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Visual Examination of Aluminum Containers for Extended Wet Storage of Non-Aluminum-Clad Spent Nuclear Fuel – FY21

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REVIEWS AND APPROVALS

Acknowledgements

This work would not have been possible without the dedication and ingenuity of Kevin Counts. His design and build work throughout the development of the EBS mockup racks were essential. The camera-mast mechanical system and associated tooling custom made for each camera that Kevin created all made for the smooth success of the inspection in L Basin.

L Basin Operations personnel were also instrumental in implementing the tooling to allow the visual examinations. Coupled with the teamwork and leadership provided by SRNL and SFP engineering, the PBI was efficiently and seamlessly carried out. Many thanks to all for aiding in the successful completion of this project.

EXECUTIVE SUMMARY

Approximately 20 metric tons of heavy metal (MTHM) comprising 2000 elements of non-aluminum-clad spent nuclear fuel (NASNF) is owned by the U.S. Department of Energy and is managed in wet storage in the L Basin at the Savannah River Site. The NASNF claddings are primarily zirconium/zircaloy or stainless steel; the NASNF fuel core materials are either uranium, uranium alloys, or pure or mixed oxides of uranium, plutonium, and thorium. These fuel elements are stored in one of the following configurations [a]: i) directly within a thin-wall (0.052”-thick) aluminum tube (bundle) with a 5” diameter, and either 12’ or 14’ in length; ii) within smaller cans that are stacked in the tubes. The management strategy for continued safe storage in L Basin is to demonstrate that these fuel containers remain structurally intact to provide safe, certain handling, and to maintain configuration for criticality control.[b] This report describes the work to interrogate the physical condition of the NASNF storage containers using a visual examination (VE) method in an inspection campaign.

The storage configurations of NASNF could cause inside-out corrosion attack of the aluminum storage containers due to galvanic couples or sediment-induced corrosion. Outside-in corrosion attack is also expected due to pitting corrosion, but with a negligible impact on structural integrity in the near term. There is no declared disposition path or retrieval schedule for the NASNF in L Basin, and the vulnerability to corrosion attack and its progression will increase with time. To verify that the condition of the fuel containers remains fit for service under continued storage, container interrogation using a VE method is being performed as a first step under the Augmented Monitoring and Condition Assessment Program (AMCAP) at the Savannah River Site.

This report describes the:

- VE camera selection and performance testing;
- mockup for L Basin deployment;
- selection of five bundles for inspection using VE; and
- inspection results

The VE method used cameras adapted to tooling for remote underwater examination of the containers. The VE deployment was mockup-tested using full-size bundles to demonstrate physical access, lighting, and that the video recording cameras provided sufficient imaging for in-situ deployment for the bundles in the Extended Basin Storage (EBS) racks used in Vertical Tube Storage (VTS) location in L Basin. In-situ deployment requires that the cameras withstand water and radiation exposure, and that the camera deployment mast would fit within the narrow gap between the tube and rack. The water and radiation tolerance of the cameras was demonstrated successfully, and the target to examine 90% or more of surfaces of the tubes in-situ was achieved in both mockup and in-situ.

Five vulnerable bundles were visually examined March 16-18, 2021. Small anomalies from outside-in corrosion were observed on the surfaces of each of the bundles. The anomalies include pitting, corrosion deposits, discoloration markings, and scratches. There were no gross areas of corrosion attack or large-scale pitting that would impact the structural integrity of the bundles to withstand handling loads. There was no evidence of anomalous debris emanating from the bundles when moved or accumulated at the bottom of the bundles.

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[a] Oversize Storage Containers (OSC) and other containers are also used to store NASNF. The L bundle and GP tube are the thinnest containers used for storage of NASNF in L Basin. The interrogation of these containers (physical condition assessment) using VE in the AMCAP program is the scope of this report.
[b] The alteration (corrosion) of the NASNF leading to its reconfiguration inside a storage container is acceptable and does not violate continued safe fuel storage management strategy.

One bundle (#0845) will be removed from the storage rack and re-inspected (summer 2021) to help identify the cause of the single large (~3/4" diameter) surface area anomaly observed during March inspection.

Three of the bundles released bubbles of gas upon movement. This occurrence is being further evaluated. Potential causes are: air released as inner small cans became flooded and/or hydrogen evolved due to uranium alloy fuel corrosion with water.

The full inspection records of videos and captured still images are stored on the site server to establish a library of inspection results. The inspection of additional vulnerable bundles using VE is planned for FY22.

The evaluation of the condition of the storage containers (bundles, OSCs, and inner cans) in L Basin in full consideration of corrosion degradation is needed to ensure their credit for safe storage. The next step in the AMCAP activities is the completion of the systems for volumetric examination of the containers using the ultrasonic examination method. The deployment of system will provide information on the local net section of the containers to assess the impact of corrosion attack.

The AMCAP inspection of the bundles met the SRNS EMO PBI 4.03 milestone "Perform In-Situ NASNF Visual Examination of 5 Bundles."

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LIST OF ABBREVIATIONS

AMCAP	Augmented Monitoring and Condition Assessment Program
CCD	Charge-coupled Device
CMOS	Complementary Metal-oxide-semiconductor
EBS	Extended Basin Storage
ERR	Elk River Reactor
ESR	Engineering Study Report
FF	Far Field
GC-MS	Gas Chromatography-Mass Spectrometry
HWCTR	Heavy Water Components Test Reactor
IMT	Insulated Metal Tube
MCNP6	Monte-Carlo N-Particle transport code version 6
MIC	Microbially Induced Corrosion
MTHM	Metric Tons of Heavy Metal
NASNF	Non-Aluminum Clad Spent Nuclear Fuel
NF	Near Field
OCP	Oxide Containment Plate
POP	Proof of Principle
RBOF	Receiving Basin for Off-Site Fuel
RMT	Restraint Metal Tube
SME	Subject Matter Expert
SMT	Segmented Metal Tube
SRL	Savannah River Laboratory
SRNL	Savannah River National Laboratory
TMT	Thorium Metal Tube
UE	Ultrasonic Examination
VE	Visual Examination
VTS	Vertical Tube Storage

1.0 Introduction

The goal of the Augmented Monitoring and Condition Assessment Program (AMCAP) program is to provide a condition assessment of the storage containers for non-aluminum-clad spent nuclear fuel (NASNF) in L Basin and demonstrate continued safe storage of all NASNF pending retrieval for ultimate disposition. The storage configuration of NASNF is vulnerable to inside-out corrosion attack.[1]

The approach being used in AMCAP is to develop and deploy examination methods for remote, in-situ inspection of the bundle storage in VTS and for OSC storage in the OSC racks.[1] A method for Visual Examination (VE) using video-recording cameras was readied as part of the full-scale mockup development, and was deployed in L Basin for the initial condition assessment work.[2] This report describes the development and the deployment of the VE for inspection of selected bundles in L Basin.

The first deployment of the VE system was for visually examining five spent fuel bundles. Bundles were chosen based on their vulnerability in terms of inner fuel contents, history, storage duration, storage configuration, and possibility of inside out corrosion due to galvanic coupling of fuel cladding with the aluminum bundle wall.

- Bundle 4302 contains Elk River Reactor (ERR) fuel within a GP tube. The ERR bundles were heavily loaded with multiple fuel rods, creating multiple areas where fuel rods touch the inner bundle wall. Each of these touch points creates a possible area for galvanic corrosion.
- Bundles 1056 and 0845 both contain Heavy Water Components Test Reactor (HWCTR) fuel within L bundles. Bundle 1056 also contains multiple fuel rods, creating multiple areas for potential galvanic corrosion within the bundle. Bundle 0845 contains one fuel rod which was possibly cut before placing it into the bundle for storage.
- Bundle 7999 contains HWCTR fuel that was loaded into an aluminum A can, which was then loaded into a GP tube. The fuel was cut before being loaded into the can, creating potential for hydrogen production if the fuel were to come in contact with water.
- Bundle 1051 also contains HWCTR fuel that was loaded into nine cans, which were then loaded into an L bundle. The various fuel and can configurations allow for possible fuel degradation and for possible inner can failure.

The inspection was led by a team of subject matter experts (SMEs) in materials characterization from SRNL and the L Basin SNF storage configuration from SFPE.

No acceptance criteria for disposition of inspection results were in force for the examination. The condition assessment provided by the visual examination of the bundles was limited to an assessment of the corrosion attack on the external surfaces. Additional examinations to assess the corrosion attack to the bundles from the inside is pending completion of the ultrasonic examination system. The inspection team used engineering judgment that the corrosion features observed were non-threatening to immediate continued storage and handling in the near-term (several years' timeframe). However, calculation of the structural capacity to withstand all anticipated handling loads is being performed. This calculation will be issued prior to removal of the bundles outside of the storage rack for augmented examination to determine the cause of the features observed on one bundle in the March 2021 examination.

Additional examinations to assess the corrosion attack to the bundles from the inside is pending completion of the ultrasonic examination system. The development of that examination system is not discussed in this report.

1.1 Full-Scale Mockup

Dry runs were performed before in-situ execution in L Basin. A full-scale mockup of a portion of an L Basin EBS rack was created and staged within a high bay in building 723-A at Savannah River National Laboratory (SRNL). A special 3x2 section of water-filled rack was loaded with full-size L bundles and GP tubes, to allow for simulated testing of tooling and cameras (Figure 1-1).

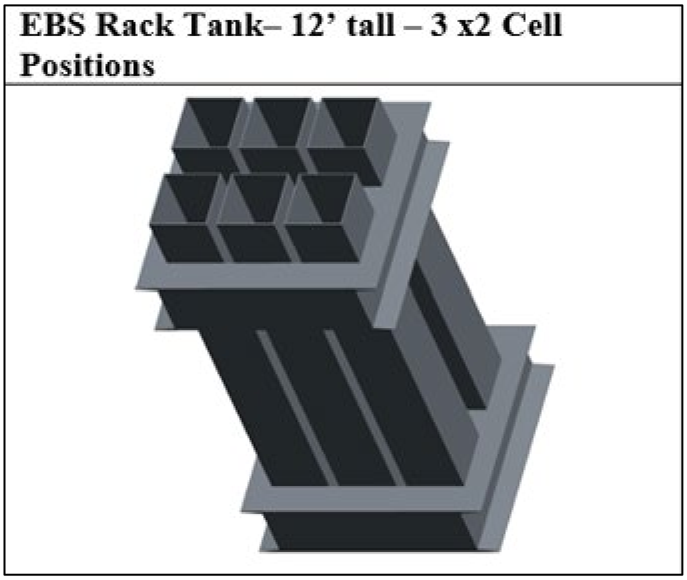
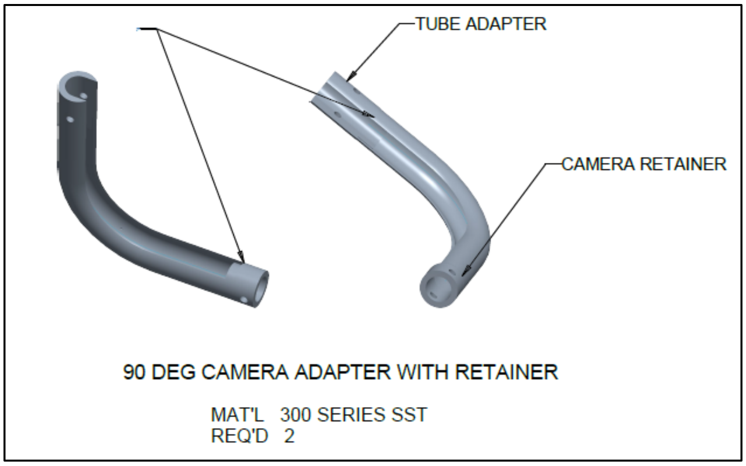


Figure 1-1. Full Scale Rack for Mockup.

A Bundled Fuel Visual Examination Guide was prepared by SRNL to guide the work to aid in choosing the most appropriate tooling and cameras (See Appendix A for Inspection Guide). On conducting dry runs within the mockup, final tooling was decided in using long pipes with cameras threaded through to guide the camera into the basin rack. The long pipes were deployed into the basin using 4ft fiberglass rods that screwed together end to end, which attached to the long pipe holding the camera with a stainless steel bracket. Camera restraints at the bottom of the pipe were initially 3D printed and tested as prototypes before machining out of aluminum for use in the basin (Figure 1-2). This ensured that small changes could be made to the tooling without encumbering the cost and time of machining a new metal piece. All tooling materials were evaluated within an Engineering Study Report (ESR) to ensure their safe use within the basin.[3]



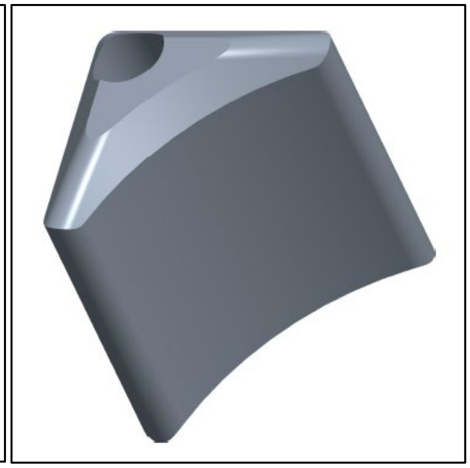


Figure 1-2. L bracket (left) to view bundle bottoms and camera wedge (right) to hold camera for sidewall imaging.

Dry runs were performed to determine optimal camera selection and tooling for both L bundles and GP tubes. A discussion of all full scale mockup project work and dry runs will be issued in a separate report.

1.2 Camera Selection

To effectively visualize the bundle exteriors, a robust camera or video system with quality imaging capability was imperative. Multiple cameras were selected for testing based on their general specifications and previous use at the Savannah River Site. These cameras were tested by taking images of various requested areas of the bundles within one third height scaled Proof of Principle (POP) racks.[1] Characteristics of interest included lighting, resolution, general size, and ability to deploy within the rack were evaluated. These camera characteristics and images were qualitatively compared to determine which camera(s) captures superior exterior and interior bundle images. The direct view cameras (or video probes) visualize from the end, while the side view cameras or video probes with a side view tip provides a 90-degree observation. When available, interchangeable tips can be designed with a variety of focal distances [i.e., far field (FF), near field (NF) etc.].

The first cameras chosen for comparison were the Sidewinder and Mini 13. They were chosen after research into characteristics and cost, but they were recommended first because of the previous SME experience with these brands.

The 6mm video probe demo unit was loaned to SRNL to test the image quality of the camera chip and ease of use, but its cable length was too short for basin use. A similar Olympus video probe (8.5mm) with an acceptable cable length was ordered based on the performance of the 6mm system. The Olympus video probe systems can capture both video and still images.

Three cameras by Intertest were also tested against the others for image quality. The Dual View camera has two lenses on the camera head. One lens gives direct view images, and the other gives side view images. A remote toggle switches the view shown by the camera. Two side view cameras were also evaluated, one with an NF capability and one with an FF capability. The Intertest cameras arrived after POP completion, and therefore were not documented in the POP mockup report.[1]

To compare the various imaging systems during the POP mockup, representative images were taken in the areas of interest on and inside each of the bundles. Once images were assembled, they were qualitatively compared for clarity, lighting, consistency, and overall quality. The visual examiner's ease of use and other technical opinions were also considered. For these visual tests, the cameras were tested in a POP mockup. The POP mockup is a smaller height than the full scale, but retains all other dimensions accurately. The various bundles of limited lengths were placed into a rack of similar design as L Basin.[1] This loaded rack was left standing dry for most of the comparison tests - the Sidewinder and Mini 13 were only deployed while dry. For some of the 8.5mm and 6mm demo unit tests, the rack was placed into a tank filled with water. Then, the camera probe was deployed by a visual examiner to perform the various visual examinations and capture representative images.

The first noted issue with the 8.5mm probe was poor tip articulation due to room size constraints. The 8.5mm video probe tip articulation is achieved using four cables running the length of the probe. For full articulation, the cable must be fully unraveled due to the friction of the articulating cables. Since the POP mockup took place in a smaller space with shorter bundles there was not enough room for the length of cable required for deployment in L Basin. Thus, the cable had to be coiled around the room instead of fully extended as it would be in the field which impacted the articulation of the camera. Reduced articulation was not experienced with the shorter 6mm cabled unit and was not problematic in the full-scale mockup.

The Sidewinder and Mini 13 created clear images but can only offer views vertically down the side of the bundle. The 6mm (demo unit) and 8.5mm probes took very clear and consistent images with all tip adapters.

The Intertest cameras were later tested in the full scale mockup. The Dual View was promising at the start with good image quality and had the ability to switch image view in situ within the full-scale mockup. However, this camera failed at the remote toggle switch and the company could not adequately fix or replace it. The NF camera was also initially promising as a side view camera that would get close up images of anomalies, but it also failed early on in testing and could not be fixed in time for use in L Basin.

The Intertest FF camera was then compared with the other cameras used in the POP mockup. Its focal distance was too long to create clear images of close-up side anomalies. However, it functioned consistently and produced quality images of the bottoms of the bundles when using custom tooling to aid in bundle bottom visual inspection.

1.2.1 Summary of Camera Down-Selection Results

Each image capturing system performs as expected and provides the same quality images regardless of which bundle is being viewed. The Sidewinder took clear images but is limited by its nonexchangeable direct tip, need for external articulation or tooling, and large diameter. The Mini 13 also provided quality images, but sometimes had poor depth of field due to its fixed focus. It also suffers from its need for external articulation and comparatively large diameter. The 6mm demo unit has the smallest diameter cable and good articulation. It provides high quality images, but the cable is too short for L Basin deployment. The 8.5mm probe has a longer working length cable. It is very robust and also gives high quality images, but the cable memory hinders the user from directing the camera appropriately.

The 8.5mm probe, the Mini 13, and the Intertest cameras all moved forward for testing in the full scale mockup. From the qualitative comparison of the camera images and abilities, the 8.5mm probe seemed to be the best performing camera due to its wide range of exchangeable tips and lens choices, articulation abilities, and slim cabling. However, the cable memory proved to be difficult to work with and was deemed to unwieldy to manage when in L Basin. Furthermore, the articulation broke and was not able to be fixed by the vendor in an adequate fashion. Although this camera had the best images, it was not the most useful in the basin setting.

The Mini 13 was ultimately chosen for giving clear, quality images, and having a robust cable and housing. This camera was chosen to be used for all direct camera views as the camera travelled downward toward the bottom of the basin. This camera showed a consistent and relatively clear view of the bundle side walls. The Intertest Side View FF camera was chosen to be used to visualize the bottom of the bundles, with an L shaped bracket tooling to hold the camera with a clear view of the bottom of the bundles (Figure 1-2).

1.3 Selected Fuel and Fuel Container -Attributes and History

Five bundles were selected for the visual examination, which contained two different types of NASNF. Four of the bundles contained HWCTR fuel and one bundle contained fuel from the ERR. The ERR bundle and two of the HWCTR bundles have direct loaded fuel, while the fuel in the other two HWCTR bundles were packed into cans prior to bundling. One bundle contained a single long aluminum “A” can and the other had multiple “K” and “E” cans. This bundle housed the only “E” cans stored in L Basin.

1.3.1 General HWCTR Fuel Background

The HWCTR was a non-defense related test reactor utilized to test candidate fuel designs for use in the civilian power industry. The reactor, located in SRS B-Area, operated from 1962 until 1964 and was retired in place in 1965. A large portion of the irradiated fuel assemblies were disassembled or cut and shipped to Savannah River Laboratory (SRL) for destructive examinations in the lab’s “High Level Caves”. The heavily shielded “High Level Caves” allowed chemical and metallurgical equipment studies on highly radioactive materials. The remaining assemblies were shipped to the spent fuel basins in R, P and H [Receiving Basin for Off-site Fuels (RBOF)] areas for storage. Upon completion of the examinations, the cut assemblies were canned and shipped to RBOF. After R-reactor was shutdown in 1964, the intact and canned assemblies in R-Basin were shipped to P Basin before being shipped to RBOF for final disposition. Since almost all the HWCTR fuel contains zirconium-based metals, it was excluded from processing in the canyons due to economic reasons. The fuel was instead shipped to L Basin for continued interim storage as part of the RBOF deinventory mission.

1.3.2 Direct bundled ERR Fuel in GP Tube 4302

Intact ERR assemblies were received at RBOF in the late 1960’s. In late 1978 and early 1979, ERR fuel assemblies were disassembled (cropped) and consolidated into 38 GP tube to increase available storage space in RBOF. Each GP tube was loaded with 125 ERR rods, the equivalent of 5 ERR assemblies. The ERR rods could be stacked vertically with a maximum of two rods in the vertical direction. The fuel rod core is pelletized UO_2 – ThO_2 cladded in stainless steel with welded end plugs. The rods are approximately half inch in diameter and 63.5 inches long.

Almost of all the rods loaded into GP tubes were intact, except for a few rods that were either already broken or were broken during the repackaging process. A total of 5 ERR GP tubes contain broken fuel rods including bundle 4302. Bundle 4302 was loaded with three broken rods which broke into 6 pieces. The broken rods were placed in an aluminum tube, crimped shut, and then placed in the GP tube. Despite the broken rods, historical documentation indicates that none of the ERR GP tubes contain loose fuel pellets.

Between October and November of 2002, all ERR GP Tubes were shipped to L Basin for RBOF deinventory. Bundle 4302 was shipped to L Basin on 10/30/2002. Prior to shipment, an engineering analysis determined the GP Tube lid bails were inadequate for the loading conditions and the lids were replaced in RBOF. The fuel weight in the bundles, approximately 408 pounds, exceeded the bundle payload design weight.

