage of the spent fuel elements awaiting hot cell dismantling. The basin storage system maintains the pH between 5.5 to 7.5 pH and the conductivity is tightly controlled from 1 to 2 μS/cm. An on-site demineralized make-up water system for the basin provides water at about 0.055 μS/cm as needed. Water chemistry is monitored every 8 hours. An old pH/water conductivity system was used only to monitor the demineralization system versus the water storage basin itself. No upsets to the water quality have been reported.

4.8.4 HFR Petten Fuel Packaging, Handling and Transportation to SRS

There were five (5) LWT casks used for the HFR Petten fuel. Each cask had 6 cask baskets with 7 assemblies per cask basket.

4.8.5 HFR Petten Storage Facility Fuel Inspections

The facility provided cropping drawing for the HFR Petten Fuel. The drawing RH-M-Al3/28 indicated both nozzle ends would be cropped off the fuel leaving an optimized doubly cropped assembly. The fuel was cropped at the HFR Petten Storage Facility.

HFR Petten fuel was inspected in November of 1998. Approximately 10 percent of the fuel was inspected. Only minor corrosion and isolated handling scratches and dents were found during the inspection.

4.8.6 HFR Petten Fuel Inspection

4.8.6.1 HFR Petten Fuel Retrieval and Debundling

The HFR Petten was the last bundle of the ten to be selected for inspection on the last inspection campaign, Campaign 4.

Assemblies F976 and F1130 showed some dark patches of discoloration over part of one side of the exterior fuel plate over the fuel meat regions.

Figure 4-30 Assembly F976 (left) and Assembly F1130 (right)

Assembly F987 was a clean assembly with no anomalies or corrosion found.

There was no video taken for the inspection assembly F950.

4.8.6.2 HFR Petten Fuel Inspection Table

On one end of the inspection assembly there appeared to be individual nodule formations on the ends of several interior fuel plates. One corrosion feature was observed on the end of one interior fuel plate in the form of a pit, though no discoloration was noted.

On the sides of the fuel plates, sparse populations of pitting corrosion nodules were formed throughout both exterior fuel plate fuel meat regions.

On the side plates, only some blemishes and scratches were found with no corrosion present.

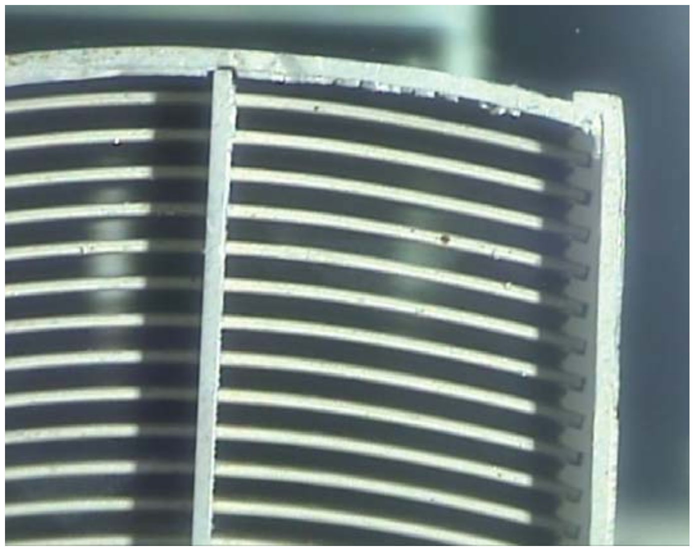


Figure 4-31 Bottom end detail of Inspection Assembly F950

Figure 4-32 Clean face but somewhat tarnished of an exterior fuel plate of Inspection Assembly F950

5.0 ANALYSIS OF THE MTR FUEL INSPECTIONS

5.1 Comparisons with Previous Facility Fuel Inspections

The AMCAP Team went back to the fuel history archives to address questions concerning the condition of the fuel when it was inspected at the country of origin (previous) facility versus what was seen for the AMCAP Fuel inspections. Many of the previous facility fuel inspections were conducted by Spent Fuel Engineering, and with nuclear material and corrosion experts/expertise from SRNL.

Many of the previous fuel inspection videos were not in a retrievable digital format, so the AMCAP Team had Savannah River Nuclear Solutions (SRNS) Media services convert the video available for the inspection assemblies/inspection bundles to usable digital media for comparison to the AMCAP Fuel Inspections. Few previous facility fuel inspections did not have video. Many previous inspections also used inspection sheets and notes with or without previous use of fuel inspection videos.

The AMCAP Team created comparison stills from digital media for previous facility and AMCAP fuel inspections. Many of these comparisons were made using video taken of the fuel removed from the inspection bundles before the fuel was placed in a slug bucket for the inspection table inspection.

Comparisons were created for 8 of the 10 AMCAP inspection bundles to include stills taken at debundling and/or from the inspection table. These comparisons were completed for Campaign 1-4 RA-3 inspection bundles (4); Campaign 2 IEA-R1 inspection bundle; Campaign 3 ENEA Galileo inspection bundle; Campaign 3 HIFAR inspection bundle; and the Campaign 4 ENEA ISPRA inspection bundle.

In all cases, the previous facility fuel inspection sheets or stills taken from the video lined-up and compared favorably to the AMCAP inspection video stills (See Appendix 3). This meant that corrosion did not progressively worsen as a result of the last 10 to 20 years of L Basin storage of these assemblies within EBS bundles housed in Vertical Tube Storage (VTS) racks.

5.2 Attributes of the Types of Corrosion Found during the Fuel Inspections

There were several prevalent types of corrosion found during the fuel inspections.

Most assemblies were of the MTR box-type fuel with two side plates and two exterior fuel plates fitted within the side plates. A couple of the box-type MTR fuels had dummy exterior plates constructed of aluminum alloys with no fuel composition. The exception to this was the HIFAR fuel which had an aluminum outer tube with no fuel composition. The HIFAR fuel was sandwiched between an outer and inner tube only viewable from one end.

In most cases the aluminum cladding on fuel plates, side plate materials, and the aluminum ends including the bails were made of aluminum alloys that were the same or very similar in composition. The one exception to this was the IEA-R1 which used aluminum alloys of 1100 for fuel cladding, 6061-T6 for side plates, and yet a separate 300 series aluminum for other fuel assembly components. It is also interesting to note, the IEA-R1 fuel as the only LEU fuel inspected.

If a bail was present on an inspection assembly (typically in the RA-3 standard assemblies) it was usually secured in the side plates via two stainless steel screws. This was commonly found on standard fuel assemblies as opposed to control assemblies.

Typical corrosion seen during all fuel inspections include: 1) side edge corrosion on side plate face edges; 2): crevice corrosion at the interface of exterior fuel plates and side plates with pitting and/or raised nodules with irregular shapes; 3) dense populations of pitting corrosion clusters of raised nodule colonies over part or the whole fuel meat region of exterior fuel plates; 4) sparse populations or single occurrences of pronounced raised nodule pitting corrosion; 5) irregular dark discolorations over the entire fuel meat region or on the edges of a fuel meat region face; 6) potential microbial settlements on the top or bottom of fuel assemblies between the fuel plates (rarely seen affirmatively); and 7) end-grain attack on cropped edges of fuel assemblies-one or both top/bottom edges. Some white-washing light discolorations over exterior fuel plates or outer dummy fuel plates was noted.

The 1) edge corrosion could have been attributed to previous facility storage conditions and handling of fuel assemblies. Some of the 2) crevice corrosion was severe enough to hardly distinguish the 1) edge corrosion which indicates a progressed state of corrosion.

Occasionally the 4) pronounced pits on an exterior fuel plate also included fuel meat region uniform discoloration or discoloration patching.

Most of the assemblies had cropped edges. This was not holistically considered during the selection of fuel for inspection. However, in most instances the frayed and sometimes dented edge showed some 8) end-grain corrosion attack on assembly cropped edges.

The HFR assembly showed galvanic crevice attack at a stainless steel screw on one side plate. A RA-3 early inspection assembly showed some crevice corrosion in an aluminum rivet on one side plate.

The summary Table 5-1 catalogs and summarizes the types of corrosion found for the 10 fuel inspection assemblies and related bundled assemblies. Some of the anomalies found were only found on the debundled assemblies.

The definitions were used in the following table include:

Definitions used in the table *with respect to corrosion found during the inspections*:

<u>Occurrence Frequency:</u>

Sparse – Appearance is intermittent and not common

Localized - Characteristic feature and commonly present

Pervasive – Predominant feature, persistent and frequently occurring

<u>Severity:</u>

Superficial – Somewhat questionable and minor, not characteristic

Moderate – Characteristic feature fitting the observation definition

Severe - Among worst found, extensive attack

Table 5-1 Types of corrosion found for the 10 fuel inspection assemblies and related bundled assemblies.

Type Fuel/ fuel plate shape	*1) Edge corrosion*	*2) Crevice corrosion*	*3) High density nodules/ pits*	*4) Sparse pronounced nodules/ pits*	*5) Dark discoloration over fuel meat region*	*6) Potential microbial settlements*	*7) End-grain attack*
	side plates	fuel plate interface	fuel plate/ fuel meat	fuel plate/ fuel meat	fuel plate/ fuel meat	Interior fuel plate ends	top and bottom fuel ends
IEA-R1 (curved)	Pervasive Severe	Pervasive Moderate	Localized Moderate	Pervasive Severe (some discoloration)	None	Sparse Superficial (isolated)	Localized Moderate
RA-3 (curved)	Localized Moderate	Localized Moderate	Localized Moderate	Localized Superficial/ Moderate	Localized Moderate (full or partial)*	None	Sparse Superficial
ENEA Galileo (flat)	Sparse Superficial	None	Sparse Superficial	Localized Moderate (trailing effect/ w/ tails)	None	None	None
ENEA ISPRA (curved)	Pervasive Severe (w/ pitting)	Pervasive Severe (w/ pitting)	None	None	None	None	Pervasive Severe (w/ pitting)
HIFAR (involute)	N/A	N/A	Localized Moderate (outer tube, not fuel)	Localized Moderate (outer tube, not fuel)	None	None	Sparse Superficial
HFR Petten (curved)	None	None	Localized Moderate	Sparse Superficial	None	None	None

*- There was evidence of darker discolorations over the several RA-3 Assemblies' fuel meat. This was discovered during debundling of the fuel for the inspection bundles. On two assemblies the darker discolorations covered the entire fuel meat of one exterior fuel plate of an assembly. There were several instances where the darker discolorations occurred only on the edges of the fuel meat region. A similar but distinct feature was observed for the highest burnup RA-3 assembly where a change in the oxide was observed at the edges of the fuel meat region, however, this oxide was not brown and considered localized, moderate for that assembly only.

Based on the observations as noted in the table, common types of corrosion observed for fuel stored in L Basin are crevice corrosion at the side plate/external fuel plate joint, edge corrosion near many cut ends, end-grain corrosion, especially at cropped ends, and pitting corrosion. While these are the common types of corrosion, most corrosion was initiated not in L Basin but at the origin facility.

Most assemblies had various type(s) of corrosion over the fuel meat region of side plates except for ENEA ISPRA. However, ENEA ISPRA had numerous side plate corrosion issues more severe than most of the other selected bundled assemblies.

5.3 Effect of Fuel Burnup on Types of Corrosion Found during the Fuel Inspections

The 10 fuel inspection assemblies were selected to comprise a wide range of fuel burnup in order to assess whether incident neutron fluence and attendant radiation/heat could be correlated with any specific corrosion indicators. It is also worth noting that the dozens of assemblies which were co-bundled with the 10 targeted assemblies also offered significant potential insight into gross impacts of burnup, as their assembly burnups are all known as well.

The assemblies examined on the inspection table ranged in burnup between 0.6 MWd/assembly (1.57 MWd/MTU) and 212 MWd/assembly (440 MWD/MTU). Assembly neutron fluence and attendant radiation post-exposure can be well correlated with assembly burnup as all reactors are light water pool type using U-235 as the dominant fissile material.

Multiple assemblies from both the Galileo and RA-3 reactors were chosen as part of the inspection set, each with disparate burnup values. This allowed for a more targeted comparison of burnup effects which ignores confounding variables that exist between reactor operating parameters and facility water quality.

The Brazilian RA-3 reactor represented four of the ten inspection assemblies, and thus four of the inspection bundles selected. It may be noted that the highest burnup RA-3 assembly (Assembly 236 with 72 MWD/assembly) did present the most extensive crevice corrosion and pitting/staining which clearly outlined the fuel meat region as compared to the other lower burnup RA-3 fuels which were inspected. However, the lowest burnup assembly could not likewise be concluded to appear the most pristine, as the two moderate burnup assemblies showed remarkably little pitting and crevice attack themselves. If burnup did indeed have an impact on the surface condition of these assemblies, it would appear the correlation is not linear, or that a relatively high burnup threshold is required to impart a significant impact.

The Italian EUREX wet storage facility operated by ENEA was the origin of three of the ten inspection assemblies and thus three inspection bundles selected. Of these, two of the inspection assemblies originated from the Galileo reactor and one originated from the ISPRA reactor. Based on inspection table summary observations of these two fuel types stored in the EUREX facility, the corrosion characteristics were found to be distinct from one another.

The two selected Galileo reactor fuel had mostly low and moderate burnup fuel. Both inspected assemblies indicated stark discoloration over the fuel meat regions. The lower burnup GA-84X showed very little pitting on the plate faces, though GA-67 featured sporadic nodules accentuated by dark streaking indicative of a coolant flow direction. Based on views from the debundling video, co-bundled Galileo fuel also had relatively clean side and fuel plate faces with the exception of these sparse nodules and accompanying streaks. Very little crevice corrosion was observed.

The higher burnup ISPRA fuel, however, displayed significant corrosion in the crevice region of its debundled assemblies and little to no pitting on the plate faces.

There appears to be no clear pattern of corrosion which can be attributed to higher burnup fuel based on examples cited. While it was true that different corrosion anomalies were found, it is not certain that these anomaly types or extent were entirely attributable to the burnup of the fuel.

5.4 Microbial Induced Corrosion

Microbes have been around for a long time in wet storage basins for SRS nuclear fuel going back to RBOF Spent Fuel Storage and Reactor Basin Storage to support SRS Reactor Operations.

Inventory studies of underwater cobweb formations and cobweb makeup analysis were conducted in the last ten years of L Basin operations.

HFR Petten fuel was selected because of its high burnup and cobweb population noted over several years prior to cobweb vacuuming of VTS Storage racks in 2014. Cobwebs were noted as the HFR Petten bundle was removed from the rack and during the removal of fuel from the selected bundle (see video and pictures in Appendix 5). However, like all the other selected fuels inspected there was no corrosion found attributed to the presence of microbes in the selected bundles. End viewing of fuels on the inspection table noted galvanically induced crevice corrosion, crevice corrosion and end grain attack. The end grain attack found on the edges of fuel plates was attributed to cropping performed either at the original storage facility or after received at SRS L Basin, prior to its L Basin storage.

Although microbe formations (to include cobwebs potentially) were observed during debundling and possibly account for flocculent product on the ends of inspection assemblies, there was no evidence of microbial induced corrosion phenomena found during the selected AMCAP MTR Fuel Inspections. This is also supported by previous work cited [10, 11].

5.5 Other Factors of Corrosion Concern during Fuel Inspections

Other factors of concern for Spent Fuel Storage bundles could include bundling order of the fuel assemblies in the EBS bundle; effect of sediment settling on the orientation of fuel assemblies within a bundle; storage location within a given rack or within a given location of the assembly in the rack within L Basin; the effect fuel handling will have on long term corrosion effects; and effect of bundle water chemistry versus bulk water chemistry affecting fuel corrosion are addressed within this section of the report. The observed effect of each factor is addressed within this section of the report.

a. *Bundling Order of the Fuel*

Some of the standard assemblies still had the bail attached to the top end of the assembly. If the bail was still intact then visual observations could be made about the attack of corrosion on the bail and surrounding side plate features such as interior mountings, bail screws and the surfaces face-out on the bail itself.

For most of the standard assemblies without a bail, the inspection table revealed inspection assembly anomalies much clearer than the limitations of the video taken at the debundling station. The top end of assemblies debundled at the debundling station could be observed. Some debundling videos were taken for these types of bundles. None of this video was clear enough for comparison of corrosion feature differences set aside bundling order differences. For inspection assemblies, the inspection table could clearly distinguish differences between the top end and the bottom end of an assembly. However, for the inspection assemblies viewed on both ends, there was no pattern concluded between the order the assemblies appeared in the bundle and the presence of corrosion for those inspection assemblies.

On the control assembly(ies), unique features were observed. These features include items such as stainless steel control rod guides; openings and voids in fuel assembly construction of placement of fuel plates within an assembly; and supplementary aluminum structure components and/or tags. Both top and bottom ends could be observed for inspection assemblies.

Only three control assemblies were observed. Two of the three were from RA-3 fuel and the other one was an ENEA Galileo Inspection Assembly. The ENEA control inspection assembly was a unique Galileo control assembly so no comparisons could be made, as there was nothing like it found during the fuel inspections. It was noted that this assembly was clean on each end top and bottom of the assembly with no corrosion present.

One of the two RA-3 control assemblies was an inspection assembly. There could be no comparisons made between the RA-3 control assemblies because the debundling video at the debundling station taken was of insufficient quality for detailed comparisons. One of these assemblies was the first debundled of four and the other was the third debundled of three assemblies in a bundle.

For the unique Australian HIFAR fuel, a quality comparison between the second assembly (UED 1556), the third assembly (ED 513) and the last assembly debundled which was the inspection assembly (UED 1567) could be made. The top end of these assemblies was completely covered by a fuel ID plate. No assembly showed any distinguishable corrosion on the fuel ID Plate. There was some darker discoloration on the side of the third debundled assembly near the top, and this was not seen on the second debundled assembly or the lastly debundled inspection assembly.

The Brazilian IEA-R1 fuel had a very comprehensive corrosion profile, with most types of corrosion seen in L Basin found on the inspection assembly (IEA-79). There was no distinguishable characteristics between the first assembly (IEA-61) and the last assembly debundled (IEA-66) or those debundled in between these assemblies. Based on limited video taken at the debundling station, their characteristics were similar, and no comparisons could be made for differences based on debundling order.

b. *Sediment Settling on Fuel Assemblies based on Fuel Orientation within a Bundle*

Sediment deposits tended to be random in nature amongst the inspection assemblies. There was not a greater concentration on the top end versus the bottom end of an assembly. For either end, the orientation tended to be of non-importance.

c. *Long Term Effects of Fuel Handling on Fuel Corrosion*

Fuel was retrieved at the origin facility and prepared for shipment to SRS. Some of the fuel discharged from the foreign research reactors was moved a couple of times to different storage facilities. The prior handling of the fuel was typically not delicate. As a result, some of the fuel assemblies of the MTR box type (the majority of the ten selected assembly types) received scratches namely on the side faces and edges of the side plates and on the concave side of the curved assemblies. The RA-3 assemblies were cleaned, and pressure washed before being loaded into the casks for SRS. Some of the other fuel types were cleaned in whole or in part based on potential for reactor reuse in the example of low burnup fuel.

After the assemblies were shipped to SRS, most assembly cask baskets were unloaded, and individual assemblies were carefully placed in square slug buckets with inserts resembling a tic-tac-toe. The assemblies were then moved to the tilt table where they were placed into a round storage bundle, with three to five assemblies in a bundle. These bundles were then moved into a storage position where they are to remain in the absence of future fuel operations.

For some of the assemblies, hand tool marks from use of the parallel gripper did not show any added corrosion within and around these marks on the fuel. Typically, these marks were seen on the top or bottom ends of the side plates and on both sides of the fuel assembly.

Until retrieval for the MTR fuel inspection, the fuel remained dormant, resting in its storage position within its stored bundle. As the assemblies were retrieved and debundled, fuel handling tools were used to grab, rotate, reload into a slug bucket; unload, move and manipulate the inspection assembly on the inspection table and reload into a slug bucket; finally load all of the assemblies back into a new bundle to place back into a storage position. There is no prediction on the effect the debundling and inspection had on the long term added effects to the corrosion history of the fuel due to handling of the fuel.

The fuel was not sparged or underwater cleaned as part of the inspection. There was little or no debris found during the debundling of the selected assembly bundles, at the saw row debundling tray.

d. *Water Chemistry Effects on Corrosion within a Bundle*

Sip tests were conducted less than 10 years ago and just prior to retrieving bundles containing the selected inspection assemblies. Sip tests are a water sample drawn through a bundle lid syringe and analyzed for many of the bulk water chemistry parameters including alpha, tritium, Cs-137, Ce-141, Co-60, Conductivity, pH, Total Inorganic Carbon (TIC), Total Organic Carbon (TOC), Aluminum, Chloride, Copper, Iron, Mercury, Microbes, trace elements; and nitrates, phosphates and sulfates. Although the water syringe samples only the top portion of the bundle, it is assumed that it is grossly representative of the entire enclosed bundle water environment.

Concerns prior to sampling include elevated alpha and Cs-137 levels prior to debundling.

Cesium levels on sampled bundles hovered the basin water bulk chemistry averages; slightly above the average in 2012 and slightly below the average in 2019. The alpha levels within the bundles were mostly elevated 15 to 20 dpm/ml over the bulk water average of 1 dpm/ml for 2012 and most bundles sampled in 2019 were at this average or below.

Conductivity is linked to the dissolved solids. Conductivity results followed the same path as the alpha results being as high as 8 μS/cm for 2012 and at or below for 2019 of the average bulk water of 0.8 μS/cm.

Most of the fuel selected for inspection had a fuel composition of uranium alloy. Although there were some prominent numerous nodules and pits over the fuel meat region, most assemblies showed very little or few instances of discoloration around the nodules or pits. Discoloration is a good indicator of fuel cladding breach. Thus, the witnessed cladding breach from the fuel inspections was minimal and low. IEA-R1 showed some dislocation over fuel meat region of its assemblies and known cladding breaches were documented for some of the assemblies as part of the original fuel inspection at the previous storage facility. A good indicator of cladding breaches would be an increase in alpha and conductivity in any given bundle. The cesium would be less likely to be a good indicator due to the soluble nature of its migration characteristics in and out of bundles. None of these indicators were found in the inspection bundles, but IEA-R1 had known fuel cladding breaches during previous facility fuel inspections and dutifully and similarly noted during the L Basin fuel inspections.

5.6 Other Fuel Inspections including Lessons Learned

The AMCAP MTR fuel inspection effort was not the first time any fuel assemblies were inspected with any rigor. Late in the 1990s there was a Uruguay fuel inspection program. This inspection program compared very low irradiated Uruguay fuel (of the same structure and characteristics) stored underwater in L Basin to a dry fuel assembly stored in the dry fuel portion of L Basin. This program occurred over a 9-year period and concluded that the fuel compared favorably without increasing in corrosion [12].

In a short program that spanned a couple of years, low irradiated fuel of two types, stored in dry fuel storage, was examined in Instrumented Test Canisters (ITCs) [13].

This program examined the condition of the dry fuel and concluded that it was stable over the brief period of examination. The program was abandoned after these conclusions were reached. The purpose of this examination was to evaluate condition parameters for the benefits of dry fuel storage.

In FY2017, a full plate was removed from a Uruguay fuel assembly in L Basin dry storage and shipped to SRNL for examination. The focus was not a corrosion evaluation. The purpose of the examination was to collect data on oxide films formed on fuel cladding for the benefits of dry fuel storage.

Both the Uruguay wet/dry fuel storage comparison program and the AMCAP MTR fuel inspection program proved that extended storage in L Basin helped preserve the characteristic of the fuel in storage without worsening the effect of corrosion. Although the initial conditions were well established corrosion anomalies on some of the fuel examined, the results for both programs were favorable and helped validate the current L Basin Water Chemistry and Corrosion Protection Program as an ample program as-is to continue its storage mission.

6.0 RECOMMENDATIONS FOR FURTHER INSPECTIONS AND MTR FUEL STUDIES

6.1 AMCAP MTR Inspection Program - Goal

The goal of the AMCAP MTR Fuel Inspection Program is to determine the condition of aluminum-clad spent nuclear fuel stored long term in L Basin through visual examination of the fuel. Demonstration of continued safe storage of the fuel would be achieved through evaluation of the impact of preset and future expected corrosion degradation. An initial special inspection of the fuel would be performed, serving as a "baseline examination," followed by reinspection after a 5-year additional storage period to evaluate whether corrosion degradation was active and significant to impact the ability to continue to store the fuel.

The special inspection program to inspect 10 assemblies in 4 separate inspection campaigns was successfully completed. The results of corrosion damage were compared to the results of inspections made at the basin of origin, or upon initial receipt in L Basin, as available. The AMCAP inspection team was able to convert original inspection video from previous facility inspections and records to provide sufficient detail to enable comparisons to the present inspection results following an approximate additional 20-year storage period in L Basin.

6.2 Conclusions

It is concluded that the water quality and the bundled storage configuration for ASNF in L Basin does not cause aggressive corrosion degradation of the fuel. It is further suggested that mitigation of the prior corrosion damage of the fuel also appears to have been achieved with the good water quality conditions of L Basin.

6.3 Summary of Results and Recommendations for Reinspection

The following paragraphs summarize the inspection results and provide the recommendations for reinspection of selected assemblies in 5 years. Inspection of these assemblies would strengthen the posture that the observed types of localized corrosion are not progressing under L Basin storage conditions.

Two of the fuel assemblies in the present inspection are not recommended for reinspection due to the minor amount of corrosion damage observed. This includes one of the two ENEA Galileo fuel assemblies and the HFR Petten Assembly.

For the RA-3 fuel it is recommended two of the four assemblies be reinspected in 5 years. This includes the first RA-3 assembly, S-113, a control assembly with stainless steel guides, and the last inspected RA-3 assembly, 236, which was a high burnup standard assembly with unique exfoliated/spalled oxide formations and stainless steel screws. All RA-3 assemblies showed similar corrosion features in the same places for edge corrosion, crevice corrosion, fuel meat corrosion both pits and nodules and end-grain corrosion on the ends of the assemblies. Additionally, there was a standard assembly 138, within the first inspection assembly bundle, that had complete dark discolorations over one face of the fuel meat region of an exterior fuel plate that is also recommended for inspection. Three RA-3 assemblies are recommended for future fuel inspections.

The two inspections associated with the Italian ENEA Storage Facilities' Galileo fuel showed minimal corrosion. The moderate corrosion profiles associated with this MTR fuel are bounded by other more severe corrosion found on inspections of other AMCAP MTR Fuel inspections. However, there were unique corrosion characteristics on the second Galileo fuel assembly, 71-GA67, that warrant a repeat inspection to monitor condition of the assembly over L Basin storage time. This second Galileo inspected fuel is recommended for reinspection.

The ENEA ISPRA Reactor fuel assembly 3-9-IX is also recommended for reinspection. It has some severe crevice and side plate corrosion, and gross end-grain corrosion with corrosion products on the ends of the assemblies. It will be interesting to reinspect for a future campaign to determine a worsening condition. It is also recommended that a high burnup assembly be selected from the same bundle and inspect it (Assembly 3-51-VI). Assembly 3-9-IX has a 30% burnup and 3-51-VI has a 60% burnup for the fuel assembly.

The IEA-R1 reactor assembly IEA-79 is also recommended for reinspection. This assembly contained pits in the fuel meat region that appeared to indicate decladding and fuel failures, in addition to a number of other corrosion phenomena, which in many cases were some of the most severe of the ten assemblies inspected. It was a low burnup assembly. It is also recommended that a high burnup assembly IEA-77 (in an adjacent stored fuel bundle, same rack) also be added for the next fuel inspection. This higher burnup fuel selection for inspection is contingent on the availability of previous facility inspection data that can be used for comparisons.

The inspected Australian Mark III fuel UED 1567 had limitations for inspecting fuel plates. Since the outer tube was only aluminum and one of the ends had a fuel ID plate installed cover the ability to view one end of the fuel plate ends, the only useful fuel inspection information observed was on one end of the fuel assembly, where an end view of the involute fuel plates could be observed. Historically based on previous facility inspection data, outer fuel plates with numerous varying surface area pits indicate a potential corrosion path to the outermost assembled involute fuel plate; however, even if both ends were exposed, it would be difficult to ascertain the fuel plate condition. There were many pictures of HIFAR inspection assembly UED 1567 taken at the time of the previous facility fuel inspection. Additionally, there was a careful inspection sheet formulated to go along with previous fuel inspection pictures. The results of the AMCAP MTR fuel inspection for assembly UED 1567 indicated no increase in corrosion than found at the origination facility. If a Mark IV assembly was selected or another Mark III, the same observations limitations would exist for observing fuel condition (i.e., only one end of the fuel plates could be observed). Although the HIFAR assembly has limited fuel inspection value a reinspection of the assembly would be good to check on regular aluminum corrosion rates within a stored bundle, focusing on the exterior aluminum tube condition over storage time.

