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Wide Area 3D Measurement System for Analysis of 3013 Inner Container Closure Weld Region

Michael J. Martínez-Rodríguez

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EXECUTIVE SUMMARY

One of the main focus areas of the 3013 Surveillance Program is a thorough evaluation of the inner container closure weld region (ICCWR) opened for destructive examination (DE). As part of the protocol to investigate the corrosion in the ICCWR, a laser confocal microscope (LCM) is used to perform close visual examination of the surface and to measure corrosion features on the surface. However, in FY20, the introduction of the Wide Area 3D Measurement System (WAMS) was tested as a method for faster inspection of the ICCWR. Optimization of the WAMS parameters for data collection was carried out using a generic tear-drop type sample containing large and fine Stress Corrosion Cracking (SCC) fractures and high resolution images were compared to the image obtained with the LCM. Although the image with the LCM shows higher resolution than the WAMS images, the small features can be still identified in the WAMS images. The advantage of collecting data for the full circumference using the WAMS is that it can take about a week to complete, which represents 1/16 of the time needed with the LCM. Nonetheless, both systems offer capabilities that combined can be utilized to expedite the examination of the ICCWR. The WAMS can be utilized to obtain images for faster screening or identification of corrosion features on the surface while the LCM can be utilized to obtain higher resolution images of those areas identified by the WAMS.

The use of the WAMS also represented an opportunity to improve the ICCWR examination protocol. This consisted in eliminating the use of the stereo microscope from the examination protocol for performing a panoramic assembly of the ICCWR, and executing the Scanning Electron Microscope (SEM) of the archive sample and the dye penetrant of the surfaces of the samples on an as-needed basis. The panoramic assembly, using the stereo microscope images, is a slow and cumbersome process with low visibility of corrosion features due to corrosion products still present on the surface. Similarly, performing the SEM of the archive sample before cleaning the corrosion products may not show corrosion features that could be present underneath. Although, SEM can be performed after the corrosion products have been removed, it is not an efficient method to screen larges areas for cracks. Also, although Energy Dispersive Spectroscopy (EDS) has been used to identify chloride species on the surface, it has been more efficient to determine the presence of chlorides using the citric acid washes and ion chromatography. For the case of the dye penetrant test, a better evaluation of the surface to distinguish potential cracks can be performed by using the WAMS. In general, the WAMS results in an efficient overall process with higher magnification images and better visibility of the ICCWR surface for identifying corrosion features.

The updated workflow of the ICCWR examination protocol consist of: (1) the sectioning of the inner container lid into easily handled pieces and weld removal, (2) surface analysis of selected pieces using SEM/EDS only if needed, (3) chemical analysis of selected pieces using wet chemistry techniques (chloride quantification), (4) dye penetrant testing of the samples only if needed, (5) further sectioning of selected pieces into 1/8 can sections in preparation for WAMS/LCM analysis, (6) cleaning selected pieces for removing corrosion products using nitric acid, (7) ICCWR full circumference examination using the WAMS, (8) surface depth profiling and high-magnification imaging using the LCM of selected corroded areas identified by the WAMS, and (9) serial metallography of pieces as necessary.

In FY20, the WAMS was utilized to complete the data collection of the ICCWR full circumference for FY17 DE04 and FY18 DE03. Although analysis of the data will continue for identification of corrosion features, the WAMS was successfully implemented for faster data collection of the full circumference of the ICCWR. Savannah River National Laboratory (SRNL) and the University of South Carolina (USC) have developed methods to extract the data from the WAMS files, without the native software, to be able to apply machine learning and continue working on methods for the analysis of the LCM and WAMS images.

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LIST OF ABBREVIATIONS

DE	Destructive Examination
EDS	Energy Dispersive Spectroscopy
FY	Fiscal Year
HAZ	Heat Affected Zone
IC	Inner Container
ICCWR	Inner Container Closure Weld Region
MIS	Materials Identification and Surveillance
LANL	Los Alamos National Laboratory
LCM	Laser Confocal Microscope
SEM	Scanning Electron Microscope
SCC	Stress Corrosion Cracking
SRNL	Savannah River National Laboratory
USC	University of South Carolina
XRT	X-Ray Tomography
WAMS	Wide Area 3D Measurement System