The concern for this bundle was inside-out corrosion caused by galvanic coupling between the numerous points where the fuel rod ends touch the thin walled, aluminum GP Tube.

1.3.3 Direct-bundled HWCTR Fuel in L Bundles 1056 and 0845

Most of the HWCTR fuel is a round, tubular design with fuel packed between a nested inner and outer tube and a hollow internal moderator region. Most of the HWCTR fuel is clad with Zircaloy-2, but some fuel is clad with Zircaloy-4. Both claddings can form a galvanic couple with the aluminum bundles. HWCTR fuel with a U metal core will expand and form an oxide if exposed to water.

L Bundle 1056 contains fourteen (14) intact HWCTR Segmented Metal Tubes (SMT). The SMT fuel core is naturally enriched U metal. SMT fuel tubes are 1.7 inches in diameter and 11.25 inches long with 0.022-inch-thick Zircaloy-2 cladding. The intact fuel tubes were stored in RBOF bucket storage before being repackaged into L Bundle 1056 for RBOF deinventory in early 2003. An oxide containment plate (OCP) was placed at the bottom of the bundle prior to loading the fuel tubes. The bundle had to be loaded with multiple tubes per stacked layer using an EBS Fuel Loader. The loaded fuel height can be estimated to be between 25 to 50 percent of the bundle height, as they were loaded in RBOF, horizontalized for shipping and verticalized for placing in EBS rack storage in L Basin. L Bundle 1056 was shipped to L Basin on 3/5/2003.

L Bundle 0845 contains one intact (1) Thorium Metal Tube (TMT) over 2.5 inches in diameter and roughly 118 inches long. The TMT fuel core is mostly thorium metal with 1.5% U metal. The TMT fuel cladding is about 50% thicker than the SMT fuel cladding at 0.030 inches. The fuel tube was stored in RBOF row storage before being repackaged into an L bundle. L Bundle 0845 was shipped to L Basin on 6/14/2001.

The primary concern for these bundles is galvanic corrosion from the fuel contacting the bundle inner walls. A secondary concern exists for degraded U metal fuel reacting with water if the cladding has failed or if the fuel has been cut. In this case, there is a potential for degraded fuel to fall to bottom of the bundle and accumulate in the bottom crevice region. Bundle 0845 may contain cut fuel.

1.3.4 Canned Fuel Loaded in GP Tube 7999 and L Bundle 1051

GP Tube 7999 houses an aluminum A can loaded with two cut pieces (75-inch piece and a 14-inch piece) of HWCTR Restraint Metal Tube (RMT). RMT has a naturally enriched U metal core with 0.06 inch-thick Zircaloy-2 cladding. It is assumed the smaller 14-inch cut fuel piece has one exposed end and the larger cut piece has two exposed ends based on a available records. This GP Tube has a removable lid which allowed for inspection of the aluminum A can in RBOF.

L Bundle 1051 houses a total of 9 aluminum cans filled with six distinct types of HWCTR fuel. The cans were stored in RBOF bucket storage before being repackaged into bundle 1051 for RBOF deinventory. During repackaging a visual inspection was performed on all cans and all cans were deemed structurally sound. The seven K cans stored in the bundle were originally stored in P-Area and are technically designated as “PK” cans. One item of note was that cans originally stored in P-Area had a higher amount of surface corrosion. A few of the K cans were packed with more than one type of cut HWCTR fuel and the two E cans were loaded wet with cut pieces of HWCTR Insulated Metal Tube (IMT) fuel, which is mostly U metal with a 1.5% molybdenum adder. L bundle 1051 was shipped to L Basin on 2/19/2003.

The concern for these bundles is degraded fuel leaving the inner cans and accumulating elsewhere, namely on the bottom of the bundle. A secondary concern is a bulged inner can exerting enough force to deform or split the bundle. The K cans and E cans in bundle 1051 are loaded similarly to the Z cans in RBOF which split due to the U metal fuel reacting with water. This reaction formed an oxide and expanded enough to split the can open and allow material to leave the can.

1.4 Fuel Bundle Dose Rate Modeling and Measurements

Estimations of absorbed gamma dose rates within specific EBS rack positions were calculated using bundle receiving history (e.g. U-235 consumption, specific burnup, and original facility discharge dates) and indirectly verified with field measurements in L Basin. Realistic, yet bounding, approximations were made based upon the known spent fuel characteristics of NASNF assemblies contained in the VT target bundles as well as the fuel in neighboring rack positions. Validation of the models was achieved through RO-7 dose rate readings outside the EBS racks. These conservative dose rate estimates were used as screening criteria to prioritize bundles for examination and cameras for exposure based on their advertised rad tolerance. Additionally, the anticipated dose rates determined from this calculation informed the radiation testing matrix implemented to ensure that the Mini 13 camera system would provide clear images at the dose rates and cumulative absorbed doses possible during the inspection campaign.

1.4.1 EBS Rack Radiation Transport Modeling

Uranium-235 consumption, either taken directly from fuel receipt documentation or inferred from given burnup values was used to estimate the amount of Cs-137 present in each fuel assembly at the provided reference date, corresponding to the transfer date of the fuel from the original facility to the spent fuel receiver. Cs-137 can be assumed to be the sole source of significant gamma dose in spent fuel 20 years or older as all other radioactive fission products with penetrating photon emissions will have decayed away to insignificant levels by this time. The estimated Cs-137 concentrations were then decay-corrected to the present day to yield a 661.7 keV photon intensity to be modeled in each bundle using the Monte-Carlo N-Particle transport code version 6 (MCNP6).

The MCNP6 is a general-purpose Monte Carlo code that can be used for neutron, photon, electron, or coupled transport.[4] It is used to calculate position-dependent and time-dependent radiation flux and resultant detector response and effective dose rate for various configurations and scenarios modeled.

The radiation transport models featured homogenized fuel assemblies with a self-shielding density of 2g/cc of U-238 and a height of 10 feet. A self-shielding density of 3.62 g/cc was specifically calculated and used for ERR fuel as it is known to be very densely packed. Cs-137 was simulated to be distributed uniformly throughout the fuel geometries with intensities specific to each bundle average (i.e. individual fuel geometry and radioactivity are smeared throughout the bundle). Specific bundle locations are sensitive and controlled information, so higher activity bundles were assumed to be clustered together in a corner surrounding the VT target bundle in order to determine the maximum possible dose rate. Furthermore, a second ring of bundles surrounding the target bundles was also modeled, using the maximum source intensity found in the first surrounding ring of bundles. A color contour map of dose rates at the axial midpoint of the modeled fuel bundles was then used to determine the range of dose rates which could be reasonably expected to be found within the rack position of each target bundle. Figure 1-3 shows an example of a dose rate map generated for RL-HWCTR-1056. The color contour map only extends to immediate neighbors, but the gamma source is still being generated in and transported through the outer ring of positions. Dose rate contributions from any locations not depicted are assumed negligible based upon diminishing returns observed from adding the secondary ring.

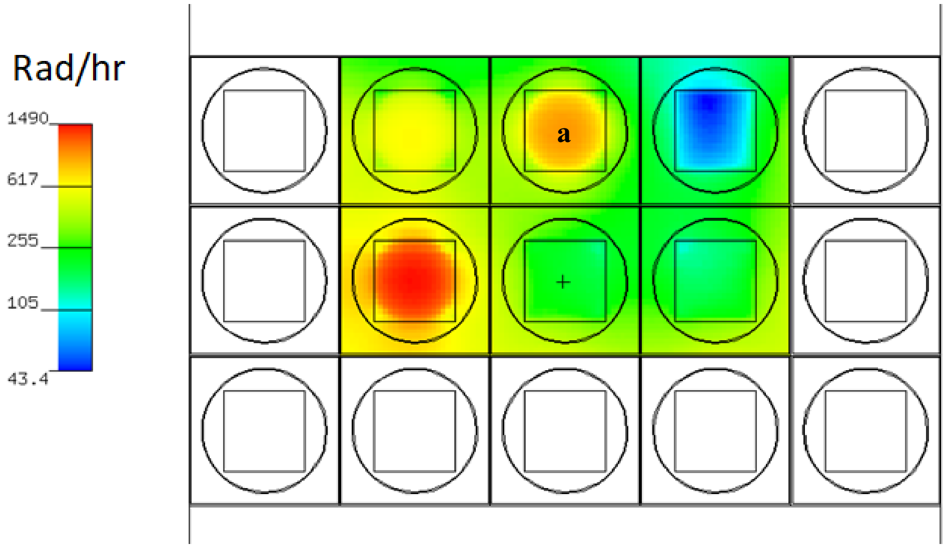


Figure 1-3. Dose rate map of RL-HWCTR-1056 (a) modeled in MCNP

1.4.2 EBS Rack Dose Rate Measurements

Confirmatory gamma dose rate measurements were taken in L Basin using an RO-7 ion chamber radiation survey instrument to validate the relative accuracy and boundedness of the MCNP modeling. The size of the RO-7 precluded its insertion into the corners of any occupied EBS rack position, but it was possible to run the instrument along the outside edge of the rack, spanning the full ~12 vertical feet of the target bundles. Dose rates were therefore computed from the same MCNP models along this external vector, 5 cm from the rack wall, to compare against the field measurements. Dose rate results from the modeling effort and the RO-7 measurements of the 5 selected fuel bundles in L Basin are given in Table 1-1.

Table 1-1. Modeled and Measured Dose Rates [rad/hr] Inside and Outside EBS Rack Positions

Bundle ID	Estimated Range in Corners	Estimated Dose @ 5 cm Outside Rack	RO-7 Dose Rate Measurements Outside Rack			
			Top	Middle	Bottom	Max
(GP) RL-HWCTR-7999	200-800	190	10	100	60	130
(L) RL-HWCTR-1051	130-280	90	0	40	10	50
(L) RL-HWCTR-1056	170-380	145	10	30	30	120
(GP) RB/ERR/4302	1400-4400	450	130	270	70	310
(L) RL-HWCTR-0845	550-1950	493	0	300	450	600

Modeled estimates of dose rates were consistently conservative by 10%-40% with the exception of RL-HWCTR-0845 where it appeared the extreme non uniformity of the bundle activity loading produced a localized hot spot according to the RO-7 data. It was concluded that the MCNP models provided realistic and bounding estimates of dose rate and that these rates should be targeted for camera reliability and image quality testing.

1.5 Camera System Radiation Testing

Due to the elevated dose rates (e.g >1,000 rad/hr) expected in the EBS rack positions, the Mini 13 camera was evaluated for reliability and image clarity throughout a series of gamma irradiation exposures performed at SRNL. Charge-coupled device (CCD) and complementary metal-oxide-semiconductor (CMOS) sensors in the camera are known to exhibit visual noise associated with the undesired electron hole pairs created by ionizing radiation. Typically, white pixels, often termed hot pixels or snowing, will appear randomly in each frame while a camera sensor is actively being exposed to ionizing radiation. The frequency of these hot pixels in gamma fields has been shown to scale linearly with the dose rate. Accumulated trapped holes at the semiconductor-oxide interface eventually lead to charge leakage and change in charge transfer efficiency, ultimately leading to permeant loss of pixels and eventual inoperability of the device. The radiation test of the Mini 13 camera system was intended to qualify the extent of these effects at various combinations of dose rates and cumulative absorbed dose to the camera sensor and other electronic components.

Irradiation of the camera system was performed using SRNL's J.L Shepherd Model 484 Co-60 gamma irradiator. This model irradiator features a 10" x 10" x 40" irradiation chamber with two toggleable Co-60 radionuclide sources at one end to deposit a desired dose rate as a function of the target's distance to the source. Dosimetry at various points in the irradiator was performed by the irradiator vendor at the time of installation with NIST traceable calibration. Decay correction of the initial 12 kCi Co-60 sources yields present day dose rates as a function of distance between sample and source(s). The Mini 13 camera system was positioned at specific locations and exposed to either one or both Co-60 sources to achieve the targeted dose rates according to the testing matrix given in Table 1-2.

Table 1-2. Camera System Gamma Irradiation Testing Matrix

Cumulative Dose	0 rad	10 krad	50 krad	100 krad	200 krad	+100 krad incr. until failure
Dose Rates	20 krad/hr	20 krad/hr	20 krad/hr	20 krad/hr	20 krad/hr	50 krad/hr
	10 krad/hr	10 krad/hr	10 krad/hr	10 krad/hr	10 krad/hr	20 krad/hr
	5 krad/hr	5 krad/hr	5 krad/hr	5 krad/hr	5 krad/hr	10 krad/hr
	1 krad/hr	1 krad/hr	1 krad/hr	1 krad/hr	1 krad/hr	5 krad/hr

At each specified cumulative dose point in the testing matrix, five seconds of video were recorded at the listed dose rates, after which the camera was exposed at rate of 10 krad/hr until the next cumulative dose point was reached. Example images at 50krad and 300krad are shown at rates of 0 rad/hr and 20 krad/hr to illustrate the cumulative (discoloration) and active (snowing) effects of the radiation on the image quality (Figure 1-4). The camera system operated until a cumulative dose of 360,000 rad had been absorbed. This far exceeded expectations based on literature searched and published rad tolerances for more expensive CCD and CMOS cameras, and it implied that the Mini 13 camera would likely survive the entire inspection campaign from a radiation exposure standpoint. It was observed during testing, however, that variable onboard LED light which illuminates the camera's target became increasingly dim, particularly at lower intensity settings which could be dialed in by the user. It was also found that in the camera would cease recording and temporarily cease transmitting video if there was insufficient light hitting the sensor to overcome the radiation induced noise. Although video transmission would resume upon increasing light intensity, there was only a subtle indication that the video had stopped recording. This discovery during radiation testing brought the importance of ample and possibly supplemental lighting to our awareness. Furthermore, the lessons learned regarding the cessation of video recording in low light conditions led to a periodic verification that the video was being recorded during the inspection by personnel during the bundle examinations in L Basin.

50 krad Cumulative Dose | 300 krad Cumulative Dose

0 rad/hr dose rate- (no radiation)

20 krad/hr dose rate

Figure 1-4. Images taken from Mini 13 during gamma irradiation testing. Cumulative Dose of 50 krad (left) and 300 krad (right). Dose rates of 0 rad/hr (top) and 20 krad/hr (bottom).

No radiation testing was performed on other cameras due to either their later receipt coupled with vendor specifications that they were radiation tolerant, or that their inner parts could be equated to the testing performed on the Mini 13.

2.0 Experimental Procedure

2.1 Dry Cave Tooling Deployment

Using the tools and knowledge gained from the mockup work, all necessary cameras and tooling were used in the dry cave in L Basin to ensure that there were no major differences between SRNL's full scale mockup and the in-situ use of tooling in L Basin racks. A dummy L bundle, GP tube, and a separate weighted L bundle were used with the accepted procedure. The tooling and cameras were successfully deployed for the GP tube and L bundle without weight. Images were taken for clarity and proof of technical function. However, when attempting to deploy the camera in all four corners of the weighted L bundle, the camera got stuck. This was a valuable time saving lesson learned, which allowed the visual inspection procedure to be changed before camera deployment for inspection in L Basin.

2.2 Visual Examination Execution

A Bundled Fuel Visual Examination Guide was created to aide in consistent, routine reporting for the bundles within this report, as well as for future AMCAP visual inspections. This guide is available in Appendix A. Initial actions involve ensuring that all camera equipment and viewing and recording devices are functioning appropriately. The Mini 13 camera was first deployed for bundle sidewall surface area examination. Upon lowering the camera into position, the camera was placed over the top of the bundle to get a clear reading of the number and to verify the original bail position before starting inspection. If the tabs were present while deploying the camera, it would also be noted in the examination. The camera was encased in the wedge tooling to have a consistent view from the camera to the side wall in each corner. The wedge also kept the camera from overly scratching the bundles and allowed for easier camera deployment without as much binding between the tooling and the bundle or rack (Figure 1-2).

After noting the bail position with relation to the northern direction within the rack, visual examination was initiated in the northeast corner, then each subsequent corner was examined in a clockwise direction around the bundle (Figure 2-1). All bundles were examined and rotated in a clockwise direction to eliminate the possibility of inadvertently loosening the bundle lids with a counterclockwise rotation. These first viewed corners are denoted as 0° position corners. The bundle was then rotated clockwise 45° and each corner was examined. This allowed for the previously obscured surface area to be viewed and gave images of 90% or more of the total bundle surface area. The corners viewed after rotation are denoted as 45° position corners.

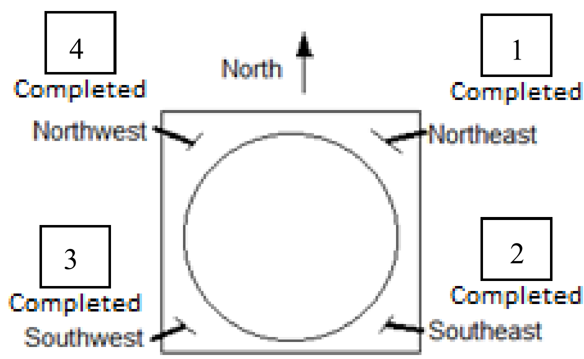


Figure 2-1. Visual Examination Inspection Diagram

Once the bundle sidewalls were fully examined, the bundle was lifted to allow visual examination of the bottom of the bundle. The FF side view camera attached to the L bracket tooling was deployed down one corner of the bundle, and then turned into place under the bundle to view upwards toward the bottom of the bundle (Figure 2-2). Bundles were only lifted high enough to deploy the camera underneath and to allow for appropriate focal distance for the camera to give optimal view of the bundle bottom. This was typically a lift of six inches or less per bundle to adequately view the bottom.

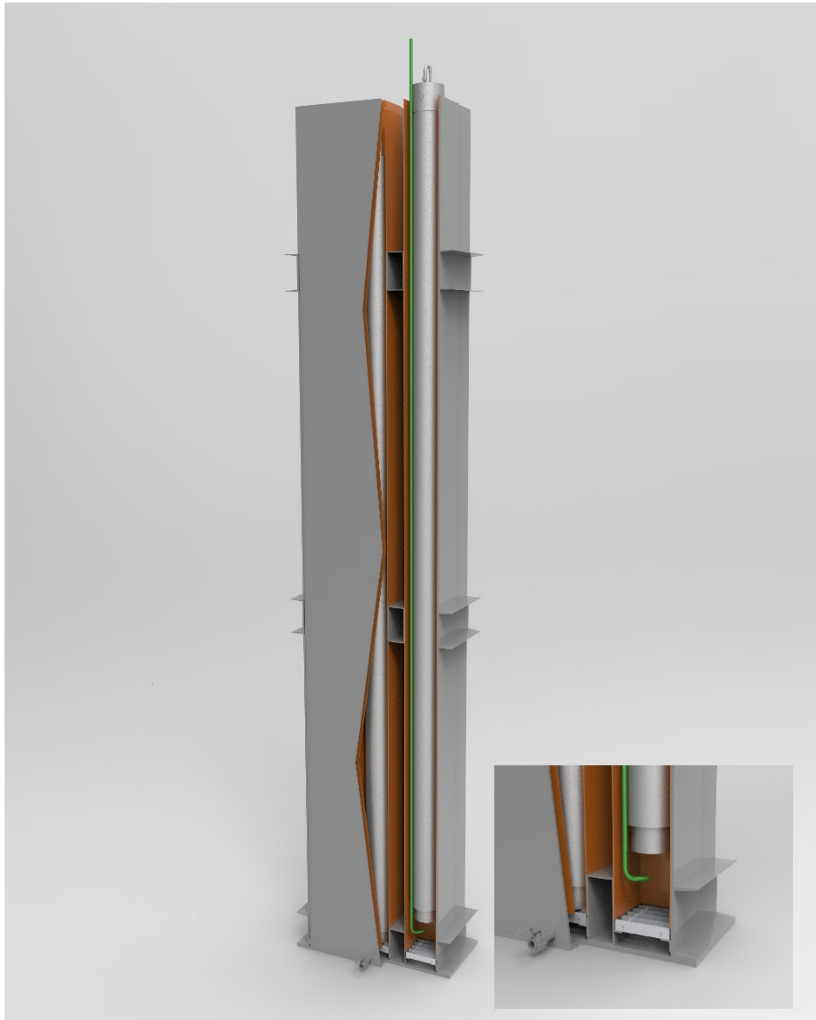


Figure 2-2. L Bracket Deployment for Bottom of Bundle View.

3.0 Results and Discussion

After extensive mockup work to ensure that all tooling and cameras would be fully functional for the work scope, a team involving SRNL, SFP engineering, and SFP operations personnel arranged to execute the PBI to visually examine five fuel bundles. Images of the bundles are included in the following sections and within Appendix B.

3.1 L Bundle 1051

L bundle 1051 was inspected on March 16, 2021. There were masses of orange-brown microbial cobweb growth on the top of the bundle, which partially occluded the identifying number from view. The tabs were not visible from any corner in the 0° or 45° position. There were raised grayish-white nodules of aluminum oxide corrosion. Nodules increased in size and connected into one long line of corrosion, closer to the bottom of the bundle. Also noted were orange-brown corrosion typically associated with iron oxide rust (perhaps due to previous steel interaction before being placed in basin) but aluminum chloride deposition is a possibility; orange-white nodules with highly raised surfaces from the bundle surface (these nodules are more likely aluminum chloride); some minor scratches; minor pitting; light gray to white discoloration, resembling liquid interface prior to being placed in the basin; and white plated corrosion. Most corrosion was noted near the bottom of the bundle. All the corrosion can be considered general corrosion and there were no serious noted issues on the surface area. There was initially minimal particulate, but it increased as the camera moved down the bundle and subsequently removed corrosion and microbial product from the bundle surface area. The camera experienced radiation effects eight minutes into the first bundle examination, but overall imaging was still clear (Figure 3-1).