Table 6-1 Corrosion Inspection results

AMCAP Original Selected MTR Fuel for Inspection	Recommended for Reinspection?	Additional Assemblies Recommended for Inspection?	Basis Comments not Previously Addressed
IEA-79 (IEA-R1)	YES (1-3,5)	IEA-77 or equivalent (1-3,5)	The inspection standard assembly was extremely low burnup (1%), the other recommended control assembly has high burnup (42%). IEA-R1 fuel has many corrosion features to monitor fuel degradation over time in storage.
S-113 (RA-3)	YES (1-4,7)	138 (1-3,7)	Assembly 138 has exposed fuel plate fuel meat region dark discolorations; S-113 has SS guide plates as it is a control assembly and SS screws attached to bail
160 (RA-3)	NO		Bounded by other RA-3 assemblies
30 (RA-3)	NO		Bounded by other RA-3 assemblies
236 (RA-3)	YES (1-3,5,6)		SS screws attached to bail
GA 84X (ENEA/ Galileo)	NO		Limited programmatic value
71-GA67 (ENEA/ Galileo)	YES		Limited programmatic value as compared to other inspections; however, it had several key anomalies that can be followed up for worsening conditions for the next inspection
3-9-IX (ENEA/ ISPRA)	YES (1-3,5)	3-51-VI (1-3,5)	Inspection assembly was low burnup, the other recommended is high burnup
UED 1567 (HIFAR)	YES (1,2,5)		Limited programmatic value due to fuel construction; however, it will serve as a good general aluminum corrosion check of a bundled assembly- focus needs to be on observations to note worsening condition on the outer tube due to storage condition and internal bundle atmosphere water chemistry
F950 (HFR Petten)	NO		Limited programmatic value due to lack of overall corrosion history, and recent years cobweb severity reductions since the 2014 bundle top vacuuming campaign

1-General Corrosion; 2-Pitting Corrosion; 3-Crevice Corrosion; 4-Galvanic Corrosion;5-End-Grain Attack; 6 Exfoliated/spalled oxide Formation; 7- Sediment Induced Corrosion

Table 6-2 Recommended Assemblies for Next MTR Fuel Inspection - Summary

Country of Origin	AMCAP MTR Fuel Inspected	Reinspect in 5 years?	New Fuel to Inspect	New Fuel Attributes
Argentina RA-3	S-113 (C)	Y	138	Fuel Meat Darkening
Argentina RA-3	30	N		
Argentina RA-3	160	N		
Argentina RA-3	236	Y		
Australia HIFAR	UED 1567	Y		
Brazil IEA-R1	IEA-79	Y	IEA-77	Higher Burnup IEA-R1 Fuel
Italy Galileo	71-GA67	N		
Italy Galileo	GA-84 X (C)	Y		
Italy ISPRA	3-9-IX	Y	3-51-VI	Higher Burnup ISPRA Fuel
Netherlands HFR Petten	F950	N		

6.4 Additional Recommendations

It is also suggested that emptied bundles be more thoroughly inspected after debundling to identify any signs of corrosion. Only six of the ten bundles pulled for this inspection received the benefit of a cursory inspection to look for gross debris (e.g., detached fuel plates), but smaller debris, corrosion product, or signs of corrosion attack of the bundle at contact points with the stored fuel may still be observed with a closer inspection.

In addition, it is suggested that the opportunity to inspect other assemblies in the target assembly's bundle is seized. While it is not recommended that each assembly be moved to the inspection table, a less extensive inspection with a pole mounted underwater camera between debundling and placement in the isolation bucket would be of programmatic value.

For consideration are improved tools for the inspection of inner fuel plates to include the use of video scopes and/or NDE techniques. Additionally, lighting changes should be thought out and prescribed for the ends to allow and facilitate better viewing of between fuel plates, as a minimum recommendation for consideration.

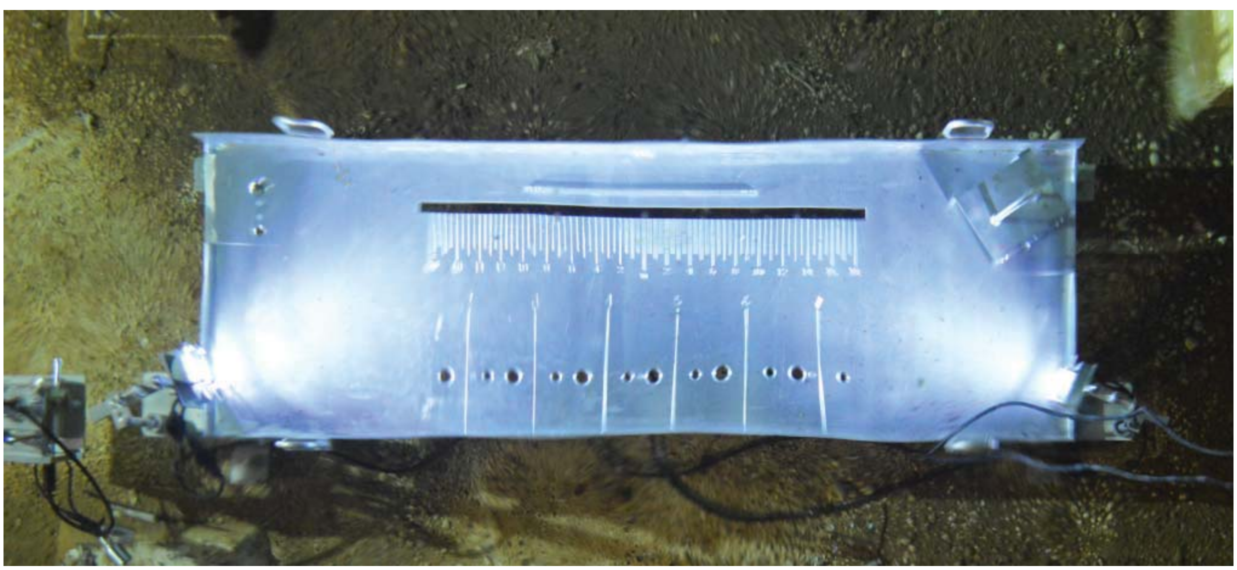
7.0 PROGRAM IMPLEMENTATION IMPACTS ON SFP NUCLEAR SAFETY AND OPERATIONS

The current safety basis for L Area, Spent Fuel Program (SFP) is a Documented Safety Analysis (DSA). The SFP DSA allows for MTR Fuel Inspections and the use of the inspection table in the Tilt Table Row of the Machine Basin to perform the fuel inspections.

The initial AMCAP MTR fuel inspection effort and reoccurring fuel inspections are not addressed in the program document for the Basin Water Chemistry and Corrosion Protection Program. This program document is an administrative credited program for the Technical Surveillance Requirements (TSRs) for SFP, which supports the DSA. The previous Uruguay fuel dry and wet inspection program was documented in the Basin Chemistry program document.

It is envisioned that future MTR fuel inspections of fuel performance and surveillance will be embraced and included comprehensively within the SFP related safety credited program documents. These revisions to DSA, TSRs and the Basin Chemistry program document will be initiated by the technical cognizant function within the Process Engineering Group of Spent Fuel Engineering.

The AMCAP MTR Fuel Inspection Program is complete until the next inspection in 5 years. Storage of the underwater MTR inspection table and its preventative maintenance should also be embraced under the applicable system health report that covers basin water chemistry and the corrosion program for L Basin with the advisory caution that the inspection table may be used for underwater NDE (both visual inspection and ultrasonic testing) fuel can inspections to support the AMCAP non-Al Fuel Containers Examination Program.



ACKNOWLEDGEMENTS

We would like to thank the many contributors to the work in the conceptualization, preparation, and execution for the inspection of aluminum SNF to demonstrate its continued safe storage in L Basin at the Savannah River Site.

Chris Verst of the Savannah River National Laboratory and Rich Deible of Spent Fuel Engineering constructed the basis and selected the ten MTR aluminum fuel assemblies for the inspection.

The design and development of the MTR Fuel Inspection Table was led by Chris Verst, Kevin Counts, Rich Deible, and Andrew Colebeck. The features of this table for remote underwater visual examination in L Basin enabled reproducible high-quality imaging via indexed positioning using the "workhorse" basin camera (in a special jig), and controlled (and replaceable) LED lighting. The Spent Fuel rigging team submerged and positioned the table in L Basin.

The inspection was facilitated by the preparation of two key procedures. The Spent Fuel Operations procedure for performing fuel movement had critical contributions from Spent Fuel Operations personnel Luke Jolley and Steve Osteen with Spent Fuel Engineering personnel Andrew Colebeck, with help in driving preparation from senior procedure writer Dave Flora. We also thank Joe Bryce for his review of this procedure. An SRNL Inspection Guide for performing the fuel inspections had contributions from Chris Verst and Josh Boerstler.

All ten fuel inspections were performed over the 2019 calendar year. This required a dedicated team of many spent fuel operations and radiological protection personnel participants and contributors. The ownership and proficiency of these folks was amazing. The operations personnel demonstrated efficiency and accuracy throughout detabbing the bundle lid, removal of the fuel at the debundling station in the saw row, and the many fuel movements required with movement of the SNF at the inspection table. The communication also with the SRNL inspection team of Chris Verst and corrosion expert, Josh Boerstler, and Spent Fuel Engineering Andrew Colebeck was excellent over the 4 separate inspection campaigns.

The post-inspection information analysis was supported by the summer intern, now site engineer, Jose Zambrano Garcia. Jose dug into our Spent Fuel Engineering's "bat cave" to provide historical information, worked to site media services to get old electronic media converted to digital medias for use in old facility inspection comparison picture snag-its, and help boiled down the voluminous historical information on the inspection fuel reactor, storage facility and fuel fabrication characteristics for use in this report.

We also thank the chief contributors for the inputs and several reviews of the report including the addition of water chemistry (Spent Fuel Engineering's Evan Morris) and corrosion sections of this report. This included Chris Verst, Josh Boerstler and John Mickalonis of SRNL. Josh deserves additional thanks for his several technical (and saving, but painful) edits of this report to get it to the finish line.

We sincerely thank all these contributors for the first-ever AMCAP MTR Fuel Inspection effort in the SRS Spent Fuel Project L Basin Facility. We have the deepest gratitude for pulling off this effort in the midst of competing, but important spent fuel mission receipt and shipping functions. This team executed with a safety focus and dedication to this mission-critical work!

Sincerely,
Michelle A. Hromyak
AMCAP Lead

Dr. Robert L. Sindelar
AMCAP Co-Lead

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APPENDIX 1

Inspection Assemblies Bundle Debundling Photos

APPENDIX 1

Inspection Assembly Bundle Debundling Photos

The debundling photos contained within this appendix were the best available at the time of debundling. All the pictures were taken with the L Basin underwater camera using only basin general lighting and the light on the camera itself. As the inspections progressed, better care was taken to ensure ample video of the assemblies for all four sides of each debundled assembly. This was identified as an AMCAP opportunity. All assemblies shown are standard assemblies unless otherwise noted.

<u>Campaign 1- Inspection 1</u> (*Conducted January 2019*)

Argentine RA-3 Bundle L-RA3-0817 (3 Assemblies)

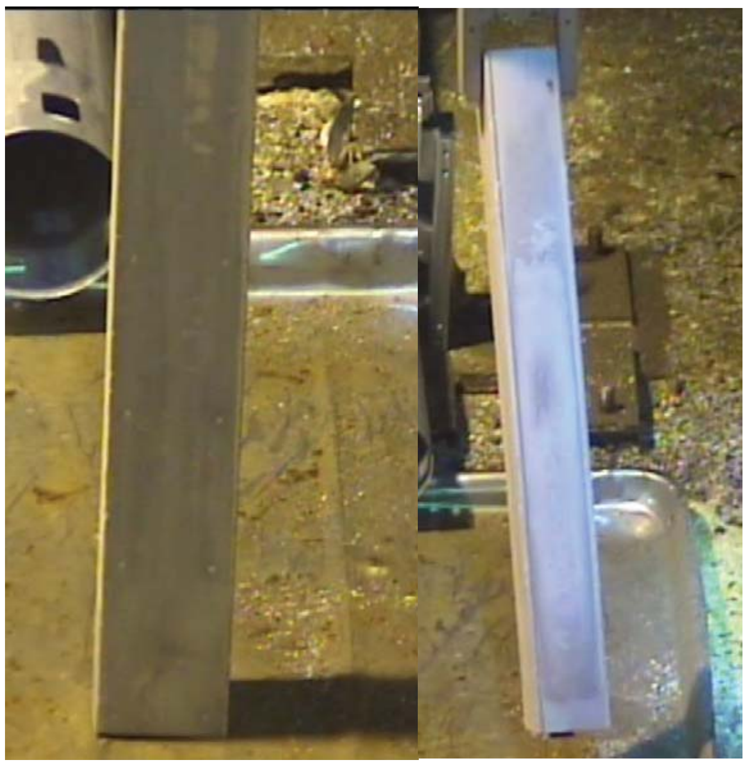


Figure A1-1 Inspection Assembly S-113 (Control Assembly)

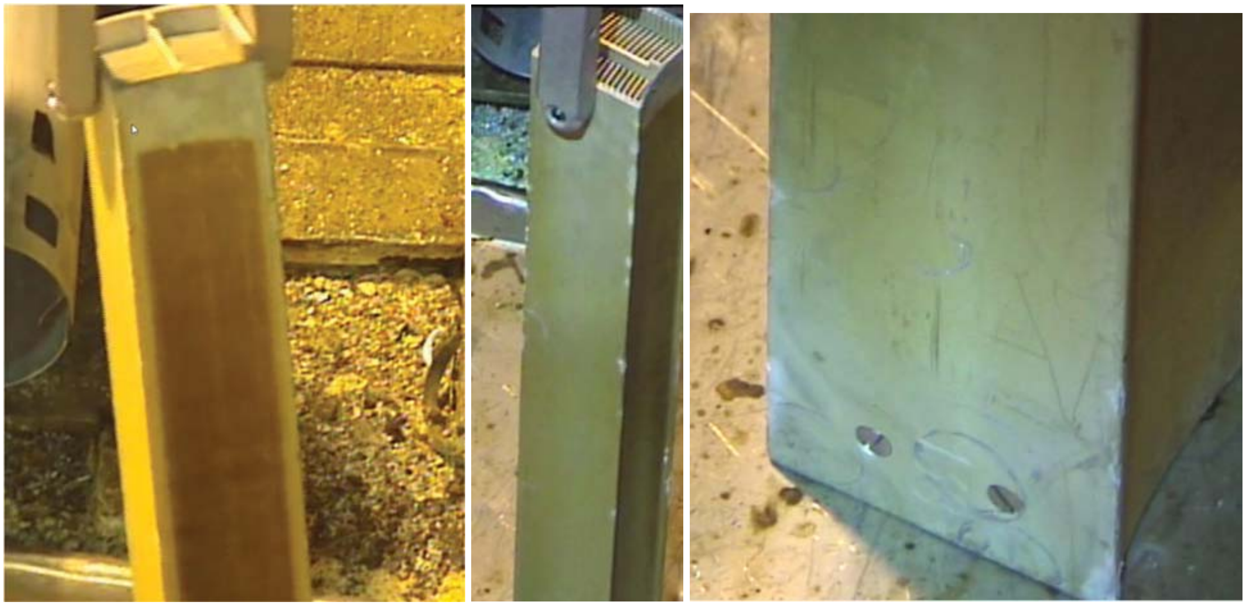


Figure A1- 2 Argentine RA-3 Bundle L-RA3-0817 (3 Assemblies) 138

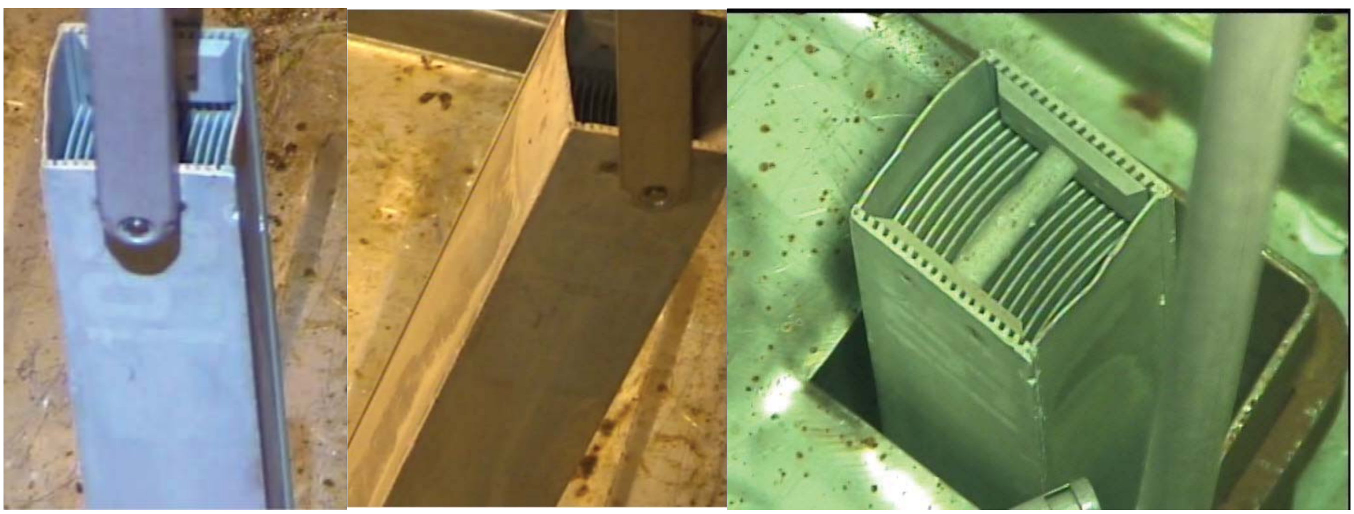


Figure A1-3 Argentine RA-3 Bundle L-RA3-0817 (3 Assemblies) 195

Campaign 2 – Inspection 2 (*Conducted June 2019*)

Brazilian IEA-R1 Bundle L-IEA-R1-0625 (5 Assemblies)

Figure A1-4 Inspection Assembly IEA 79

Campaign 2 – Inspection 2 (*Conducted June 2019*) (Contd)

Brazilian IEA-R1 Bundle L-IEA-R1-0625 (5 Assemblies) (Contd)

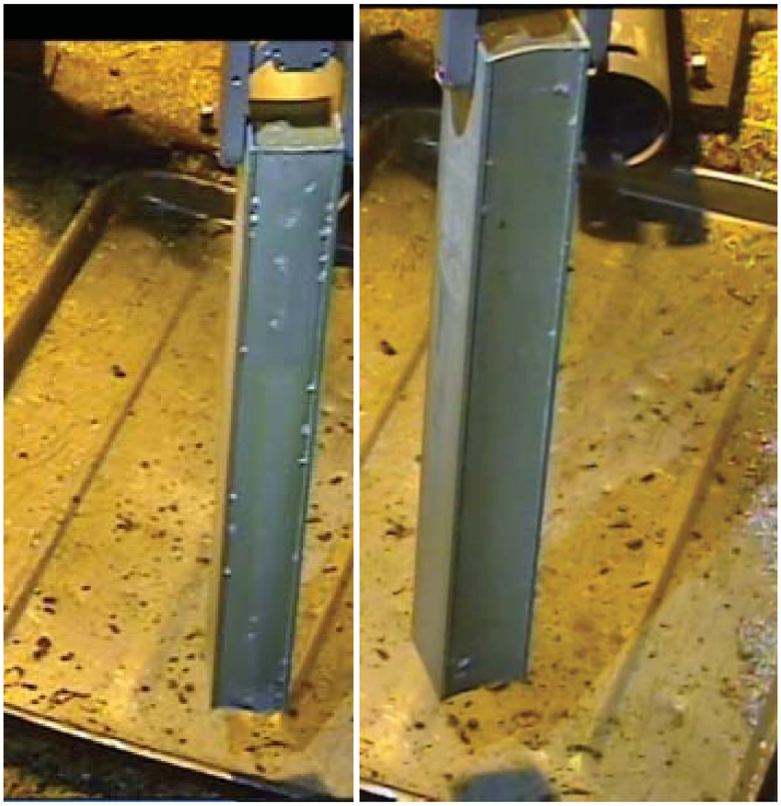


Figure A1-5 IEA-59

IEA-61

Campaign 2 – Inspection 2 (Conducted June 2019) (Contd)

Brazilian IEA-R1 Bundle L-IEA-R1-0625 (5 Assemblies) (Contd)

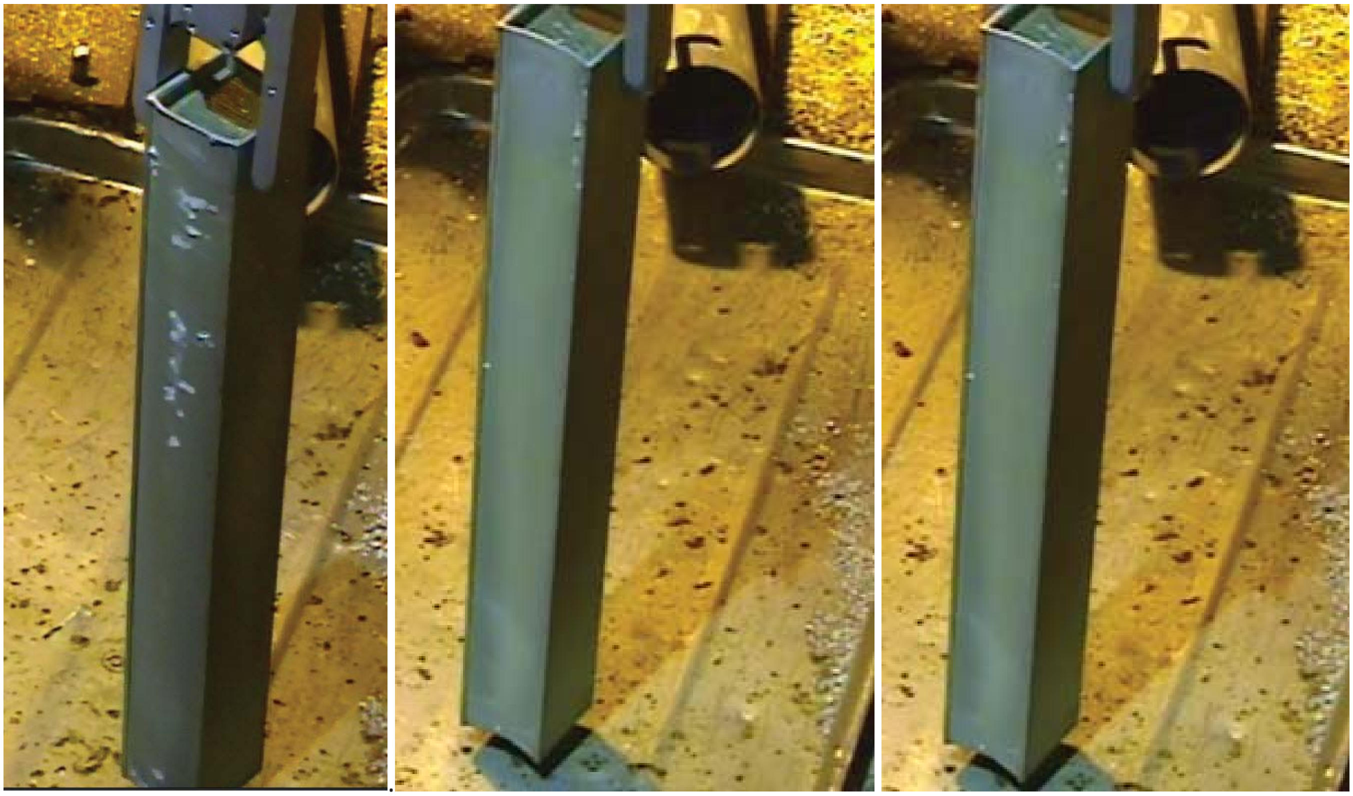


Figure A1- 6 IEA-66 ***IEA-72***

<u>Campaign 2 – Inspection 3</u> (*Conducted June 2019*)

Argentine RA-3 Bundle L-RA3-0822 (4 Assemblies)

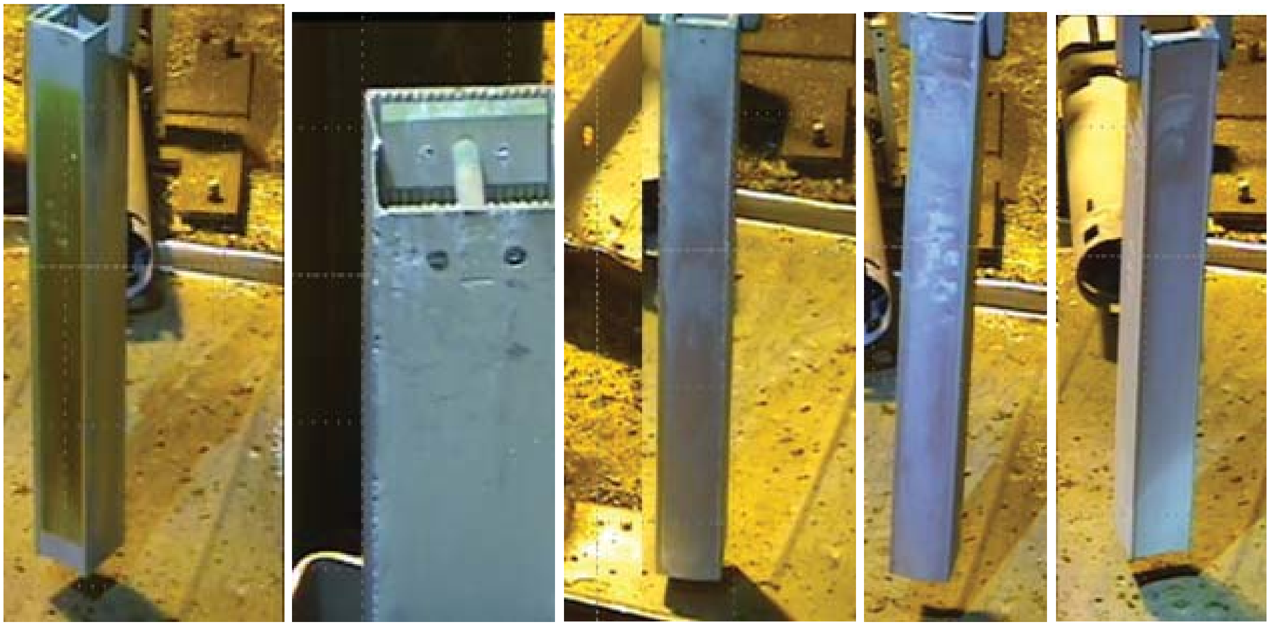


Figure A1-7 110 ***139*** ***CNEA-301***

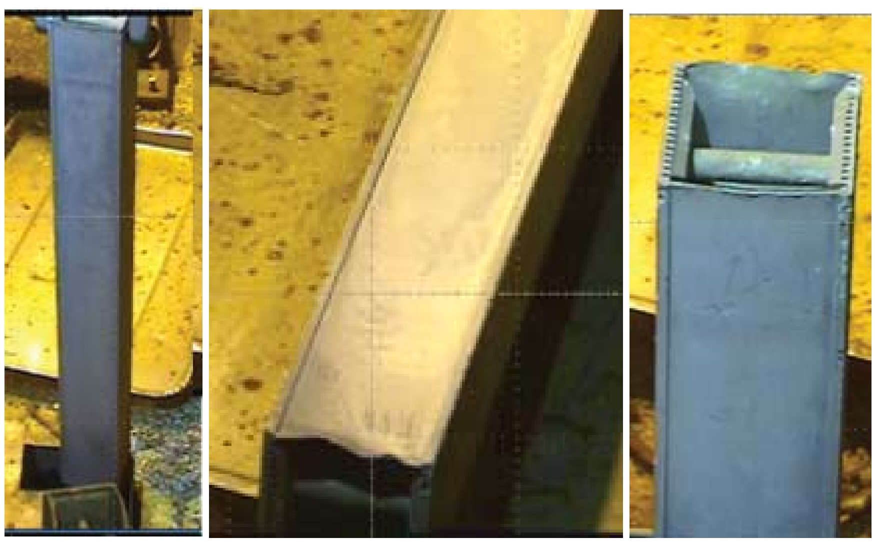


Figure A1-8 Inspection Assembly 160

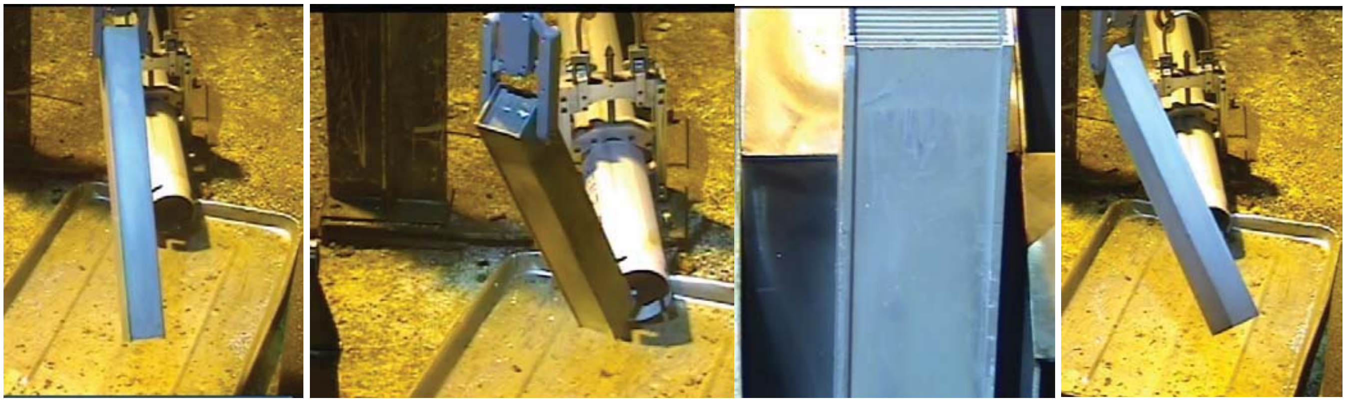


Figure A1-9 CMN 7 *GA 12*

<u>Campaign 2 – Inspection 4</u> (*Conducted June 2019*)