1.0 Introduction

The 2014 test plan for assessing the potential of stress corrosion cracking (SCC) of the 3013 inner container was issued by the Materials Identification and Surveillance (MIS) Corrosion Working Group to determine if SCC is plausible within the 50-year design life of a 3013 storage container [1]. One of the main focus areas is a thorough evaluation of the inner container closure weld region (ICCWR) opened for destructive examination (DE), which is part of the 3013 Surveillance Program. A protocol to investigate the corrosion in the ICCWR was developed to characterize the type of corrosion (i.e., mechanisms), the extent of corrosion (percentage of area and depth of attack) and the variables impacting this corrosion (chloride concentration and metallurgical condition) [2, 3]. Figure 1 shows an overview of the protocol for the examination of the ICCWR as FY19 [4], which includes some updated steps from the original version [5]. The steps include (1) the sectioning of the inner container lid into easily handled pieces and weld removal, where the sections are labeled as A, B, C and D in clockwise direction when facing the interior of the lid, (2) low-magnification imaging of the entire circumference of the ICCWR, (3) surface analysis of selected pieces using Scanning Electron Microscope (SEM) and Energy Dispersive Spectroscopy (EDS), (4) chemical analysis of selected pieces using wet chemistry techniques, (5) dye penetrant examination of exterior surfaces, (6) further sectioning of selected pieces into 1/8 can sections in preparation for LCM analysis (i.e. section C cut into subsections C1 and C2), (7) cleaning selected pieces for removing corrosion products using nitric acid, (8) surface depth profiling and high-magnification imaging of the cleaned pieces with identified corroded areas within the ICCWR using LCM, and (9) serial metallography of pieces as necessary. Results from this characterization are used to assign a corrosion categorization to the respective ICCWR.

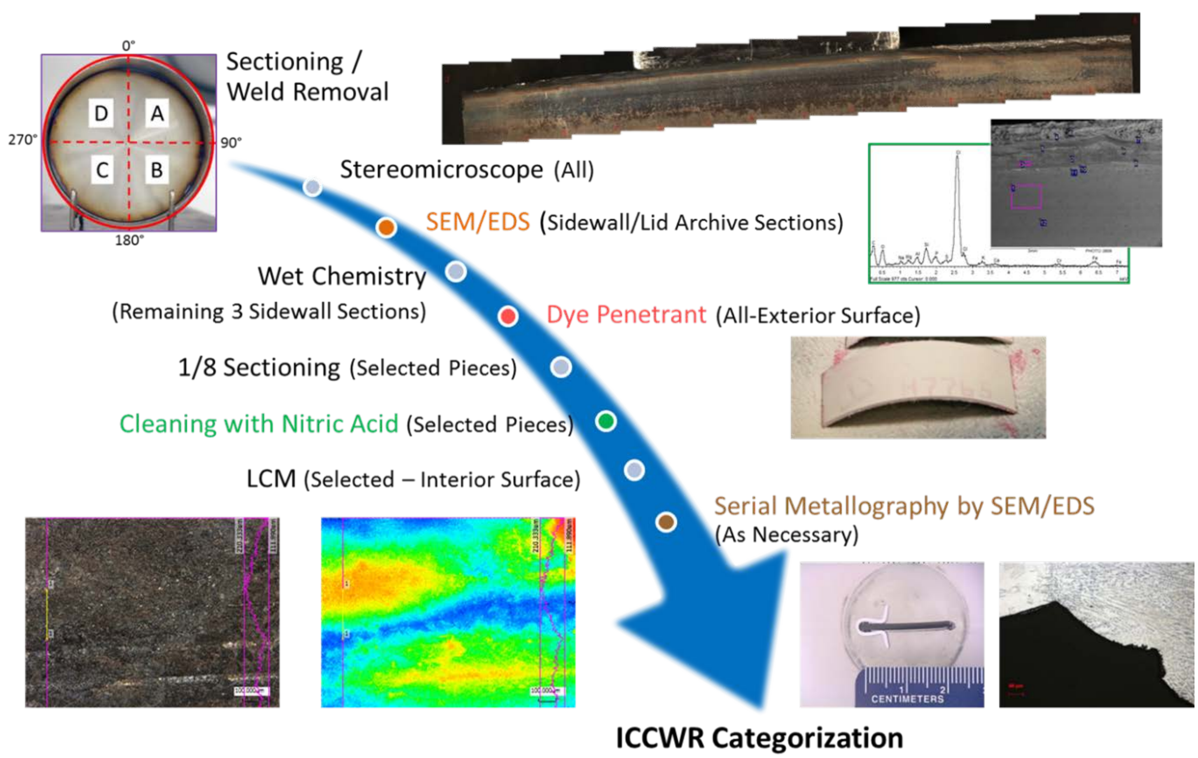

Figure 1. Protocol overview for the examination of the ICCWR.

As part of the ICCWR examination protocol, a Keyence 3D laser confocal microscope (LCM) model VK-X110 is used to perform close visual examination of the surface at the ICCWR and surface profile measurements for pit depths or other corrosion features on the surface. Figure 2 shows the general topography of the ICCWR. In the weld fusion zone, the weld beads on the surface resemble valleys and mountains. In the heat affected zone (HAZ) the surface is mostly flat with a beveled region where the machining marks are located. The fusion zone is considered Zone 1, the region with machining marks is considered Zone 2 and the flat portion of the HAZ is considered Zone 3.