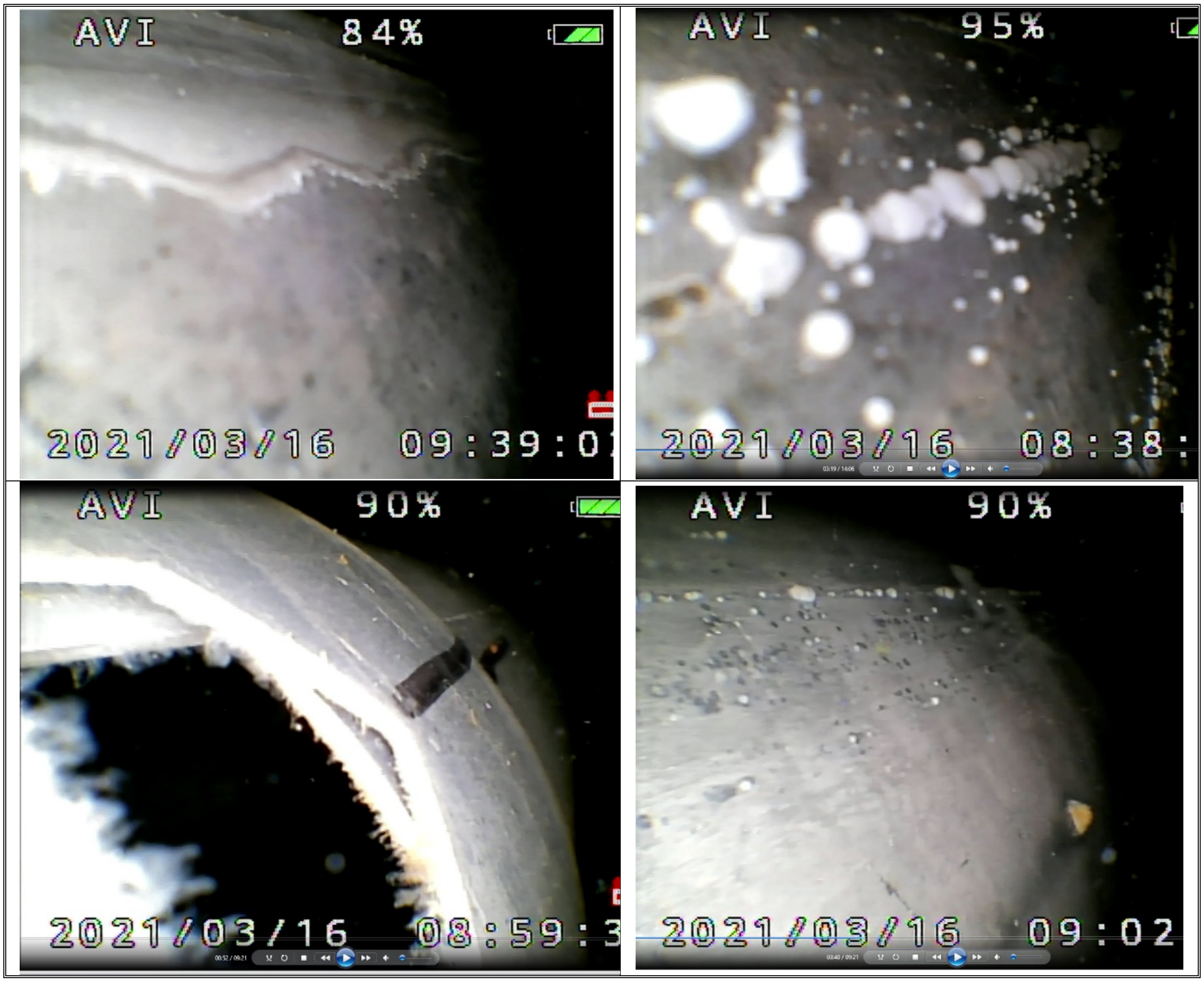


Figure 3-1. Representative Images of L Bundle 1051. Upper left – Discoloration resembling liquid interface. Upper right – White nodular corrosion. Lower left – Tab hole with microbial growth. Lower right – White and yellow nodular corrosion with darker spots resembling pitting.

In deploying the side view FF camera for viewing the bottom of the bundle, radiation effects to the camera were immediately noticeable. The camera still produced reasonably clear images of the bundle bottom without noticeable corrosion, discoloration, or deformation of the weld (Figure 3-2). The bolts for the OCP are visible and intact as well.

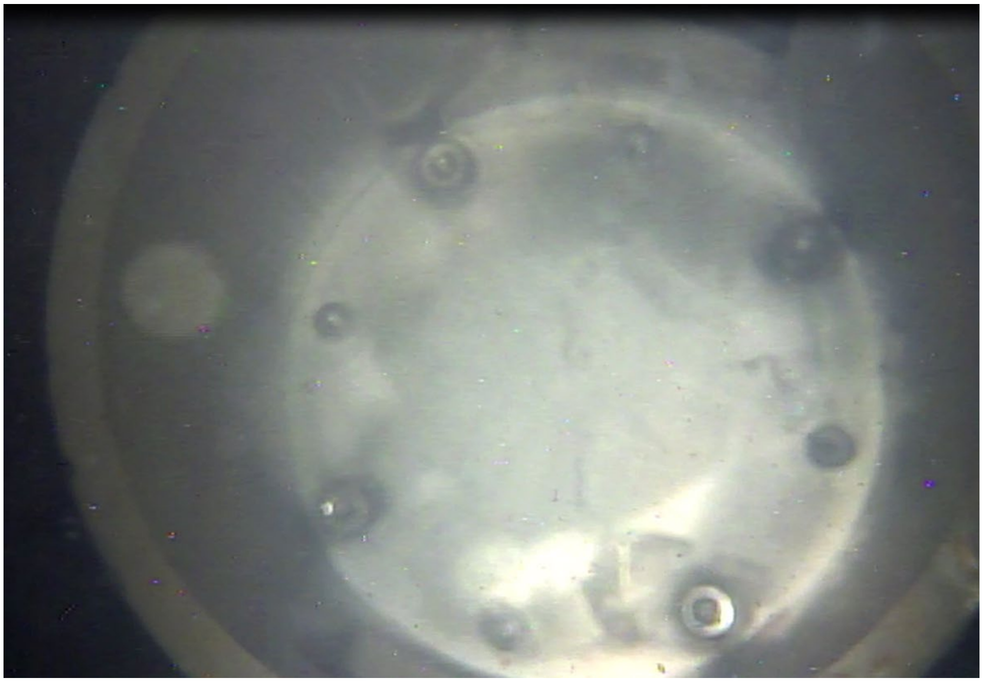


Figure 3-2. Bottom of L Bundle 1051.

Upon turning L bundle 1051, large gas bubbles emanated from the lid holes as seen on the L basin camera. The bubbles culminated into one large bubble slightly larger than a softball. This could be anywhere from 0.3-0.5L of gaseous release. This bundle was loaded with nine aluminum cans with different loaded fuel elements, which lead to three possibilities for the gas release upon bundle movement:

- Air became trapped between the cans when loaded into the bundle and the air bubbles have remained in place since the bundle was loaded into the basin. Upon bundle movement, the air bubbles were released.
- The vented E cans were loaded wet. The water and uranium fuel reacted over time, and hydrogen was released upon bundle movement.
- Some or all the cans failed and allowed the uranium fuel to react with water and form hydrogen, which was then released upon bundle movement.

3.2 L Bundle 1056

L bundle 1056 was inspected on March 16, 2021. Orange and brown cobwebs totally occluded the identifying number on the lid. Operations personnel used a hook to brush away the cobwebs for identity confirmation. Reddish spots on the top of the lid were noted. It was unclear whether these spots were more microbial growth, discoloration, or some form of corrosion. The lid weld was clearly intact, with no noticeable deformation. Mottled gray surface corrosion was noted in many areas. Some raised nodules followed a previously formed scrape, increasing in size and connected into one raised line of corrosion, as imaged toward the bottom of the bundle. Some pitting also was noted in association with the same vertical scrape. The mottled surface corrosion was less prevalent near the bottom of the bundle. Some scratches were noted that seemed to have some depth. Approximate location will be available in the field note appendix (Appendix B). Green microbial growth or algae was noted upon entry into the rack, which grew down the bundle from the lid a few inches. There was a small corroded region on the side of the lid. Raised orange white nodules most likely associated with aluminum chloride were noted, along with some very small black spots. While these are possibly small holes, there is no definitive answer without further examination. Slight pitting was noted, along with various scratches and circumferential scrapes with orange discoloration. This is most likely due to a steel piece causing the scrape and leaving behind some steel within the scrape that subsequently rusted on the aluminum bundle. Some scaling corrosion was noted near the bottom of the bundle. While there were items to note in every corner, this bundle had very little overall general corrosion. This also contributed to less particulate in the camera images, as the camera was not dislodging corrosion into the water. The bundle bottom looked clean, intact, and without any weld deformation or corrosion (Figure 3-3).

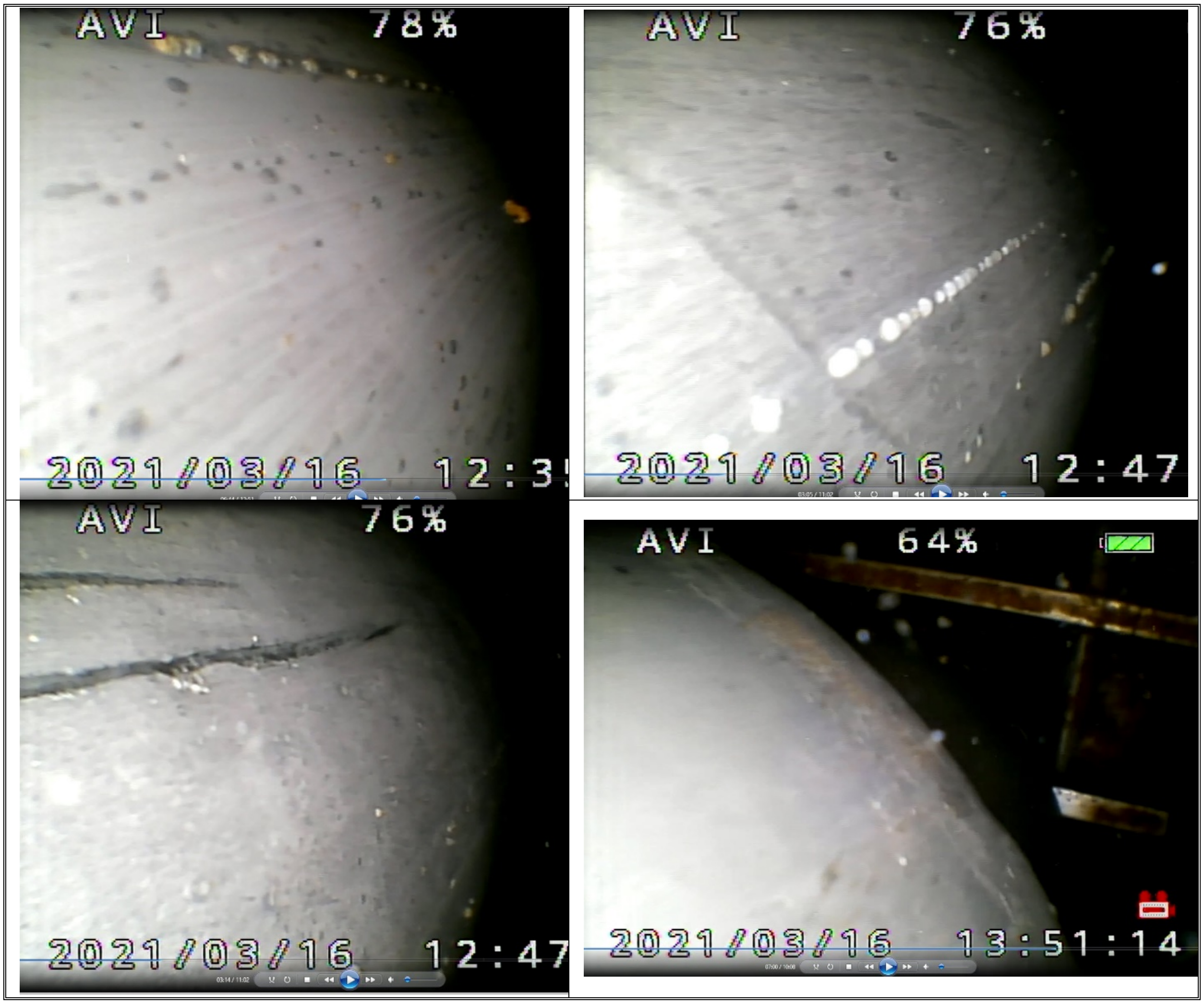


Figure 3-3. Representative images of L Bundle 105
6. Upper left – Nodular corrosion. Upper right – Nodular corrosion following scratch on surface. Lower left – Scratches wit depth. Lower right – Corrosion on bottom sidewall edge of bundle.

3.3 GP Tube 4302

GP tube 4302 was inspected on March 17, 2021. There was a missile shield over this bundle. Upon missile shield removal, some microbial growth and particulate fell into the rack. The identifying number was visible, as there was very little microbial growth on the lid. Only one small orange spot was noted. Welds were noticeable on the lid from removal of an old bail. The tabs were easily visible and in place, not overly bent with an approximate 30-45° angle bend into the lid. An abundance of microbial growth was seen inside the bundle. The microbial growth was a diaphanous white mass inside the tab opening. Some growth or corrosion was also seen just below the tab opening. It was unclear from the camera angle whether this was growth or corrosion, due to the color of the growth noted inside the bundle. Bundle number 4302 was etched on the side of the bundle and black writing was seen. Upon passing the top of the bundle with the camera wedge, a fine particulate powder was noted. This was the corrosion or growth product dislodging from the bundle. A deep scrape was noted above the rack with brown discoloration (most likely deposited iron oxide) along with other circumferential scrapes. Other items of note include very few orange-white nodules, some small scratches with and without associated corrosion, some pale orange growth or corrosion above the rack, minor pitting associated with an axial scratch, some small concentrated areas of corrosion with orange discoloration and pitting, some circumferential scratches with significant depth, a large diameter pit with minimal depth, and one small area on the sidewall at the bottom of the bundle that appears to be a deformation or protrusion with associated orange-brown discoloration. Particulate increased as the camera moved to the bottom of the bundle with the camera wedge dislodging corrosion or growth product from the bundle sidewalls. The bottom lip of the bundle from the sidewall camera viewpoint had some minor deformation. The bottom of the bundle was intact and shiny with some dull areas that could be corrosion initiation. The weld was intact, also with one noted dull area. Overall, the bottom had no noticeable issues associated with structural integrity (Figure 3-4).

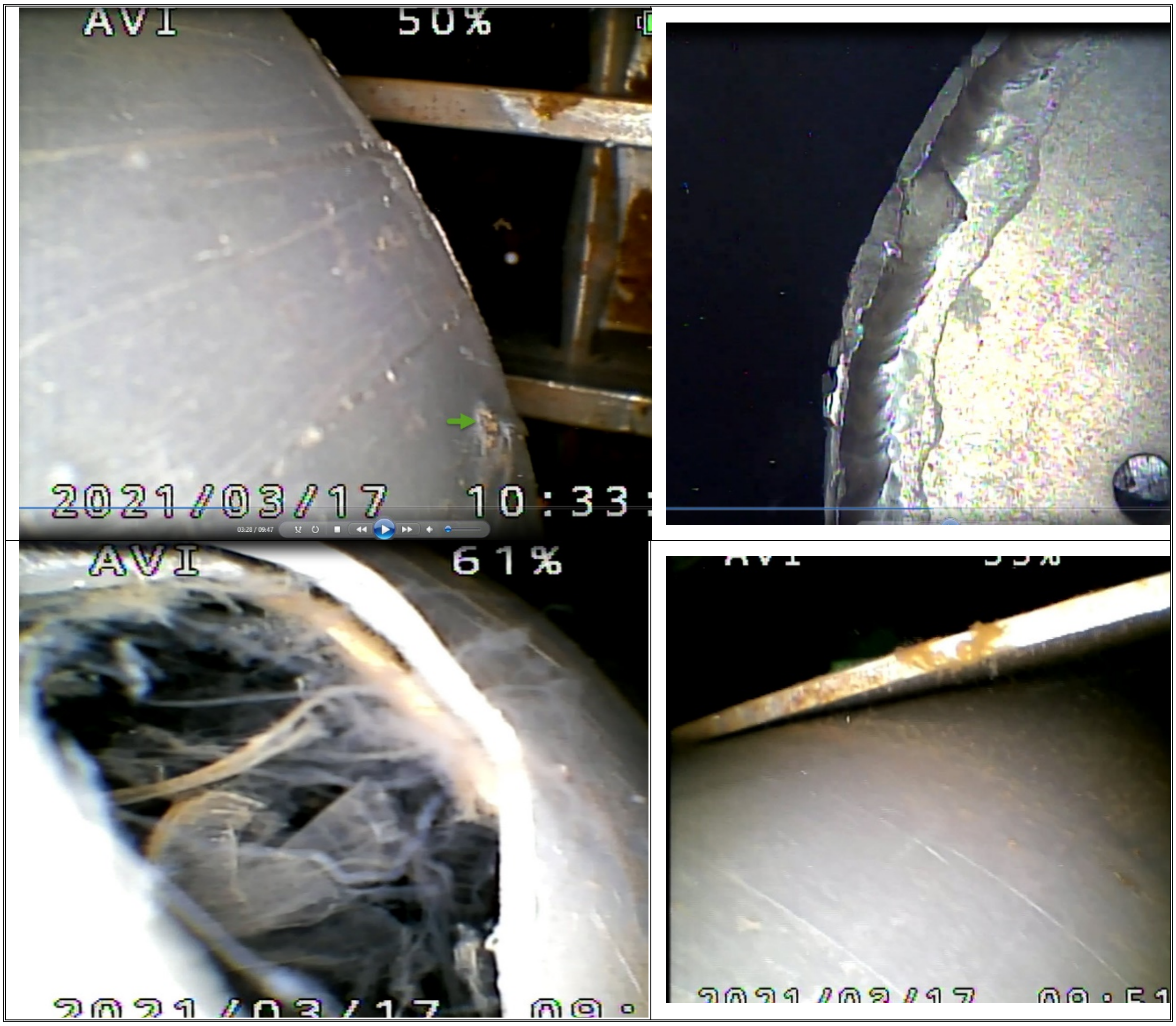


Figure 3-4. Representative images of GP Tube 4302. Upper left (green arrow) – Nodular protrusion at bottom edge of sidewall. Upper right – Small dull area in weld on bottom of bundle. Lower left – Tab hole with microbial growth inside bundle. Lower right – Orange brown microbial growth on bundle sidewall growing down into the rack.

3.4 GP Tube 7999

GP tube 7999 was inspected on March 17, 2021. This bundle had a removeable lid, so no tabs could be inspected. The identifying number was very barely legible as written on the lid, in very pale ink. This is possibly due to fading over time. There were orange and white microbial cobweb growth along the rack edge and upon rack entry. Writing on the side of the bundle was noted. There was brown corrosion, white scaling corrosion with associated pits, brown corrosion on the sidewall near the bottom edge of the bundle, irregular shallow pitting, and some pitting with depth and associated orange and white discoloration. There were semicircular brown discolorations, many areas with mottled surface discoloration associated with watermark liquid interface, and one unique bright yellow discoloration. There were scrapes with associated brown discoloration probably due to iron oxide deposition, a circumferential scratch with orange-white nodular corrosion. Many raised orange-white nodules without associated scratches were also seen, along with orange nodules with associated black features, and a bulge at the bottom edge of the sidewall in one of the inspected corners.

There was a very small spot on the bundle bottom with a dent, associated with the bulging area of the bundle. The bottom of the bundle was shiny and otherwise intact, with an intact weld without associated corrosion. Two holes in the bottom of the bundle showed some type of metal content. This is possibly due to inner can failure and fuel elements visible through the holes or could be a lighting issue with the camera creating an illusion of metal reflecting light through the holes. However, it should be noted that no other bundle bottoms depicted any similar sort of camera illusion (Figure 3-5).

Upon turning the bundle, several small gas bubbles emanated from the lid holes. This gas release was much less in volume than L bundle 1051. However, GP tube 7999 was also loaded with a can and so the same possibilities for gas origination can be used. The gas is most likely either due to trapped air upon loading the can into the bundle or hydrogen product from uranium fuel reaction with water.