Italian ENEA Galileo Bundle L-ENEA-0024 (5 Assemblies)

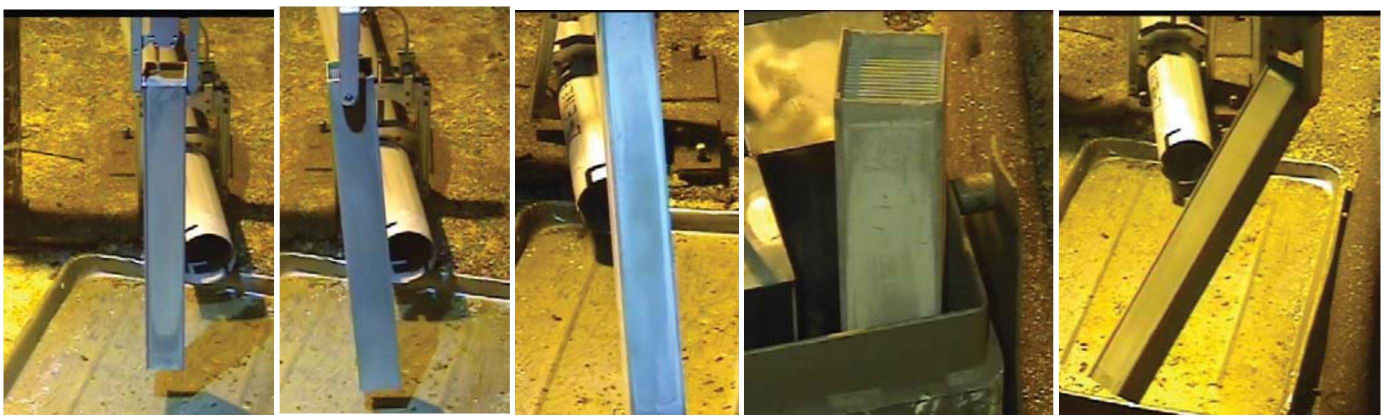


Figure A1-10 GA 16 *GA 45* *GA 84X (Inspection Assy.)*

Campaign 3 – Inspection 5 (*Conducted August 2019*)

Argentine RA-3 Bundle L-RA3-0794 (4 Assemblies)

S-121 is a Control Assembly (like Inspection 1 S-113 Inspection Assembly)

Figure A1-11 153 CNEA-257 S-121 Inspection Assembly 30

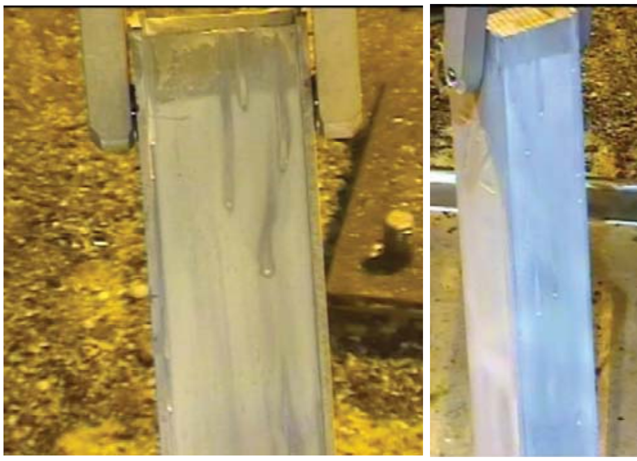
Campaign 3 – Inspection 6 (*Conducted August 2019*)

Italian ENEA Galileo Bundle L-ENEA-0352 (5 Assemblies)

Figure A1-12 71-GA67 (Inspection Assy.) 71-GA69

Campaign 3 – Inspection 6 (*Conducted August 2019*) (Contd)

Italian ENEA Galileo Bundle L-ENEA-0352 (5 Assemblies) (contd)



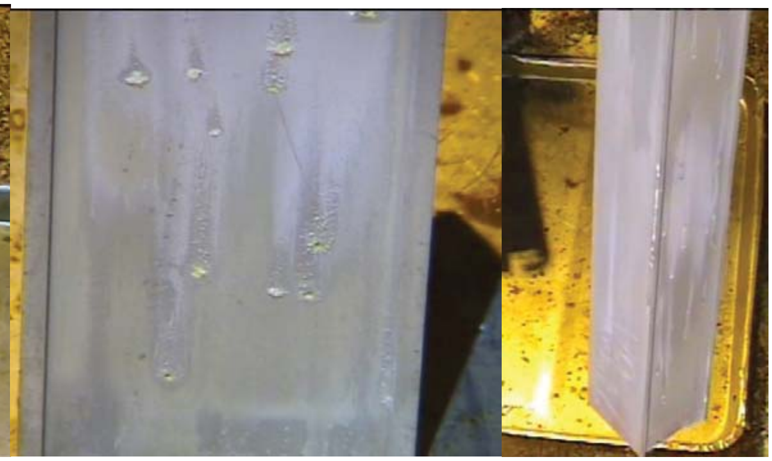


Figure A1-13 71-GA72 ***71-GA76***

Figure A1-14 71-GA77

Campaign 3 – Inspection 7 (*Conducted August 2019*)

Australian HIFAR Bundle L-HIFAR-1918 (5 Assemblies)

Figure A1-15 ED 513 ***UED 1553*** ***UED 1556***

Figure A1-16 ***UED 1556 Contd*** ***UED 1561*** ***Inspection Assembly UED 1567***

Campaign 4 – Inspection 8 (*Conducted December 2019*)

Argentine RA-3 Bundle L-RA3-0787 (4 Assemblies)

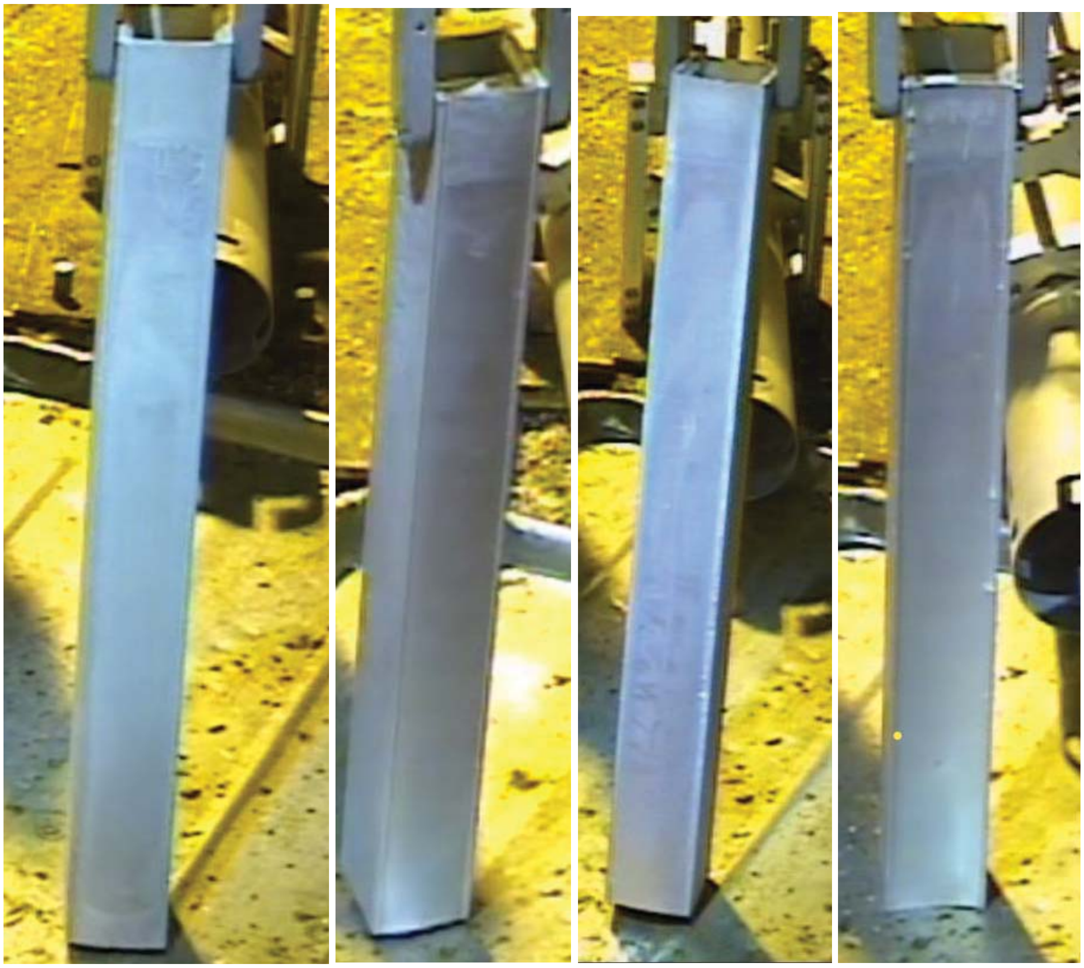


Figure A1-17 263 270 271 272 (Inspection Assembly)

Campaign 4 – Inspection 9 (*Conducted December 2019*)

Italian ENEA Galileo Bundle L-ENEA-0356 (5 Assemblies)

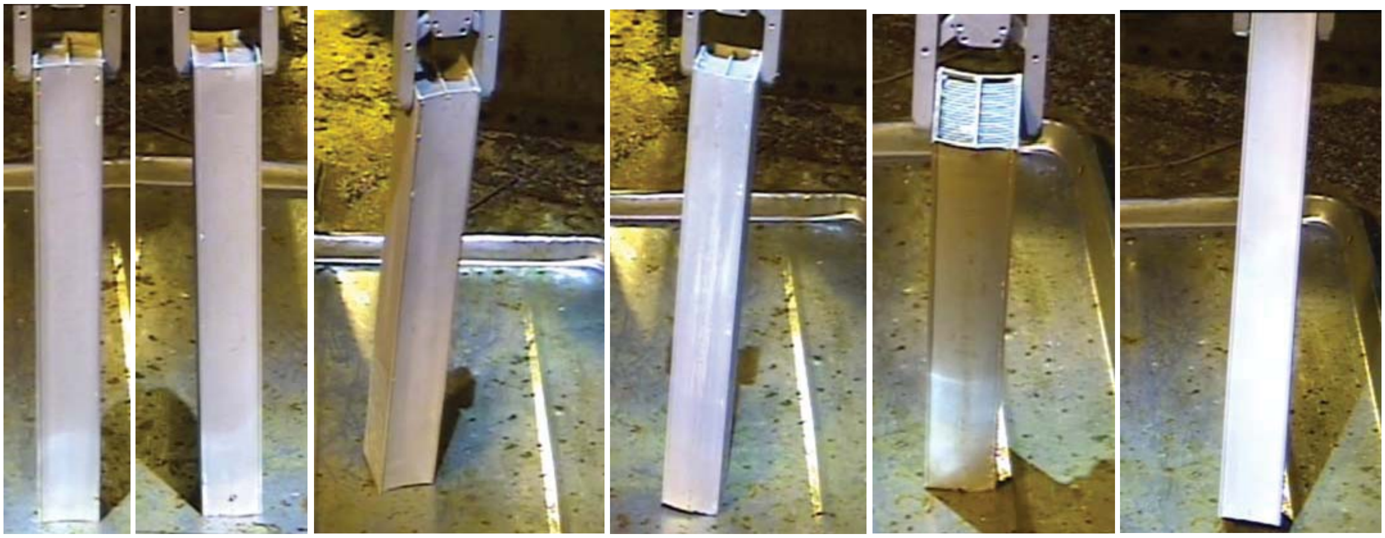


Figure A1- 18 3-1-IX   3-5-IX   Inspection Assembly 3-9-IX

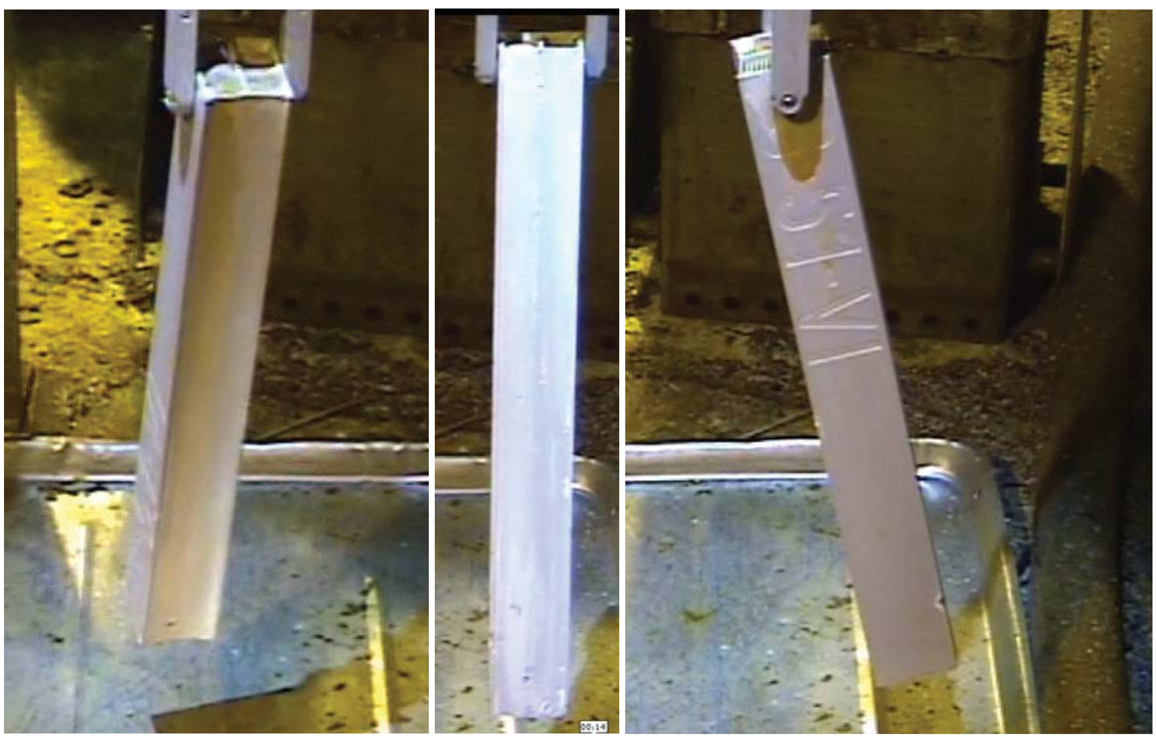


Figure A1-19 3-12-IX debundling no video available   3-51-IV

Campaign 4 – Inspection 10 (*Conducted December 2019*)

Amsterdam HFR Petten Bundle L-HFR-1435 (4 Assemblies)

Inspection Assembly F950 debundling no video available

Figure A1-20 F976 F987 F1130

APPENDIX 2

Inspection Assemblies Photos

APPENDIX 2
Inspection Assemblies Photos

Inspection Videos were taken on the MTR Fuel Inspection Table starting with one end then progressing through the inspection of the four assembly sides and finishing with the other end of the assembly. For the HIFAR involute fuel, there were three sides of the round fuel inspected.

The inspection table has 8 camera slots. The end camera slots are Slot 1 and Slot 8. The remaining 6 slots (Slots 2 through 7) are used to inspect each side. For four sides that means 24 camera positions are used for the inspection. The video is taken with varying the two light banks. This light cycling included both light banks (Light 1 and Light 2) on, then one on and one off (Light 1 on, Light 2 off, then Light 1 off and Light 2 on). The intent is to have at least three lighting contrasts for each camera view. Zooming of the camera was performed at the discretion of the inspection team (SFP Engineer Lead and SRNL Nuclear Materials Management Lead).

Refer to the SRNL Inspection Guide (Appendix 6) and the figure listed below extracted from the guide:

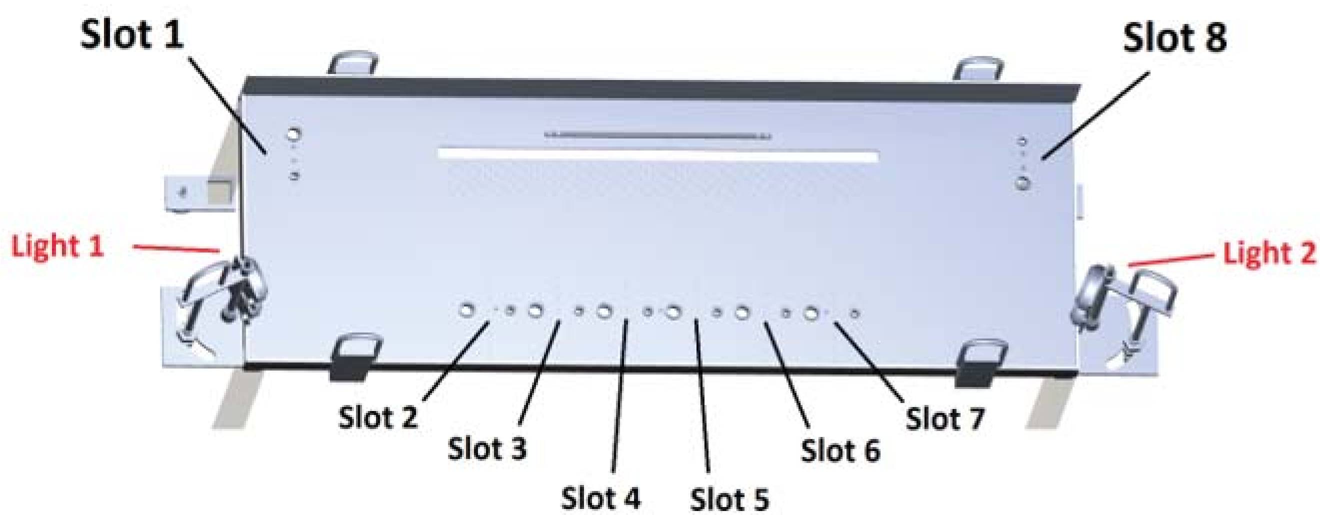


Figure A2-1 Inspection Table Slot and Light Labels

Campaign 1- Inspection 1 (*Conducted January 2019*)

Argentine RA-3 Inspection Assembly S-113

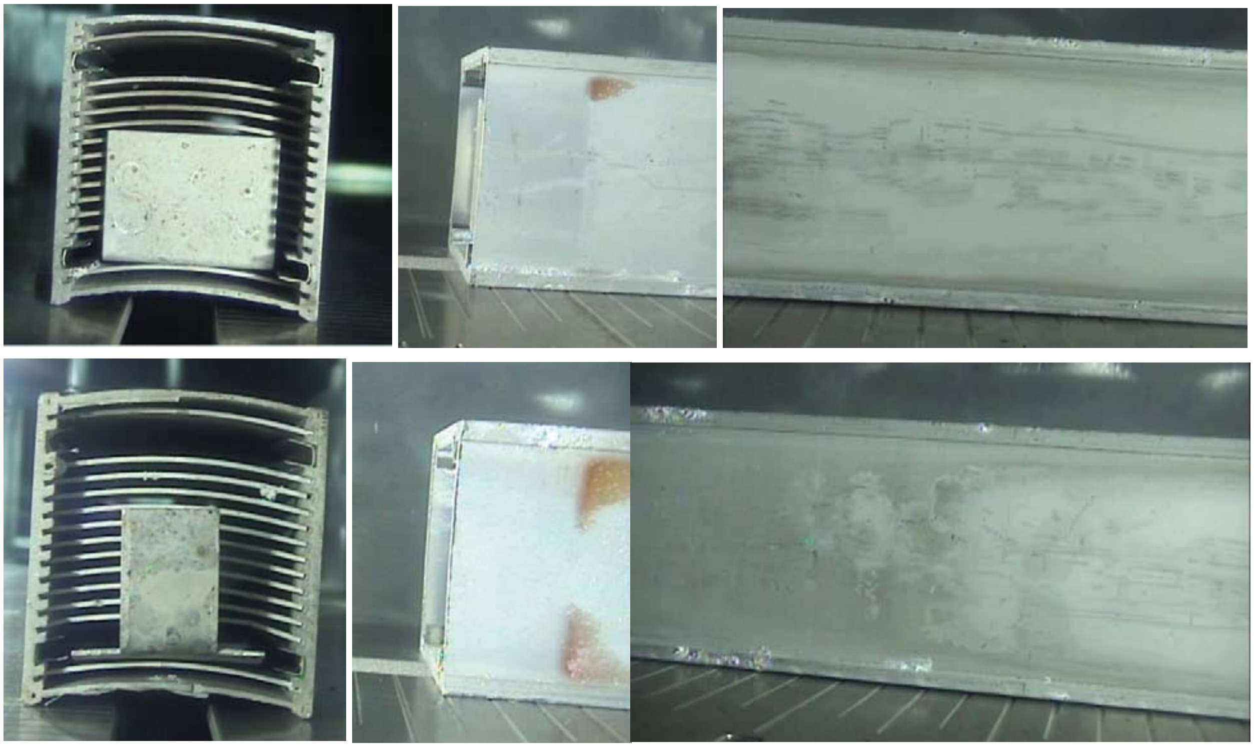


Figure A2-2 First inspection assembly. Pictures of fuel ends (left) with concave and convex exterior fuel plates (right).

Campaign 1- Inspection 1 (*Conducted January 2019*) (Contd)

Argentine RA-3 Inspection Assembly S-113 (contd)

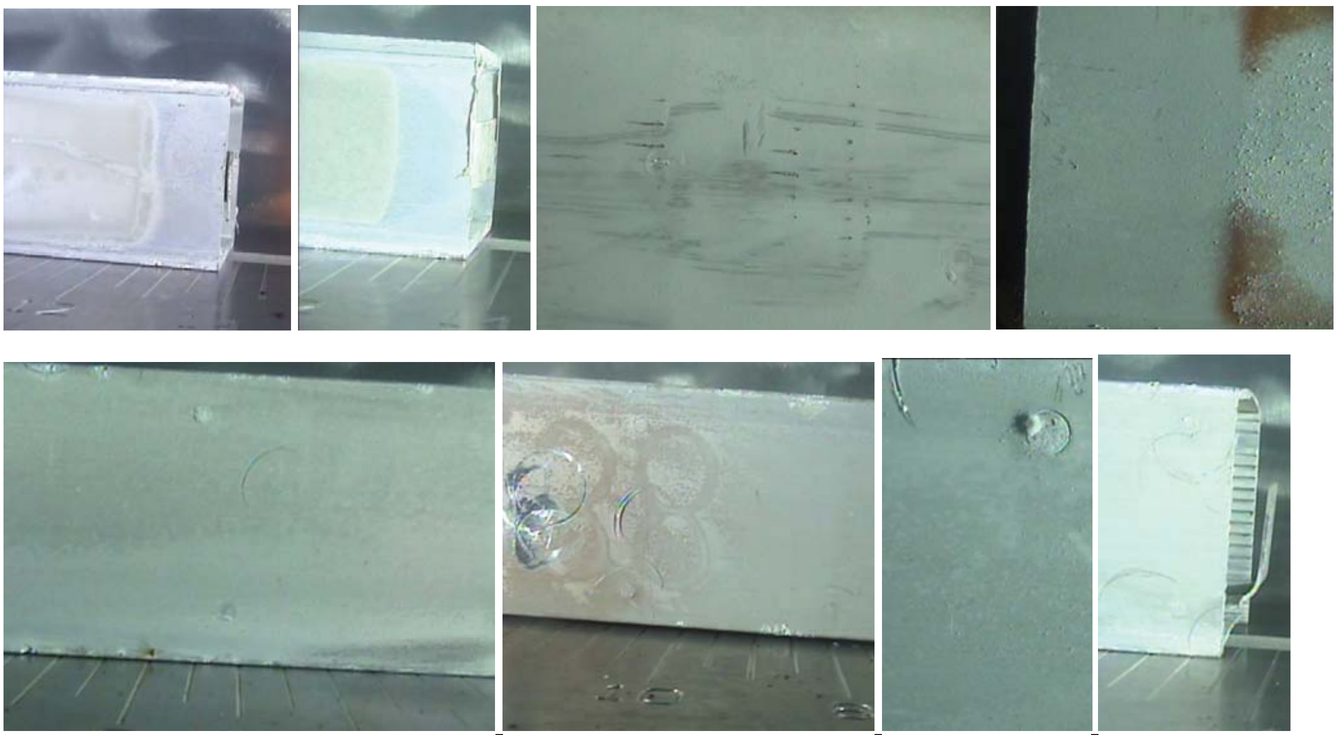


Figure A2-3 Concave and convex exterior fuel plate ends (left) followed by exterior fuel plate details (right).

Campaign 2 – Inspection 2 (*Conducted June 2019*)

Brazilian IEA-R1 Inspection Assembly IEA-79

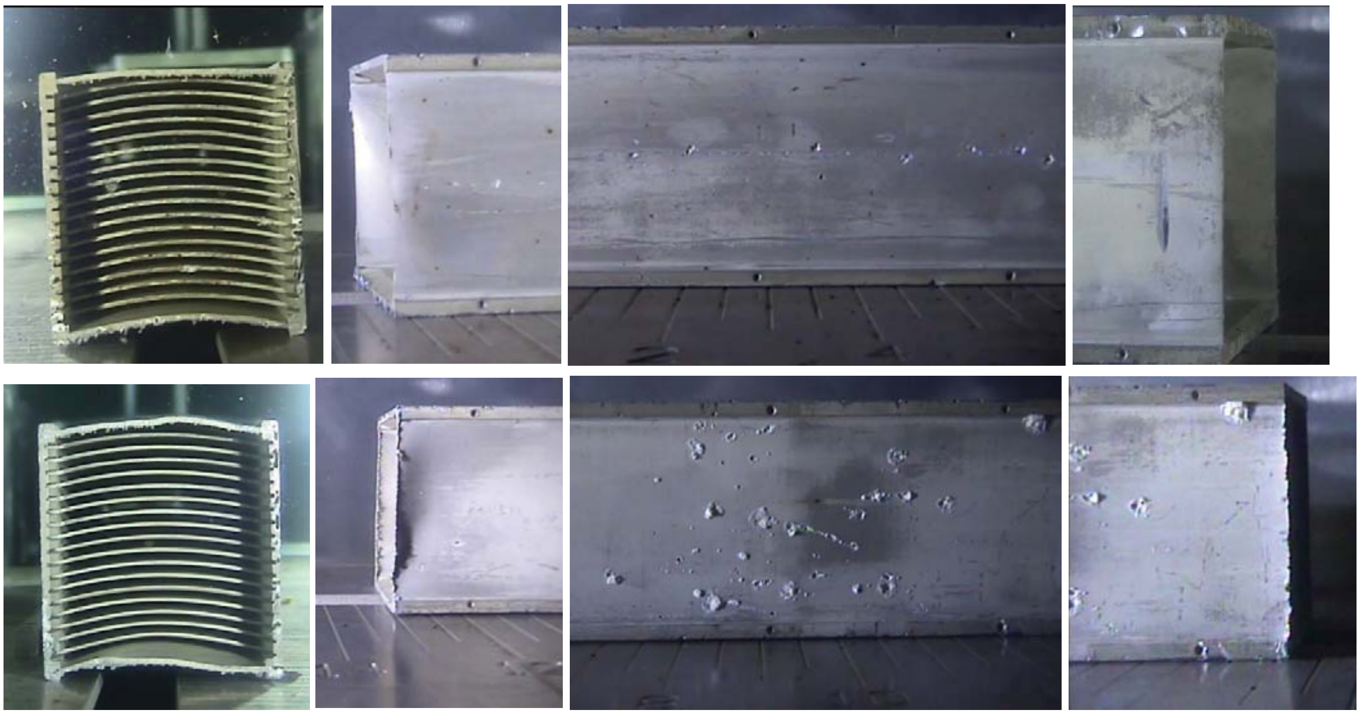


Figure A2-4 Second inspection assembly. Pictures of fuel ends (left) with concave and convex exterior fuel plates (right).