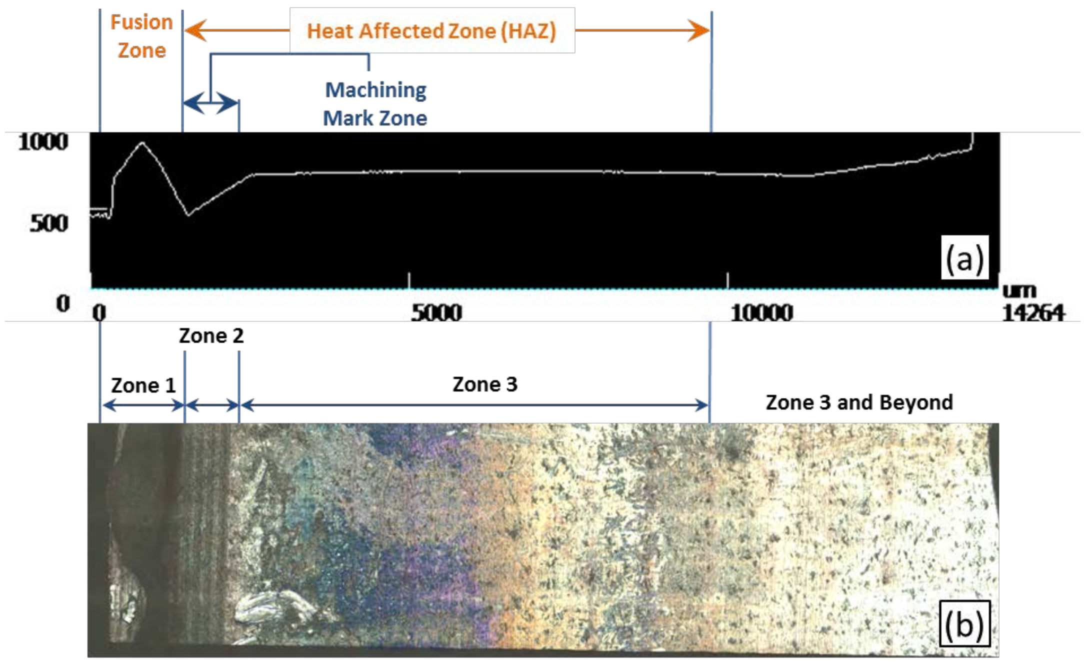

Figure 2. General topography of an ICCWR sidewall sample. Image of FY11 HHMC-90° sidewall showing (a) side view of surface profile and (b) top view optical image of surface [5, 6].

Initial analysis of selected DE containers using the LCM revealed several challenges for acquiring, processing and interpreting the data [5, 7]. These challenges include topography of the ICCWR sample, surface features, and the amount of surface area for collecting data at high magnification conditions. Consequently, the LCM parameters were investigated by imaging several samples with known cracks of different sizes to identify the appropriate parameter values for data acquisition and identification of regions of interest. Using these parameter values, selected DE containers were analyzed to determine the extent of the ICCWR to be examined. These parameters and conditions have been defined and reported in FY17 [6].

DE containers from FY13 through FY16 were evaluated to select candidates for a full circumference analysis of the ICCWR. This information will be used to perform a statistical analysis with Los Alamos National Laboratory (LANL) that will help support a determination of how much of an ICCWR needs to be examined in order to make the assertion of whether or not cracking has occurred and develop an ICCWR sampling plan for analysis of subsequent containers. In FY17, the following DE containers were selected for full circumference analysis of the ICCWR with the following prioritization order: FY15 DE07, FY16 DE05, and FY15 DE08 [6]. In FY18 the selected DE containers for full circumference analysis were processed according to the ICCWR protocol described above [8] and LCM data collection was completed for the full circumference only for FY15 DE07. In FY19 the remaining DE containers were completed [4].

The three ICCWRs show general and localized corrosion on the surface. However, FY15 DE08 show more areas with agglomerated pits in Zones 2 and 3 than the other two DEs. The major suspect corrosion events were observed for FY15 DE07 on Sections C1 and C2 and for FY16 DE05 on Section C2 as shown in Figure 3. These events correspond to suspect cracks or crack-like features identified with a unique name to easily refer to each feature [4, 8]. FY15 DE07 shows a crack-like feature, identified as Acrux, in Section C1 and three features in Section C2 identified as Bellatrix, Cursa Minor and Cursa Major. Acrux and Bellatrix are located at the boundary of Zone 2 and Zone 3. Cursa Minor and Cursa Major are in Zone 2. FY15 DE08 shows two crack-like features, identified as Denebola and Draco, in Section C2. Additional characterization on the locations where the crack-like features were found started in FY20. Sections C1 and C2 of FY15 DE07 were sent to LANL for characterization by X-Ray Tomography (XRT). Section C2 of FY16 DE05 was kept at SRNL to perform serial metallography for characterization of the cross-sections by SEM.

In FY20, the introduction of the Keyence Wide Area 3D Measurement System (WAMS) model VR-5000 was tested as a method for faster inspection of the ICCWR while the LCM can be used to obtain close visual examination of the surface at higher magnification of the areas of interest identified by the WAMS. The use of the WAMS also present an opportunity to improve the ICCWR examination protocol. This report describes the implementation of the WAMS and resulting changes to the ICCWR examination protocol.