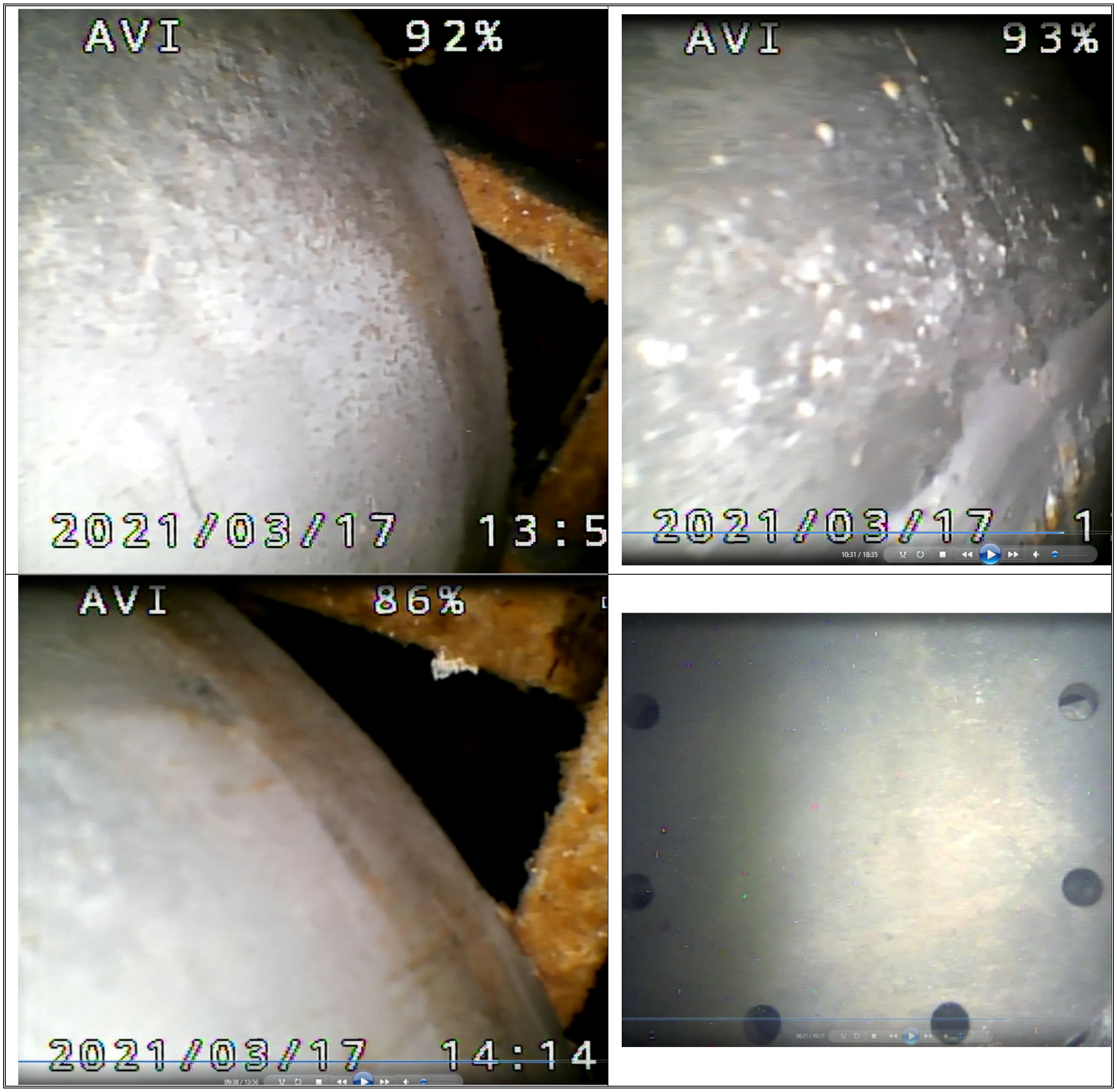


Figure 3-5. Representative Images of GP Tube 7999. Upper left – Bulge at bottom edge of sidewall. Upper right – Nodular and pitting corrosion. Lower left – corrosion at bottom edge of sidewall. Lower right – Material visible through holes on bottom of bundle.

3.5 <u>L Bundle 0845</u>

L bundle 0845 was inspected on March 18, 2021. There was significant yellow and white cobweb microbial growth on the lid, totally occluding the identifying number. Cobwebs were brushed away to verify the identifying number. Moving the camera closer to the lid, green and brown discoloration was noticeable on the lid that continued down the sidewall. This large mass was more indicative of microbial growth than corrosion. This entire visual examination had lots of particulate in the camera images, due to significant dislodged microbial growth. Writing was noted on the sidewall. Raised, pale green crystalline nodules were noted on this bundle and were unique to this bundle. Brown irregular corrosion was noted, along with irregular brown corrosion near the weld on the sidewall, orange nodular corrosion, and a very few white nodules. A black discoloration with an orange semicircular halo was observed, semicircular brown features, and a black discoloration resembling a crack. Pitting with red-orange discoloration and other areas of minor pitting were noted. Many various black features were seen, including small circular features, black irregular spots in a circumferential line; small black features following a scratch and scratches without associated corrosion; two moderate black features resembling holes; large, elongated black features; and three small black features resembling holes at the bottom edge of the sidewall meeting the weld.

The bottom of the bundle was intact with no noticeable corrosion. The impact limiter partially occluded total view of the weld, but visible portions showed no corrosion or deformation (Figure 3-6).

Two very small gas bubbles emanated from this bundle upon turning it to the 45° position. While this bundle contained no cans, there is still the smaller possibility of hydrogen generation with the low uranium content fuel. These bubbles were so small as to be relatively inconsequential in comparison to the two other bundles with gas emanation.

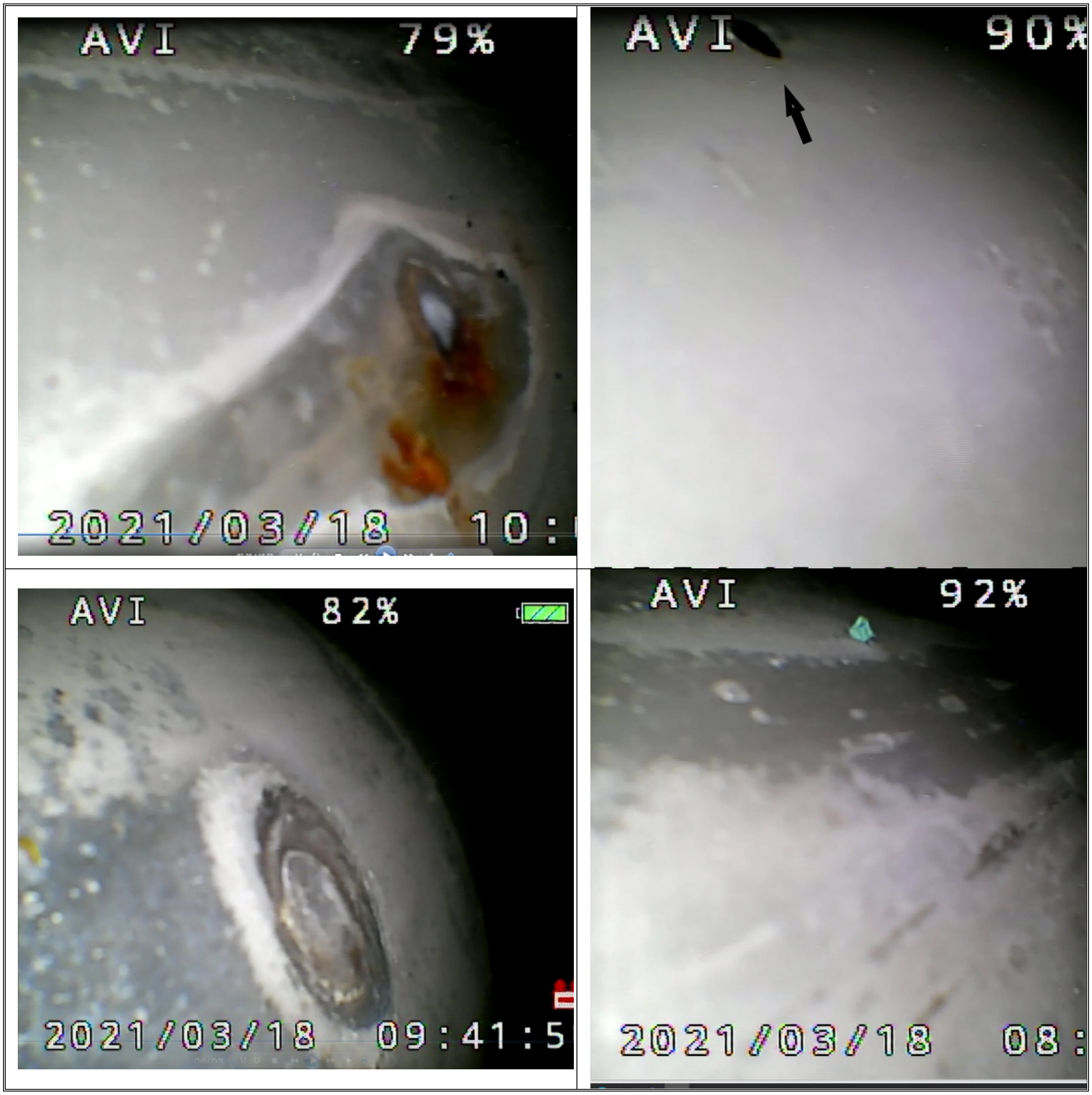


Figure 3-6. Representative Images of L Bundle 0845. Upper left – Corrosion with discoloration and nodule. Upper right (arrow) – Moderate black feature resembling hole. Lower left – Large raised corrosion feature. Lower right – Pale green crystalline growth, unique to this bundle.

4.0 Conclusions

The development of the VE system, and its deployment for a condition assessment of selected bundles in L Basin was successfully completed, and the condition assessment of the bundles using the inspection results is reported.

The cameras used for the inspection were rigorously evaluated in terms of radiation tolerance and water compatibility. The results from the work show the primary camera to provide good images and utility for the inspection of NASNF containers.

4.1 Condition of Bundles

The bundles exhibited an incidence of outside-in corrosion attack that was expected with the storage history in RBOF and L Basin. None of the attack was significant in terms of threatening structural integrity to continue to safely handle and move the fuel. The following are the primary conclusions from the condition assessment.

- All bundles showed general corrosion in many forms of aluminum oxide nodules, probable aluminum chloride nodules, scaling corrosion, and pitting. While these features were present, it is unknown whether the corrosion initiated in L Basin or if it were present before the bundles were placed within the basin. None of this minor general corrosion was deemed deleterious to the integrity of the bundle.

- Two bundles (7999 and 0845) exhibited corrosion along the sidewall edge near the weld at the bottom of the bundle. While the weld regions of both bundles were intact on the bottom, this sidewall to weld interface may be the most vulnerable point for inside out corrosion susceptibility. This would be especially important for bundles with potential for degraded fuel inside. The degraded fuel would gather in the inner crevice and corrode the thinner heat affected zone of the aluminum sidewall before any noticeable corrosion were seen on the underside of the thicker bottom portion of the bundle.

- All bundles contained scratches, scrapes or abrasions on their sidewalls. Many were clearly created before the bundle was placed in the basin and perhaps before the bundle was loaded with fuel. Circumferential scratches with associated orange or brown corrosion is most likely due to turning the bundles on steel racks, leaving a steel deposit on the aluminum surface. None of these features were currently deleterious to the bundle integrity.

- L bundle 4302 had one small and unique anomaly on the sidewall at the bottom near the weld. It appears to be protruding from the bundle, with an associated pale yellow orange color. This bundle was overloaded with fuel beyond the design limit, but no conclusion could be made about whether there was any definitive protrusion from this bundle.

- GP tube 7999 had a noticeable bulge at the bottom on one side. The bottom of the bundle had a dent on the side associated with the bulge. As noted by an issued calculation, bundles will bulge if dropped instead of tearing open.[5] While the bundle is slightly deformed, the fuel currently remains contained within the bundle.

- Small black features of different sizes were noted at many areas on most bundles. The cause of the black features was not definitively identified. Potential causes could be patches of dark-colored oxide, shadowing from raised nodules, or local penetration. An additional examination is planned for August on L bundle 0845 with supplemental lighting. The in-progress calculation on bundle integrity shows the high tolerance of the bundles with through-bundles defects against all handling loadings.

- There was debate over whether particulate and sediment in the basin would affect the visual examinations. The particulate was generally dependent on the detritus that was dislodged from the bundle. More associated microbial growth or corrosion on the bundle created more particulate in the water. The sediment at the bottom of the rack was nearly non-existent. While there was noticeable red-brown sediment, it was very minimal. Neither the particulate nor sediment had any negative effect in completing the visual examinations.

- L bundle 0845 exhibited pale green nodules. There is no direct conclusion that can be made on these nodules without some form of chemical analyses to determine its molecular composition. There is a belief that these nodules are iron sulfate, which would be potential evidence for microbially induced corrosion (MIC). While all bundles showed some form of microbial growth, there was no direct correlation to MIC, and no large mass cobweb growth or biofilm was visible in the regions around the pale green nodules. While there is still the possibility for MIC in the future, there was no distinctly associated corrosion near areas of cobweb microbial growth.

- GP tube 4302 exhibited microbial growth inside the bundle, which was housed under a missile shield. This clearly shows that microbial eradication will be difficult within the basin. Microbial growth in the basin is prevalent and thriving.

- There seems to be a connection with bundles loaded with inner cans and gas emanation. While no direct conclusions can be drawn about what gas arose from the bundles, it will be important to look for gas emanation in bundles that contain cans in L Basin or for bundles that may be received in the future. Given the handling and decades of storage, and the consideration of the joint (weak protection against in-leakage), our "best speculation" is that the bubble were an agglomeration of hydrogen that was from the corrosion reaction of the low alloy uranium.

4.2 Cameras

The Mini 13 camera is a robust camera that remained waterproof throughout the examination of all five bundles. There were slight radiation effects noted in Mini 13 use, and lighting degradation may have been a factor particularly in the last bundle examination, L bundle 0845. Overall, this camera functioned exactly as written within product specifications.

A side view near field camera was also purchased to use for anomalies needing closer inspection. It was rated with the same specifications as the side view far field camera used for viewing the bottoms of the bundles. However, this camera failed during dry run use. A side view anomaly camera may have helped clarify uncertainties in viewing L bundle 0845.

The Intertest far field camera used for viewing the bundle bottoms also functioned well for all five bundle examinations. It suffered greater radiation damage over time than the Mini 13 and radiation 'snow' was visible in every examination imaging and was prevalent in the last bundle, L bundle 0845.

5.0 Recommendations

The visual examination provided a condition assessment limited to the type and prevalence of corrosion attack on the external surfaces of the bundles.

The inspection team used engineering judgment that the corrosion features observed were not threatening to continued storage and handling in the near-term (several years' timeframe). However, a formal calculation of the structural capacity to withstand all anticipate handling loads is being performed; this calculation will be issued prior to removal of the bundles outside of the storage rack.

Additional examinations to assess the corrosion attack to the bundles from the inside is pending completion of the ultrasonic examination system.

The following recommendations include follow-up examinations to better identify the cause of features observed during this present inspection of the five bundles, and for improvements to the visual examination system:

- Large elongated black features that appeared larger near the bottom of the bundle were noted on the sidewalls of L bundle 0845. There was discussion that these features were potentially elongated holes originating from a degraded weld region. These elongated features were at the very edge of the camera's angle of view and the camera's degraded lighting only increased uncertainty. Upon turning the bundle to the 45° position, the suspect features were on the opposite side of the angle of view. These elongated features, along with the many other unusual and somewhat concerning features have led to the decision to re-examine L bundle 0845. This examination is tentatively scheduled for August 2021 and will require a slow and methodical lifting of the bundle out of the rack with stops every few inches (as yet undetermined) to fully and closely inspect any anomalies along that section of bundle newly visible outside of the rack. Lifting the bundle out of the rack and having other cameras available for use will rectify any concerns noted for L bundle 0845.
- GP tube 7999 exhibited a bulge which most likely occurred from a drop or fall.[5] This information coupled with metal visible through holes in the bundle bottom, corrosion along the sidewall edge near the weld at the bottom of the bundle, and gas bubbles emanating as bundle was turned all depict potential issues with this bundle. It is plausible that the inner A can failed at some point within the basin or even at the time the bundle was dropped. This could mean fuel is degrading and collecting in the inner crevice and possibly causing inside out corrosion. It should be noted that the A can is vented, and the bubbles may have arisen from the vent. However, this bundle is recommended for near term re-examination (within the next several years) with visual and ultrasonic examination (UE) due to all the features described.
- GP tube 4302 and other ERR fuel-loaded bundles should be closely examined at the sidewall edge near the weld for any deformations or protrusions. The overloaded fuel will create stress points with the increased weight on the thin wall near the weld at the bottom of the bundle. Furthermore, with so many fuel elements loaded into the bundle there are many touch points for galvanic corrosion inside the bundle. ERR fuel-loaded bundles are recommended for continued monitoring and surveillance with both visual and ultrasonic examination.
- A reliable side anomaly camera is recommended to clearly identify the small black features. This type of camera will be useful for future examinations in many other close up aspects of determination as well.
- The cause of the bubbles observed during movement of the bundles with inner cans for the inspection is considered to be from entrained air during inner can loading, or from built-up hydrogen with continued corrosion of the fuel, or a combination of both. Additional bubbling of the bundles is not occurring. A handheld hydrogen detector or gas chromatography-mass spectrometry (GC-MS) could be deployed to sniff the bubbles in a future movement of bundles to determine if hydrogen gas is released.
- Readiness to observe and record potential bubbling from bundles, especially those with inner cans during their movement should be in practice. This would increase data points to determine gaseous bubble emanation.

The safe storage of NASNF in L Basin was verified in part with the visual examination performed in 2021. While there were features showing corrosion due to prolonged wet storage noted in all the bundles, their overall condition is not considered threatening to continued basin storage. This first-time examination to provide information for a condition assessment will be maintained and tracked in a library of information throughout the remaining storage of SNF in L Basin.

As VE is planned for fiscal year 2022, the bundle conditions seen in FY21 will help guide the bundles to inspect. As the bundles in L Basin continue to need safe storage, their material containment will degrade over time. This makes the visual examinations and the planned ultrasonic examinations essential to ensure continued safe storage of NASNF in L Basin.

6.0 References

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4. D.B. Pelowitz, Ed., LA-CP-13-00634 Rev. 0, *MCNP6TM User's Manual,* Los Alamos National Laboratory, Los Alamos, NM (May 2013).
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Appendix A. Bundled Fuel Visual Examination Guide

AUGMENTED MONITORING AND CONDITION ASSESSMENT PROGRAM (AMCAP)
BUNDLED FUEL VISUAL EXAMINATION

1.0 Purpose

To provide instructions for remote in-situ inspection of fuel bundles stored in the Extended Basin Storage racks in Vertical Tube Storage location in L-Basin. The inspection is to be performed using enhanced visual examination testing (VT). Included are requirements for and descriptions of:

- Examination equipment and methods
- Examination regions
- VT personnel training/experience
- Evaluation of indications
- Reporting

The physical condition of containers for handling and storage of non-aluminum spent nuclear (NASNF) are being evaluated as part of the Augmented Monitoring and Condition Assessment Program (AMCAP). The goal of the AMCAP is to provide a condition assessment of the storage containers and thereby demonstrate continued safe storage of all NASNF pending retrieval for ultimate disposition. The containers are subject to various degradation mechanisms such as inside-out corrosion due to the galvanic couple between direct bundled fuel or corrosion products and container.

Containers will be selected by the AMCAP Team based on a desired priority from a vulnerability evaluation [N-ESR-L-00030] which impacts this examination scope emphasis for the type of fuel containers. The high-level requirements for inspection of the containers in provided in the Full-Scale Mockup Requirements [SRNL-TR-2020-00342, Rev. 1].

The inspection is to be performed in two steps, first Visual Examination and second Ultrasonic Examination. This present document provides instructions for the Visual Examination of bundles for an initial inspection campaign. It is to be accomplished using remote enhanced Visual Testing (EVT) methods using camera systems deployed in-situ into the EBS racks. This inspection is aimed to check that the bundles are not severely degraded with through-wall penetrations.

2.0 Fuel Container Selection

Figure 1 depicts the four fuel container types which comprise the majority of NASNF outer container inventory in L Basin’s Expanded Basin Storage (EBS) racks. Each container geometry presents different challenges to camera system accessibility. The specific containers to be examined in an inspection campaign will be pre-selected by SFPE and concurred by SFP Operations.