Campaign 2 – Inspection 3 (*Conducted June 2019*)

Argentine RA-3 Inspection Assembly 160

Figure A2-5 Pictures of fuel ends (left) with concave and convex exterior fuel plates (right)

Campaign 2 – Inspection 3 (*Conducted June 2019*) (Contd)

Argentine RA-3 Inspection Assembly 160 (contd)

Figure A2-6 Two Side Plates shown (different rows)

Campaign 2 – Inspection 4 (*Conducted June 2019*)

Italian ENEA Galileo Inspection Assembly GA 84X

Pictures of fuel ends (*left*) with exterior fuel plates (*right*).

Figure A2-7 Pictures of fuel ends (left) with exterior fuel plates (right)

Campaign 3 – Inspection 5 (*Conducted August 2019*)

Argentine RA-3 Inspection Assembly 30

Figure A2-8 Pictures of fuel ends (left) with concave and convex exterior fuel plates (right)

<u>Campaign 3 – Inspection 5</u> (*Conducted August 2019*) (Contd)

Argentine RA-3 Inspection Assembly 30 (contd)

Figure A2-9 Two Side Plates shown below (different rows).

<u>Campaign 3 – Inspection 6</u> (*Conducted August 2019*)

Italian ENEA Galileo Inspection Assembly 71-GA67

Figure A2-10 Pictures of fuel ends (left) with exterior fuel plates (right)

Campaign 3 – Inspection 6 (*Conducted August 2019*) (Contd)

Italian ENEA Galileo Inspection Assembly 71-GA67 (contd)

Figure A2-11 Two Side Plates shown (different rows)

Campaign 3 – Inspection 7 (*Conducted August 2019*)

Australian HIFAR Inspection Assembly UED 1567

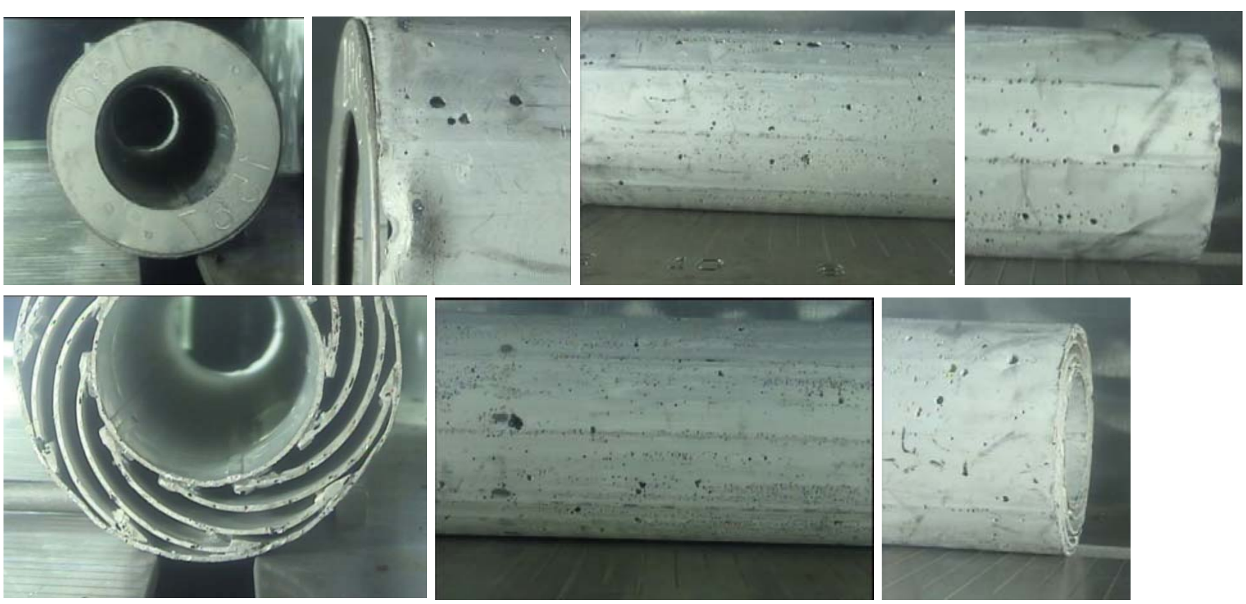


Figure A2-12 End views with outer shell (aluminum) side views

Campaign 4 – Inspection 8 (*Conducted December 2019*)

Argentine RA-3 Inspection Assembly 236

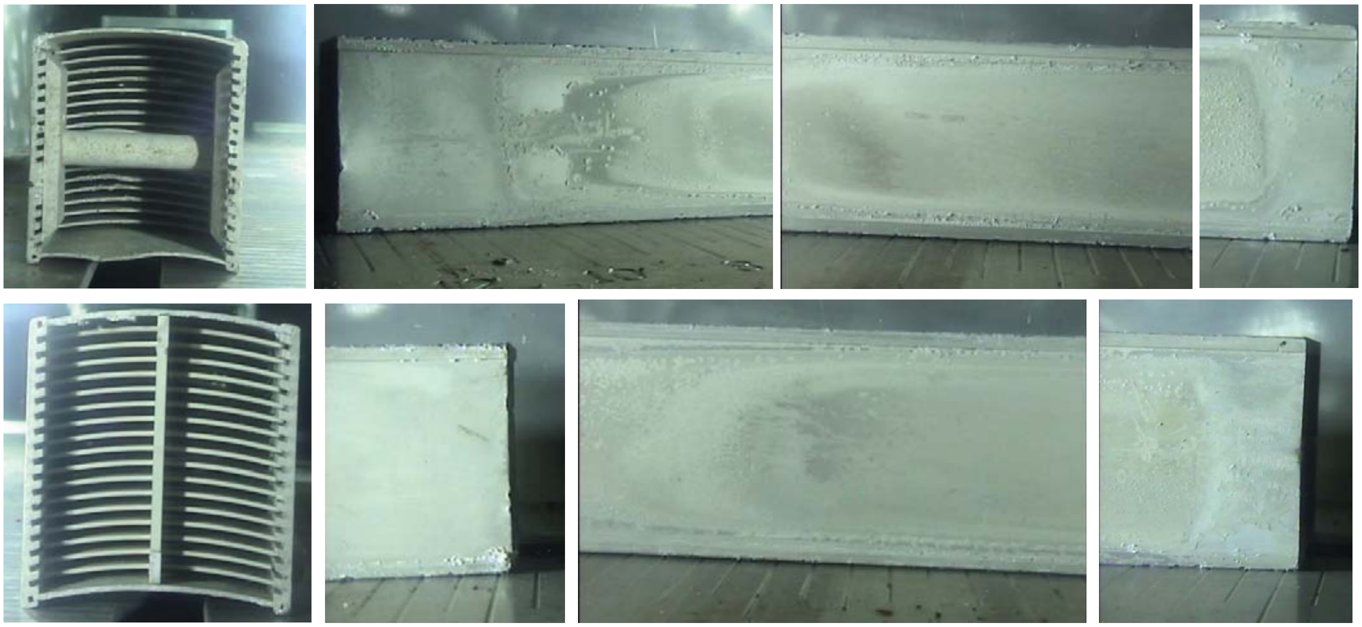


Figure A2-13 Pictures of fuel ends (left) with concave and convex exterior fuel plates (right)

Campaign 4 – Inspection 8 (*Conducted December 2019*) (Contd)

Argentine RA-3 Inspection Assembly 236 (contd)

Figure A2-14 Two Side Plates shown (different rows)

Campaign 4 – Inspection 9 (*Conducted December 2019*)

Italian ENEA Galileo Inspection Assembly 3-9-IX

Figure A2-15 Pictures of fuel ends (left) with concave and convex exterior fuel plates (right)

<u>Campaign 4 – Inspection 9</u> (*Conducted December 2019*) (Contd)

Italian ENEA ISPRA Inspection Assembly 3-9-IX (contd)

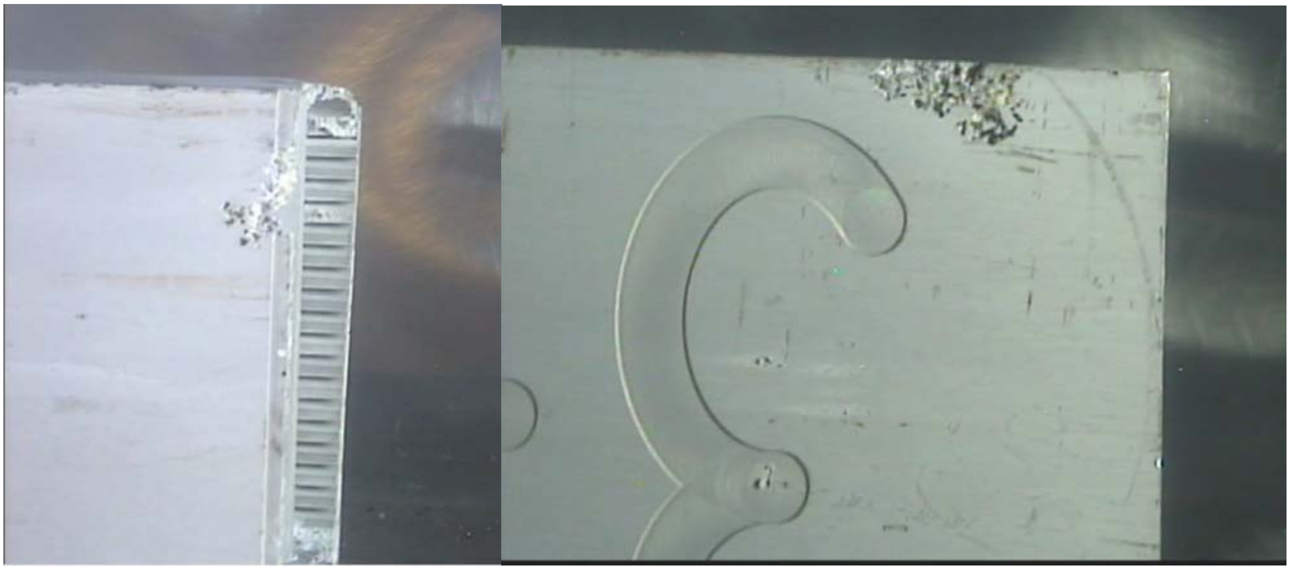


Figure A2-16 Side plate details

<u>Campaign 4 – Inspection 10</u> (*Conducted December 2019*)

Amsterdam HFR Petten Inspection Assembly F950

Figure A2-17 Pictures of fuel ends followed by concave and convex exterior fuel plates

APPENDIX 3

Inspection Assembly Bundle Debundling/Inspection Pictures with Previous Facility Inspections

APPENDIX 3
Inspection Assembly Bundle Debundling/Inspection
Pictures with Previous Facility Inspections

For comparison photos shown, the photo to the left is the original storage facility inspection.

Campaign 1- Inspection 1 (*Conducted January 2019*)

Argentine RA-3 Bundle L-RA3-0817 (3 Assemblies)

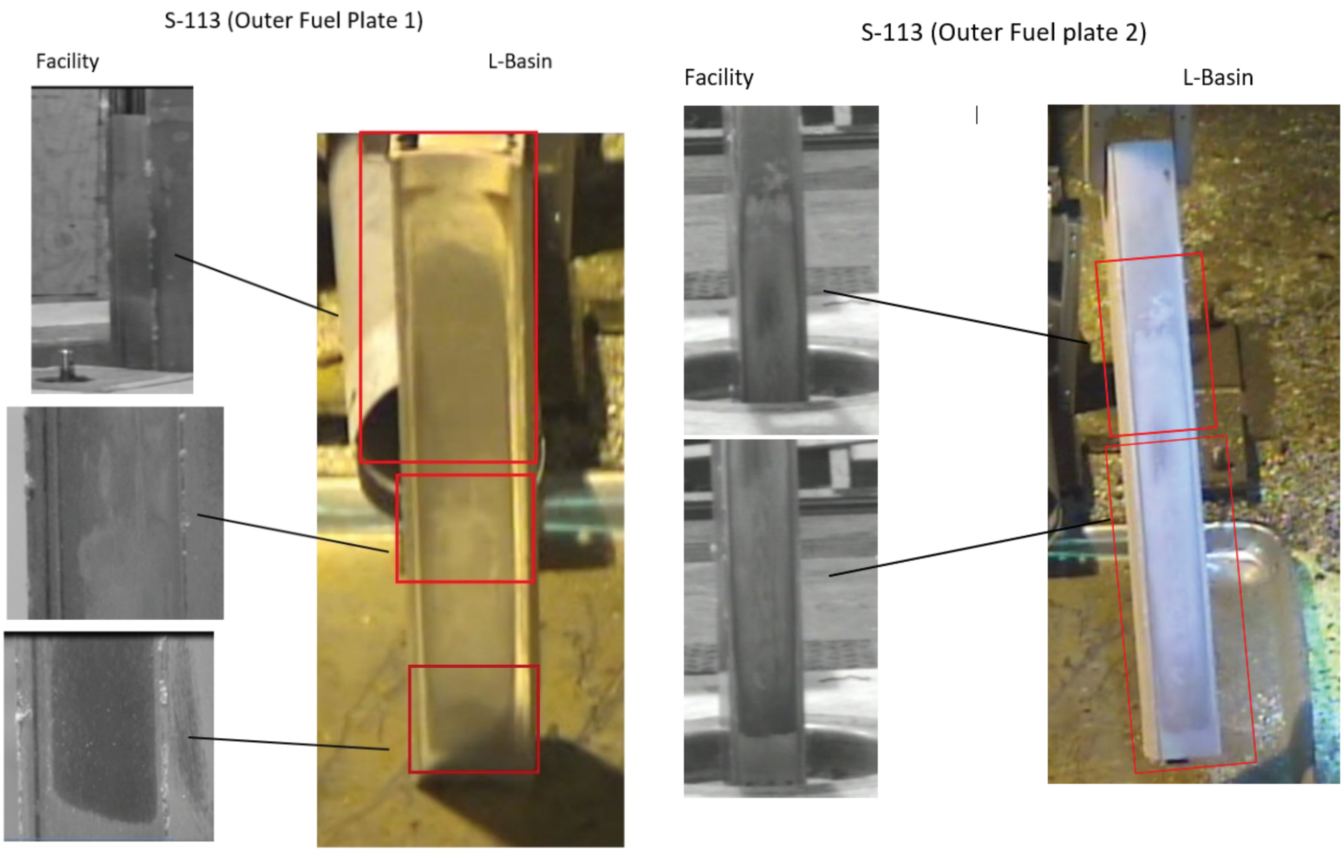
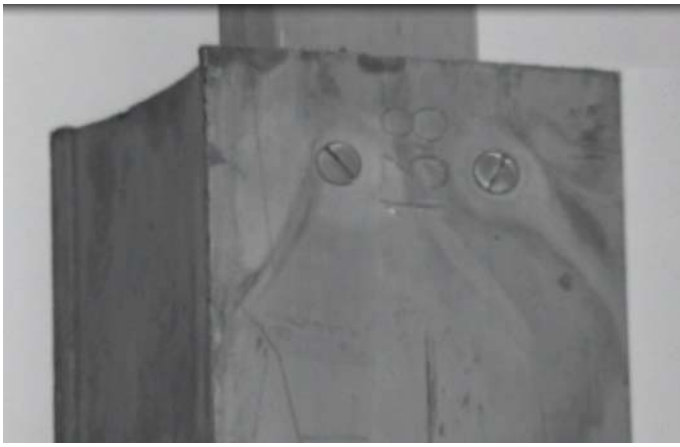


Figure A3-1 Inspection Assembly 113

<u>Campaign 1- Inspection 1</u> (*Conducted January 2019*)

Argentine RA-3 Bundle L-RA3-0817 (3 Assemblies)

Facility (1999) L Basin (2019)



Facility (1999) L Basin (2019)

Figure A3-2 Assembly 138

<u>Campaign 2 – Inspection 2</u> (*Conducted June 2019*)

Brazilian IEA-R1 Bundle L-IEA-R1-0625 (5 Assemblies)

Debundled Assembly IEA-59 shown in the Report.

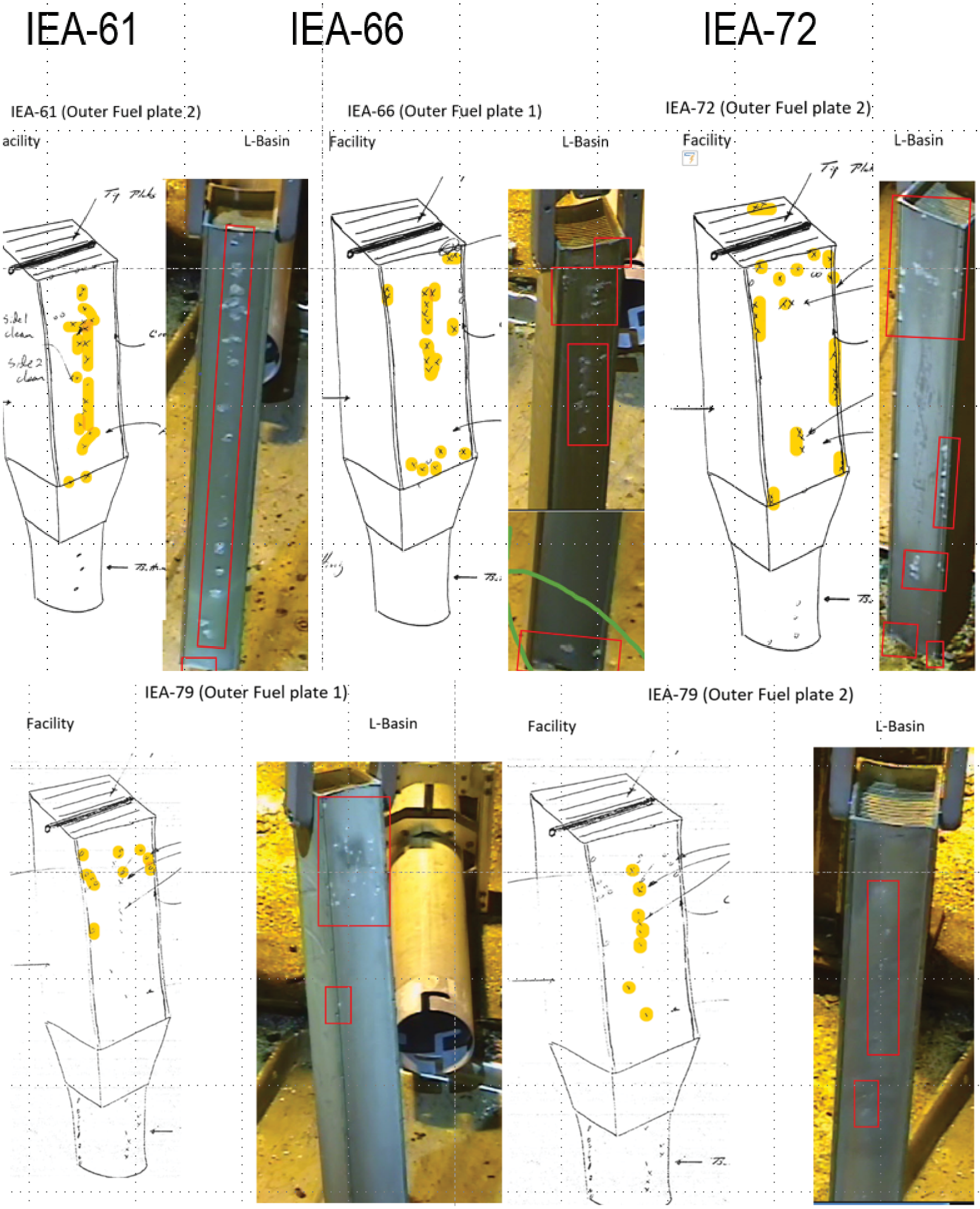


Figure A3-3 Debundled Assembly IEA-59 shown in the Report

Campaign 2 – Inspection 3 (*Conducted June 2019*)

Argentine RA-3 Bundle L-RA3-0822 (4 Assemblies) Inspection Assembly 160

Facility (1999) L Basin Inspection Table (2019)

Facility (1999) L Basin Inspection Table (2019)

Figure A3-4 Inspection Assembly 160

Campaign 2 – Inspection 3 (*Conducted June 2019*) (Contd)

Argentine RA-3 Bundle L-RA3-0822 (4 Assemblies) (contd) Assembly 110

Facility Inspection (1999) L Basin (2019)

Figure A3-5 Assembly 110

Campaign 2 – Inspection 4 (*Conducted June 2019*)

Italian ENEA Galileo Bundle L-ENEA-0024 (5 Assemblies)

Inspection sheets were not available for the selected bundle assemblies.

Campaign 3 – Inspection 5 (*Conducted August 2019*)

Argentine RA-3 Bundle L-RA3-0794 (4 Assemblies)

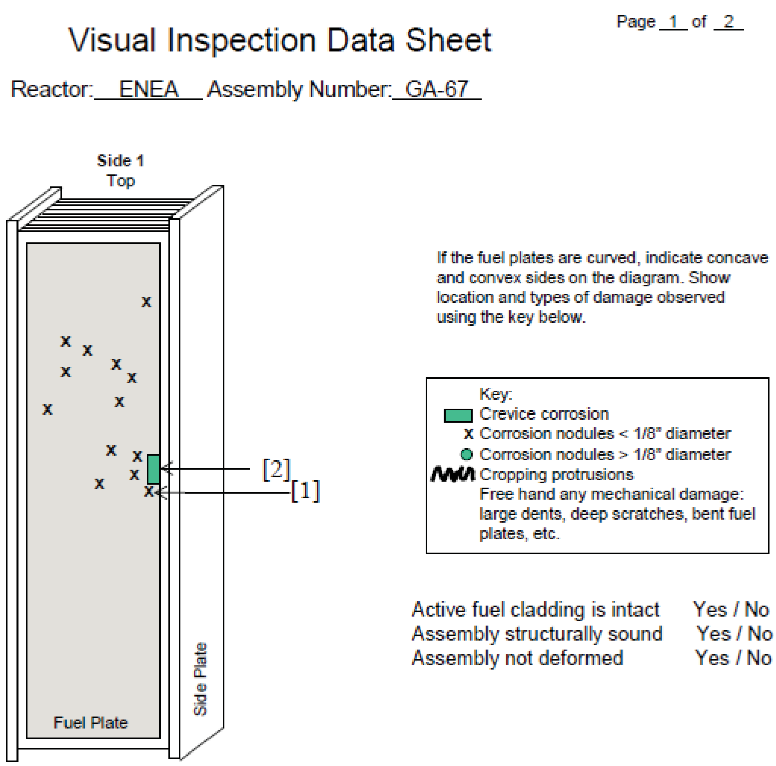
Facility Inspection (1999) | L Basin Inspection Table (2019) (side plate and adjoining side fuel plate)

Figure A3-6 Inspection Assembly 30

Campaign 3 – Inspection 6 (*Conducted August 2019*)

Italian ENEA Galileo Bundle L-ENEA-0352 (5 Assemblies)

At the ENEA Storage Facility (1997) L Basin (2019)


Page 1 of 2

Visual Inspection Data Sheet

Reactor: ENEA Assembly Number: GA-67

If the fuel plates are curved, indicate concave and convex sides on the diagram. Show location and types of damage observed using the key below.

Key:
Crevice corrosion
x Corrosion nodules < 1/8" diameter
Corrosion nodules > 1/8" diameter
Cropping protrusions
Free hand any mechanical damage: large dents, deep scratches, bent fuel plates, etc.