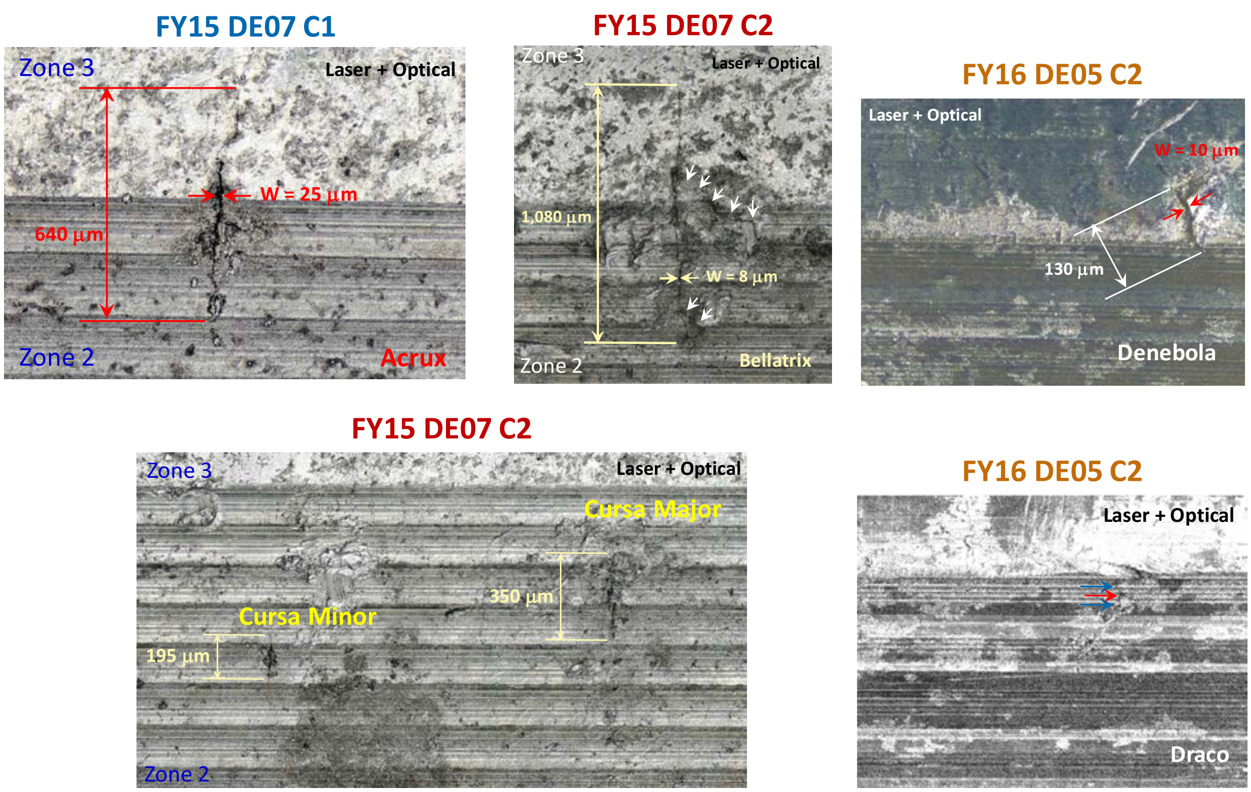

Figure 3. Major suspect corrosion events observed for FY15 DE07 on Sections C1 and C2 and for FY16 DE05 on Section C2.

2.0 Wide Area 3D Measurement System (WAMS)

In FY20, A Keyence VR-5000 optical microscope with 3-dimensional (3D) wide area collection capability was employed to carry out high resolution rapid imaging of the ICCWR samples. The WAMS is a 3D surface microscope, similar to the LCM, with capabilities to collect digital optical images and height measurements. However, the WAMS uses a white LED as the measurement light source compared to the LCM, which uses a red laser as the measurement light source. Figure 4 shows pictures of the Keyence WAMS and LCM used for the examination of the ICCWR. The WAMS has the capability to measure a wide area simultaneously with high accuracy at an unprecedented speed. Although the WAMS can produce high resolutions images, the LCM has the capability to produce higher resolution images, due to its laser source, but at the expense of slower speeds as it has to scan the surface focusing into smaller areas than the WAMS at a time. Nonetheless, both systems offer capabilities that combined can be utilized to expedite the examination of the ICCWR. The WAMS can be utilized to obtain images for faster screening or identification of corrosion feature on the surface while the LCM can be utilized to obtain higher resolution images of those areas identified by the WAMS.

(a) WAMS: *Fast Screening of Large Areas.*

(b) LCM: *Smaller Section Details at Higher Resolution.*

Figure 4. Microscopes for examination of the ICCWR: (a) Keyence Wide Area 3D Measurement System (WAMS) model VR-5000 and (b) Keyence Laser Confocal Microscope (LCM) model VK-X110.