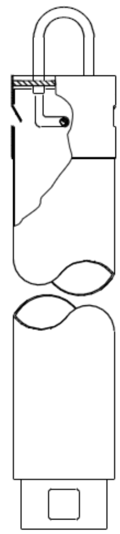
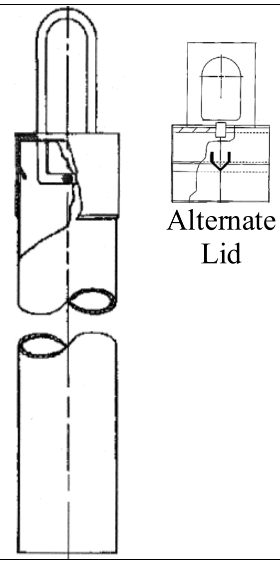
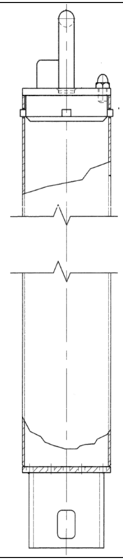
L Bundle ~11.75' tall 0.052" wall	**GP Tube ~14.7' tall 0.052" wall**	**EBWR Square Tube ~11.75' tall 0.125" wall**	**FF Can ~11.75' tall 0.052" wall**
			

Figure *1*

3.0 References

3.1 Performance References

A. Manual 1Q, Quality Assurance, Procedure 10-1 *Inspection*
B. Manual WSRC-IM-95-58, Guide No. 01101-G, *Maintenance Inspection Practices for Structure and Components*
C. Manual WSRC-IM-95-58, *Nondestructive Examination (U)*
D. Manual 8Q, Employee Safety Manual
E. Manual 1B, MRP 3.3.1, "Records Management"
F. Manual 1Q, QAP 17-1, "Quality Assurance Records Management"
G. ASME BPVC, Section V, Article 9

3.2 Developmental References

A. N-NCS-L-00018 NCSE: Double Contingency Analysis for L Disassembly Basin
B. N-NCS-L-00132 NCSE: Reactivity Effects of Closed Fitting Reflectors, Non-Fuel Fissile Material, and Internal Array Voids
C. S-CLC-L-00005 *Criticality Frequency in L Basin*
D. SOP-DHS-095-*L Fuel Criticality Rules – Surveillance Requirements and Review Data* -
E. SOP-DHS-186-L, *In-Situ Inspection of Selected Bundles*
F. SOP-DHS-059-L *VTS Carriage Movement*
G. ESR by Katie

4.0 General Information

Working in accordance with SOP-DHS-186-L, *In-Situ Inspection of Selected Bundles,* and this guide. Operations and Inspection Team personnel shall perform the following activities:

A. Perform all VTS Carriage Movement in accordance with SOP -DHS-095-L
B. Verify all lifting devices used will not exceed its lifting capabilities

C. Inspection Team (SRNL, SFPE, etc.) are assembled and ready to start
D. Ensure appropriate process areas are in the operation mode prior to performing activity.
E. Locate the first fuel bundle to be inspected and record Lane, Rack and Position.
F. Communicate this information to the Inspection Team
G. If necessary, remove the missile shield
H. Position Basin Camera to allow view of graduated measurements on deployment system.
I. Verify with Inspection team if video system is ready to record inspections
J. If determined by the Inspection Team, camera tips may be changed if approved by BFLM and Engineering concurrence.
K. If necessary, a non-fuel handling tool may be used to facilitate insertion of camera.
L. Operations is not allowed to lift fuel bundle while attempting to insert camera into corners or perform in-situ inspection (per BFLM direction with Engineering concurrence.
M. If BFLM determines, with Engineering concurrence, the fuel bundle may be raised for further inspections.
N. If the bundle is a GP Tube, using the camera verify both lid tabs are intact.
O. Operation to re-verify lifting devices will not exceed load limits.
P. Operations to lift fuel bundle approximately 2-inches
Q. Ops to rotate fuel bundle clockwise approximately 45^0 to facilitate inspections.
R. Ops to lower fuel bundle until bottoms in EBS rack.
S. Ops attempts to re-insert camera into each corner
T. Inspection team perform full length inspection of fuel bundle at the direction of BFLM and with Engineering concurrence.
U. Once all side inspections are complete, BFLM determines, with Engineering concurrence, to raise fuel bundle for fuel bundle bottom inspections.
V. Note: If the bundle is a GP Tube verify lid tabs are intact using the camera before attempting to lift.
W. Ops to re-verify lifting devices will not exceed fuel load
X. Ops to lift bundle to minimum height to inspection of fuel bundle bottom per BFLM guidance and Engineering Concurrence.
Y. Inspection team insert camera for in-situ inspection of fuel bottom with BFLM direction with Engineering concurrence.
Z. If missile was removed from the bundle, Ops to replace and verify the shield installed on all positions containing ERR fuel listed in the Fuel Storage Book.

5.0 Definitions and Abbreviations

A. **INDICATION** – The response or evidence from the application of a nondestructive examination. Inspection team will categorize indications as forming/fabrication related or occurred during service.
B. **LINEAR INDICATION** – An indication with a length that exceeds three times (>3X) the width of the indication.
C. **ROUNDED INDICATION** – An indication that is circular or elliptical and has a length of less than or equal to three times (≤3X) the width of the indication.
D. **DISCONTINUITY** – A lack of continuity or cohesion; an interruption in the normal physical structure of material or product form.
E. **RECORDABLE INDICATION** - – An imperfection or unintentional discontinuity that is detectable by a nondestructive examination and subject to documentation and

evaluation. Any "Reportable Flaw" judged significant by a subject matter expert shall be evaluated to determine if it is fit for continued service.

F. **CORROSION** - Material degradation due to chemical attack that may result in the reduction of cross-sectional thickness.

6.0 Responsibilities – Personnel for VT Team

The Visual Testing (VT) inspection team should consist of at least one personnel each from SFP engineering and SRNL. Others subject matter experts maybe added, as/if needed. Team members should be familiar with corrosion and corrosion damage of aluminum alloys in basin water and the general features in the design and function of the containers used in L Basin for NASNF storage. 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-186-L, *In-Situ Inspection of Selected Bundles.*

No other special training or certification requirements are made.

7.0 Precautions and Limitations

A. Safety

1. Following all General Site Safety Requirements per Manual 8Q
2. Actively participating in pre-job briefings, Assisted Hazard Analysis (AHA), and Hazard Analysis Process (HAP) development, as appropriate.
3. Following all specific Safety Requirements identified in the text of this procedure.
4. Following all directions for 105-L facility entrance.

WARNING !

1. **Inspecting condition of all power cables and video signal cables prior to use. Use Ground Fault Circuit Interrupters (GFCI's) for equipment using 110Vac current.**
2. **DO NOT use energized equipment in wet areas or underwater unless equipment was designed and intended for such use.**
3. **Performing an evaluation of potential hazards as they relate to the specific equipment prior to the use of spark and/or heat producing equipment in areas where explosive or flammable vapors exist.**

CAUTION

Any item that could be dropped or lost in the L-Basin shall have a lanyard or retrieval device attached.

B. Security

1. Following all security requirements for 105-L.

WARNING !

Cameras brought into the 186-L facility must be pre-approved by Security.

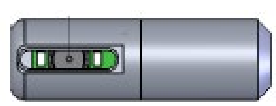
8.0 Prerequisites

A. Tools and Equipment

1. Measuring devices shall provide graduations appropriate for determining dimensions of detected indications. Degree of accuracy required shall be determined by applicable acceptance criteria. [i.e., device(s) capable of 1/4-inch (or less) measurements shall be used when acceptance criteria are stated in 1/4-inch increments.]
2. Ops RCS-3110 Basin underwater camera and tilt/pan head
3. Visual Examination Table
4. Image recording device(s) as required to support identified video equipment, monitor, image storage media, and other items as needed.
5. Camera Deployment Devices as designed or supplied by SRNL Mechanical System & Custom Equipment Development.

B. Video Systems

1. Remote visual inspection equipment shall be waterproof, radiation tolerant and include, as a minimum the following will be available for use:

Mini 13: USA Borescope Mini 13 13mm diameter color camera 30-meter length cable; Fixed focus camera, Direct View (DV) tip		
Dual View Custom iShot Mini 0.550" diameter Color Camera 30-meter length cable; Direct and side view cameras: - DV at bottom of camera tip - Side View (SV) at side of camera tip		
Dual View Custom iShot Mini 0.460" diameter Color Camera 30-meter length cable; Side view camera:		
8.5mm Video Probe: Olympus IPLEX RT, Model IV98200RT-B 8.5mm diameter color videoscope 20 meters length; 70° articulation, Tips: - Direct View 120° field of view (FOV), Far Focus (FF) (25mm-∞) & Near Focus (NF) (4-190mm) - Side View 120° FOV, FF (5mm-∞) & NF (1-25mm)		

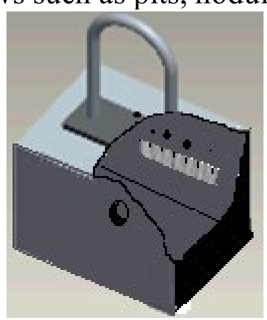
Note: Additional remote visual inspection systems may be added when deemed necessary by the inspection team. Prior to new system use, it shall be subjected to the same Video System Qualifications and Security evaluations as the above listed systems.

B. Video System Qualification

1. Video system qualification of the underwater video and recording equipment shall be performed and documented before each inspection campaign. In addition, at the beginning of each shift the camera(s) will be positioned to observe the gauge/pattern to verify continued system performance and account for changes in the Basin conditions. System to be tested includes the underwater camera, mounted and/or 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 and documented on the system with the replacement component.

Note

A visual aid gauge (10-inch metal ruler or equal) is provided to assist the inspectors in characterizing the size of surface flaws such as pits, nodules, and general corrosion.



1. Examination of an artificial imperfection or simulated condition located on the surface or a similar surface to be examined which is housed in a darkened enclosure. A curved plate (or pipe) constructed of Aluminum 1100 or 6061 to serve as the qualification standard. For the purposes of fuel bundle canister damage inspection, it is necessary to be able to see a pit or nodule with a diameter of at least 1/16" diameter. Note - a pit of 1/16" diameter emanating from the outside of the bundle is a nonrelevant indication. The lighting during this demonstration shall simulate the least favorable light intensity expected (auxiliary and/or camera lighting) during the examination.

9.0 Performance

A. General Actions:

1. At the beginning of each shift a pre-examination camera system check (see paragraph 8.B.2) shall consist of positioning each camera to be used in the basin to observe the camera check resolution panel/artificial imperfections. If the image or light is judged to be inadequate a timeout shall be called until the problem is corrected. In addition to the verification of image quality and sufficient illumination, the system image recording shall be verified.

2. Prior to start of bundle examination, capture an image of the bundle from above for future identification. Confirm at least two open corners of the selected bundle in the cell can be accessed and the corresponding side walls examined before the initial examination begins and any bundle movement is performed. The corners shall be identified as illustrated in Figure 2.

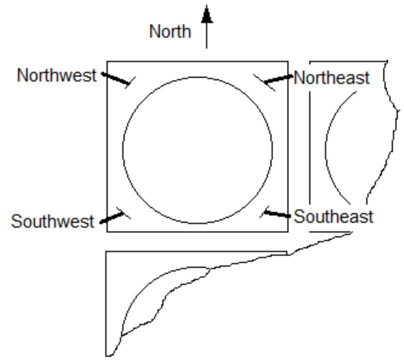


Figure 2

3. All non-planned bundle movement shall be requested, when necessary. SFP Operations shall perform requested bundle movement as allowed by the applicable operations procedures. Each bundle may be moved slightly with minimum lift to access all four corners and sides as needed. Any movement request shall be listed on the Inspection Notes sheet for that bundle.
4. Identify the corners accessed on Field Notes and Appendix A. Get as many corners as possible. Camera sequencing shall be established based on accessibility and expected radiation dose. The Dual View, Mini 13 and other approved cameras are to be used as much as possible. These additional studies may include articulating camera angles and/or manual adjustment of light source to provide various viewing angles on identified anomalies. Only when necessary, the 8.5mm Olympus Video Probe may be used for the study of identified anomalies.
5. The Mini 13 camera shall be the primary camera for the for the sides of the bundles. The Duel View camera or other approved side viewing camera will be used for the study of anomalies noted during the use of the Mini 13 and with approved tooling examination of the bundle bottoms.
6. Inspection goal is $\geq$ 90% coverage of all external surfaces. To achieve the goal, it will be necessary to request SFP to rotate bundle clockwise, approximately 45^0 from its original position for future reference. Before camera re-entry into corners take another image of the bundle from above to document the location.
7. Once all accessible corners are examined (original bundle position and + 45^0 rotation), request SFP Operations to lift the bundle to optimal height for viewing base plate and weld region to perform bundle bottom examination. Once lifted, position camera(s) to capture an image to evaluate structural integrity and then examine bottom.

   Note: To achieve maximum coverage of the bottom, the bundle shall be turned 360 degrees. Document the applicable details how the bundle bottom was examined on Appendix A.

8. All inspection notes will be documented on Attachment A (AMCAP Inspection Notes).
9. During examination of each bundle, develop an initial draft for “Inspection Notes”. This draft should include as a minimum: Primary and Secondary Subject Matter Experts, Bundle ID, the camera(s) used, camera position (i.e., location by circumferential and vertical), image storage location details, reportable flaws, lid condition, bottom condition, etc..
10. Conditions observed not addressed in this guide shall be documented on Appendix A.

B. Lighting
    1. Lighting requirements - the camera resolution shall be evaluated as adequate in area of poorest lighting to be examined. Light sources, technique used, and light level verification is required to be demonstrated one time, documented, and maintained on file.

NOTE
It is not necessary to measure illumination levels on each examination surface when same type of portable light source or similar installed lighting equipment is demonstrated to provide specified illumination at maximum examination distance. The pre-examination demonstration shall serve to verify adequate illumination is present for these examinations.

C. Evaluation
    1. Nonrelevant indications
        a) Indications resulting from pre-service activities, external indicated corrosion or similar conditions may be considered nonrelevant unless the extent of damage (mechanical or corrosion) is greater that an area of approximately a 1” diameter circle
        b) When any indication that is believed to be nonrelevant could mask or be confused with an unacceptable discontinuity, then regard the indication as a reportable flaw. Post examination technical evaluation may later classify the indication as nonrelevant.

    2. Relevant Indications

    The following guidelines shall be used to determine whether indications are relevant.
        a) Indications resulting from mechanical discontinuities with major dimensions greater than 1/4 inch where it appears that the indication is a service-induced flaw emanating from inside the container shall be considered relevant (reportable flaw).
        b) Linear Indications are those having a length exceeding three times (>3X) width of indication. This also includes curvilinear (crescent shaped) indications.

c) Rounded Indications are those which are circular or elliptical, having a length less than or equal to three times (≤3X) width of indication.

D. Bundle Evaluation

1. The inspection team shall determine which type of bundle and/or specific bundles are to be examined. Once established, the appropriate bundle test sheet will be used to begin and document the inspection.
2. In addition to the bundle test sheet the AMCAP Inspection Notes form (Appendix A) shall be used to annotate specific details of the inspection.

Post-Performance

Reports

1. **COMPLETE** Appendix A *AMCAP Visual Inspection Notes* for each examination performed (including results of examination, sketches or images of indications, or conditions showing dimensions, location, orientation, and all other pertinent data).

2. **INCLUDE** the following, as a minimum, on the final report(s):

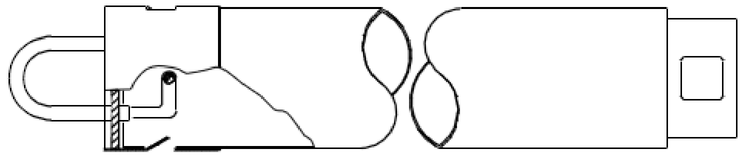
A. Date of examination.
B. Identification of materials under examination, specifications, and acceptance standards.
C. Procedure identification and revision used.
D. Details of performance of visual examination.
E. Surface condition.
F. Method of surface preparation, if any.
G. Special illumination, instruments, or equipment to be used, if any.
H. Verification of image quality and illumination
I. Results of examination.
J. Location of unacceptable discontinuities,
K. Inspection Team and Subject Matter Experts contributing to the final evaluation/disposition of inspected bundles.

Attachments

1. L Bundle Attribute sheet
2. GP Tube Attribute sheet
3. FF Can Attribute sheet
4. EBWR Square Tube Attribute sheet

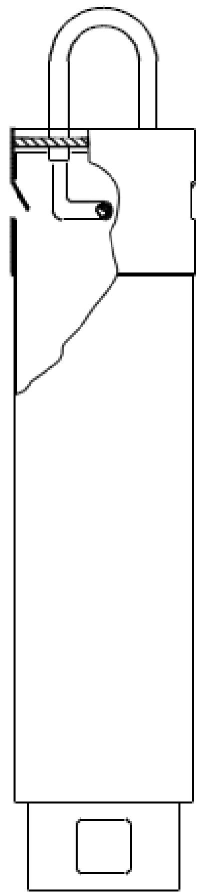
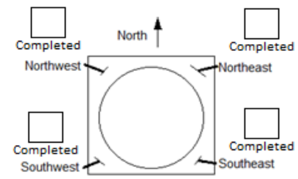
Appendix A - AMCAP Visual Inspection Notes

L BUNDLE VISUAL TEST

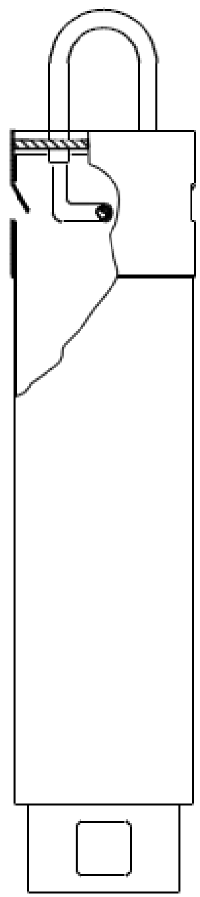
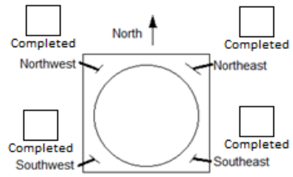
Bundle ID:	***Rack Position:***
L Bundle **~11.75' tall** **0.052" wall**	

Actions	***Progress***
L.1.1 Perform pre-examination camera checks on each of the camera systems to be used. This check shall include the verification of camera performance, recording and adequate lighting.	Acceptable Mini 13 ________ Dual View ________ Side View ________ Other ________ ________
L.1.2 The camera delivery device shall be positioned to allow camera(s) access to one or more corners. Identify (circle) and insert selected camera(s) to ensure movement and adequate control prior to beginning visual examination. Save Image of the bundle top to be examined.	Corners: NW NE Mini 13 SW SE Dual View Side View other Complete: ________ Other
L.1.3 Identify (circle) camera(s) used to examine bundle lid area. Using any of the cameras, visually examine the bundle lid area including external weldments (lifting bail, lid rim, and locking bar) can be visualized. Examine and document external weldments inspection. Note: 90% coverage is the goal. To achieve 90% coverage request Operations to lift the bundle and rotate clockwise 45^0.	Camera(s) used Mini 13 Dual View Side View other Est. surface examined ____ % Complete: ______________
L.1.4 Using selected camera(s), confirm the lid tabs are intact and bent inward Identify on the "Appendix A" all anomalies observed.	Complete: ___________
L.1.5 When possible, examine all accessible bundle sidewalls using the Mini 13 camera. Identify and document in the "Visual Inspection Notes" if any of the following anomalies are observed (discoloration, debris, extensive pitting, blistering, etc.). 90% coverage is the goal. Confirm 90% (or less) of the side walls of the bundle was examined.	Camera(s) Mini 13 Dual View Side View other Est. surface examined ____% Complete: ___________
L.1.6 Request Operations to lift the bundle optimal height for camera access. Using the Duel View camera with side view capabilities or Side View camera, examine the bottom of the bundle (baseplate). Once bundle is lifted, position camera(s) to capture an image to evaluate structural integrity and then examine bottom. To achieve maximum coverage of the bottom, the bundle shall be turned 360 degrees. Document the applicable details how the bundle bottom was examined and the estimated coverage on Appendix A.	Camera(s) used Mini 13 Dual View Side View other Est. surface examined ____ % Complete: ___________

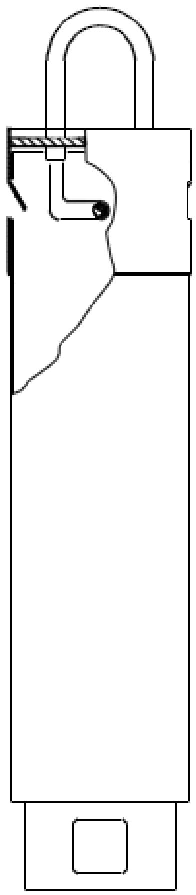
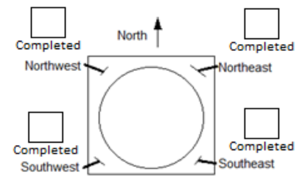
L Bundle Field Notes

L Bundle	Location Corner Degree / Elevation	Noted Conditions Bundle Position (0-Degree)
		

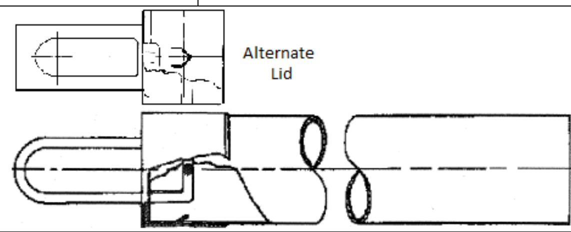
L Bundle Field Notes

L Bundle	***Location*** *Corner* *Degree / Elevation*	***Noted Conditions*** Bundle Position (45-Degree)
		

L Bundle Field Notes

L Bundle	***Location*** ***Corner*** ***Degree / Elevation***	***Noted Conditions*** Bundle Bottom Inspection
		

GP TUBE VISUAL TEST

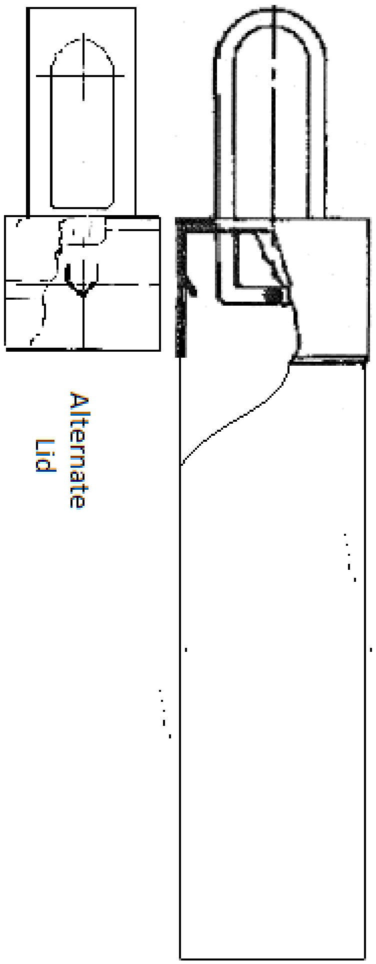
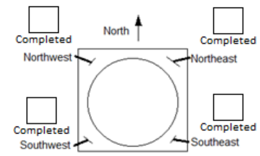
<table>
<tr><td colspan="2">Bundle ID:</td><td colspan="2">Rack Position:</td></tr>
<tr><td>GP Tube
~14.7’ tall
0.052” wall</td><td colspan="3">
</td></tr>
<tr><th colspan="3">Actions</th><th>Progress</th></tr>
<tr><td colspan="3">GP.1.1 Perform pre-examination camera checks on each of the camera systems to be used. This check shall include the verification of camera performance and adequate lighting.</td><td>Acceptable
Mini 13 ________
Dual View ________
Complete: ____________</td></tr>
<tr><td colspan="3">GP.1.2 The camera delivery device shall be positioned to allow camera(s) access to one or more corners. Identify and insert selected camera(s) to ensure movement and adequate control prior to beginning visual examination. Save Image of the bundle top to be examined.</td><td>Corners ____ / Mini 13
Dual View

Complete: __________</td></tr>
<tr><td colspan="3">GP.1.3 Select and identify camera(s) used to examine bundle lid area.