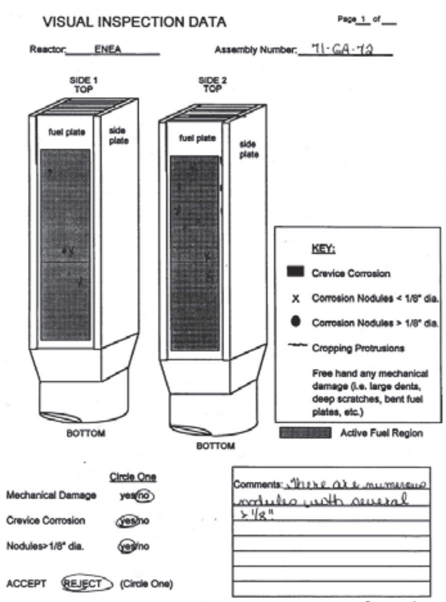
Active fuel cladding is intact	Yes / No
Assembly structurally sound	Yes / No
Assembly not deformed	Yes / No

Figure A3-7 Inspection Assembly 71-GA67

Campaign 3 – Inspection 6 (*Conducted August 2019*)

Italian ENEA Galileo Bundle L-ENEA-0352 (5 Assemblies)

At the ENEA Storage Facility (1997) L Basin (2019)


VISUAL INSPECTION DATA Page 1 of __

Reactor: ENEA Assembly Number: 71-GA-72

	Circle One
Mechanical Damage	yes/no
Crevice Corrosion	yes/no
Nodules>1/8" dia.	yes/no

ACCEPT REJECT (Circle One)

Comments: there are numerous nodules with several > 1/8"

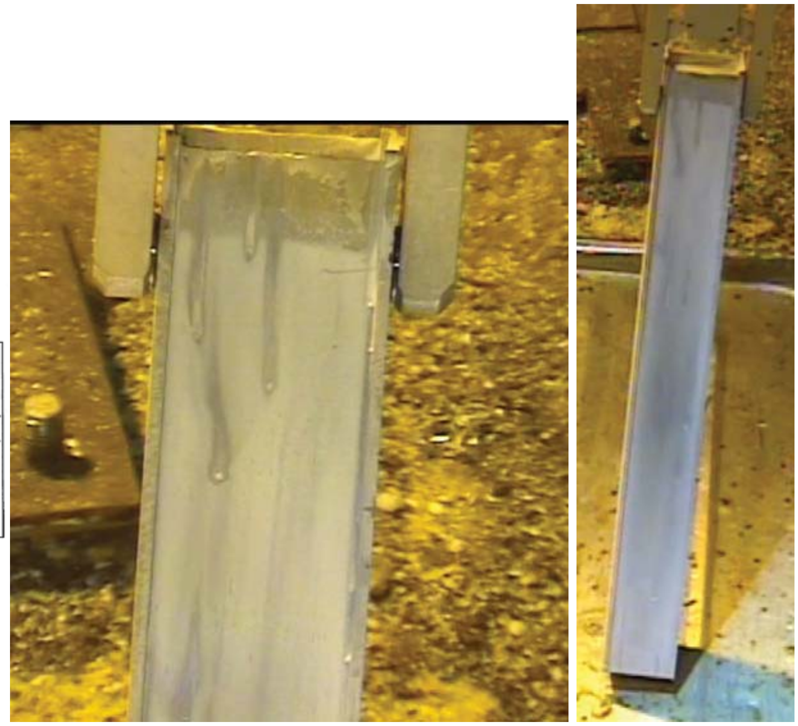
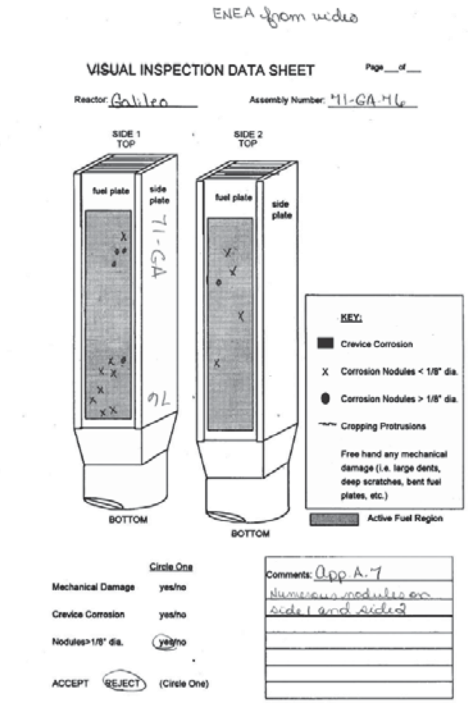


Figure A3-8 Assembly 71-GA72

Campaign 3 – Inspection 6 (*Conducted August 2019*)

Italian ENEA Galileo Bundle L-ENEA-0352 (5 Assemblies)

At the ENEA Storage Facility (1997) L Basin (2019)


ENEA from video

VISUAL INSPECTION DATA SHEET Page __ of __

Reactor: Galileo Assembly Number: 71-GA-76

SIDE 1 TOP — fuel plate — side plate — 71-GA 76 — BOTTOM

SIDE 2 TOP — fuel plate — side plate — BOTTOM

KEY:
- Crevice Corrosion
- X Corrosion Nodules < 1/8" dia.
- ● Corrosion Nodules > 1/8" dia.
- Cropping Protrusions
- Free hand any mechanical damage (i.e. large dents, deep scratches, bent fuel plates, etc.)
- Active Fuel Region

	Circle One
Mechanical Damage	yes/no
Crevice Corrosion	yes/no
Nodules>1/8" dia.	yes/no

ACCEPT REJECT (Circle One)

Comments: App A.7
Numerous nodules on side 1 and side 2

Figure A3-9 Assembly 71-GA76

Campaign 3 – Inspection 7 (*Conducted August 2019*)

Australian HIFAR Bundle L-HIFAR-1918 (5 Assemblies)

HIFAR Facility (red) (*typical*) L Basin (gray) (*typical*)

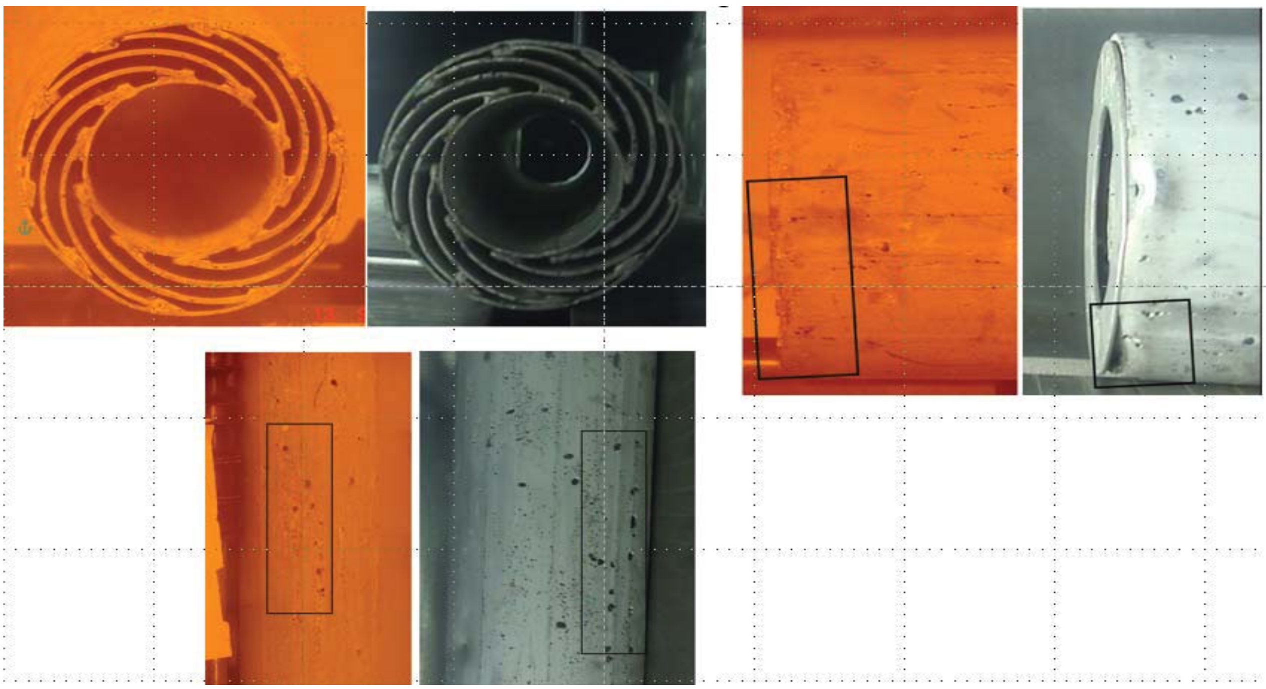


Figure A3-10 Australian HIFAR Bundle L-HIFAR-1918

Campaign 4 – Inspection 8 (*Conducted December 2019*)

Argentine RA-3 Bundle L-RA3-0787 (4 Assemblies)

Facility L Basin

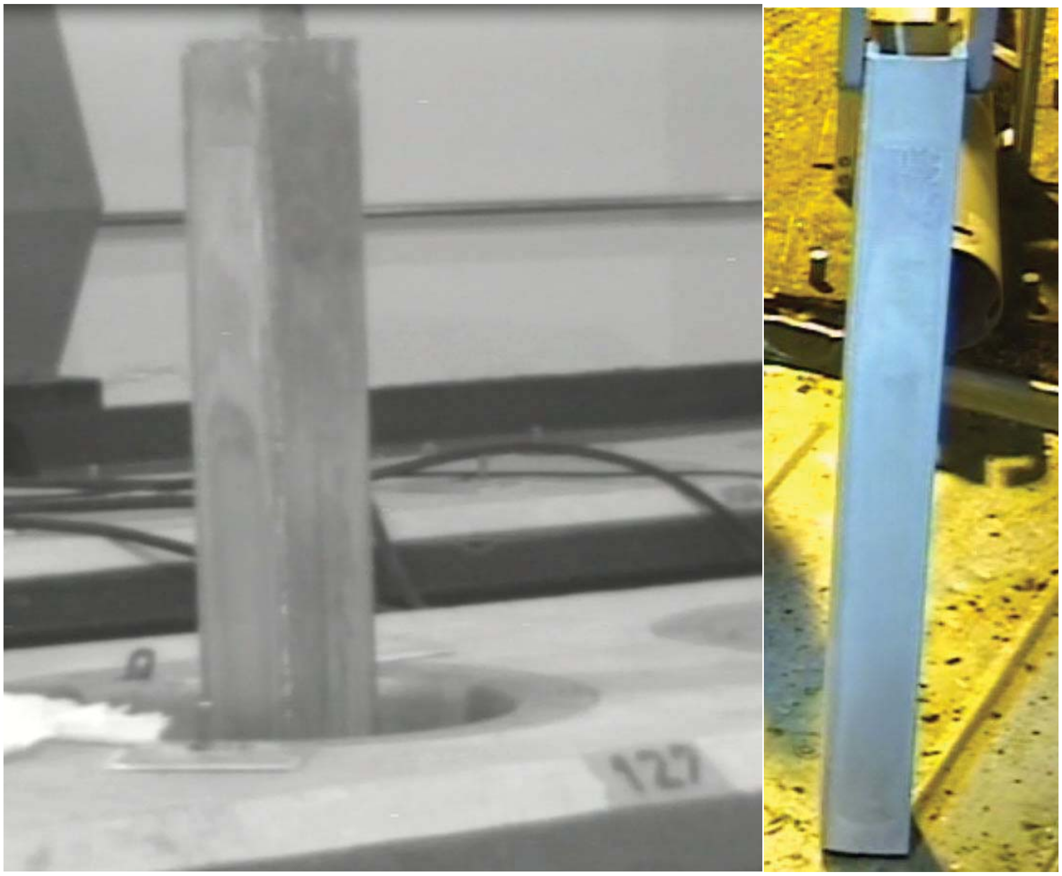


Figure A3-11 Inspection Assembly 236

Campaign 4 – Inspection 8 (*Conducted December 2019*) (Contd)

Argentine RA-3 Bundle L-RA3-0787 (4 Assemblies) (contd)

Facility (1999) L Basin (2019)

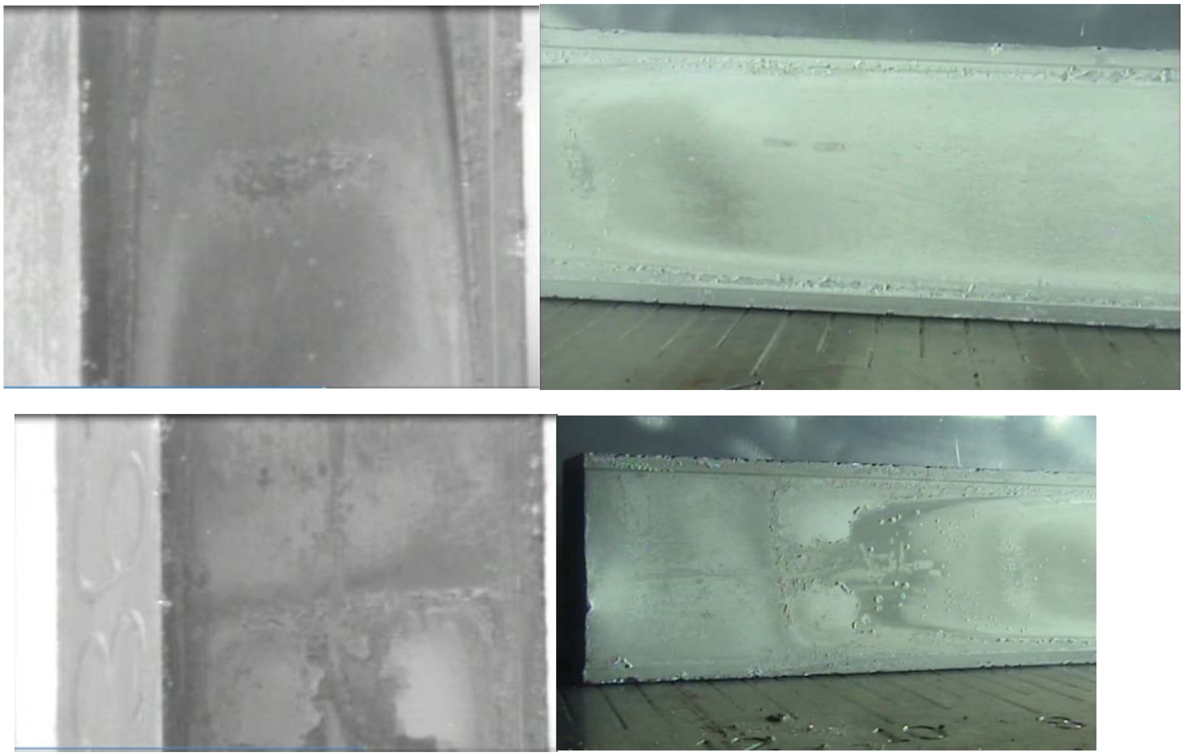
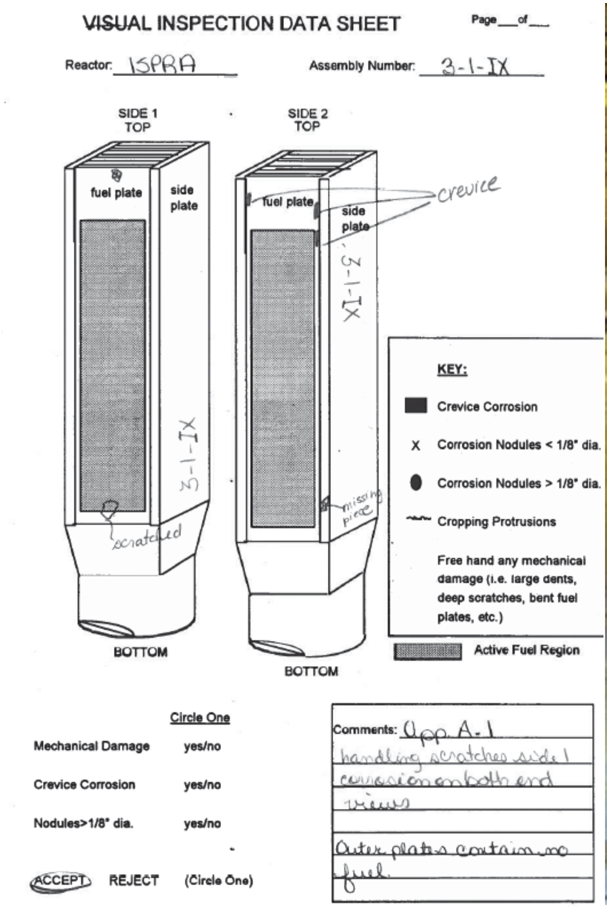


Figure A3-12 Inspection Assembly 236

Campaign 4 – Inspection 9 (*Conducted December 2019*)

Italian ENEA Galileo Bundle L-ENEA-0356 (5 Assemblies)

Facility Inspection (1997) L Basin Inspection (2019)



VISUAL INSPECTION DATA SHEET Page ___ of ___

Reactor: ISPRA Assembly Number: 3-1-IX

KEY:
- Crevice Corrosion
- X Corrosion Nodules < 1/8" dia.
- Corrosion Nodules > 1/8" dia.
- Cropping Protrusions
- Free hand any mechanical damage (i.e. large dents, deep scratches, bent fuel plates, etc.)
- Active Fuel Region

	Circle One
Mechanical Damage	yes/no
Crevice Corrosion	yes/no
Nodules>1/8" dia.	yes/no

ACCEPT REJECT (Circle One)

Comments: App. A-1
handling scratches side 1
corrosion on both end views

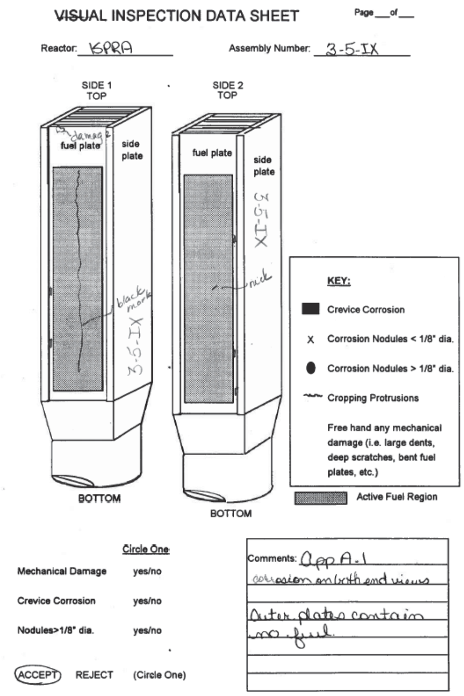
Outer plates contain no fuel.

Figure A3-13 3-1-IX Assembly

Campaign 4 – Inspection 9 (*Conducted December 2019*) (Contd)

Italian ENEA Galileo Bundle L-ENEA-0356 (5 Assemblies) (contd)

Facility Inspection (1997)



VISUAL INSPECTION DATA SHEET

Page __ of __

Reactor: KPRA

Assembly Number: 3-5-IX

SIDE 1 TOP

damage

fuel plate

side plate

black mark

3-5-IX

BOTTOM

SIDE 2 TOP

fuel plate

side plate

3-5-IX

nick

BOTTOM

KEY:

Crevice Corrosion

X Corrosion Nodules < 1/8" dia.

Corrosion Nodules > 1/8" dia.

Cropping Protrusions

Free hand any mechanical damage (i.e. large dents, deep scratches, bent fuel plates, etc.)

Active Fuel Region

	Circle One
Mechanical Damage	yes/no
Crevice Corrosion	yes/no
Nodules>1/8" dia.	yes/no

ACCEPT REJECT (Circle One)

Comments: App A.1
corrosion on both end views

Outer plates contain no fuel.

L Basin Inspection (2019)
(*rotate to compare*)

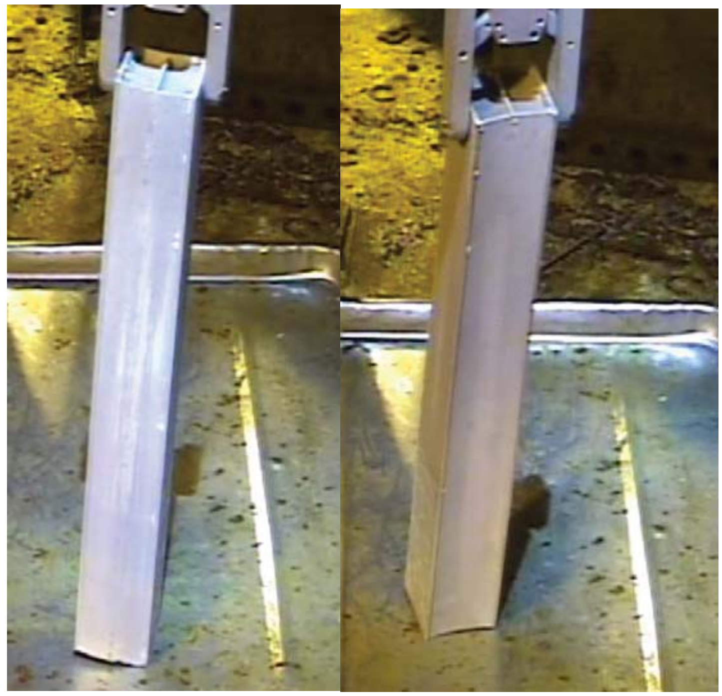


Figure A3-14 3-5-IX Assembly

Campaign 4 – Inspection 9 (*Conducted December 2019*) (Contd)

Italian ENEA Galileo Bundle L-ENEA-0356 (5 Assemblies) (contd)

Facility Inspection (1997) L Basin Inspection (2019)

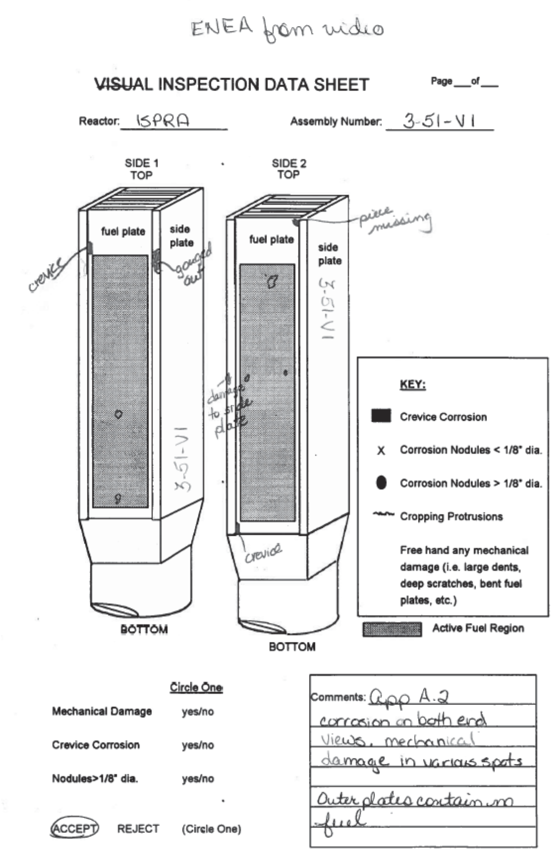


Figure A3-15 3-51-VI Assembly

Campaign 4 – Inspection 10 (*Conducted December 2019*)

Amsterdam HFR Petten Bundle L-HFR-1435 (4 Assemblies)

Video from a previous facility inspection of the fuel (prior to cropping) was available for some of the HFR Petten assemblies but not the ones listed for the selected bundle for inspection. The video included rotational views of the fuel under water. Many of the same type staining over the fuel meat region was prevalent on the video for other fuel assemblies. There were no substantial anomaly patterns or features present for assemblies on the video. This favorably compared in likeness to the inspected bundle assemblies.

APPENDIX 4

MTR Fuel Inspection Campaigns Digital Media Catalog

APPENDIX 4

MTR Fuel Inspection Campaigns Digital Media Catalog

The digital media catalog lists the digitized download files from DVD recording disks used during the MTR Fuel Inspections. The purpose of this catalog is to serve as a reference basis for quick retrieval of digital media in the event that additional pictures or proof of the condition assessment is warranted or desired.

In most views on the inspection table, close-up video was achieved by the zoom feature of the basin underwater camera housed within the inspection jig. Note the inspection table was designed to enable a full and overlapping view of each assembly up to 36 inches long. The zoom feature was used at the discretion of the inspection team. Thus, the availability of video for closeups of anomalies was subjective and covers most but not regions of potential interest07.

Below is a picture of the plan of the MTR Fuel Inspection Table. The picture shows the two end slots for the camera and six lateral side slots. These camera slots will be referred to in the Digital Media Catalog for the positioning of the fuel. The fuel is centered on the table once it is placed on the table and for each side rotation the fuel is re-centered. All of the 10 inspected assemblies were cropped on at least one end and the fuel generally occupies about 25 to 30 inches of the table lengthwise or about 12.5 to 15 inches left and right of center ("0") on the table.

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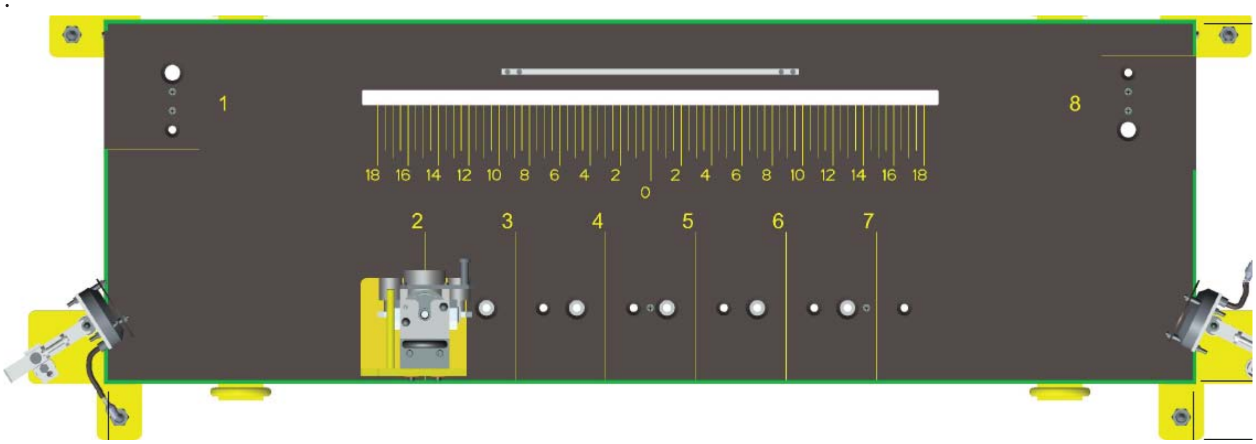


Inspection 1 – RA3 Bundle L-RA3-0817 with Inspection Assembly S-113 (3 Assemblies in the Bundle)

The inspection bundle L-RA3-0817 was retrieved from storage in VTS and transferred to the Saw Row of the Machine Basin. In the saw row, the bundle lid was detabbed. Then the fuel was carefully removed from the bundle one assembly at a time. As each assembly was removed it was placed in a slug bucket. After the 3 assemblies were in the slug bucket, the slug bucket was moved to the Tilt Table Row. In the Tilt Table Row the slug bucket was moved south to the Inspection Table. The inspection assembly S-113 was removed from the slug bucket and placed on the inspection table for a comprehensive fuel inspection. When the inspection was completed the fuel assembly inspection, the inspected assembly was placed back into the slug bucket and the slug bucket was transferred north to the Tilt Table. At the tilt table the fuel was rebundled in a new L bundle. A removable lid was installed after the bundle was loaded. Lastly, the bundle was transferred back to its storage position in VTS.

Disk 1

Video 1 – Detabbing at Debundling/ Collar Installation

Video 2 – Detabbing at Debundling 2

Video 3 – Bundle Raising/ Lid Removal/ Bundle Position for Assembly Removal

Video 4 – 1st Assembly S-113 Removal from Bundle

Video 5- Handling of S-113 at Debundling Tray

Disk 2

Video 1– Assembly 138 Handling at Debundling Tray

Video 2 – Debundling of 195 Assembly (3rd of 3)

Video 3 – Handling of 195 Assembly at Debundling Tray

Video 4 – Empty Bundle Video

Video 5- Slug Bucket Video/ Removal of S-113 from Slug Bucket

Disk 3

Video 1– Inspection Assembly S-113 on the Inspection Table – Top End View Slot 1/Side Plate View w/ Concave Fuel Plate Side Down Slot 2 End and Slot 3

Video 2 - Inspection Assembly S-113 on the Inspection Table – Side Plate View w/ Concave Fuel Plate Side Down Slots 3 through 5

Video 3 – Inspection Assembly S-113 on the Inspection Table – Side Plate View w/ Concave Fuel Plate Side Down Slot 4 and Slot 5

Video 4 – Inspection Assembly S-113 on the Inspection Table – Side Plate View w/ Concave Fuel Plate Side Down Slot 6 and Slot 7/ Slot 8 Bottom End View of Inspection Assembly S-113

Video 5- Turning of S-113 to Concave Fuel Plate Side for Inspection/ Concave Fuel Plate Side Inspection Slot 7

Inspection 1 – RA3 Bundle L-RA3-0817 with Inspection Assembly S-113 (3 Assemblies in the Bundle) (Contd)

Disk 4

Video 1– S-113 Inspection Assembly Concave Fuel Plate Side Inspection Slot 6 and Slot 7

Video 2 - S-113 Inspection Assembly Concave Fuel Plate Side Inspection Slots 2 through 5

Video 3 – S-113 Inspection Assembly Concave Fuel Plate Side Inspection Slot 2/ Side Plate 2 (Convex Fuel Plate up) Slots 2 through 5

Video 4 – Side Plate 2 (Convex Fuel Plate up) Slots 6 and 7/Convex Fuel Plate Inspection Slot 6 and Slot 7

Video 5- Convex Fuel Plate Inspection Slots 6 and 7/ Side Plate 2 Slots 2 through 7

Inspection 2 – IEA-R1 Bundle L-IEA-R1-0625 with Inspection Assembly IEA-79 (5 Assemblies in the Bundle)

The inspection bundle L-IEA-R1-0625 was retrieved from storage in VTS and transferred to the Saw Row of the Machine Basin. In the saw row, the bundle lid was detabbed. Then the fuel was carefully removed from the bundle one assembly at a time. As each assembly was removed it was placed in a slug bucket. After the 5 assemblies were in the slug bucket, the slug bucket was moved to the Tilt Table Row. In the Tilt Table Row the slug bucket was moved south to the Inspection Table. The inspection assembly IEA-79 was removed from the slug bucket and placed on the inspection table for a comprehensive fuel inspection. When the inspection was completed the fuel assembly inspection, the inspected assembly was placed back into the slug bucket and the slug bucket was transferred north to the Tilt Table. At the tilt table the fuel was rebundled in a new L bundle. A removable lid was installed after the bundle was loaded. Lastly, the bundle was transferred back to its storage position in VTS.