The LCM has been used to produce data with high magnification images for the full circumference of the ICCWR but it is a time intensive task with large number of images [8]. This is because the curvature of the sample (in the x-direction) and the tilt (in the x and y direction) increases the data collection time as it increases the range in the z-direction that the LCM needs to scan and focus the image. It required approximately 4 months to complete the full circumference of FY15 DE07, which produced more than 10,000 images. These images required stitching to obtain a larger view of the area to be analyzed. Conversely, the WAMS can produced the data into a single file and image of the whole sample stitched automatically as shown in Figure 5 for the case of the baseline container. This image represents 1/8 of the circumference of the ICCWR and can take 0.5 – 4 hrs to collect the data depending of the parameters chosen and desired resolution. Consequently, collecting data for the full circumference using the WAMS can take about a week to complete, which represents 1/16 of the time needed with the LCM.

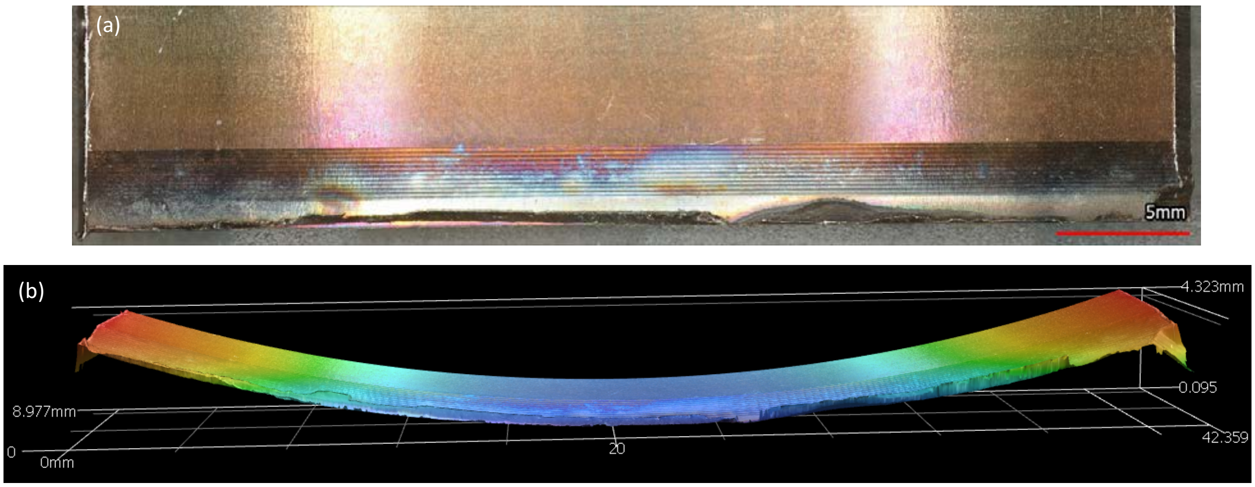

Figure 5. Baseline container CPD-6 Section D1 showing (a) WAMS optical image of the ICCWR and (b)corresponding WAMS height measurement 3D image.

3.0 Updates to the ICCWR Examination Protocol

The introduction of the WAMS represented an opportunity to improve the ICCWR examination protocol. One of the first steps, after sectioning and removing the weld of the inner container (IC) lid, is collecting images with the stereo microscope of the ICCWR and performing a panoramic assembly of the images. However, this process is performed manually, and it is time consuming. In addition, at this point of the examination protocol, the samples have corrosion products, which covers any cracks or other corrosion features that could be present underneath. In contrast, with the WAMS, collecting images of the ICCWR is performed after the sample have been cleaned from corrosion products. Table 1 shows a comparison and advantages of collecting images with the WAMS for examination of the full circumference instead of using a stereo microscope and manually assembling the images. The WAMS results in an efficient overall process with higher magnification images and better visibility of the ICCWR surface for identifying corrosion features. Consequently, the use of the stereo microscope can be eliminated from the examination protocol for performing a panoramic assembly of the ICCWR.

Table 1. Comparison of the stereo microscope for performing a panoramic assembly of the ICCWR with application of the WAMS.

Description	Stereo Microscope (Panoramic Assembly)	WAMS
Occurrence	After Sectioning and Removing Weld of IC Lid	After Cleaning of Corrosion Products
Image Collection	Low Magnification	High Magnification
Image Assembly	Manual Panoramic Assembly	Automatic Stitching by Software
Process	Time Consuming / Cumbersome	Time/Work Saving
Corrosion Products	Present	Removed

The ICCWR examination protocol also include steps, such as SEM/EDS of the archive sample and dye penetrant of the surfaces of the samples. As described previously, utilization of the WAMS offer a fast method of collecting images of the full circumference of the ICCWR with enough magnification to screen for corrosion features after the samples have been cleaned from corrosion products. Performing SEM of the archive sample has the disadvantage that corrosion products are still present on the surface. Although, SEM can be performed after the corrosion products have been removed, it is not an efficient method to screen larges areas for cracks. Also, although EDS has been used to identify chloride species on the surface, it has been more efficient to determine the presence of chlorides using the citric acid washes and ion chromatography [8]. Unless, there is a need to perform SEM/EDS before removing corrosion products, this step can be performed on an as-needed basis. Another step that can be performed on an as-needed basis is the dye penetrant [5]. The rough surface near the ICCWR can retain some dye that can be released during the developer step and make it difficult to distinguish potential cracks. A better evaluation of the surface can be performed by using the WAMS. By executing these steps on an as-needed basis will help to move the samples faster down the ICCWR examination workflow. Figure 6 shows an updated workflow of the ICCWR examination protocol, which includes the changes explained above, the LCM being utilized to obtain higher resolution images of those areas identified by the WAMS, and techniques, such as XRT and serial metallography, for further characterization of corrosion feature as necessary.