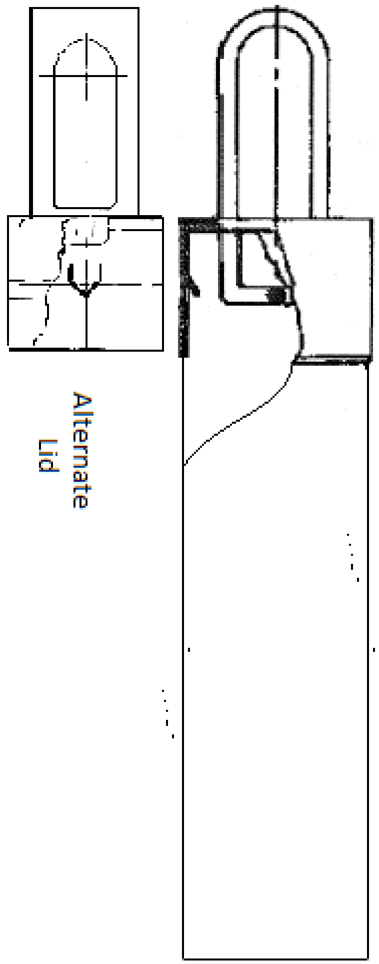
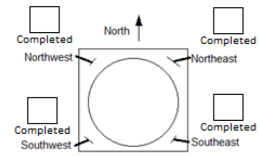
Using any of the three cameras, confirm that 90% (or less) of the bundle lid area including external weldments (lifting bail, lid rim, and locking bar) can be visualized. Examine and documents external weldments inspection. Note: To achieve the goal of 90% coverage, request Operations to lift the bundle and rotate clockwise 45^0.</td><td>Camera used Mini 13
Dual View
Side View other

Est. surface examined ____ %
Complete: ______________</td></tr>
<tr><td colspan="3">GP.1.4 Using selected camera(s), confirm the lid tabs are intact and bent inward (or screws are fully engaged for removable bundle lid). Identify on the “Appendix A” all anomalies observed.</td><td>Complete: ___________</td></tr>
<tr><td colspan="3">GP.1.5 When possible, examine all accessible bundle sidewalls using the Mini 13 camera. Identify and document in the “Visual Inspection Notes” if any of the following anomalies are observed (discoloration, debris, extensive pitting, blistering, etc.).
Confirm 90% (or less) of the side walls of the bundle was examined.</td><td>Camera used Mini 13
Dual View
Side View other
Est. surface examined ____%
Complete: ___________</td></tr>
<tr><td colspan="3">GP.1.6 Request Operations to lift the bundle optimal height for camera access. Using the Duel View camera with side view capabilities or Side View camera, examine the bottom of the bundle (baseplate). Once bundle is lifted, position camera(s) to capture an image to evaluate structural integrity and then examine bottom. To achieve maximum coverage of the bottom, the bundle shall be turned 360 degrees. Document the applicable details how the bundle bottom was examined and the estimated coverage on Appendix A.</td><td>Camera used Mini 13
Dual View
Side View other
Est. surface examined ____ %
Complete: ___________</td></tr>
</table>

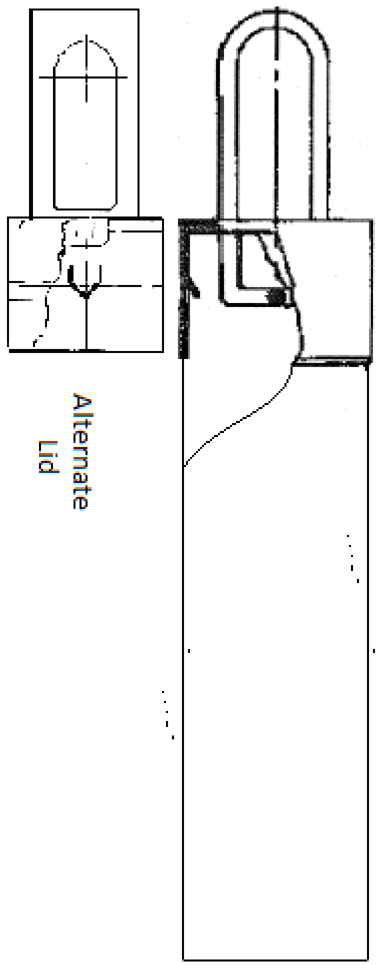
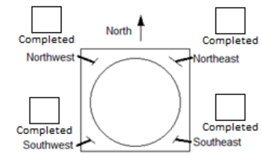
GP Tube Field Notes

GP Tube	***Location*** ***Corner*** ***Degree / Elevation***	***Noted Conditions*** Bundle Position (0-Degree)
		

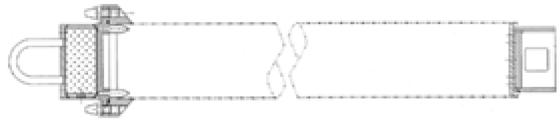
GP Tube Field Notes

GP Tube	***Location*** *Corner* *Degree / Elevation*	***Noted Conditions*** Bundle Position (45-Degree)
		

GP Tube Field Notes

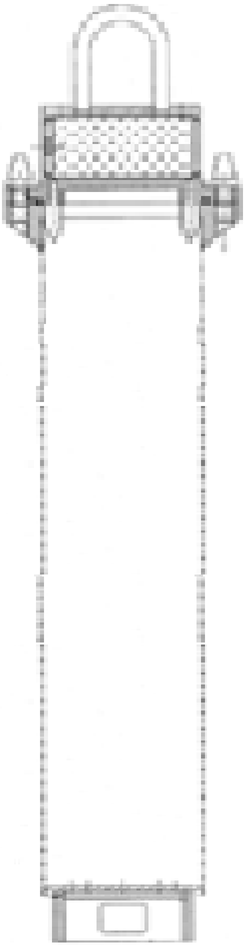
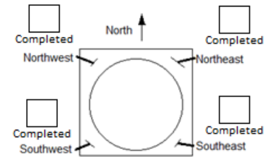
GP Tube	***Location*** ***Corner*** ***Degree / Elevation***	***Noted Conditions*** Bundle Bottom Inspection
		

FF CAN VISUAL TEST

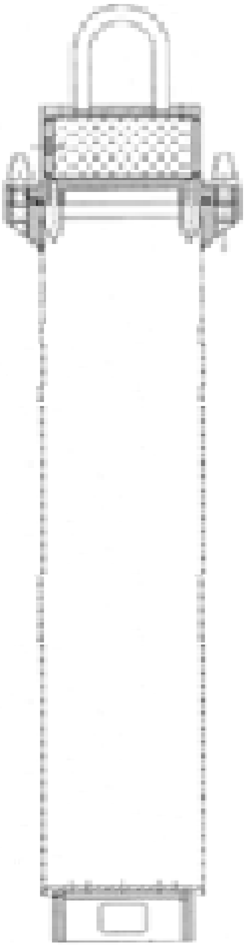
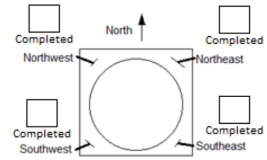
Bundle ID:	***Rack Position:***
FF Can **~11.75' tall** **0.052" wall**	

Actions		***Progress***
FF.1.1	Perform pre-examination camera checks on each of the camera systems to be used. This check shall include the verification of camera performance and adequate lighting..	Acceptable Mini 13 ________ Dual View ________ Other ________ Complete: ____________
FF.1.2	The camera delivery device shall be positioned to allow camera(s) access to one or more corners. Identify and insert selected camera(s) to ensure movement and adequate control prior to beginning visual examination. Save Image of the bundle top to be examined.	Corners ____ / Mini 13 Dual View Side View other Complete: __________
FF.1.3	Select and identify camera(s) used to examine bundle lid area. Using any of the three cameras, confirm that 90% (or less) of the bundle lid area including external weldments (lifting bail, lid rim, and locking bar) can be visualized. Examine and documents external weldments inspection. Note: To achieve the goal of 90% coverage, request Operations to lift the bundle and rotate clockwise 45^0.	Camera used Mini 13 Dual View Side View other Est. surface examined ____ % Complete: ______________
FF.1.4	Using selected camera(s), confirm the lid tabs are intact and bent inward (or screws are fully engaged for removable bundle lid). Identify on the "Appendix A" all anomalies observed.	Complete: ___________
FF.1.5	When possible, examine all accessible bundle sidewalls using the Mini 13 camera. Identify and document in the "Visual Inspection Notes" if any of the following anomalies are observed (discoloration, debris, extensive pitting, blistering, etc.). Confirm 90% (or less) of the side walls of the bundle was examined.	Camera used Mini 13 Dual View Side View other Est. surface examined ____% Complete: ___________
FF.1.6	Request Operations to lift the bundle optimal height for camera access. Using the Duel View camera with side view capabilities or Side View camera, examine the bottom of the bundle (baseplate). Once bundle is lifted, position camera(s) to capture an image to evaluate structural integrity and then examine bottom. To achieve maximum coverage of the bottom, the bundle shall be turned 360 degrees. Document the applicable details how the bundle bottom was examined and the estimated coverage on Appendix A.	Camera used Mini 13 Dual View Side View other Est. surface examined ____ % Complete: ___________

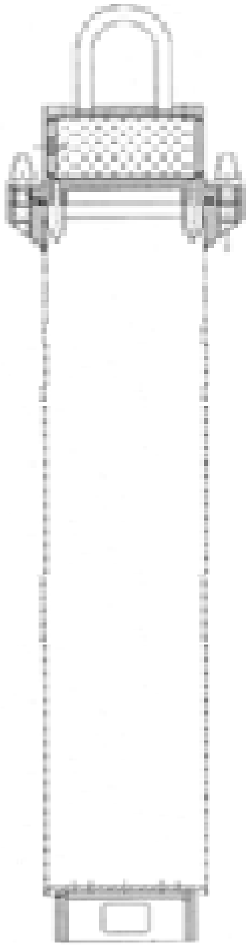
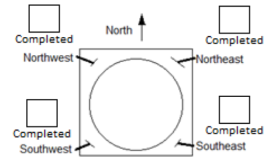
FF Can Field Notes

FF CAN	***Location*** ***Corner*** ***Degree / Elevation***	***Noted Conditions*** Bundle Position (0-Degree)
		

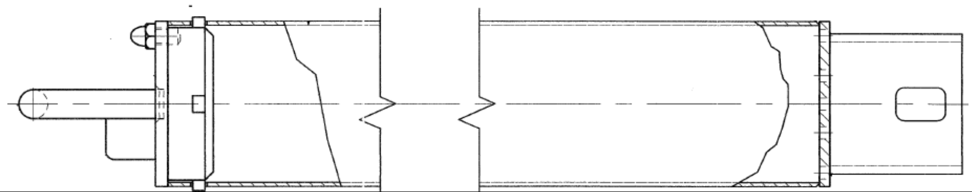
FF Can Field Notes

FF CAN	***Location*** *Corner* *Degree / Elevation*	***Noted Conditions*** Bundle Position (45-Degrees)
		

FF Can Field Notes

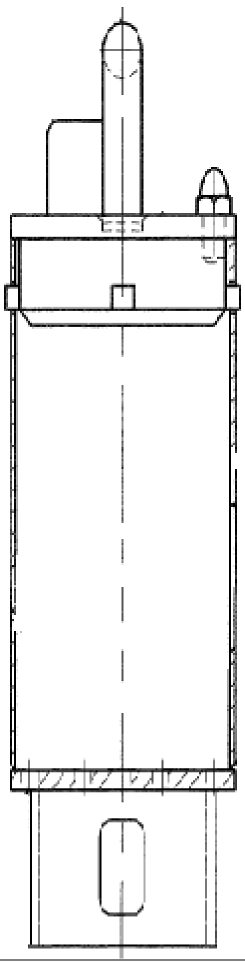
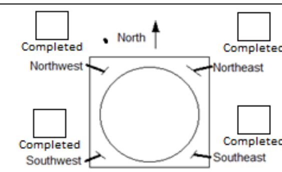
FF CAN	***Location*** ***Corner*** ***Degree / Elevation***	***Noted Conditions*** Bundle Bottom Inspection
		

EBWR Square Tube

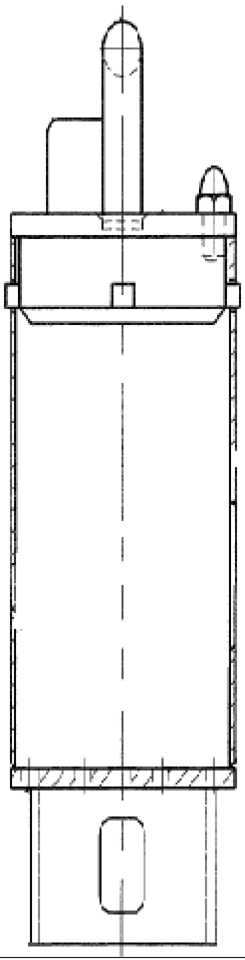
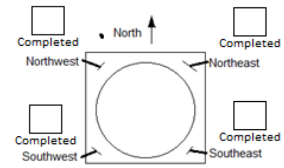
Bundle ID:	***Rack Position:***
EBWR Square Tube ~11.75' tall 0.125" wall	

Actions		***Progress***
ERWR.1.1	Perform pre-examination camera checks on each of the camera systems to be used. This check shall include the verification of camera performance and adequate lighting.	Acceptable Mini 13 ________ Dual View ________ Other ________ Complete: ____________
ERWR.1.2	The camera delivery device shall be positioned to allow camera(s) access to one or more corners. Identify and insert selected camera(s) to ensure movement and adequate control prior to beginning visual examination. Save Image of the bundle top to be examined.	Corners ____ / Mini 13 Dual View Side View other Complete: ____________
ERWR.1.3	Select and identify camera(s) used to examine bundle lid area. Using any of the three cameras, confirm that 90% (or less) of the bundle lid area including external weldments (lifting bail, lid rim, and locking bar) can be visualized. Examine and documents external weldments inspection. Note: To achieve the goal of 90% coverage, request Operations to lift the bundle and rotate clockwise 45^{0}.	Camera used Mini 13 Dual View Side View other Est. surface examined ____ % Complete: ______________
ERWR.1.4	Using selected camera(s), confirm the lid tabs are intact and bent inward (or screws are fully engaged for removable bundle lid). Identify on the "Appendix A" all anomalies observed.	Complete: ___________
ERWR.1.5	When possible, examine all accessible bundle sidewalls using the Mini 13 camera. Identify and document in the "Visual Inspection Notes" if any of the following anomalies are observed (discoloration, debris, extensive pitting, blistering, etc.). To achieve 90% coverage request Operations to lift the bundle and rotated 45%. Confirm 90% (or less) of the side walls of the bundle was examined.	Camera used Mini 13 Dual View Side View other Est. surface examined ____% Complete: ___________
ERWR.1.6	Request Operations to lift the bundle optimal height for camera access. Using the Duel View camera with side view capabilities or Side View camera, examine the bottom of the bundle (baseplate). Once bundle is lifted, position camera(s) to capture an image to evaluate structural integrity and then examine bottom. To achieve maximum coverage of the bottom, the bundle shall be turned 360 degrees. Document the applicable details how the bundle bottom was examined and the estimated coverage on Appendix A.	Camera used Mini 13 Dual View Side View other Est. surface examined ____ % Complete: ___________

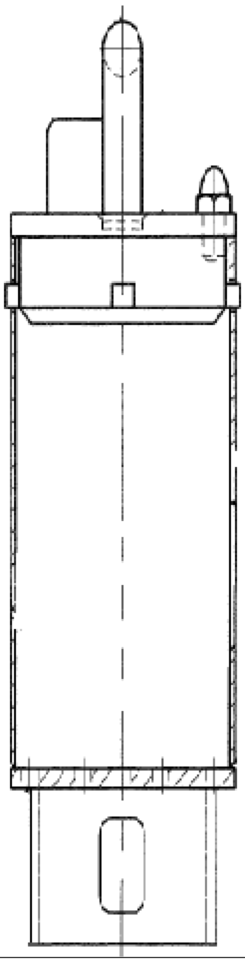
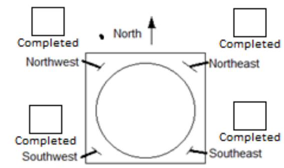
EBWR Square Tube Field Notes

EBWR Square Tube	***Location*** ***Corner*** ***Degree / Elevation***	***Noted Conditions*** Bundle Position (0-Degrees)
		

EBWR Square Tube Field Notes

EBWR Square Tube	***Location*** ***Corner*** ***Degree / Elevation***	***Noted Conditions*** Bundle Position (45-Degrees)
		

EBWR Square Tube Field Notes

EBWR Square Tube		***Noted Conditions*** Bundle Bottom Inspection
		

AMCAP Visual Inspection Notes

Primary Inspector
Name: ______________________________ Date: ___/___/___

Secondary Inspector
Name: ______________________________ Date: ___/___/___

Bundle ID: ______________________ Rack Position: ______________

Camera performance: Identified cameras image resolution and supplied lighting were evaluated prior to inspection and found acceptable ___________________. (Inspection Team signature)

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

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

Fuel Movement

Video Playback Time:______:________ (hh:mm)

Initial Comments: ____

____

Lid Inspection (lifting bail, lid rim, and locking bar): ____

____

Lid tabs (intact and bent inward or screws are properly tightened for removable bundle lid). __________

____

____

Bundle bottom inspection: ____

____

____

____

____

____

Additional Comments/Observations: ____

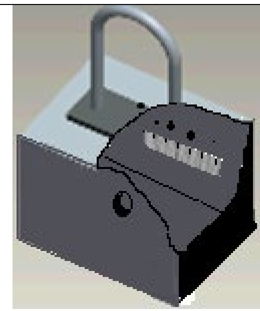
____

____

____

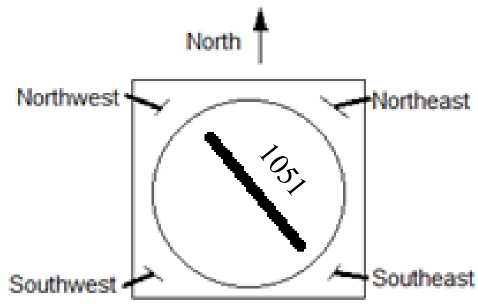
____

Attachment 1

A visual aid gauge is provided to assist the inspectors in characterizing the size of surface flaws such as pits, nodules, and general corrosion. Item to be observed is inside an enclosure darkened to simulate the most poorly lighted area being examined.	

Appendix B. Field Notes

Item Inspected on 03 16 21:
L Bundle loaded with **K cans and E Cans – HWCTR 1051 – 19 C 7**
"0 degrees" 4 corner visual examination (MH) *Field Observations*
Start Location- *LID POSITION LOOKING DOWN FROM THE NORTH- (e.g. tilted right, 2 o'clock position)*
Comprehensive view of Lid Weldments Video Complete? – **First bundle. Fuel ID not visible from L camera (basin camera).



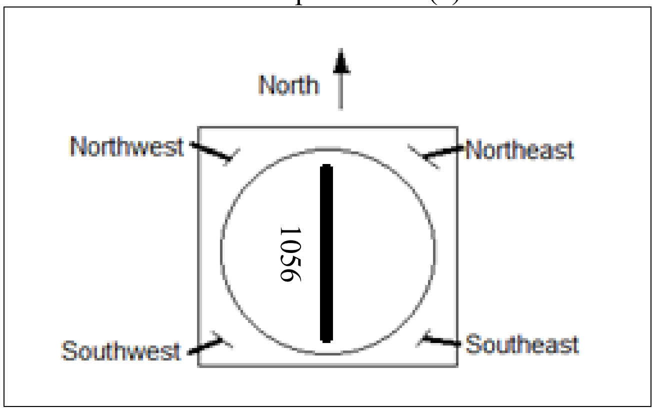
Reminder- Get aerial position shot for each corner
1st corner/ NE corner – 8:22am – Orange brown cobwebs on rack. Corrosion in very small nodules. Iron rust. Particulate increased as going down bundle. Camera image starting to snow at 8:30am from radiation. Impact limiter with orange brown sediment.
2nd/ SE Corner – 8:35am – Nodules. Particulate due to corrosion rubbing off bundle. Moderate to severe corrosion at 56in. Scratch near bottom. Minor pitting where corrosion (is present). Most corrosion noted near bottom of bundle.
3rd/ SW Corner – 8:50am – Large orange spot at 47in. No corrosion noticeable. Minimal pitting.
4th/ NW Corner- 8:59am – Tab not visible. Moderate corrosion with particulate rubbing off. Pitting all along vertical camera bracket. 78in. large orange white nodule. More than one nodule noted -> orange white highly raised surface. Orange discoloration, possibly with depth, camera angle not clear. Arrow written on side showing tab placement. Pointing up to tab.