Disk 1

Video 1 – Bundle Retrieval from the Rack and Movement in VTS

Video 2 – Bundle Movement in VTS/Debundling 1st Assembly from the Bundle (attempting)

Video 3 – Debundling 1st Assembly IEA-61 from the Bundle (actual) into Debundling Tray and Placement in Slug Bucket/ IEA-72 Debundling and Handling

Video 4 –IEA-72 Debundling and Handling and Placement in Slug Bucket/

Video 5- IEA-79 Debundling and Handling (3rd assembly)/ IEA-59 Debundling and Handling (4th assembly)

Disk 2

Video 1– IEA-79 Inspection on Inspection Table Slot 1 Bottom End/ Side Plate View w/ Concave Fuel Plate Side Down Slot 2 Bottom End and Slot 3

Video 2 - Side Plate View w/ Concave Fuel Plate Side Down Slots 3 through 7

Video 3 – Side Plate View w/ Concave Fuel Plate Side Down Slot 7/ Slot 8 Top End/ Concave Fuel Plate Side Inspection Slot 2

Video 4 –Concave Fuel Plate Side Inspection Slots 2 through 6

Video 5- Concave Fuel Plate Side Inspection Slots 6 and Slot 7/ Side Plate (2nd Side) View w/ Convex Fuel Plate Side Up Slot 7

Inspection 2 – IEA-R1 Bundle L-IEA-R1-0625 with Inspection Assembly IEA-79 (5 Assemblies in the Bundle) (Contd)

Disk 3

Video 1– Side Plate (2nd Side) View w/ Convex Fuel Plate Side Up Slots 5 through 7

Video 2 - Side Plate (2nd Side) View w/ Convex Fuel Plate Side Up Slots 2 through 4

Video 3 – Side Plate (2nd Side) View w/ Convex Fuel Plate Side Up Slot 2/ Convex Fuel Plate Side Inspection Slot 2 and Slot 3

Video 4- Convex Fuel Plate Side Inspection Slot 3 through 5

Video 5- Convex Fuel Plate Side Inspection Slot 6 and Slot 7

Inspection 3 – RA-3 Bundle L-RA3-0822 with Inspection Assembly 160 (4 Assemblies in the Bundle)

The inspection bundle L-RA3-0822 was retrieved from storage in VTS and transferred to the Saw Row of the Machine Basin. In the saw row, the bundle lid was detabbed. Then the fuel was carefully removed from the bundle one assembly at a time. As each assembly was removed it was placed in a slug bucket. After the 4 assemblies were in the slug bucket, the slug bucket was moved to the Tilt Table Row. In the Tilt Table Row the slug bucket was moved south to the Inspection Table. The inspection assembly 160 was removed from the slug bucket and placed on the inspection table for a comprehensive fuel inspection. When the inspection was completed the fuel assembly inspection, the inspected assembly was placed back into the slug bucket and the slug bucket was transferred north to the Tilt Table. At the tilt table the fuel was rebundled in a new L bundle. A removable lid was installed after the bundle was loaded. Lastly, the bundle was transferred back to its storage position in VTS.

Disk 1

Video 1 – Retrieval of Inspection Bundle from VTS/ Debundling of 1st RA-3 Assembly CNEA-301 from the Bundle and placement in slug bucket

Video 2 – Debundling of 2nd RA-3 Assembly 110 from the Bundle and placement in slug bucket/ Debundling of 3rd RA-3 Assembly 139 and placement in slug bucket

Video 3– Debundling of 4th RA-3 Assembly 160 and placement in slug bucket/ Inspection of Assembly 160 Top End (Slot 8)/ Side Plate View w/ Concave Fuel Plate Side Up (Convex Side Down) Slot 7

Video 4- Side Plate View w/ Concave Fuel Plate Side Up (Convex Side Down) Slots 4 through 7

Video 5 -Side Plate View w/ Concave Fuel Plate Side Up (Convex Side Down) Slot 2 and Slot 3/ Inspection of Assembly 160 Bottom End (Slot 1)

Disk 2

Video 1 – Concave Fuel Plate Side Inspection Slots 2 through 5

Video 2 - Concave Fuel Plate Side Inspection Slot 6 and Slot 7

Video 3 – Side Plate (Side 2) View w/ Concave Fuel Plate Side Down (Convex Side Up) Slots 5 through 7

Video 4 – Side Plate (Side 2) View w/ Concave Fuel Plate Side Down (Convex Side Up) Slots 2 through 5/ Convex Fuel Plate Side Inspection Slot 2

Video 5 - Convex Fuel Plate Side Inspection Slots 3 through 7

Inspection 4 – ENEA Galileo Bundle L-ENEA-0024 with Inspection Assembly GA-84X (5 Assemblies in the Bundle)

The inspection bundle L-ENEA-0024 was retrieved from storage in VTS and transferred to the Saw Row of the Machine Basin. In the saw row, the bundle lid was detabbed. Then the fuel was carefully removed from the bundle one assembly at a time. As each assembly was removed it was placed in a slug bucket. After the 5 assemblies were in the slug bucket, the slug bucket was moved to the Tilt Table Row. In the Tilt Table Row the slug bucket was moved south to the Inspection Table. The inspection assembly GA-84X was removed from the slug bucket and placed on the inspection table for a comprehensive fuel inspection. When the inspection was completed the fuel assembly inspection, the inspected assembly was placed back into the slug bucket and the slug bucket was transferred north to the Tilt Table. At the tilt table the fuel was rebundled in a new L bundle. A removable lid was installed after the bundle was loaded. Lastly, the bundle was transferred back to its storage position in VTS.

Unique feature of ENEA Galileo fuel is that the fuel assemblies have flat plates versus curved. Previous 3 inspections had curved plates. Inspection assembly GA 84X is a control assembly; whereas, the other 4 bunded assemblies are standard assemblies with more fuel plates. The inspection assembly has few center fuel plates.

Disk 1

Video 1 – Retrieval of Inspection Bundle from VTS/ Debundling of 1st ENEA Galileo Assembly GA 45 (Actually 67 GA 45) from the Bundle and placement in slug bucket

Video 2 – Debundling of 2nd ENEA Assembly GA 12 (Actually 67 GA 12) from the Bundle and placement in slug bucket/ Debundling of 3rd ENEA Assembly GA 84X (Inspection Assembly) (Actually 72 GA 84X)

Video 3 – Placement of 3rd ENEA Assembly GA 84X (Inspection Assembly) into slug bucket/ Debundling of 4th ENEA Assembly CMN 7 from the Bundle and placement in slug bucket/ Debundling of 5th & Last ENEA Assembly GA 16 (Actually 67 GA 16) from the Bundle and placement in slug bucket

Video 4 – Inspection of Assembly GA 84X Bottom End (Slot 1)/ Inspection of Side plate 1 Slot 2 End through Slot 5

Video 5- Side plate 1 Slot 5 through Slot 7/ Inspection of Assembly GA 84X Top End (Slot 8)/ Fuel Plate Side 1 Slot 7

Disk 2

Video 1– Fuel Plate Side 1 Slots 5 through 7

Video 2 - Fuel Plate Side 1 Slots 2 through 5/ Inspection of Side plate 2 Slot 2 End

Video 3 –Inspection of Side plate 2 Slots 2 through 4

Video 4 –Inspection of Side plate 2 Slots 5 through 7 / Fuel Plate Side 2 Slot 6 and Slot 7

Video 5- Fuel Plate Side 2 Slots 2 through 5

Inspection 5 – RA-3 Bundle L-RA3-0794 with Inspection Assembly 30 (4 Assemblies in the Bundle)

The inspection bundle L-RA3-0794 was retrieved from storage in VTS and transferred to the Saw Row of the Machine Basin. In the saw row, the bundle lid was detabbed. Then the fuel was carefully removed from the bundle one assembly at a time. As each assembly was removed it was placed in a slug bucket. After the 4 assemblies were in the slug bucket, the slug bucket was moved to the Tilt Table Row. In the Tilt Table Row the slug bucket was moved south to the Inspection Table. The inspection assembly 30 was removed from the slug bucket and placed on the inspection table for a comprehensive fuel inspection. When the inspection was completed the fuel assembly inspection, the inspected assembly was placed back into the slug bucket and the slug bucket was transferred north to the Tilt Table. At the tilt table the fuel was rebundled in a new L bundle. A removable lid was installed after the bundle was loaded. Lastly, the bundle was transferred back to its storage position in VTS.

Disk 1

Video 1 – Retrieval of Inspection Bundle from VTS

Video 2 – Debundling of 1st RA-3 Assembly S-121 (Control Assembly)

Video 3 – Handling of 1st RA-3 Assembly S-121 (Control Assembly)

Video 4 – Debundling of 2nd RA-3 Assembly 257 and placement into the slug bucket/ Debundling of 3rd RA-3 Assembly 30 (Inspection Assembly)

Video 5- Handling of 3rd RA-3 Assembly 153 and placement into the slug bucket/ Debundling of 4th RA-3 Assembly 153 and placement into the slug bucket

Disk 2

Video 1– Inspection of Assembly 30 Side Plate View w/ Concave Fuel Plate Side Up (Convex Side Down) Slots 2 through 4

Video 2 - Inspection of Assembly 30 Side Plate View w/ Concave Fuel Plate Side Up (Convex Side Down) Slots 5 through 7/ Inspection of Assembly 30 Top End Slot 8

Video 3 – Inspection of Assembly 30 Top End Slot 8/ Convex Fuel Plate Side Inspection Slots 2 through 6

Video 4 – Convex Fuel Plate Side Inspection Slot 6 and Slot 7/ Inspection of Assembly 30 Side Plate (Side 2) View w/ Concave Fuel Plate Side Down (Convex Side Up) Slots 5 through 7

Video 5- Side Plate (Side 2) View w/ Concave Fuel Plate Side Down (Convex Side Up) Slots 2 through 4/ Concave Fuel Plate Side Inspection Slots 2 through 5

Inspection 5 – RA-3 Bundle L-RA3-0794 with Inspection Assembly 30 (4 Assemblies in the Bundle) (Contd)

Disk 3

Video 1– Concave Fuel Plate Side Inspection Slot 6 and Slot 7

Video 2 – Concave Fuel Plate Side Inspection Slot 5 and Slot 6

Video 3- Concave Fuel Plate Side Inspection Slot 4 (redo)

Video 4- Concave Fuel Plate Side Inspection Slot 3 (redo)

Video 5- Concave Fuel Plate Side Inspection Slot 2 (redo)

<u>Inspection 6 – ENEA Galileo Bundle L-ENEA-0352 with Inspection Assembly 71-GA67 (5 Assemblies in the Bundle)</u>

The inspection bundle L-ENEA-0352 was retrieved from storage in VTS and transferred to the Saw Row of the Machine Basin. In the saw row, the bundle lid was detabbed. Then the fuel was carefully removed from the bundle one assembly at a time. As each assembly was removed it was placed in a slug bucket. After the 5 assemblies were in the slug bucket, the slug bucket was moved to the Tilt Table Row. In the Tilt Table Row the slug bucket was moved south to the Inspection Table. The inspection assembly 160 was removed from the slug bucket and placed on the inspection table for a comprehensive fuel inspection. When the inspection was completed the fuel assembly inspection, the inspected assembly was placed back into the slug bucket and the slug bucket was transferred north to the Tilt Table. At the tilt table the fuel was rebundled in a new L bundle. A removable lid was installed after the bundle was loaded. Lastly, the bundle was transferred back to its storage position in VTS.

Unique feature of ENEA Galileo fuel is that the fuel assemblies have flat plates versus curved. This is the second of two Galileo fuels that were scheduled to be inspected.

<u>Disk 1</u>

<u>Video 1 – Retrieval of Inspection Bundle from VTS/ Debundling of 1st ENEA Galileo Assembly 71-GA69 from the Bundle</u>

<u>Video 2 – Debundling of 1st ENEA Galileo Assembly 71-GA69 from the Bundle and placement in a slug bucket w/ slug bucket details (top of assembly)/ Debundling of 2nd ENEA Assembly 71-GA72 from the Bundle and placement in slug bucket/ Placement of 3rd ENEA Assembly 71-GA76</u>

<u>Video 3 – Placement of 3rd ENEA Assembly 71-GA76 and placement in slug bucket/Debundling of 4th ENEA Assembly 71-GA77 from the Bundle and placement in slug bucket/Debundling of 5th & Last ENEA Assembly 71GA67 (Inspection Assembly) from the Bundle and placement in slug bucket</u>

<u>Video 4 – Last ENEA Assembly 71GA67 (Inspection Assembly) from the Bundle and placement in slug bucket/ Inspection of Assembly 71-GA67 Bottom End (Slot 1)/ Inspection of Side plate 1 Slot 2 End through Slot 4</u>

<u>Video 5- Inspection of Side plate 1 Slot 4 through Slot 7/ Inspection of Assembly 71-GA67 Top End (Slot 8)/ Fuel Plate Side 1 Slot 7</u>

<u>Disk 2</u>

<u>Video 1– Fuel Plate Side 1 Slots 4 through 7</u>

<u>Video 2 - Fuel Plate Side 1 Slots 2 through 4/ Inspection of Side Plate 2 Slot 2 and Slot 3</u>

<u>Video 3 – Inspection of Side Plate 2 Slots 2 through 6</u>

<u>Video 4 – Inspection of Side Plate 2 Slot 7/ Fuel Plate Side 1 Slots 5 through 7</u>

<u>Video 5- Fuel Plate Side 1 Slots 2 through 4</u>

Inspection 7 – HIFAR Bundle L-HIFAR-1918 with Inspection Assembly UED-1567 (5 Assemblies in the Bundle)

The inspection bundle L-HIFAR-1918 was retrieved from storage in VTS and transferred to the Saw Row of the Machine Basin. In the saw row, the bundle lid was detabbed. Then the fuel was carefully removed from the bundle one assembly at a time. As each assembly was removed it was placed in a slug bucket. After the 5 assemblies were in the slug bucket, the slug bucket was moved to the Tilt Table Row. In the Tilt Table Row the slug bucket was moved south to the Inspection Table. The inspection assembly UED 1567 was removed from the slug bucket and placed on the inspection table for a comprehensive fuel inspection. When the inspection was completed the fuel assembly inspection, the inspected assembly was placed back into the slug bucket and the slug bucket was transferred north to the Tilt Table. At the tilt table the fuel was rebundled in a new L bundle. A removable lid was installed after the bundle was loaded. Lastly, the bundle was transferred back to its storage position in VTS.

The HIFAR fuel is cylindrical with an outer aluminum shell and an inner aluminum shell. The fuel plates are sandwiched between the outer and inner shells in an involute curved pattern that are symmetrically placed. Each fuel plate is brazed welded at each inner and outer tube interface joint.

Disk 1

Video 1 – Retrieval of Inspection Bundle from VTS/ Debundling of 1st HIFAR Assembly UED 1553 from the Bundle

Video 2 – Handling of 1st HIFAR Assembly UED 1553 from the Bundle and placement in slug bucket/ Debundling of 2nd HIFAR Assembly UED 1556 from the Bundle and placement in slug bucket/ Debundling of 3rd HIFAR Assembly ED 513 from the Bundle

Video 3 – Handling of 3rd HIFAR Assembly ED 513 from the Bundle and placement in slug bucket/ Debundling of 3rd HIFAR Assembly ED 513 from the Bundle/ Debundling of 4th HIFAR Assembly UED 1561 from the Bundle and placement in slug bucket/ Debundling of 5th HIFAR Assembly UED 1567 (Inspection Assembly) from the Bundle and placement in slug bucket/ Inspection Assembly UED 1567 on the Inspection Table Bottom End Slot 8/

Video 4 – Inspection of Side 1 Slot 5 through Slot 7 End

Video 5- Inspection of Side 1 Slot 2 through Slot 4/ Inspection Assembly UED 1567 on the Inspection Table Top End Slot 1

Disk 2

Video 1– Inspection of Side 2 (1st Rotation) Slots 2 through 4

Video 2 - Inspection of Side 2 (1st Rotation) Slots 5 through 7

Video 3 – Positioning of the fuel to reach the 2nd rotation on the table

Video 4 –Inspection of Side 3 (2nd Rotation) Slots 2 through 5

Video 5- Inspection of Side 3 (2nd Rotation) Slots 5 through 7

Inspection 8 – RA-3 Bundle L-RA3-0787 with Inspection Assembly 236 (4 Assemblies in the Bundle)

The inspection bundle L-RA3-0787 was retrieved from storage in VTS and transferred to the Saw Row of the Machine Basin. In the saw row, the bundle lid was detabbed. Then the fuel was carefully removed from the bundle one assembly at a time. As each assembly was removed it was placed in a slug bucket. After the 4 assemblies were in the slug bucket, the slug bucket was moved to the Tilt Table Row. In the Tilt Table Row the slug bucket was moved south to the Inspection Table. The inspection assembly 236was removed from the slug bucket and placed on the inspection table for a comprehensive fuel inspection. When the inspection was completed the fuel assembly inspection, the inspected assembly was placed back into the slug bucket and the slug bucket was transferred north to the Tilt Table. At the tilt table the fuel was rebundled in a new L bundle. A removable lid was installed after the bundle was loaded. Lastly, the bundle was transferred back to its storage position in VTS.

Disk 1

Video 1 – Retrieval of Inspection Bundle from VTS / Debundling of 1st RA-3 Assembly CNEA 272 and placement in slug bucket/ Debundling of 2nd RA-3 Assembly CNEA 270

Video 2 – Handling of 2nd RA-3 Assembly CNEA 270 and placement in slug bucket/ Debundling of 3rd RA-3 Assembly CNEA 271 and placement in slug bucket/ Debundling of 4th and last RA-3 Inspection Assembly 236

Video 3 – Handling of 4th RA-3 Inspection Assembly 236 and placement in slug bucket/ Inspection of Assembly 236 Top End (Slot 2)/ Inspection of Assembly 236 Side Plate View w/ Concave Fuel Plate Side Up (Convex Side Down) Slots 2 through 4

Video 4 – Inspection of Assembly 236 Side Plate View w/ Concave Fuel Plate Side Up (Convex Side Down) Slots 4 through 7/ Concave Fuel Plate Side (Fuel Plate Side 1) Inspection Slot 6 and Slot 7

Video 5 - Concave Fuel Plate Side (Fuel Plate Side 1) Inspection Slots 2 through 5

Disk 2

Video 1– Inspection of Assembly 236 Side Plate (side Plate Side 2) View w/ Concave Fuel Plate Side Down (Convex Side Up) Slots 2 through 4

Video 2 - Inspection of Assembly 236 Side Plate View w/ Concave Fuel Plate Side Down (Convex Side Up) Slots 5 through 7

Video 3 –Convex Fuel Plate Side (Fuel Plate Side 2) Inspection Slots 5 through 7

Video 4 –Convex Fuel Plate Side (Fuel Plate Side 2) Inspection Slot 4

Video 5- Convex Fuel Plate Side (Fuel Plate Side 2) Inspection Slot 2 and Slot 3

<u>Inspection 9 – ENEA ISPRA Bundle L-ENEA-0356 with Inspection Assembly 3-9-1X (5 Assemblies in the Bundle)</u>

The inspection bundle L-ENEA-0356 was retrieved from storage in VTS and transferred to the Saw Row of the Machine Basin. In the saw row, the bundle lid was detabbed. Then the fuel was carefully removed from the bundle one assembly at a time. As each assembly was removed it was placed in a slug bucket. After the 4 assemblies were in the slug bucket, the slug bucket was moved to the Tilt Table Row. In the Tilt Table Row the slug bucket was moved south to the Inspection Table. The inspection assembly 3-9-IX was removed from the slug bucket and placed on the inspection table for a comprehensive fuel inspection. When the inspection was completed the fuel assembly inspection, the inspected assembly was placed back into the slug bucket and the slug bucket was transferred north to the Tilt Table. At the tilt table the fuel was rebundled in a new L bundle. A removable lid was installed after the bundle was loaded. Lastly, the bundle was transferred back to its storage position in VTS.

<u>Video 1 – Retrieval of Inspection Bundle from VTS/ Debundling of 1st ENEA ISPRA Assembly 3-5-IX and placement in slug bucket/ Debundling of 2nd ENEA ISPRA Assembly 3-51-IV and placement in slug bucket/ Debundling of 3rd ENEA ISPRA Assembly 3-1-IX and placement in slug bucket/ Debundling of 4th ENEA ISPRA Assembly 3-9-IX and placement in slug bucket/ Debundling of 5th and Last ENEA ISPRA Assembly 3-12-IX and placement in slug bucket/</u>

<u>Video 2 – Inspection of Assembly 3-9-IX Top End (Slot 8)/ Inspection of Assembly 3-9-IX Side Plate View w/ Concave Fuel Plate Side Up (Convex Side Down) Slots 4 through 7</u>

<u>Video 3 – Inspection of Assembly 3-9-IX Side Plate View w/ Concave Fuel Plate Side Up (Convex Side Down) Slot 2 and Slot 3/ Inspection of Assembly 3-9-IX Top End (Slot 8)/ Concave Fuel Plate Side Inspection Slots 2 through 5</u>

<u>Video 4 –Concave Fuel Plate Side Inspection Slot 6 and Slot 7/ Inspection of Assembly 3-9-IX Side Plate View w/ Concave Fuel Plate Side Down (Convex Side Up) Slots 5 through 7</u>

<u>Video 5- Inspection of Assembly 3-9-IX Side Plate View w/ Concave Fuel Plate Side Down (Convex Side Up) Slots 2 through 4/ Convex Fuel Plate Side Inspection Slots 2 through 7</u>

Inspection 10 – HFR Petten Bundle L-HFR-1435 with Inspection Assembly F950 (4 Assemblies in the Bundle)

The inspection bundle L-HFR-1435 was retrieved from storage in VTS and transferred to the Saw Row of the Machine Basin. In the saw row, the bundle lid was detabbed. Then the fuel was carefully removed from the bundle one assembly at a time. As each assembly was removed it was placed in a slug bucket. After the 4 assemblies were in the slug bucket, the slug bucket was moved to the Tilt Table Row. In the Tilt Table Row the slug bucket was moved south to the Inspection Table. The inspection assembly F950 was removed from the slug bucket and placed on the inspection table for a comprehensive fuel inspection. When the inspection was completed the fuel assembly inspection, the inspected assembly was placed back into the slug bucket and the slug bucket was transferred north to the Tilt Table. At the tilt table the fuel was rebundled in a new L bundle. A removable lid was installed after the bundle was loaded. Lastly, the bundle was transferred back to its storage position in VTS.

Video 1 – Retrieval of Inspection Bundle from VTS/ Debundling of 1st HFR Assembly F987 and placement in slug bucket/ Debundling of 2nd HFR Assembly F1130 and placement in slug bucket/ Debundling of 3rd HFR Assembly F1130 and placement in slug bucket/Debundling of Inspection Assembly F950 *occurred next but is not in the video file*/ Inspection of Assembly F950 Side Plate View w/ Concave Fuel Plate Side Up (Convex Side Down) Slot 6 and Slot 7

Video 2 – Inspection of Assembly F950 Side Plate View w/ Concave Fuel Plate Side Up (Convex Side Down) Slots 2 through 6/ Inspection of Assembly F950 Bottom End Slot 1/ Inspection of Assembly F950 Top End Slot 8/ Concave Fuel Plate Inspection Slots 5 through 7

Video 3 – Fuel Plate (Concave) Side 1 Inspection Slots 2 through 4/ Inspection of Assembly F950 Side Plate (Side 2) View w/ Concave Fuel Plate Side Down (Convex Side Up) Slot 2

Video 4 – Inspection of Assembly F950 Side Plate (Side 2) View w/ Concave Fuel Plate Side Down (Convex Side Up) Slots 2 through 7

Video 5- Convex Fuel Plate Inspection Slots 2 through 7

APPENDIX 5

Opportunity Inspection Pictures of Interest

APPENDIX 5

Opportunity Inspection Pictures of Interest

This attachment includes miscellaneous pictures of interest not shown in the report or in other appendices. An explanation or caption noting the interest follows each picture.

Campaign 1- Inspection 1 (*Conducted January 2019*)

Argentine RA-3 Bundle L-RA3-0817 (3 Assemblies)

Figure A5-1 This is the first picture of debundling an assembly from an inspection bundle

Figure A5-2 Tagging of 138 assembly. One of two ways typical for RA-3 Standard Assemblies. As shown the number is located between two screws on one end of the assembly.

Campaign 2 – Inspection 2 (*Conducted June 2019*)

Brazilian IEA-R1 Bundle L-IEA-R1-0625 (5 Assemblies)

Figure A5-3 Hooking onto Bundle L-IEA-R1-0625

Figure A5-4 Side plate face up in the debundling tray for a typical IEA-R1 Assembly

<u>Campaign 2 – Inspection 3</u> (*Conducted June 2019*)

Argentine RA-3 Bundle L-RA3-0822 (4 Assemblies)

***Figure A5-5** Assembly 139 debundled sitting in a slug bucket. Edge of concave fuel plate bent inwards. Several types of corrosion shown. Galvanically induced corrosion found on the interior of the fuel bail screw holes (2). Surface and edge corrosion on the facing side plate. Edge corrosion on the side plate length also shown.*

***Figure A5-6** (Left) Substantial crevice corrosion at the interface (Right) Concrete Fuel Tubes at the Ezeiza, Argentina of an inner fuel plate and a side plate grove. Storage Facility for Inspection Assembly 160 (1999).*

Campaign 2 – Inspection 4 (*Conducted June 2019*)

Italian ENEA Galileo Bundle L-ENEA-0024 (5 Assemblies)

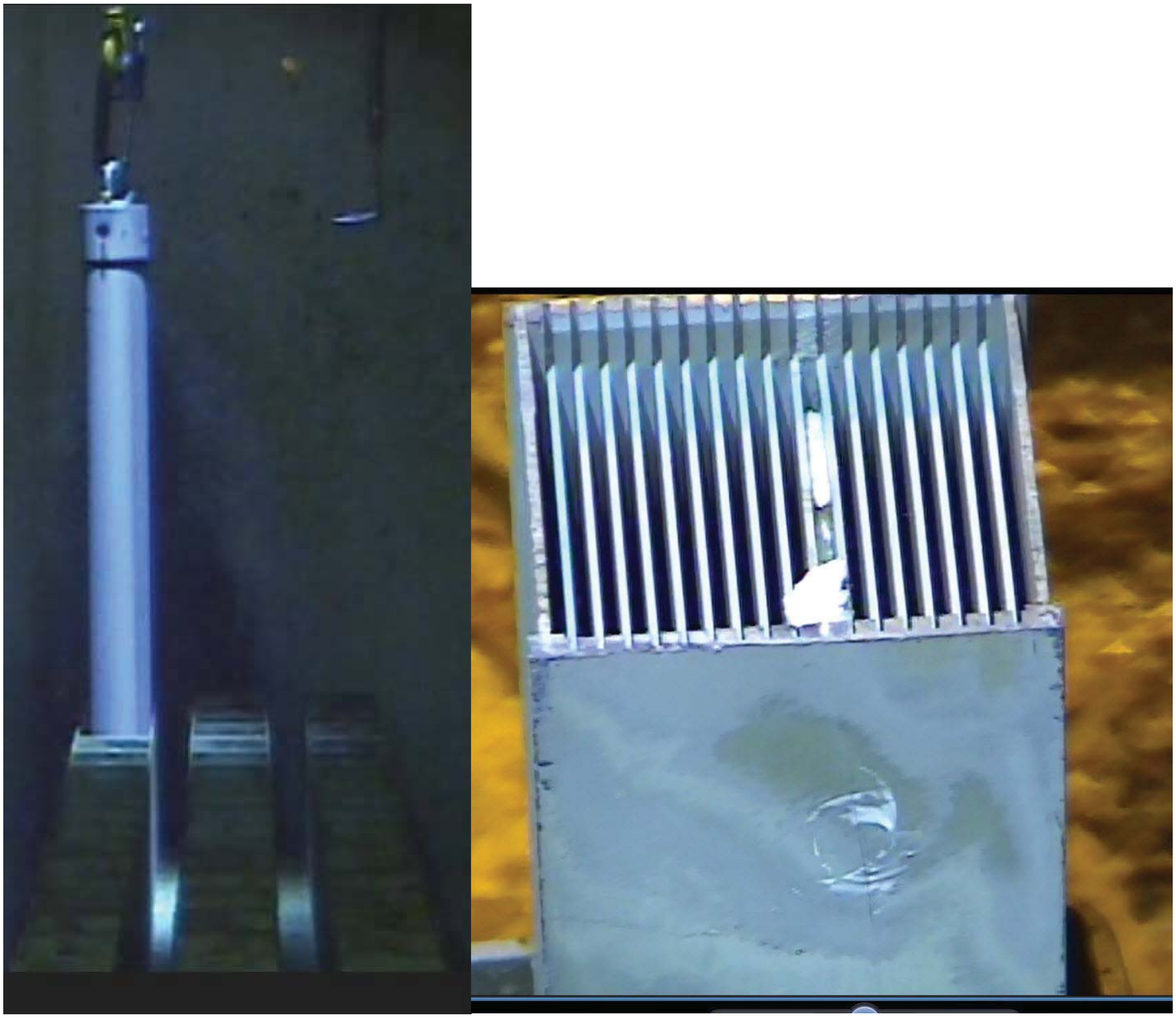


Figure A5-7 (Left) Bundle L-ENEA-0024 (Right) CMN 7 assembly closeup inside of slug bucket lifting out of the rack (1/2 way out)

<u>Campaign 3 – Inspection 5</u> (*Conducted August 2019*)

Argentian RA-3 Bundle L-RA3-0794 (4 Assemblies)

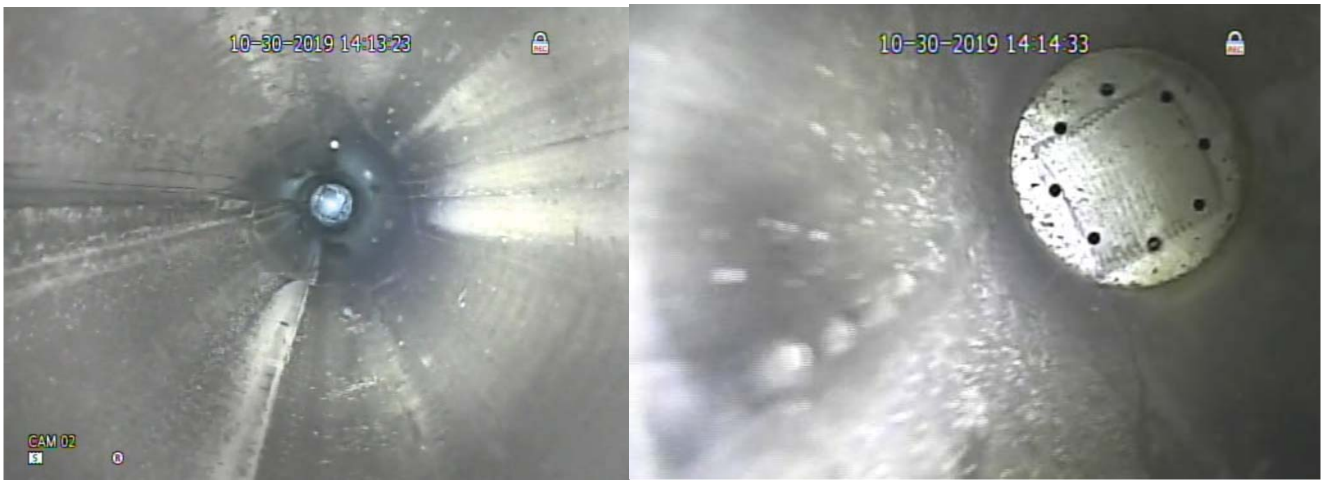


Figure A5-8 Inside of vacated bundle L-RA3-0794 about half-way down inside (left) noting fuel assembly imprint (right)

Figure A5-9 Less than desirable shadowing effect due to underwater camera light and basin lighting which evolved this multi-color looking fuel plate phenomena on debundled assembly 257.