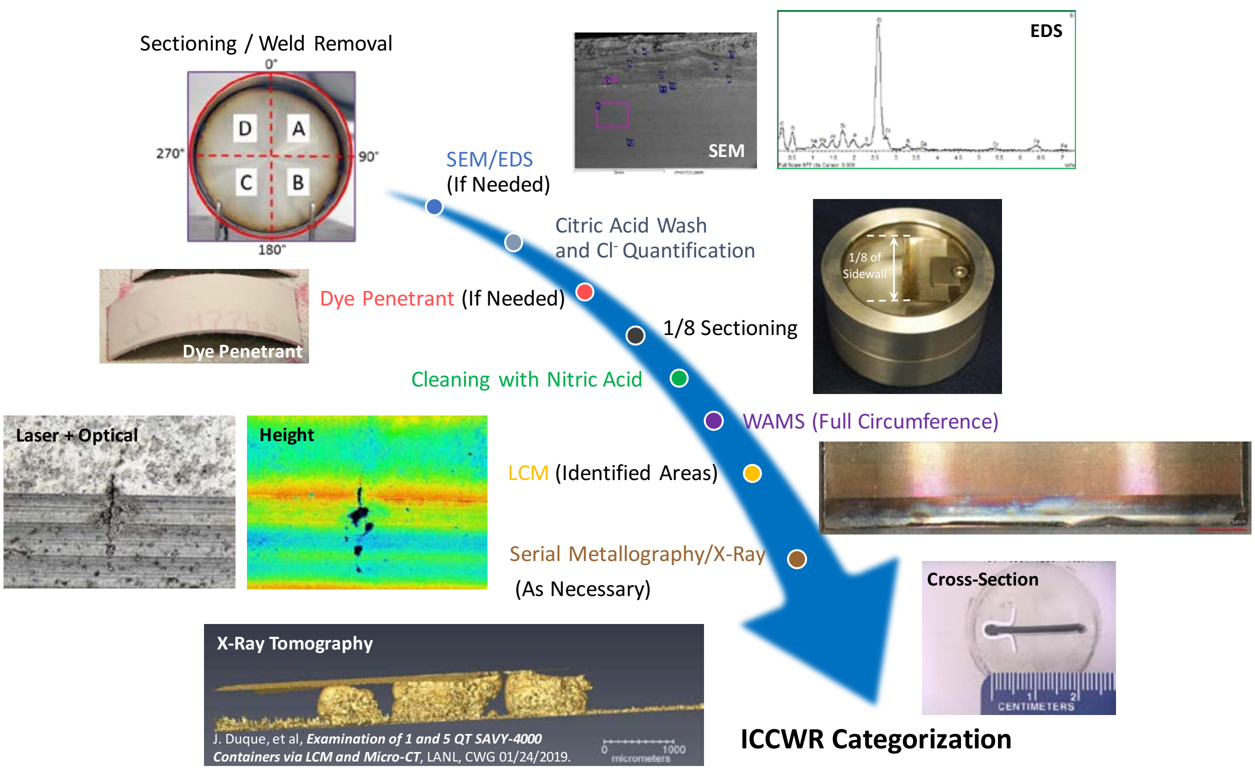

Figure 6. Updated protocol for the examination of the ICCWR.

4.0 Evaluation of DE Containers from the Backlog for Starting ICCWR Examination

When the LCM parameters were established for analyzing the ICCWR, DE containers from FY13 through FY16 were evaluated and three candidates were selected for the full circumference analysis of the ICCWR [6]. This evaluation was expanded to include DEs from FY17 and FY18 to select candidates to start the ICCWR examination on DEs from the backlog. Table 2 shows a summary of the DE containers divided in three groups: (1) not selected, (2) honorable mention, and (3) finalists. The standard categorization for each DE container set is indicated in Table 2 with the definitions of each category given in Table 3. The three DE containers indicated as completed correspond to the DEs selected for the full circumference analysis of the ICCWR, which was completed in FY19.

Table 2. Standard corrosion categorization for 3013 containers.