"45 degrees" rotated clockwise
Finish Location- *LID POSITION LOOKING DOWN FROM THE NORTH- (e.g. tilted right, 2 o'clock position)*
**Bundle turned to 12 o'clock-6 o'clock position within rack. Bubbles arose from fuel bundle movement, from lid holes. View from L camera appeared to be slightly larger than softball sized conglomeration of bubbles.
Reminder- Get aerial position shot for each corner
1st corner/ NE corner – 9:19am – Discoloration, reddish iron corrosion. Nodules (moderate) increasing down bundle.

2nd/ SE Corner – 9:26am – Mottled black, gray, white discoloration. Lots of particulate due to tight corner rubbing off corrosion. Little to no nodules. Fine particulate powder upon removing camera from corner.
3rd/ SW Corner – (Didn't note time) - Discoloration resembling weld or liquid interface, light gray to white. White plated corrosion.
4th/ NW Corner- 9:50am - Intact weld on lid. Nodules starting at top. Some nodules very large. Red orange iron rust spots.

Bottom Viewing Notes: No time stamp on FF side view camera. Snow immediately visible due to radiation. Bottom with no noticeable corrosion, or discoloration.

Item Inspected on 03 16 21:
L Bundle loaded with **U tubes 14 SMT – HWCTR 1056- 19 C 27**
Comprehensive view of Lid Weldments Video Complete? - **Cobwebs on lid, brown to orange to clear (translucent), bail weld intact. Reddish corrosion spots on lid (2).



Reminder- Get aerial position shot for each corner
1st corner/ NE corner – 12:28pm – Mottled gray surface. Many spots. Some nodules following scratch. Pitting along same scratch with associated nodules. Lighter color, no mottling nearer to bottom of bundle. Particulate coming up due to corrosion removal (from bundle).

2nd/ SE Corner – 12:44pm – Weld visible on lid. Writing on side. Nodules following scratch at top. Two scratches with depth at 58.5in. Very slight mottling, pitting. Overall smaller nodules near bottom.

3rd/ SW Corner – 12:55pm – Green algae/cobwebs upon entry. Green growth moving down bundle. Writing. Scratches with nodules to follow. Almost no corrosion this corner. Iron (rust) colored circumferential scratch.

4th/ NW Corner- 1:05pm – Orange white nodule. Little corrosion. Mottled surface with dark spots. Camera stuck at 89in. Slight pitting.

"45 degrees" rotated clockwise
Finish Location- *LID POSITION LOOKING DOWN FROM THE NORTH- (e.g. tilted right, 2 o'clock position)* **Bundle moved to 'one o'clock' position.
Reminder- Get aerial position shot for each corner
1st corner/ NE corner – 1:26pm – Writing. Mottled surface. Pitting. Gray scrape. Scratches continuing down bundle, little associated nodules. Fairly clean, little corrosion.

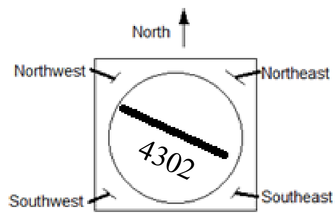
2nd/ SE Corner – 1:35pm – Slightly mottled, little corrosion. Few nodules starting at near bottom. Corroded region on side of lid.

3rd/ SW Corner – 1:44pm – SW corner tab with loose metal piece? Writing. Little corrosion, few nodules. Nodules following scratch. Circumferential iron scratch. Scaled corrosion near bottom.

4th/ NW Corner- 1:53pm – Little corrosion. Some scaled corrosion near bottom. Few mottled spots. Fairly uniform, intact surface area.
NOTES:

Bottom Viewing Notes: Bottom clean, intact. Weld with no corrosion.

Item Inspected on 3-17-2021:
GP Tube loaded with **ThO_2/UO_2 SS 125 ERR 4302 – 19 A 21**
"0 degrees" 4 corner visual examination (MH) *Field Observations*
Start Location- *LID POSITION LOOKING DOWN FROM THE NORTH- (e.g. tilted right, 2 o'clock position)*
Comprehensive view of Lid Weldments Video Complete? **Missile shield removal with particulate coming off. Welds on top from removal of old bail. Lots of cobwebs in tab opening. Growth or corrosion just below tab. One small orange spot on lid.



Reminder- Get aerial position shot for each corner
1st corner/ NE corner – 9:26am – 4302 etched on side. Black writing. Growth and/or corrosion with particulate near top of bundle before rack entry. Small scratches without associated corrosion. No mottled surface area. Small nodules near bottom of bundle. Orange-white nodules.

2nd/ SE Corner – Time not denoted – Fine powder particulate upon passing top of bundle. Deep gouge above rack with brown discoloration. Some particulate upon rack entry. Orange discoloration near top of bundle. Very few orange nodules. (Camera) wedge stuck at 101in. Re-entry at 10:23am – One small mottled area (pit initiation?). Orange discoloration with one-two nodules.

3rd/ SW Corner – 9:49am – Circumferential scratches outside rack. Axial scratches noticeable upon entry to rack. Small scratches without associated corrosion. Some pale orange growth/corrosion above rack. Stuck at top of mast ~1in. line. Re-entry at 10:29am – Small pits above rack in concentrated small area. Small scratches with minimal associated corrosion. Small nodules following axial scratch. Particulate increasing toward bottom. Gouge with associated orange-brown corrosion at bottom (deformation, protrusion).

4th/ NW Corner- 9:59am – Pale orange growth/corrosion above rack on bundle. Circumferential scratch without associated corrosion. Minor pitting associated with axial scratch. Few orange white nodules. *Large orange scrape at top of mast aligned with lid. No mottled appearance on surface.
TABS were SEEN on WHICH VIEW?_**Both tabs in place, not overly bent. 30-45 degree angle.

"45 degrees" rotated clockwise
Finish Location- *LID POSITION LOOKING DOWN FROM THE NORTH- (e.g. tilted right, 2 o'clock position)* **Moved to 'five o'clock' position. May have made 180 degree plus turn. Need to confirm with video examination. Doesn't affect inspection outcome.
Reminder- Get aerial position shot for each corner
1st corner/ NE corner – 10:45am – Circumferential scratch without associated corrosion. White corrosion 'patch' near top bundle. Particulate minimal, but present. Axial scrapes without associated corrosion. Orange discoloration with nodule. Brown sediment minimal at bottom of rack.

2nd/ SE Corner – 10:54am – Small amount of pitting associated with scratch. Small pale orange nodule. 3-4 circumferential scratches with depth. Large pit with minimal depth, pale orange slightly above pit at bottom. Sediment may be microbe growth?

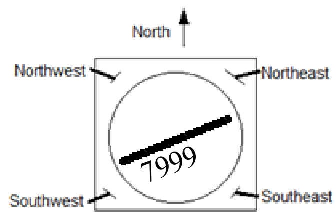
3rd/ SW Corner – 11:02am – Large scratch axial with pitting. Small scratches without associated corrosion. Increasing particulate going down, as wedge getting stuck. Stuck at 75in. measured from top of missile shield. Re-entry at 11:11am – White corrosion patch. Large scrape, outwards sticking material? 77in from top of missile shield. Large scrapes, no associated corrosion. Orange brown pitting following scrape. Scrapes with associated corrosion leading down.

4th/ NW Corner- 11:19am – Particulate minimal but present upon rack entry. Small orange brown pit. Very few nodules. No mottled appearance on surface. Metal lip on bottom with some disfiguration.

Notes

Bottom Viewing Notes: Bottom intact with some dull areas. Weld intact with one dull spot. Clean, no structural integrity issues.

Item Inspected on 3-17-2021:
GP Tube loaded with **U Metal RMT A Can 7999 – 3 C 19**
Comprehensive view of Lid Weldments Video Complete? **Tab with removeable lid bar showing. Weld on lid intact # not visible.



Reminder- Get aerial position shot for each corner
1st corner/ NE corner – 1:49pm – Writing on side, brown corrosion. Semicircular brown scrape. Scratches. Another semicircular scrape. White plating corrosion, with associated pits. Scratch with orange white nodules circumferential. Lots of orange white nodules. Mottled discoloration, pitting. Brown rust associated with Al corrosion. Raised orange white nodule. Bulge at corner.

2nd/ SE Corner – 2:04pm – Orange cobwebs along rack edge. Orange growth/corrosion upon rack entry. Small orange discoloration. Nodule associated with watermark discoloration. Circumferential brown scratch. Lots of mottled surface resembling watermark. Two orange marks. Large orange nodules. Brown corrosion near bottom of bundle. Minimal to no particulate.

3rd/ SW Corner – 2:19pm – Brown corrosion near top of bundle. Pitting following line. Dark black to brown features, very small (hole?). Orange-brown corrosion. Brown circular features, Al gray in center. Brown corrosion or growth at bottom near weld. 92in. potential small holes times 3.

4th/ NW Corner- 2:31pm – Orange circumferential scratch outside rack. Orange cobwebs. Black features, small. Mottled appearance, some plated corrosion. Orange white corrosion not associated with scratch 135in. with deep pitting white with orange center.

"45 degrees" rotated clockwise
Finish Location- *LID POSITION LOOKING DOWN FROM THE NORTH- (e.g. tilted right, 2 o'clock position) -3:30*
**Many bubbles with bundle turn.
Reminder- Get aerial position shot for each corner
1st corner/ NE corner – 2:51pm – White cobwebs above rack on bundle. Small black features. Orange surface discoloration. Mottled with surface corrosion, little depth. Pits. More clear view of deep pitting corrosion from NW corner at 0 degree.

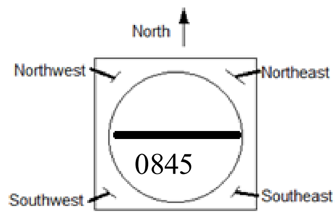
2nd/ SE Corner – 3:00pm – Pale orange growth/corrosion upon entering rack. Orange nodule with black feature. Scrapes associated with white corrosion. Circumferential scratch with orange discoloration. Orange white nodules. Pitting following axial scratch. Powder particulate near bottom.

3rd/ SW Corner – 3:07pm – Orange growth/corrosion above rack. Little to no particulate. White pitting, irregular. Scratch with pitting. Mottled surface area.

4th/ NW Corner- 3:13pm – Small black features. Shallow pits. Brown discoloration. Bright yellow spot. Mottled appearance, flat to surface. Metal missing from bottom of bundle, dented?
NOTES:

Bottom Viewing Notes: Little to no growth in rack. Lots of growth on bundle above rack. Bottom clean, intact, weld intact. Two holes showing inner contents or bail?

Item Inspected 3-18-2021:
L Bundle loaded with **Th/U tube 1 TMT – HWCTR 0845 – 2 C 21**
"0 degrees" 4 corner visual examination (MH) *Field Observations*
Start Location- *LID POSITION LOOKING DOWN FROM THE NORTH- (e.g. tilted right, 2 o'clock position)*
Comprehensive view of Lid Weldments Video Complete? **Too many cobwebs to see # on lid. Yellow to white cobwebs.



Reminder- Get aerial position shot for each corner
1st corner/ NE corner – 8:12am – Brown growth, corrosion on lid. Brown growth moving down (bundle with camera). Pale green nodules. Black features, small spots. Brown irregular corrosion. Black discoloration resembling crack. Black spot with brown edge (hole?). Large black spot, look to SE corner. 111in. from top of bundle, possible holes. Black spots getting larger near bottom. **Stopped camera to attach extension cord.

2nd/ SE Corner – Time not denoted – Green growth on lid. Little to no particulate. Iron discoloration. Mottled surface. Minor pitting, very small. Black irregular spots in circumferential line (holes). Particulate out of holes?? Semi-circular pale brown. Cobwebs as particulate near bottom. Irregular bottom edge near weld above impact limiter.

3rd/ SW Corner – 8:48am – Writing on side. Lots of particulate upon entry. Minor pitting. Mottled appearance. Orange growth as particulate. Bright green nodule, camera knocked off to show pit underneath. Lots of particulate. Tight space, camera removing corrosion/growth from bundle. Fewer black spots this side.

4th/ NW Corner- 9:01am – Orange nodule near lid. Small black spots following line. Axial scratch without associated corrosion. Orange discoloration in line. Two large holes 101in. from bundle lid. Three holes at bottom edge meeting weld.
TABS were SEEN on WHICH VIEW?_________TABS LOOK OKAY to PROCEED?_________

"45 degrees" rotated clockwise
Finish Location- *LID POSITION LOOKING DOWN FROM THE NORTH- (e.g. tilted right, 2 o'clock position)*
**~2 small bubbles upon bundle movement
Reminder- Get aerial position shot for each corner
1st corner/ NE corner – 9:17am – Minor pitting. Mottled appearance. Moderate particulate. Black spot with orange halo, one side. 82in. from lid axial dark spot may be with depth. Large axial hole length -> 80in bottom of hole to 84.5in. top. Red-orange discoloration in pit. Roughly 2in. axial gap along axial weld.

2nd/ SE Corner – 9:41am – Pits following axial scratch. Some nodules. Some corrosion along edge meeting weld above impact limiter. Fairly clean.

3rd/ SW Corner – 9:49am – Orange growth toward lid. Mottled appearance. Minor pitting. Few white nodules. Bottom edge intact, relatively clean.

4th/ NW Corner- 9:57am – Mottled appearance. Pitting with little depth. Irregular corrosion with nodule, bleeding orange discoloration. Bright red discoloration, with pitting. Circumferential scratch with associated corrosion, orange yellow connected nodules. Orange corrosion/growth bottom edge near weld.

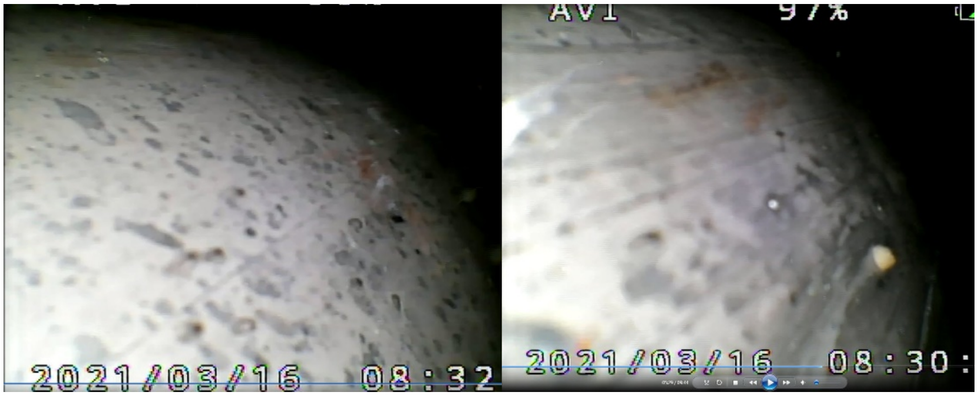
Notes

Bottom Viewing Notes: Bottom intact, relatively clean. No noticeable corrosion.

Appendix C. Bundle Image

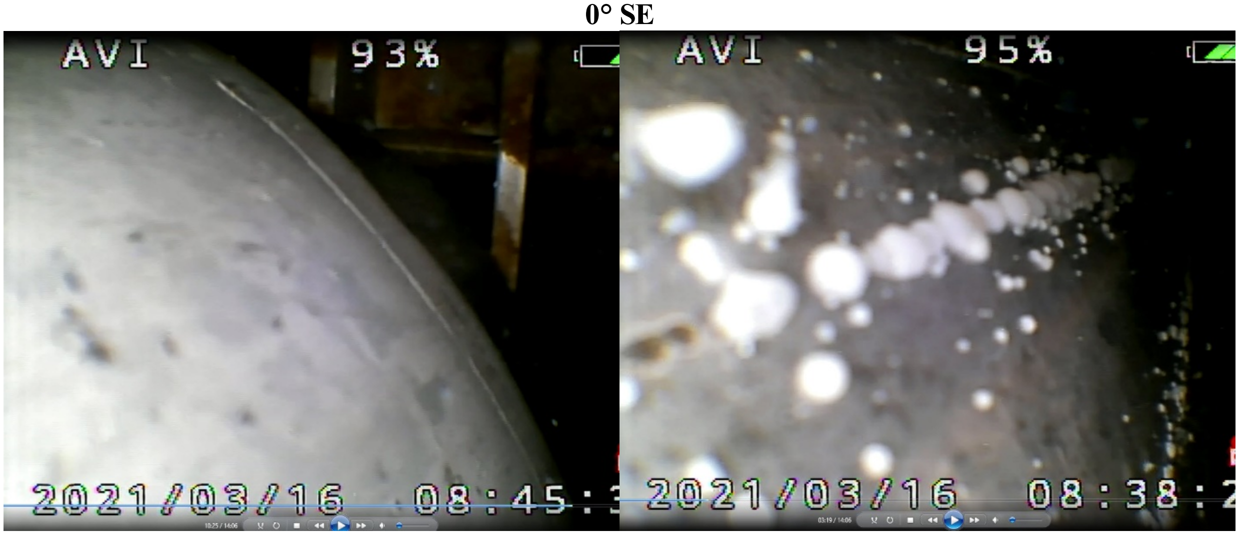
L Bundle loaded with K Cans and E Cans – HWCTR 1051 – 19 C 7

0° NE



0° NW

0° SE



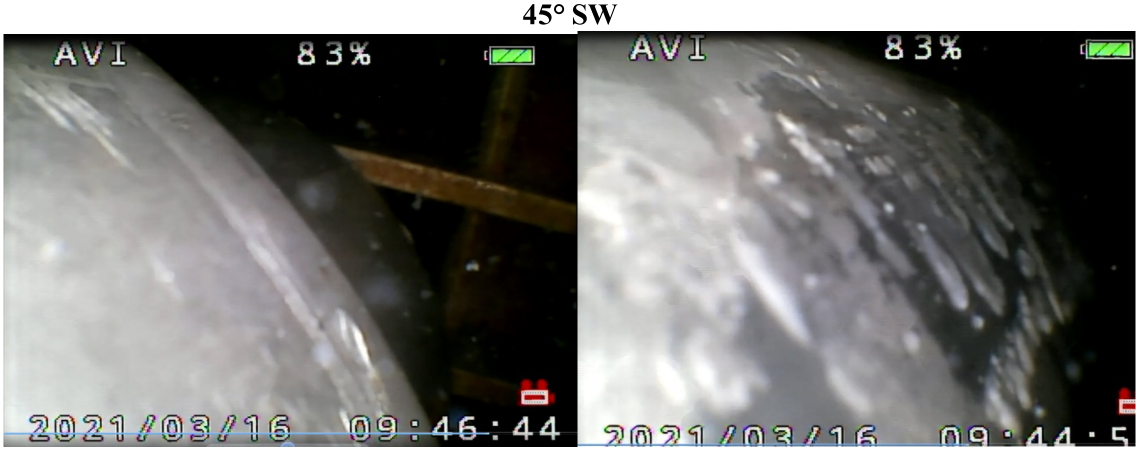
0° SW

45° NE

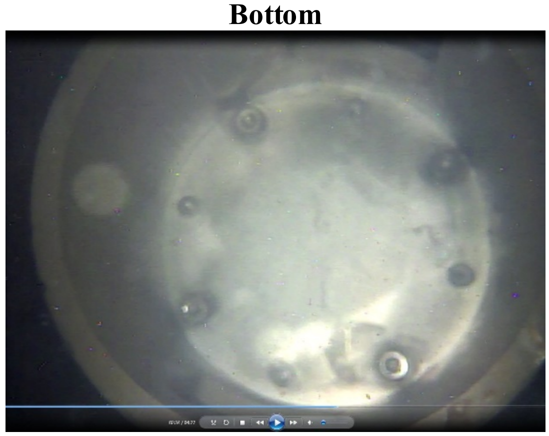
45° NW

45° SE

45° SW



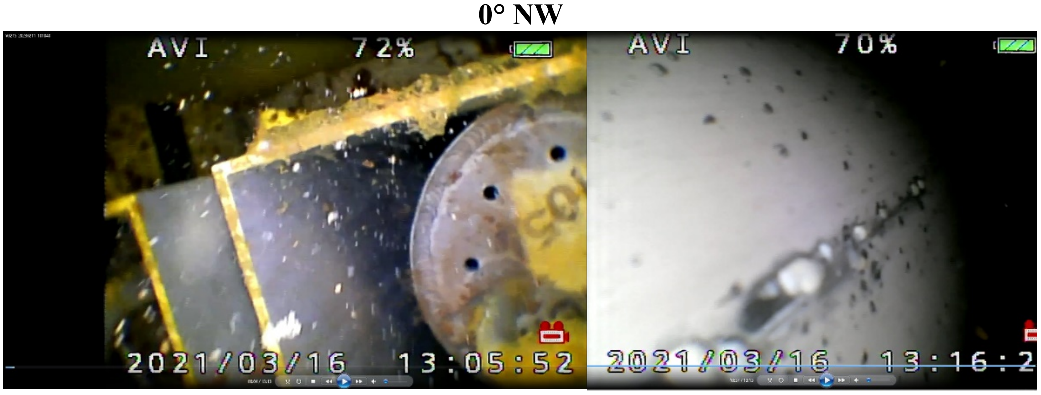
Bottom



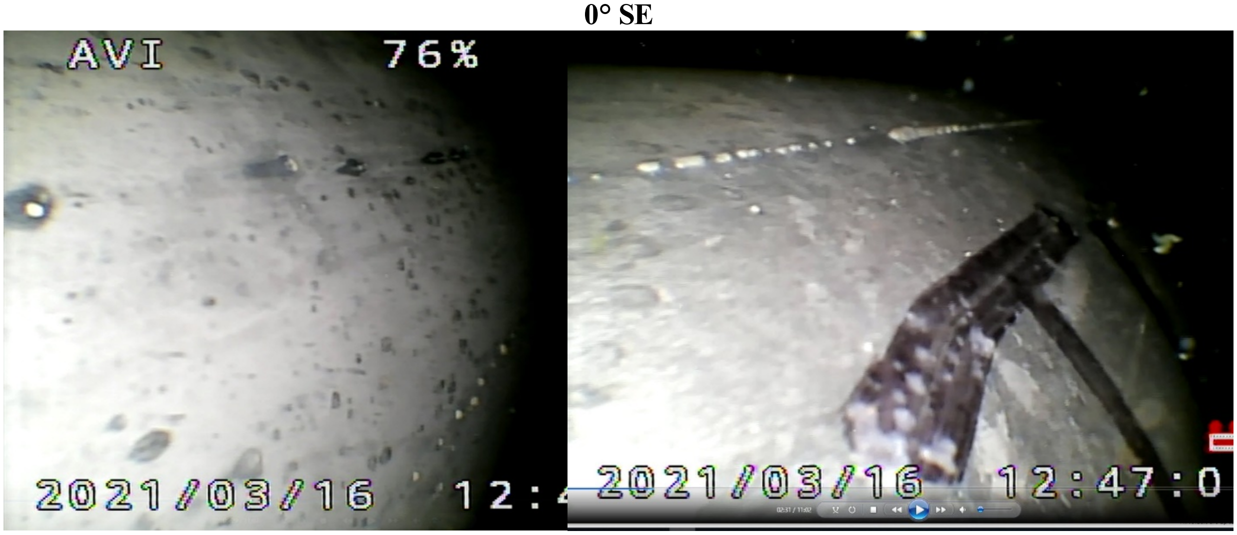
L Bundle loaded with U Tubes 14 SMT – HWCTR 1056 – 19 C 27