Campaign 3 – Inspection 6 (*Conducted August 2019*)

Italian ENEA Galileo Bundle L-ENEA-0352 (5 Assemblies)

Figure A5-10 (Left) Bundle L-ENEA-0352 clearing the rack (Right) Closeup of 71-GA77 exterior fuel plate with noting L Bundle "impact limiter" bottom distinct raised nodules in the fuel meat region.

Figure A5-11 Debri and staining but no corrosion found after inspecting L-ENEA-0351 emptied bundle.

Campaign 3 – Inspection 7 (*Conducted August 2019*)

Australian HIFAR Bundle L-HIFAR-1918 (5 Assemblies)

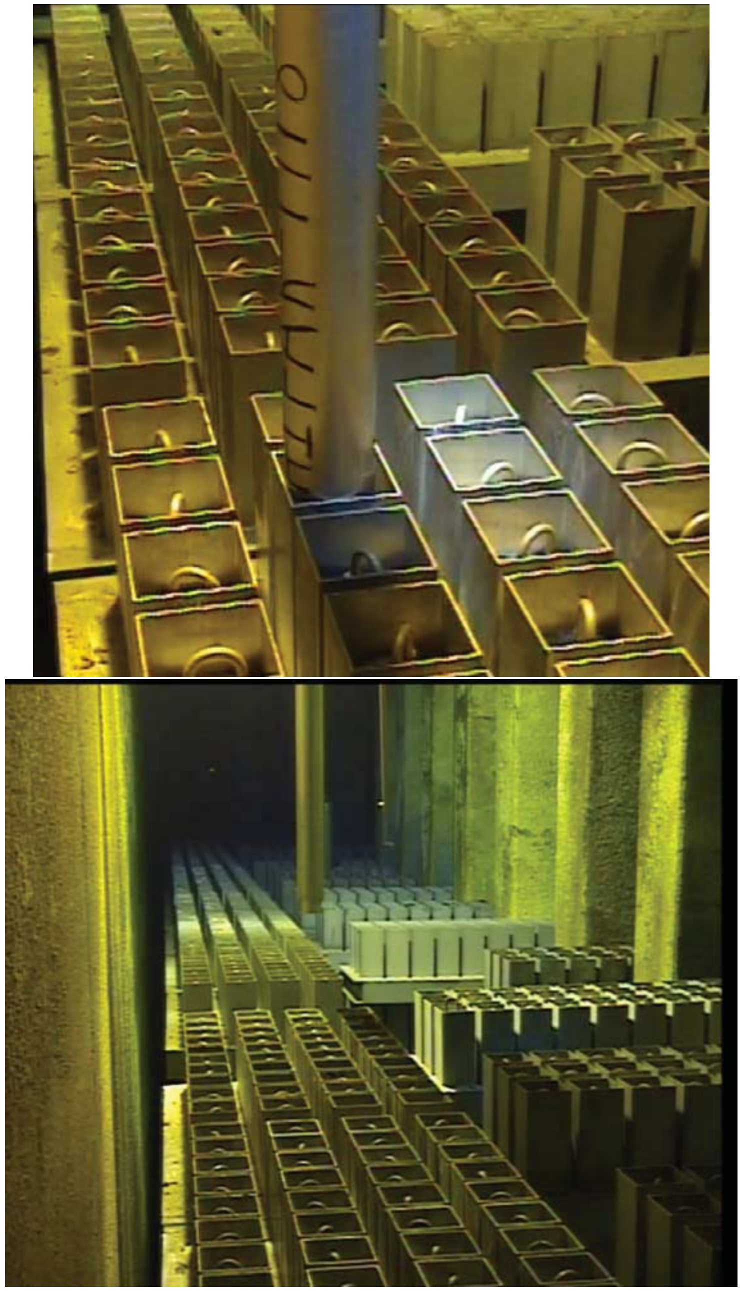


Figure A5-12 (Top) HIFAR bundle coming out of rack (Bottom) Movement of Bundle L-HIFAR-1918 turning east in the 4 by 20 rack rows

Campaign 3 – Inspection 7 (*Conducted August 2019*) (Contd)

Australian HIFAR Bundle L-HIFAR-1918 (5 Assemblies) (contd)

Figure A5-13 Handling of 1st Debundled assembly. Bottom of the inside of vacated HIFAR Bundle 1553 using round parallel grippers L-HIFAR-1918 showing bottommost fuel imprint.

Figure A5-14 Unique corrosion formation inspection assembly 1567 in the midst of a multitude of pitted holes.

<u>Campaign 4 – Inspection 8</u> (*Conducted December 2019*)

Argentine RA-3 Bundle L-RA3-0787 (4 Assemblies)

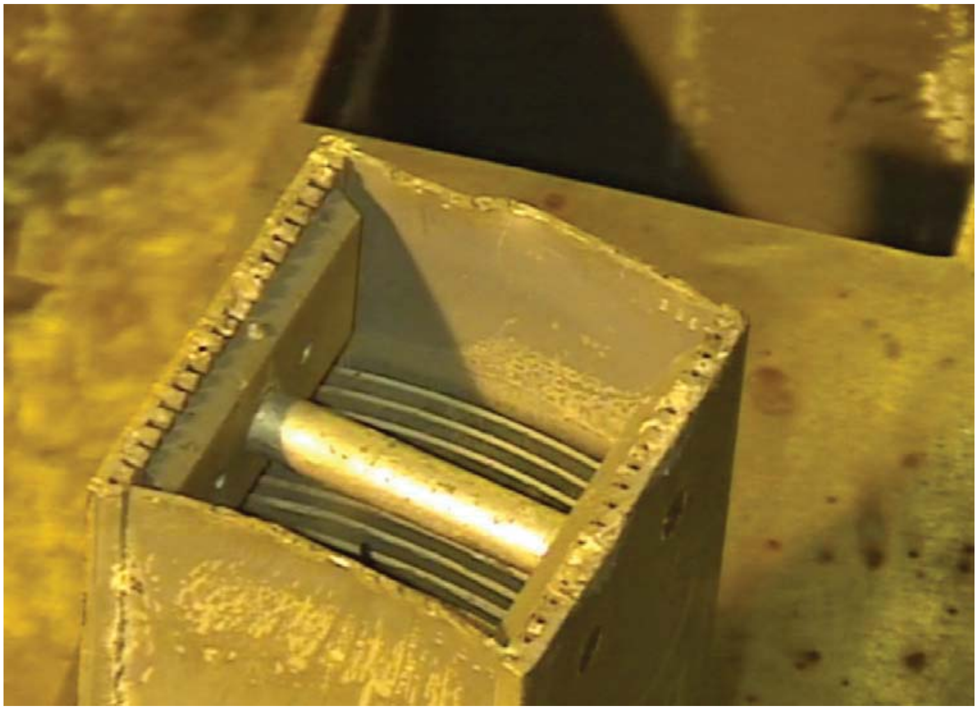


Figure A5-15 1st assembly debundled CNEA 272 sitting in slug bucket.

Figure A5-16 Inspection assembly 236 Bird Eye View on Inspection Table.

<u>Campaign 4 – Inspection 8</u> (*Conducted December 2019*) (Contd)

Argentine RA-3 Bundle L-RA3-0787 (4 Assemblies) (contd)

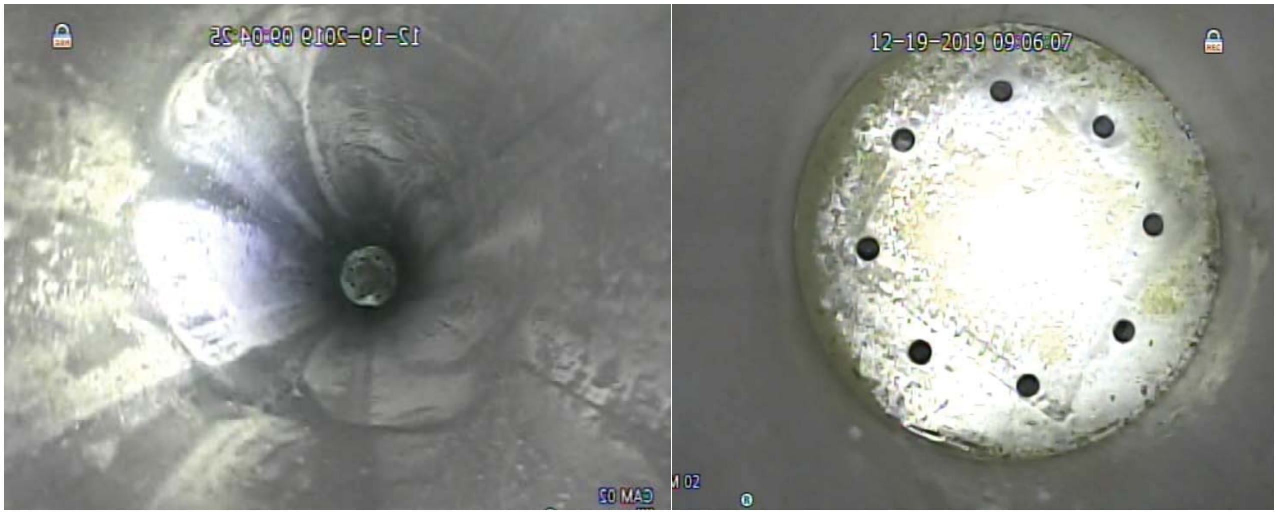


Figure A5-17 Inside of vacated bundle L-RA3-0787 two-thirds down inside (left) no corrosion on bottom crevice (right).

<u>Campaign 4 – Inspection 9</u> (*Conducted December 2019*)

Italian ENEA Galileo Bundle L-ENEA-0356 (5 Assemblies)

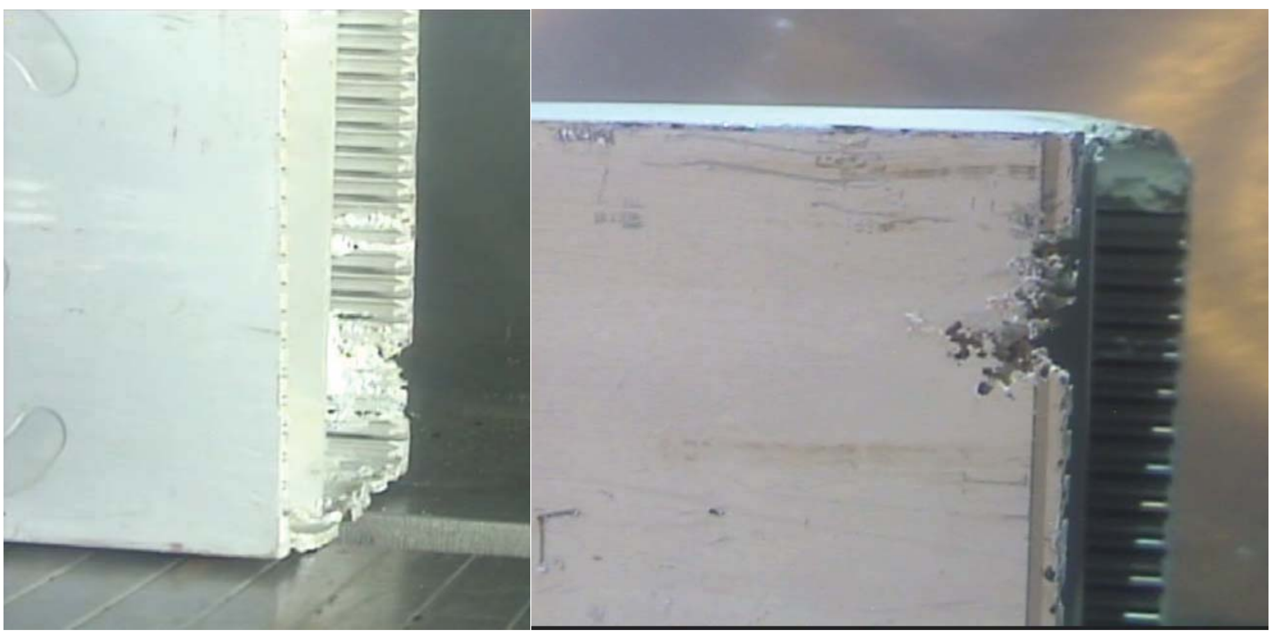


Figure A5-18 (Left) Crevice corrosion inside of top end
(Right) Opposite side of side plate from left view of inspection assembly 3—9-1X

Campaign 4 – Inspection 10 (*Conducted December 2019*)

Amsterdam HFR Petten Bundle L-HFR-1435 (4 Assemblies)

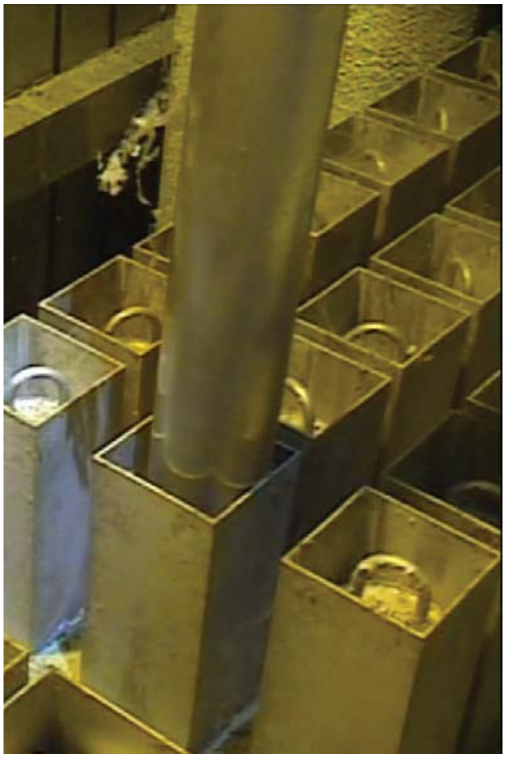


Figure A5-19 Cobwebs on left side of bundle as inspection bundle L-HFR-1435 is pulled out of the rack.

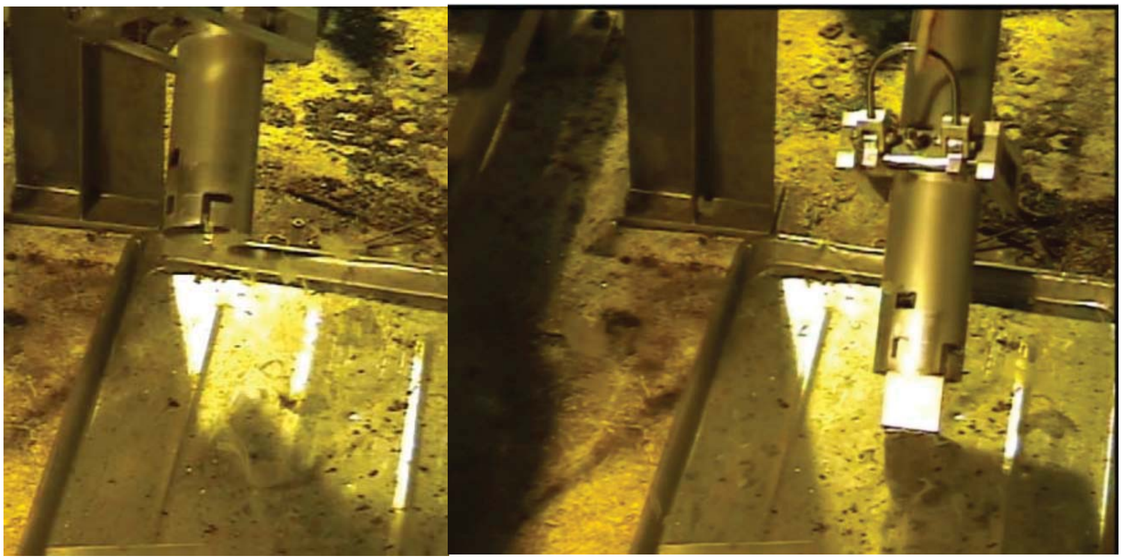


Figure A5-20 Cobwebs exiting the bundle (Left) as the 1st Assembly is removed from the bundle with cobwebs (Right).

APPENDIX 6

SRNL MTR Fuel Inspection Guide

APPENDIX 6
SRNL MTR Fuel Inspection Guide

BUNDLED FUEL VISUAL INSPECTION

Purpose

To provide instructions for visually inspecting fuel stored in bundles.

Scope

This procedure covers the inspection of fuel stored in bundles.

References

3.1 **Performance References**

SOP-DHS-030-L *Checkout of Underwater Saw*

SOP-DHS-059-L *VTS Carriage Movement*

SOP-DHS-095-L *Fuel Criticality Rules – Surveillance Requirements and Review Data - Disassembly*

SOP-DHS-166-L *Inspection of Selected Fuel Assemblies for Corrosion Degradation*

3.2 **Developmental References**

N-NCS-L-00018 *NCSE: Double Contingency Analysis for L the Disassembly Basin (U)*

S-CLC-L-00005 *Criticality Frequency in L Basin*

Responsibilities

Basin Facility Operations personnel are responsible for the performance of this procedure with assistance from various support organizations.

Precautions and Limitations Prerequisite Actions

Required Equipment/Tools:

-Dedicated RCS-3110 underwater camera and tilt/pan head
-Dedicated UL-212-30 underwater lights (x2)
-Dedicated 15 ft. poll camera mount
-Dedicated Visual Examination Table
-C-element tool
-Remote camera control unit
-DVD recorder
-USB microphone

1.0 OVERVIEW

1.1 Objective

The following visual inspection procedure will support the needs of the AMCAP program to evaluate the condition of stored spent fuel assemblies with suspected existence of corrosion and/or mechanical damage and monitor the progression of such damage over the duration of the fuel's storage. The information obtained from this continuous monitoring will help gauge the effectiveness of basin water chemistry and will assist in determining the timeline for safe continuous operation of the L-Basin storage facility.

Ten (10) fuel assemblies have been selected to serve as the basis for this visual inspection program. These assemblies were chosen based on several conditions in order to provide a varied collection of designs and irradiation history. Fuel examinations will be organized into campaigns, each of which should comprise the inspection of all 10 assemblies and be completed within 5 years. The timing of assembly inspections within each campaign will be determined by the L-area operations schedule. Any follow-up examinations will occur as deemed necessary by the Inspection Review Committee (IRC). Fuel inspections will follow the procedure laid out in *Section 2.0* of this document and should be performed by the Basin Operations group under the direction of the inspection team.

Performing inspectors will keep digital records of the fuel retrievals and examinations using the recording software associated with the underwater camera. Additionally, physical notes should be taken using the provided *Visual Inspection Notes* sheets contained in *Appendix A* of this document. The notes should contain observations of changes in the degradation state of the fuel and annotations of any anomalies found during the inspection procedure. Specific flaws and defects should also be tracked in the Surface Anomaly Logbook which is separate from this document. Further guidance on note keeping can be found in *Sections 2.1.2 and 2.1.3*.

A final report will be prepared describing the key observations made regarding the appearance of degradation and change in corrosion rates for each fuel assembly examined. This report will be a living document to which additional observations from future campaigns will be added.

1.2 Requirements

The fuel examination will be performed using the RCS-3110 underwater camera currently installed in L-Basin which is routinely used by operations to assist in locating and identifying items in the basin water. The visual inspection table and accompanying lights, depicted in Figure 2, will be used to hold the fuel assembly and camera during inspections. Operation of the camera for the purposes of this fuel inspection program will adhere to all procedural guidelines currently in place regarding the use and handling of the underwater camera. Manipulation of the camera should be executed by the basin operators under the direction of the inspection team. Following any changes made to this hardware (e.g. different lights or camera model), a review should be performed by the IRC to assess the potential impacts on image accuracy and comparability to previous visual records.

The Visual Testing (VT) inspection team should consist of at least one personnel each from SFP engineering and SRNL. These inspectors should be familiar with corrosion and corrosion damage of aluminum alloys in basin water. Those performing or assisting in the surveillance, monitoring, handling of fuel stored in L-Basin shall be fully qualified to do so in accordance with guidelines set forth by Savannah River Site. SFP Operations will support the fuel inspections using procedure SOP-DHS-166-L, Inspection of Selected Fuel Assemblies for Corrosion Degradation.

1.3 Fuel Selection

Below is a description of the five fuel types which comprise the 10 aluminum clad fuel assemblies scheduled for visual inspection. The primary considerations governing the selection of fuel assemblies are design, burnup, presence of microbiological growth, and suspected degree of damage at present. These factors allowed restriction of the fuel selection to assemblies that would provide a wide variety of fuels most that are susceptible to corrosion degradation.

Applying these selection criteria to the accessible fuel inventory of nearly 13,000 assemblies reduced the list of possible candidates to only a few hundred assemblies that were shipped to the basin from a handful of foreign spent fuel pools. From this point, a final selection was determined based upon relative time spent in detrimental water conditions as well as distribution of Uranium-235 burnup. Specifically, the rationale for choosing each fuel type is:

IEA-R1

This is a very low burnup assembly from Brazil that was known to contain pits when received in L Basin. The assembly has been stored out of the reactor for at least 48 years.

Saluggia

The three fuel assemblies from the Saluggia facility in Italy have varying burnups. The GA-67 assembly is known to have exhibited pits when received in L Basin. Two of the Saluggia assemblies have been stored out of the reactor for 32 years, and the third assembly has been stored out of the reactor for 39 years.

RA-3

The four RA-3 assemblies from Argentina have varying burnups. The fuel assemblies have been stored out of the reactor for 25, 34, 37, and 40 years. The fuel assemblies are known to be pitted.

HIFAR

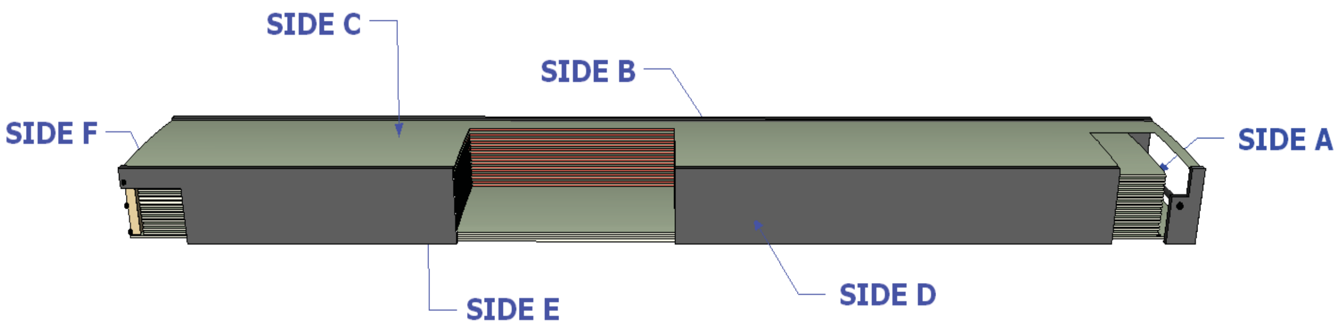
The HIFAR Mark III fuel assembly from Australia is known to contain pits. It has a medium burnup and is the only tube assembly inspected. It has been stored out of the reactor for 41 years.

HFR Petten

The HFR Petten assembly is a high burnup assembly stored in a fuel position with the highest cobweb severity. The Petten assemblies are known to be in excellent condition. The Petten assembly has been stored out of the reactor for 12 years.

1.4 Surface Identification

The fuel examination procedure is divided into six sections corresponding to the six distinct faces of the MTR assembly. Each face of the assembly will be referred to using an identifier A through F. This identification scheme shall be maintained throughout performance of the inspection and during disposition of the results. See Figure 1 for an illustration of the general naming convention. Note that Side A includes the lifting bail and Side F should contain the cut edge of cropped fuel assemblies. Side C is always the outer fuel plate with a convex exterior surface for curved plate fuel. For flat plate and involute/cylindrical assemblies, Side B is the side with identification number. Several assemblies possess a high degree of symmetry and may lack identification numbers. For these cases, surface identification will be specified during the baseline inspection campaign using identifying marks or flaws visible during inspection and recorded in the observation sheet.



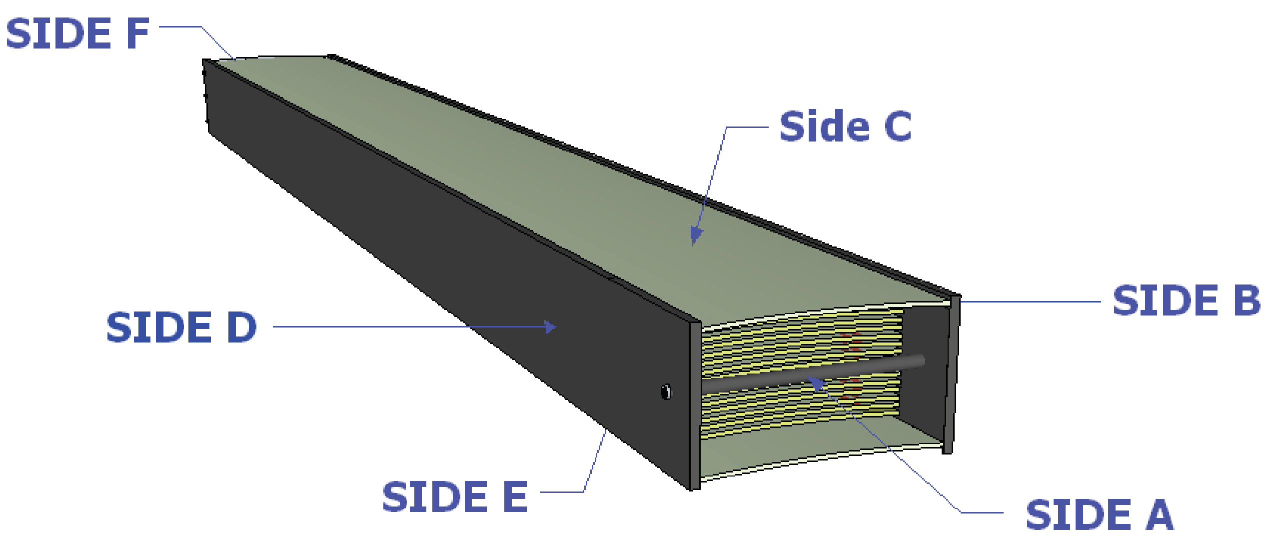


Figure A6-1 Typical MTR Face Labels. Profile View (top) Angled View (bottom)

1.5 Camera Location Identification

The Inspection Table consists of 8 distinct camera locations. The locations are marked by slots in which to drop the camera holding tool. The 8 slots will be referenced throughout the procedure according to the naming convention shown in Figure 2 below.