Category	Description
0	Nothing or wipeable coating
0*	Rocky Flat (RF) and Lawrence Livermore (LL) can if corrosion is observed
1	Adherent coating on convenience can
2	Pitting <50 µm on convenience can
3A	Suspect pitting > 50 µm on convenience can – pit covered with corrosion
3B	Confirmed pitting > 50 mm on convenience – generally confirmed with SEM
4	Adherent coating on inner can
5	Pitting < 50 µm on inner can
6	Pitting > 50 µm on inner can
7	SCC in the inner can

The candidates for starting the ICCWR on DEs from the backlog were selected as those likely having more corrosion features in this region. Parameters such as, higher humidity at DE, coating observed on the convenience container, material or "stuff" found on top of the weld oxide, dust in the inner container, and signs of corrosion observed with the stereo microscope increases the possibilities of finding corrosion in the ICCWR. The same process for selection discussed in the previous report [6] is presented here as reference. DE inner containers that did not show signs of corrosion were not selected. Generally, this group corresponds to DE containers with categories 3B and below. These categories are assigned to DE containers with corrosion features in the convenience container which also correspond to DE containers that do not show corrosion in the inner container. Honorable mention is the group of DE containers with categories 4 and above which have corrosion features, but these features occur in less magnitude than the DEs selected as finalist. Categories 4 and above correspond to the containers with corrosion features such as adherent coating and pitting in the inner can. The finalist group contains the candidates for the full circumference analysis of the ICCWR.

The recommended finalist group contains the candidates for starting the analysis of the ICCWR on DEs from the backlog. The DE containers in the recommended finalist group are FY15 DE06, FY16 DE02, FY17 DE04, FY18 DE03 and FY17 DE02. Images of these DE containers are shown in Figure 7. The parameters for the likelihood of finding corrosion in the ICCWR are color coded as green (low), yellow (medium), and red (high). The overall ranking of the DEs with higher probability of finding corrosion in the ICCWR is ordered from left (low) to right (high) as shown

Table 3. Summary of DE containers from the backlog evaluated for starting the ICCWR examination.

							Conv Can Appearance		IC Lid Appearance			
DE ID		Standard Categorization	Not Selected	Honorable Mention	Finalist	Humidity at DE	Coating	Adherent?	Weld Oxide	Stuff on Top of Weld Oxide	Stereo Microscope	Notes
FY13	DE01	6		x								
FY14	DE01	0	x									
	DE02	3A	x									
	DE03	3A	x									
	DE04	3A	x									
	DE05	3A	x									
	DE06	0	x									
	DE07	0	x									
	DE08	4		x		1.5	HS / Lid	Yes	Blue (25%)	White	GC	
	DE09	0	x									
FY15	DE01	0*	x									
	DE02	0	x									
	DE03	0	x									
	DE04	0		x		0.6	Dust		Blue	White		Water stain mark on IC lid.
	DE05	6		x		1.6	Dust		Blue	White		Cat 6 bc only 1 pit.
	DE06	5			x	1.6	HS / Lid	Yes	Blue	White/Brown	GC	
	DE07	5			x (1st FC)	1.8	HS / Lid	Yes	Blue	White		IC with dust inside.
	DE08	5			x (3rd FC)	2.8	Dust		Blue	White/Brown	Ring on Sidewall	Visible suspect corrosion close to gap opening.
	DE09	3A	x									
FY16	DE01	3A	x									
	DE02	6			x	4.5	HS / Lid	Yes	Blue	White/Brown	Ramdon Pitting	
	DE03	6+			x	1.4	HS / Lid	Yes	Blue	White	Ramdon Pitting	Shows suspect spot outside of IC.
	DE04	3A	x									
	DE05	6			x (2nd FC)	1	HS / Lid	Yes	Blue	White	Ramdon Pitting	
	DE06	3A	x									
FY17	DE01	4	x									
	DE02	6			x	7	HS / Lid	Yes	Blue	White/Brown	GC / Pitting	IC with dust inside.
	DE03	5		x		3.9	Clean		Blue	White	GC / Pitting	
	DE04	6			x	2.6	HS	No	Blue	White/Brown	GC / Pitting	IC with dust inside.
	DE05	5		x		2.8	Clean		Blue	White	GC / Pitting	
	DE06	0	x									
FY18	DE01	5		x		3.5	HS	No	Blue	White	GC / Pitting	
	DE02	6			x	2.2	HS / Lid	Yes	Blue	White	GC / Pitting	
	DE03	6			x	5.7	HS / Lid	Yes	Blue	White/Brown	GC / Pitting	IC with dust inside.
	DE04	5			x	1.1	HS / Lid	No	Blue	White	GC / Pitting	
	DE05	6			x	0.5	HS / Lid	Yes	Blue	White	GC / Pitting	
	DE06	6			x	1.4	Light Dust		Blue	White	GC / Pitting	

GC = General Corrosion HS = Headspace
IC = Inner Container

Completed	Hold	Finalist	Recommended Finalist

in Figure 7.Consequently, FY17 DE02 and FY18 DE03 were recommended as the candidates to start the ICCWR examination. Before sectioning the inner container lids, He leak testing was performed on these lids [9]. However, a non-flat stainless-steel seal ring adhered to FY17 DE02 caused issues on obtaining a good seal on this lid. Consequently, while troubleshooting was performed on this lid, FY17 DE04 was used as the next lid, together with FY18 DE03, for starting the analysis of the ICCWR.