0° NE

0° NW

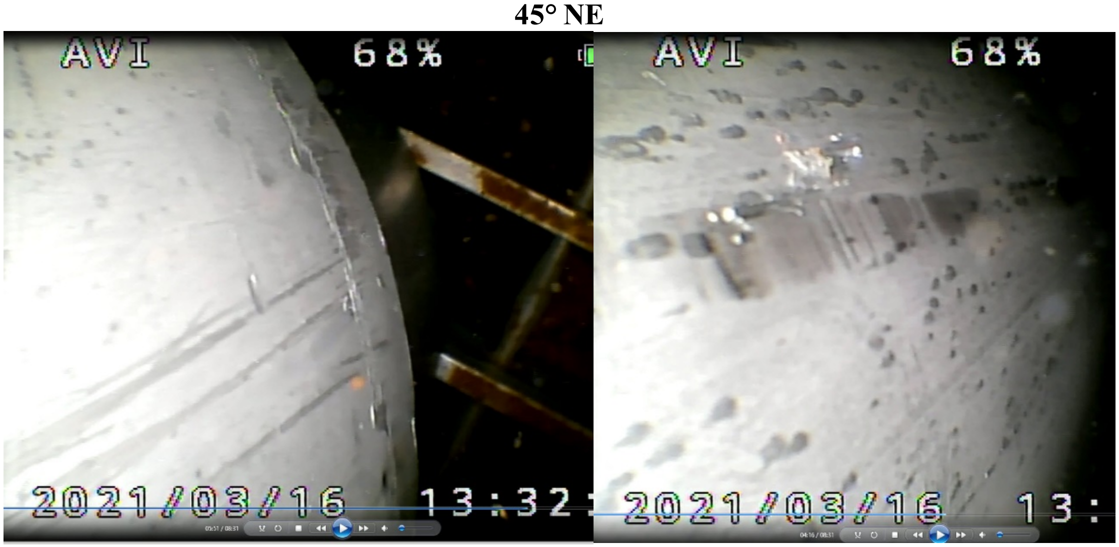


0° SE

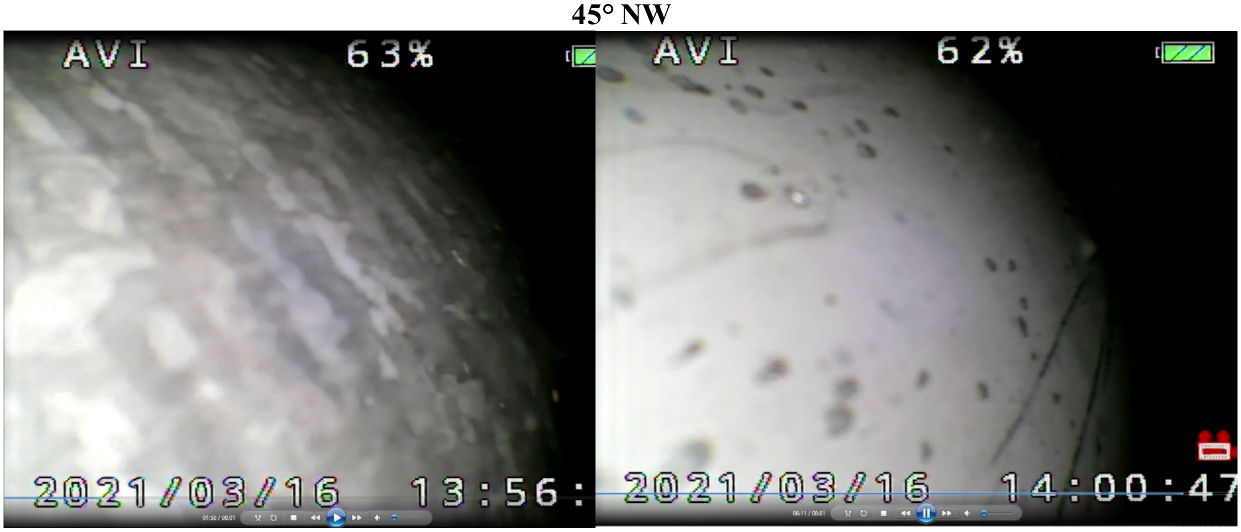


0° SW

45° NE



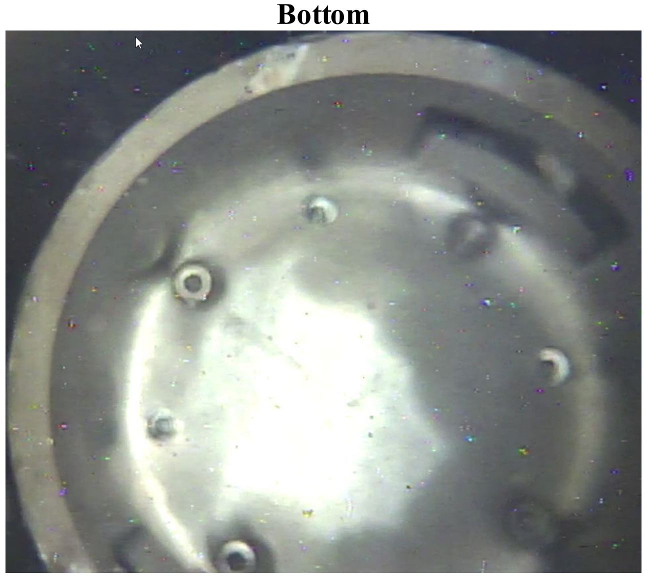
45° NW



45° SE

45° SW

Bottom



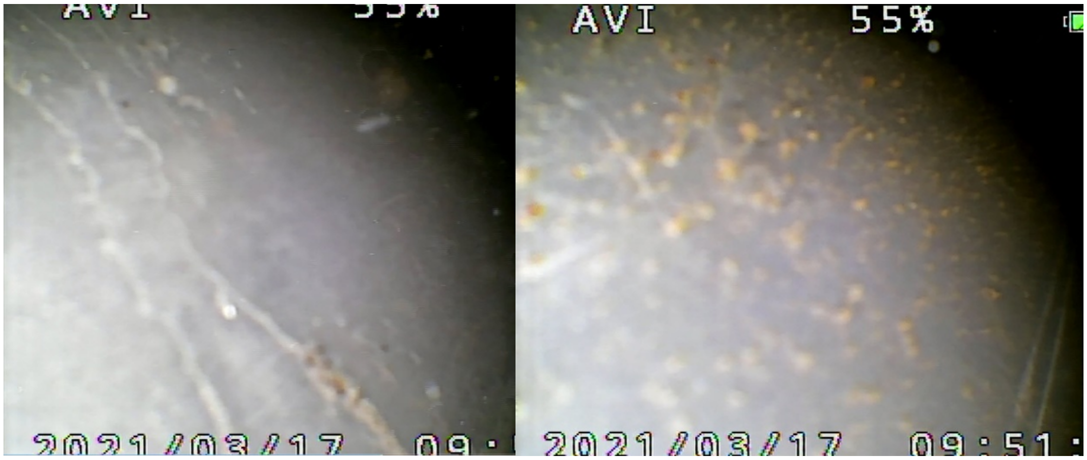
GP Tube loaded with ThO_2/UO_2 SS 125 ERR 4302 – 19 A 21

0° NE

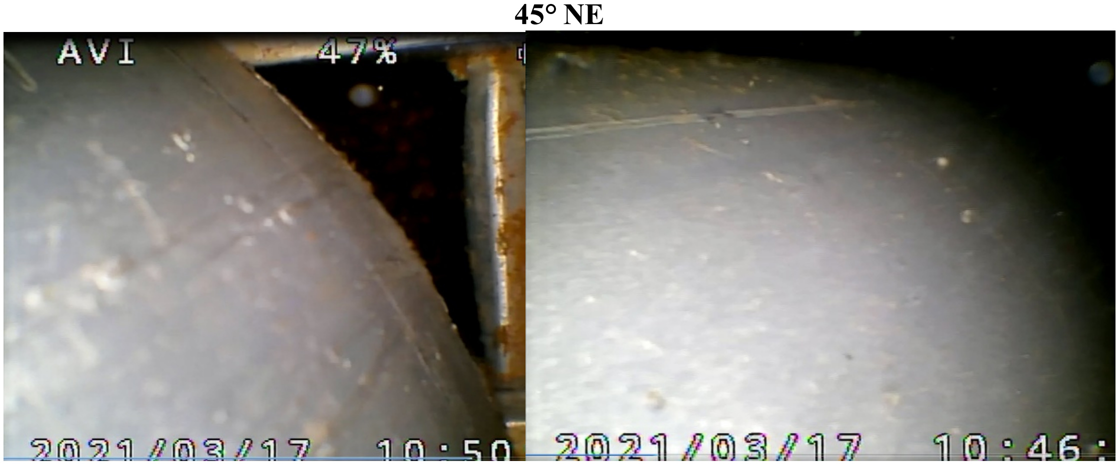

0° NW

0° SE


0° SW



45° NE

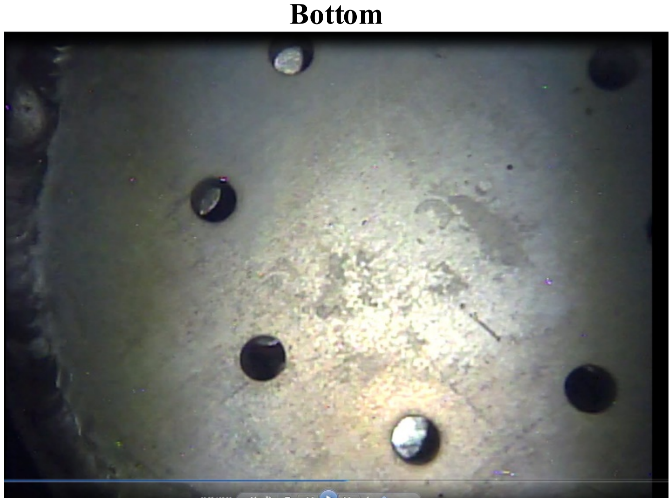


45° NW

45° SE

45° SW

Bottom



GP Tube loaded with U Metal RMT A Can 7999 – 3 C 19

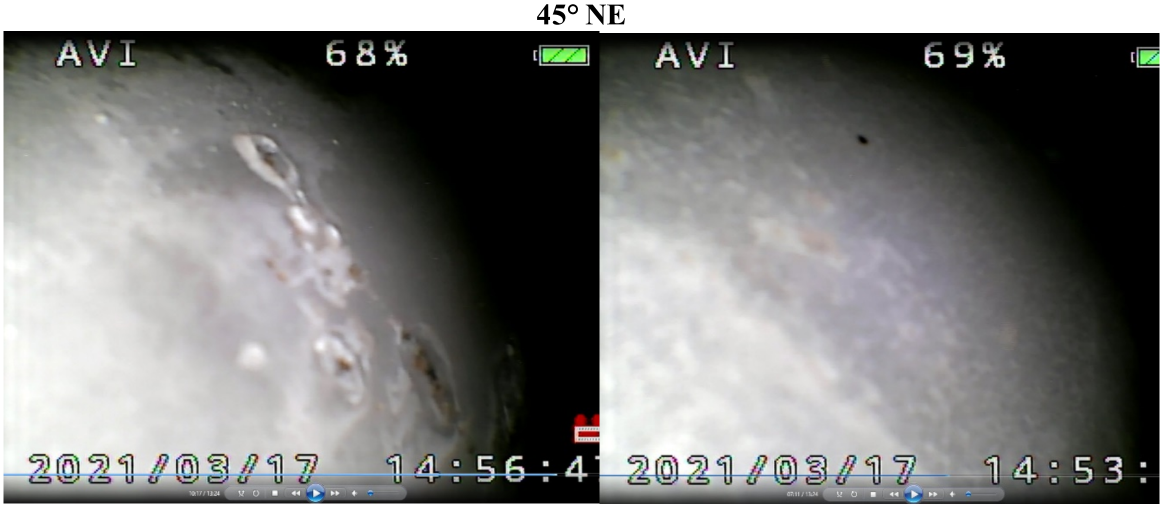
0° NE

0° NW

0° SE

0° SW

45° NE

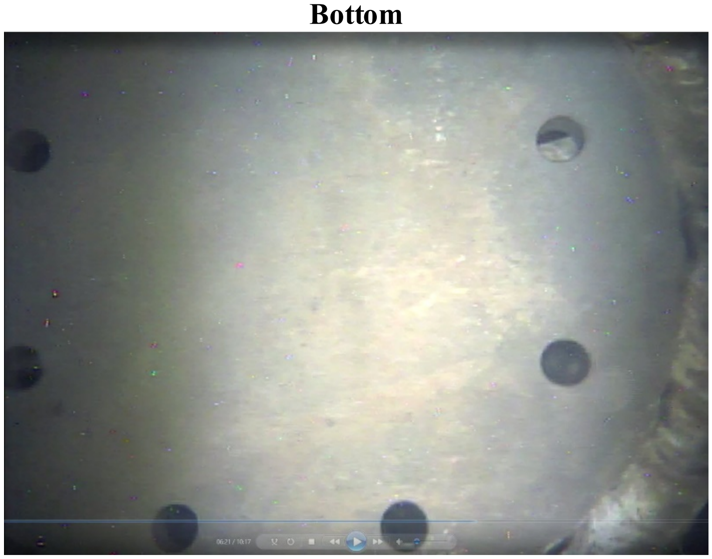


45° NW

45° SE

45° SW

Bottom

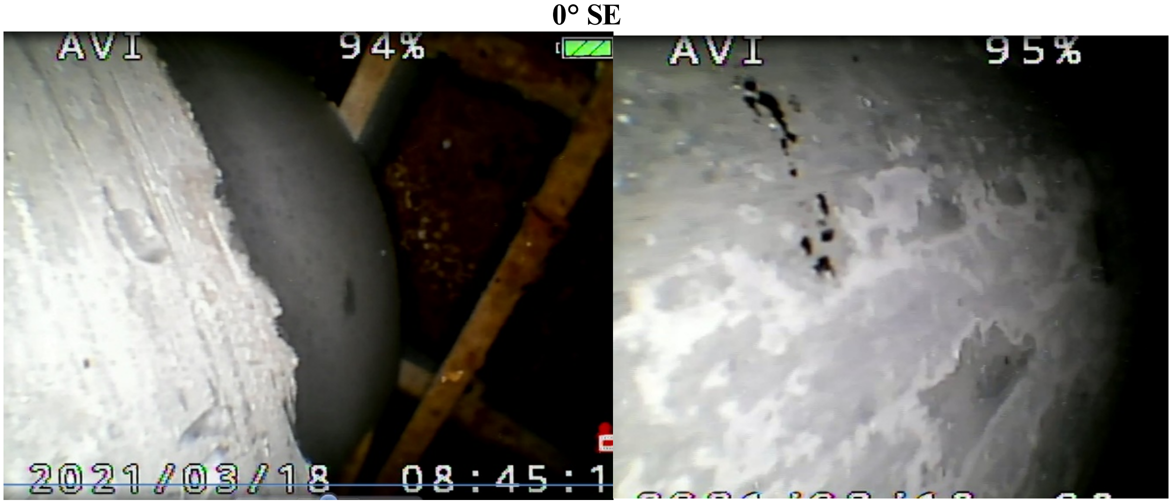


L Bundle loaded with Th/U TMT – HWCTR 0845 – 2 C 21

0° NE

0° NW

0° SE

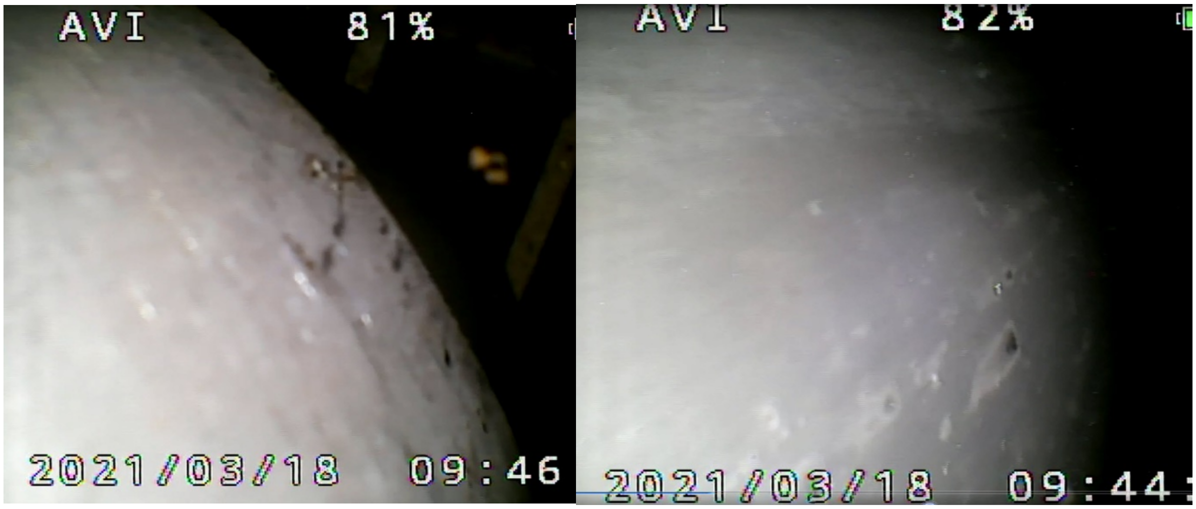


0° SW

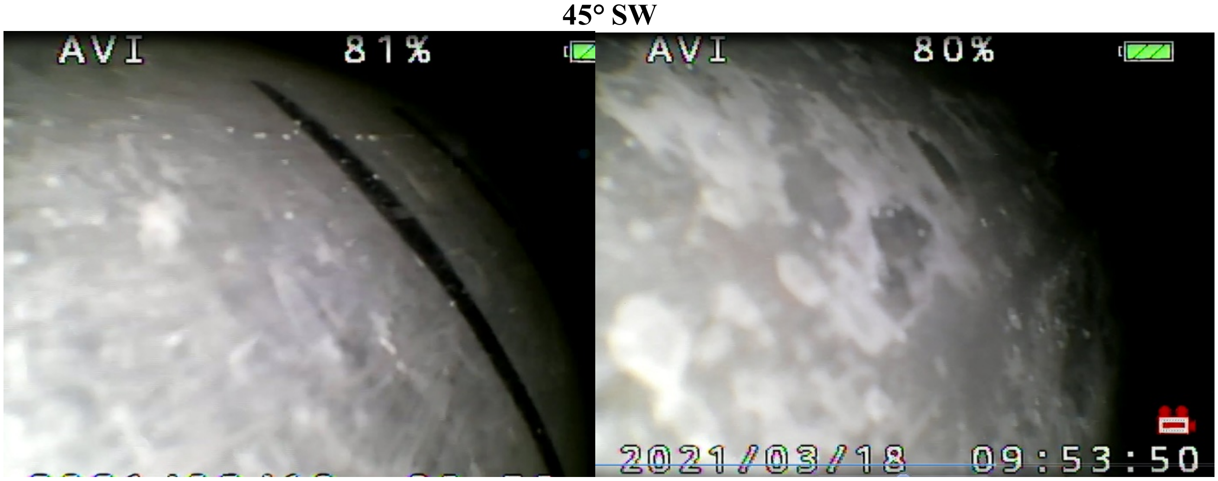
45° NE

45° NW

45° SE



45° SW



Bottom