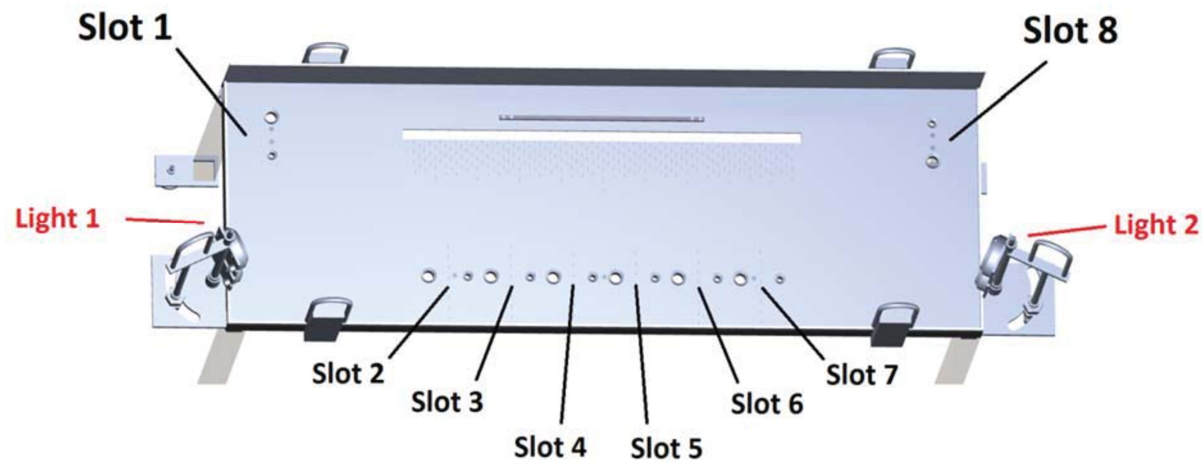
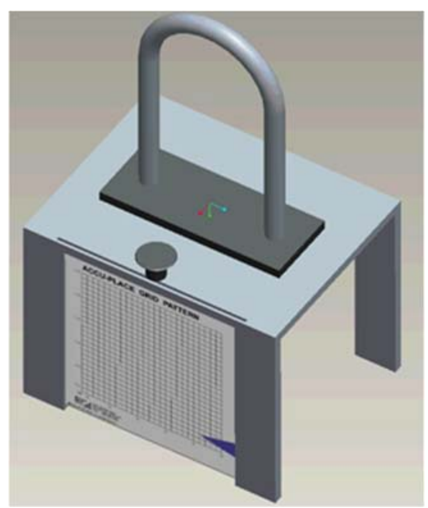


Figure A6-2 Inspection Table Slot and Light Labels

Remote controlled LED lights are also included in the inspection table design. These lights will be toggled on/off alternately throughout the procedure to provide optimal viewing conditions of certain regions of the fuel. Lights 1 & 2 correspond to the left and right lights as shown in Figure 2 above.

1.6 Visual Aid Gauge

A visual aid gauge is provided to assist the inspectors in characterizing the size of surface flaws such as pits, nodules, and general corrosion. This tool can be placed overtop the target assembly to overlay a calibrated semi-transparent grid on the camera view. The grid line pitch is 2 mm or approximately 1/12”.



1.7 Video System Qualification

The purpose of this section is to outline the actions that need to be taken to qualify the underwater video recording equipment to be used in the periodic visual examination of bundled spent fuel assemblies stored in L-Basin as part of the Fuel Inspection Program. The qualification is to be performed before each inspection campaign and is designed to ensure that the components of the system are capable of providing adequate magnification and resolution necessary to identify and distinguish surface flaws that will be of interest during the fuel inspection. Equipment to be tested includes the underwater camera, mounted and independent lights, remote controller, and recording software. If any components of the underwater video system fail or are replaced for any reason, requalification must be performed on the system with the replacement component.

Qualification of the underwater video system will meet the requirements laid out by ASME Section V, Article 9 regarding Visual Examination. In general, demonstration of visual capabilities of a system is accomplished by examination of an artificial imperfection or simulated condition located on the surface or a similar surface to that which will be examined. Additionally, because the fuel inspection program falls under the category of a remote visual examination, it must be determined that the system has resolution capabilities at least equivalent to that obtainable by direct visual observation at a distance of more than 24 inches from the surface to be examined.

A mockup curved plate assembly has been constructed of Aluminum 6061 to serve as the qualification standard. Artificial imperfections were permanently imposed on the mockup in the form of variably sized drill holes, ink marks that do not physically deform the surface, and raised drops of epoxy which simulate nodules and blisters. These features are placed at distinct locations along the assembly.

For the purposes of spent fuel corrosion damage inspection, it is necessary to be able to see a pit or nodule with a diameter of at least 1/16". Both the validation of the equipment's ability to meet this minimum requirement and the verification that the system's design characteristics are sufficient to perform the actions laid out in the procedure will be achieved through a "Dry Run" process in L-Basin.

The dry run approach will determine the examination capabilities of the equipment and procedure through observation of the mockup assembly under conditions representative of the fuel inspection while indicating on the provided checklist (*Appendix B)* which of the several unique defects can be identified and resolved. These results can then be easily compared to a direct visual observation to meet the ASME resolution requirement of a remote examination. The procedure and scheduling of this qualification method is outlined in *Section 2.2 Dry Run.*

2.0 FUEL EXAMINATION PROCEDURE

2.1 Procedure Guidance

The following sections detail the scope of the examination procedure as well the additional actions that must be taken prior to and following the fuel inspection procedure.

2.1.1 Setup Parameters

The inspection procedure is laid out such that each step provides the camera with an ideal, reproducible snapshot view of assembly surfaces. The consistency of image angles and lighting will be achieved through the use of the Inspection Table and the procedure laid out in Section 2.3. The table has been designed to provide several discrete camera positions located around the fuel assembly trough. The Inspection Table also houses two independently controlled light fixtures. The lighting position and camera zoom levels have been established during the mockup execution of the examination procedure.

2.1.2 Image Stills, Inspection Notes and Surface Anomaly Logbook

An inspection Final Report will be issued upon completion of each inspection campaign. This living document will incorporate the images, video annotations, flaw characterizations, and condition assessments for the initial set of fuel examinations as they are generated.

Following the inspection, post processing of the video recording will yield several still images of the fuel assembly surface at the designated camera locations as well as from video taken during bundle movement and fuel transfer. These images will serve as a permanent record of previous inspections which can be easily referenced in future examinations, so it is important to follow the procedure precisely to limit inconsistency between chronological images.

The Inspection Notes sheet (*Appendix A*) attached to this document shall be used by inspection personnel to record qualitative assessments of each view during the inspection. In addition to following the procedure in order to provide snapshot views, camera operators and inspection personnel will be expected to locate and identify regions on the assembly where corrosion is particularly advanced or progressing quickly. Inspector personnel may manipulate the camera and lighting (position, angle, intensity, zoom, etc.) in order to obtain a better view of the regions of interest once they have completed the present section of the procedure and secured the specified snapshot views corresponding to each listed action in that section. Observations made during these auxiliary examinations should be recorded in the Inspection Notes sheet (*Appendix A)* of this document and should include video timestamp information.

The Surface Anomaly Logbook which contains itemized characterizations of significant surface flaws should also be updated during each inspection. This logbook contains specific descriptions and severity/dimensional characterization of major surface flaws as well as a timeline of images from previous inspections. Inspectors are responsible for re-characterizing all listed flaws using the Visual Aid Gauge described in Section 1.6 and creating new logbook entries for new flaws observed during the examination.

Inspection personnel should have copies of all previous Inspection Notes and logbook entries related to the fuel assembly being inspected as well as printed stills obtained from earlier inspections. He or she will compare these descriptions and accompanying photos to the current observable condition of the fuel to determine if further investigation of certain regions is warranted.

2.2 Dry Run

A dry run through the procedure must be performed at the start of each new inspection campaign or if 6 months have elapsed since the last fuel inspection. The dry run procedure which is given in *Section 2.2.2 Dry Run Procedure* utilizes a mock-up fuel assembly (Drawing No. R-R1-A-00052) which contains no fissile material, radioactive source, or moderating material. The dry run will verify that all necessary steps, details, equipment, and personnel are available and capable of executing the inspection procedure safely and completely before radioactive spent fuel is handled.

Furthermore, this preliminary test procedure will provide critical information pertaining to video recording equipment qualification, placement, and setup. As discussed in *Section 1.7*, a video qualification must be completed regularly to ensure that changes to the basin environment over time do not impair the quality of the remote visual inspection equipment and procedure. As such, the defect checklist described in *Section 2.2.1* below must be filled out during the dry run to satisfy this requirement. If any of the 35 listed defects cannot be identified in the dry run, the IRC shall evaluate the need replace the inspection dummy or equipment before continuing with a fuel inspection.

In addition to completion of a mandatory dry run for each inspection campaign and following each 6 month hiatus, supplemental dry runs may become necessary in the event of a significant change in the basin testing environment or video recording equipment. Such an event would not only require requalification of the system, but also re-evaluation of this procedures efficacy.

2.2.1 Defect Checklist

The purpose of this checklist is to ensure that the video system used to perform the underwater fuel examination meets the ASME standard requirements for a remote visual inspection. At a minimum, this qualification must be performed for each dry run at the start of every inspection campaign interval to account for changes in the Basin conditions.

The mock-up MTR assembly labeled “Inspection Dummy” that is used for video system qualification contains several artificial defects design to simulate corrosive damage that may be apparent on fuel assembly. During the dry run, a subset of these defects must be located using the underwater camera system. If a feature in the below checklist is visible and distinguishable from surrounding features, place a check mark in the corresponding box.

Defect Checklists to be filled out as needed can be found in Appendix B of this document.

Table A6-1 Features observable through direct visual examination at 24"

Feature		Distance from Side A				
		5"	10"	15"	20"	25"
Side C	1/8" hole	✓	✓	✓	✓	✓
	3/32" hole	✓	✓	✓	✓	✓
	1/16" hole	✓	✓	✓	✓	✓
	3/64" hole	✓	✓	✓	✓	✓
	1/32" hole	✓	✓	✓	✓	✓
Side D	1/4" blister	✓	✓	✓	✓	✓
	1/8" blister	✓	✓	✓	✓	✓

2.2.2 Dry Run Procedure

Actions	*Progress*
1) Place "Inspection Dummy" assembly on inspection table with Side C facing Slots 2-7 and Side A facing Slot 1. Center assembly using etched increments on table surface.	Complete: ____
2) Relocate Camera Holding Tool to Slot 1. Zoom in/out and pan until assembly width fills the screen. Toggle all three light settings (Light 1 on only, Light 2 on only, both on).	Complete: ____
3) Relocate Camera Holding Tool to Slot 2. Zoom camera out and pan camera left/right until the viewing angle is centered. Use Camera Angle Guide in *Section 2.3.2* to assist in centering the camera. Toggle all three light settings. Identify on the defect checklist whether the features corresponding to this side and camera slot can be visually identified.	Complete: ____
4) Repeat Step 3 for camera Slots 3-7.	Complete: ____
5) Repeat Step 2 for camera Slot 8.	Complete: ____
6) Rotate fuel such that Side D is facing Slots 2-7 and Side A is facing Slot 1. Relocate camera holding tool to Slot 2. Zoom camera out and pan camera left/right until the viewing angle is centered. Use Camera Angle Guide in *Section 2.3.2* to assist in centering the camera. Toggle all three light settings.	Complete: ____
7) Repeat Step 6 for camera Slots 3-7.	Complete: ____
8) Ensure the Defect Checklist (Appendix B) is completed and the underwater camera video recording is saved.	Complete: ____

2.3 EXAMINATON PROCEDURE

2.3.1 Preparation and Dry Run

- Bring the inspection table into position between two catwalks of the machine basin. Orient the table such that Slots 1 through 8 are accessible from the catwalks. Row KK is suggested.
- It is suggested to mount the camera into the camera holding tool above water and lock into place using the locking lever before lowering tool to table.
- Attach camera poll to mounted camera flange by twisting clockwise completely.
- Turn on the inspection table lights and ensure they are working properly.
- Ensure that the camera controls are working properly and that recording software is running.
- Check for presence of all necessary operational staff, tools, and documents.
- Prepare *Inspection Notes* sheet and record video start time.
- Retrieve the most recent revision of the *Surface Anomaly Logbook* and *Inspection Notes* from the previous campaign.

Important

If :

<u>Six months have elapsed since the last execution of the inspection procedure OR if this is the beginning of a new inspection campaign.</u>

Then:

You must complete a Dry Run of the procedure (Sections 2.2.2) using the “Inspection Dummy” in place of a fuel assembly. You must also fill out a defects checklist form from *Appendix B* to ensure equipment and procedure capability. Be sure to note the date of the Dry Run on the form. If all defects can be identified on the mockup assembly throughout the course of the dry run, you may begin video recording and start the procedure to examine the selected spent fuel assembly.

2.3.2 Assembly Placement and Camera Angle Guide

The assembly staging area of the table features a **backstop**, **fuel trough** and **engraved ruler markings** to assist in consistent placement of assemblies. Rectangular fuels should be pressed against the backstop while cylindrical fuels should rest in the fuel trough. Lateral positioning is achieved using the engraved ruler markings to ensure left/right centering. The fuel is centered when both edges of the assembly fall on the same ruler marking number on either side of the centerline, 0. *Table 2* lists the expected edge placement locations for the 5 fuel types included in the AMCAP scope.

Table A6-2 Assembly Placement Locations

Fuel Type Designation	Dimensions [cm]	Assembly Edge Placement [inches from center]
IEA-R1	7.6 H x 8.3 W x 66.04 L	13
RA-3	8.4 H x 7.6 W x 72.01 L	14.2
SALUGGIA	8.04 H x 7.61 W x 65.50 L	12.9
HIFAR	10.16 OD x 63.83 L	12.6
HFR Petten	8.46 H x 7.6 W x 67.31 L	13.25

The table features 8 discrete camera locations designated Slots 1 through 8. Once a slot is occupied, the camera can pan and tilt to investigate anomalies and regions of interest. However, the camera angle must first be centered following relocation to a new slot in order to provide a full viewed snapshot of each 6" segment of the fuel. To obtain these images, first ensure that the camera is zoomed out, then pan the camera until the range of ruler markings indicated in *Table 3* can be seen at the base of the fuel assembly.

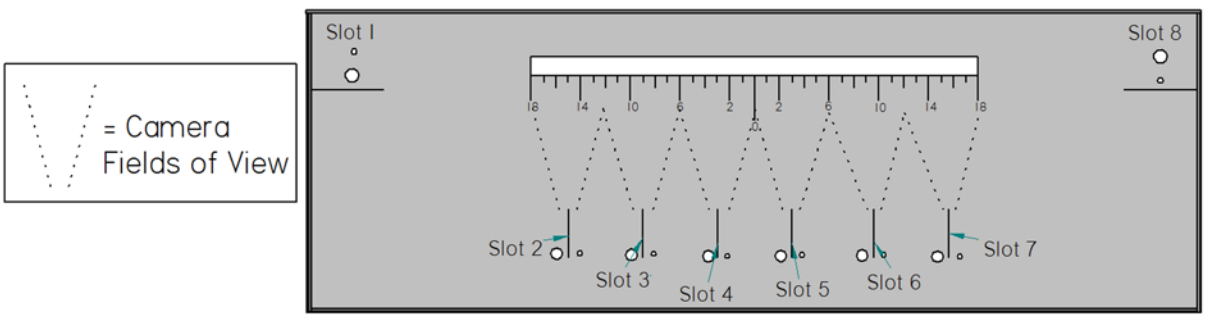


Table A6-3 Camera Angle Fields of View

Slot #	**Slot 2**	**Slot 3**	**Slot 4**	**Slot 5**	**Slot 6**	**Slot 7**
Viewable Ruler Markings	18 – 12	12 – 6	6 – 0	0 – 6	6 – 12	12 – 18

2.3.3 Fuel Movement Observations

Actions	*Progress*
1) Prior to bundle movement, perform sip test using SOP-DHS-XXX and record results.	Complete: ____
2) Record video of Bundle being removed from rack and transported to tilt table.	Complete: ____
3) Record video of gross external bundle surface area. Zoom to investigate any signs of degradation which may impact future retrievability	Complete: ____
4) Record video of de-bundling at tilt table.	Complete: ____

2.3.4 Side A: On-End Fuel and Lifting Handle

Actions	*Progress*
1) Transfer assembly from bundled storage can to saw basin. Place assembly on inspection table with Side B facing Slots 2-7. Center assembly using etched increments on table surface.	Complete: ____
2) Relocate Camera Holding Tool to Slot 1. Zoom in/out and pan until assembly width fills the screen. Toggle all three light settings (Light 1 on only, Light 2 on only, both on).	Complete: ____
3) Check ends of fuel plates and side plates for damage.	Complete: ____
4) Examine interior region of side plates Examine *crevices* created by fuel plate intersections. Assess condition of *lifting bail* joint.	Complete: ____
5) Note any visible obstructions between fuel plates along the interior fuel region.	Complete: ____
6) Fill out *Visual Inspection Notes* sheet for Side A. Describe general condition of fuel and cladding. Indicate video timestamp of Side A inspection.	Complete: ____
7) Review the *Surface Anomaly Logbook* for side A. Re-characterize all discovered defects and note any significant visual changes from previous inspection campaign.	Complete: ____
8) If any new defects or regions of corrosion susceptibility are observed, describe the discovery in the *Inspection Notes* sheet and create new entry in the *Surface Anomaly Logbook.* Zoom, pan, and tilt the camera until the new defect is clearly visible on the monitor. Be sure to indicate the relative position on the fuel and video timestamp of anomaly inspection in the new defect entry. Attempt to characterize the size of the defect using the Visual Aid Gauge Repeat step 8 until all new defects on Side A are catalogued.	Complete: ____

2.3.5 Side B: Side Plate and Lift Handle [MTR]

Actions	***Progress***
1) Ensure that side B is facing slots 2-7. Relocate camera holding tool to Slot 2. Zoom camera out and pan camera left/right until the viewing angle is centered. Use Camera Angle Guide in *Section 2.3.2* to assist in centering the camera. Toggle all three light settings.	Complete: ____
2) Assess condition of Side plate and any viewable weldments/crevices.	Complete: ____
3) Review the *Surface Anomaly Logbook* for side B, current slot. Re-characterize all discovered defects and note any significant visual changes from previous inspection campaign.	Complete: ____
4) If any new defects or regions of corrosion susceptibility are observed, describe the discovery in the *Inspection Notes* sheet and create new entry in the *Surface Anomaly Logbook.* Zoom, pan, and tilt the camera until the new defect is clearly visible on the monitor. Be sure to indicate the relative position on the fuel and video timestamp of anomaly inspection in the new defect entry. Attempt to characterize the size of the defect using the Visual Aid Gauge. Repeat step 4 until all new defects on Side B, current slot, are catalogued.	Complete: ____
5) Relocate camera holding tool to Slots 3-7. Zoom out and use Camera Angle Guide in *Section 2.3.2* to assist in centering the camera. For each Slot, repeat steps 2 through 4.	Complete: ____
6) Fill out *Visual Inspection Notes* sheet for Side B. Describe general condition of fuel and cladding. Indicate video timestamp of Side B inspection.	Complete: ____

2.3.6 Side C: External Surface of Outer Plate [MTR]

Actions	*Progress*
1) Rotate fuel such that Side C is facing slots 2-7. Relocate camera holding tool to Slot 2. Zoom camera out and pan camera left/right until the viewing angle is centered. Use Camera Angle Guide in *Section 2.3.2* to assist in centering the camera. Toggle all three light settings.	Complete: ____
2) Assess condition of cladding. Examine crevices created by fuel plate intersections.	Complete: ____
3) Review the *Surface Anomaly Logbook* for side C, current slot. Re-characterize all discovered defects and note any significant visual changes from previous inspection campaign.	Complete: ____
4) If any new defects or regions of corrosion susceptibility are observed, describe the discovery in the *Inspection Notes* sheet and create new entry in the *Surface Anomaly Logbook.* Zoom, pan, and tilt the camera until the new defect is clearly visible on the monitor. Be sure to indicate the relative position on the fuel and video timestamp of anomaly inspection in the new defect entry. Attempt to characterize the size of the defect using the Visual Aid Gauge. Repeat step 4 until all new defects on Side C, current slot, are catalogued.	Complete: ____
5) Relocate camera holding tool to Slots 3-7. Zoom out and use Camera Angle Guide in *Section 2.3.2* to assist in centering the camera. For each Slot, repeat steps 2 through 4.	Complete: ____
6) Fill out *Visual Inspection Notes* sheet for Side C. Describe general condition of fuel and cladding. Indicate video timestamp of Side C inspection.	Complete: ____

2.3.7 Side D: Side Plate and Lift Handle [MTR]

Actions	*Progress*
1) Rotate fuel such that Side D is facing slots 2-7. Relocate camera holding tool to Slot 2. Zoom camera out and pan camera left/right until the viewing angle is centered. Use Camera Angle Guide in *Section 2.3.2* to assist in centering the camera. Toggle all three light settings.	***Complete:*** ____
2) Assess condition of Side plate and any viewable weldments/crevices.	***Complete:*** ____
3) Review the *Surface Anomaly Logbook* for side D, current slot. Re-characterize all discovered defects and note any significant visual changes from previous inspection campaign.	***Complete:*** ____
4) If any new defects or regions of corrosion susceptibility are observed, describe the discovery in the *Inspection Notes* sheet and create new entry in the *Surface Anomaly Logbook.* Zoom, pan, and tilt the camera until the new defect is clearly visible on the monitor. Be sure to indicate the relative position on the fuel and video timestamp of anomaly inspection in the new defect entry. Attempt to characterize the size of the defect using the Visual Aid Gauge. Repeat step 4 until all new defects on Side D, current slot, are catalogued.	***Complete:*** ____
5) Relocate camera holding tool to Slots 3-7. Zoom out and use Camera Angle Guide in *Section 2.3.2* to assist in centering the camera. For each Slot, repeat steps 2 through 4.	***Complete:*** ____
6) Fill out *Visual Inspection Notes* sheet for Side D. Describe general condition of fuel and cladding. Indicate video timestamp of Side D inspection.	***Complete:*** ____

2.3.8 Side E: External Surface of Outer Plate [MTR]

Actions	***Progress***
1) Rotate fuel such that Side E is facing slots 2-7. Relocate camera holding tool to Slot 2. Zoom camera out and pan camera left/right until the viewing angle is centered. Use Camera Angle Guide in *Section 2.3.2* to assist in centering the camera. Toggle all three light settings.	Complete: ____
2) Assess condition of cladding. Examine crevices created by fuel plate intersections.	Complete: ____
3) Review the *Surface Anomaly Logbook* for side E, current slot. Re-characterize all discovered defects and note any significant visual changes from previous inspection campaign.	Complete: ____
4) If any new defects or regions of corrosion susceptibility are observed, describe the discovery in the *Inspection Notes* sheet and create new entry in the *Surface Anomaly Logbook.* Zoom, pan, and tilt the camera until the new defect is clearly visible on the monitor. Be sure to indicate the relative position on the fuel and video timestamp of anomaly inspection in the new defect entry. Attempt to characterize the size of the defect using the Visual Aid Gauge. Repeat step 4 until all new defects on Side E, current slot, are catalogued.	Complete: ____
5) Relocate camera holding tool to Slots 3-7. Zoom out and use Camera Angle Guide in *Section 2.3.2* to assist in centering the camera. For each Slot, repeat steps 2 through 4.	Complete: ____
6) Fill out *Visual Inspection Notes* sheet for Side E. Describe general condition of fuel and cladding. Indicate video timestamp of Side E inspection.	Complete: ____

2.3.9 Side F: On-End Fuel

Actions	***Progress***
1) Rotate fuel such that Side B is facing slots 2-7. Relocate camera holding tool to Slot 8. Toggle all three light settings.	Complete: ____
2) Check ends of fuel plates and side plates for damage.	Complete: ____
3) Examine interior region of side plates Exam*ine crevices* created by fuel plate intersections.	Complete: ____
4) Note any visible obstructions between fuel plates along the interior fuel region.	Complete: ____
5) Fill out *Visual Inspection Notes* sheet for Side F. Describe general condition of fuel and cladding. Indicate video timestamp of Side F inspection.	Complete: ____
6) Review the *Surface Anomaly Logbook* for side F. Re-characterize all discovered defects and note any significant visual changes from previous inspection campaign.	Complete: ____
7) If any new defects or regions of corrosion susceptibility are observed, describe the discovery in the *Inspection Notes* sheet and create new entry in the *Surface Anomaly Logbook.* Zoom, pan, and tilt the camera until the new defect is clearly visible on the monitor. Be sure to indicate the relative position on the fuel and video timestamp of anomaly inspection in the new defect entry. Attempt to characterize the size of the defect using the Visual Aid Gauge. Repeat step 8 until all new defects on Side F are catalogued.	Complete: ____

Appendix A
Visual Inspection Notes

SRNL Inspector

Name:________________________________ Date: ___/____/___

SFP Engineering Inspector

Name:________________________________ Date: ___/____/___

Fuel Identification ____________________

Bundle ID: ________________ ______ Assembly: ______ ____

Lane: _____ _____ Rack: ____ ______ Position: ____ ________

Inspection Observations Indicate general condition of examined regions and possible evidence of cladding or structural material degradation (discoloration, debris, pitting, blistering).

Video Annotations Reference video play time of important observations for future review of recorded video.

Fuel Movement
Video Playback Time:______:________:______ (hh:mm:ss)

Side A
Video Playback Time:______:_________:_______ (hh:mm:ss)

Side B:
Video Playback Time:______:_________:_______ (hh:mm:ss)

Side C:
Video Playback Time:______:_________:_______ (hh:mm:ss)

Side D:
Video Playback Time:______:_________:_______ (hh:mm:ss)

Side E:
Video Playback Time:______:_________:_______ (hh:mm:ss)

Side F:
Video Playback Time:______:_________:_______ (hh:mm:ss)

Additional Notes:

Appendix B
Defect Checklists

VISUAL INSPECTOR(S): ______________________ DATE: ____/____/_____

Reason (circle one) : Initial Dry Run / Mid-Campaign Requalification / Basin Event or Procedure Change

Feature		Distance from Side A 5”	10”	15”	20”	25”
Side C	1/8" hole					
	3/32" hole					
	1/16" hole					
	3/64" hole					
	1/32" hole					
Side D	1/4" blister					
	1/8" blister					

VISUAL INSPECTOR(S): ______________________ DATE: ____/____/_____

Reason (circle one) : Initial Dry Run / Mid-Campaign Requalification / Basin Event or Procedure Change

Feature		Distance from Side A 5”	10”	15”	20”	25”
Side C	1/8" hole					
	3/32" hole					
	1/16" hole					
	3/64" hole					
	1/32" hole					
Side D	1/4" blister					
	1/8" blister					

VISUAL INSPECTOR(S): ______________________ **DATE:** ___/___/_____

Reason (circle one) : **Initial Dry Run / Mid-Campaign Requalification / Basin Event or Procedure Change**

Feature		Distance from Side A 5"	10"	15"	20"	25"
Side C	1/8" hole					
	3/32" hole					
	1/16" hole					
	3/64" hole					
	1/32" hole					
Side D	1/4" blister					
	1/8" blister					

VISUAL INSPECTOR(S): ______________________ **DATE:** ___/___/_____

Reason (circle one) : **Initial Dry Run / Mid-Campaign Requalification / Basin Event or Procedure Change**

Feature		Distance from Side A 5"	10"	15"	20"	25"
Side C	1/8" hole					
	3/32" hole					
	1/16" hole					
	3/64" hole					
	1/32" hole					
Side D	1/4" blister					
	1/8" blister					

VISUAL INSPECTOR(S): ______________________ **DATE:** ___/___/_____

Reason (circle one) : **Initial Dry Run / Mid-Campaign Requalification / Basin Event or Procedure Change**

Feature		Distance from Side A 5"	10"	15"	20"	25"
Side C	1/8" hole					
	3/32" hole					
	1/16" hole					
	3/64" hole					
	1/32" hole					
Side D	1/4" blister					
	1/8" blister					

VISUAL INSPECTOR(S): ______________________ DATE: ___/___/_____

Reason (circle one) : Initial Dry Run / Mid-Campaign Requalification / Basin Event or Procedure Change

Feature		Distance from Side A 5”	10”	15”	20”	25”
Side C	1/8" hole					
	3/32" hole					
	1/16" hole					
	3/64" hole					
	1/32" hole					
Side D	1/4" blister					
	1/8" blister					