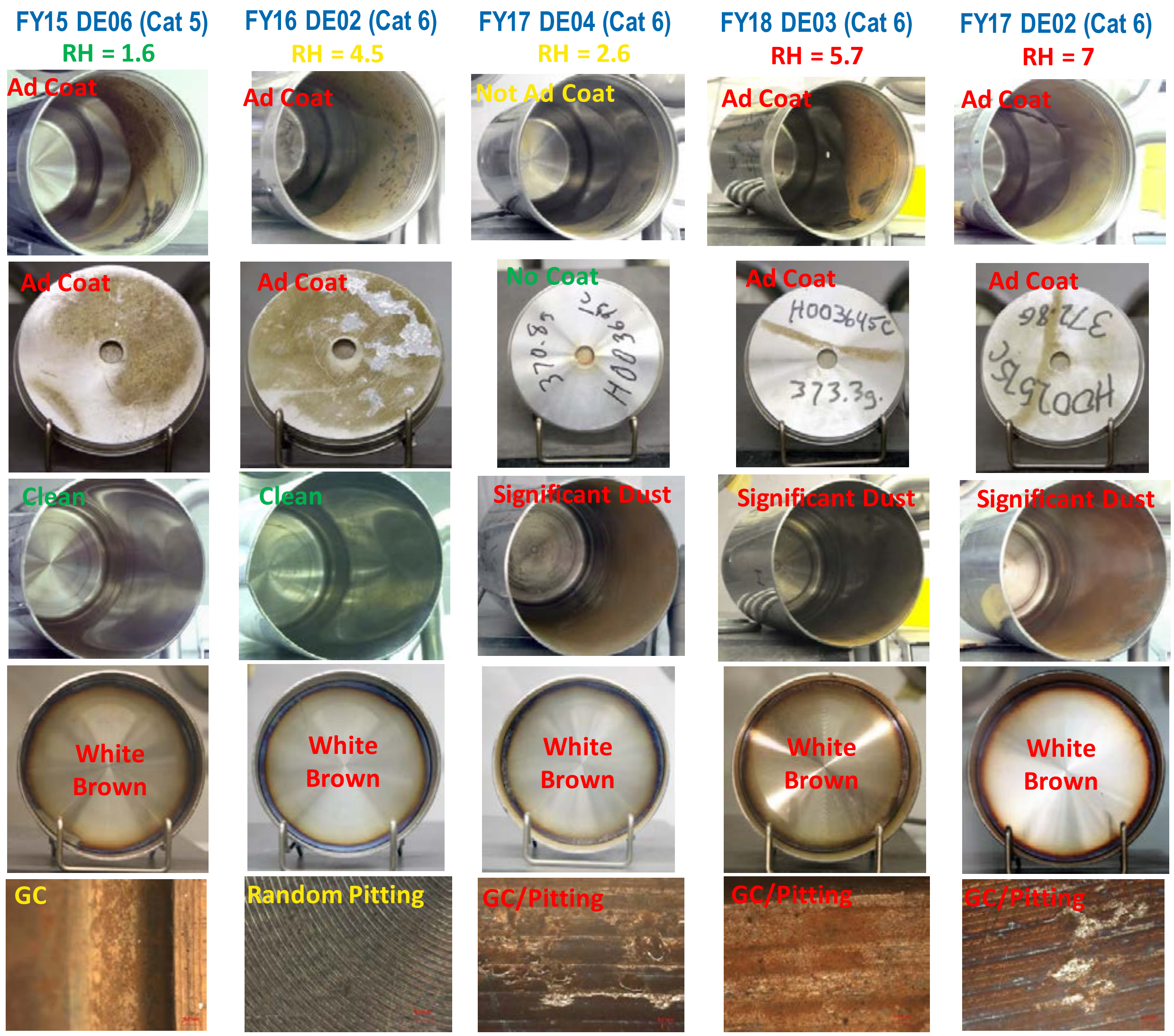

Figure 7. Recommended candidates for starting the examination of the ICCWR on DEs from the backlog (Ad Coat = Adherent Coating, GC = General Corrosion).

5.0 ICCWR Examination by WAMS

Optimization of the WAMS parameters for data collection was carried out to resolve very fine fractures or corrosion features on the ICCWR. A generic tear-drop type sample containing large and fine SCC fractures was employed to carry out the optimization process. The following parameters, but not limited to, were considered in the optimization process:

- Automatic Options: Full Auto, Auto High Resolution, Manual.

- Magnification: 40X and 160X.
- Focus Options: Z-axis motion – To explore the differences between Automatic and Specified Limits options.
- Light Sources: To attempt to enhance shadows (the WAMS has a left and right light sources).
- Collection Mode: Fine or Standard.
- Camera Setting: Exposure - To minimize image saturation due to reflective surfaces. Considered Auto and Manual options.
- Camera Setting: Brightness - To minimize image saturation due to reflective surfaces.
- Camera Setting: Edge Enhance – To digitally enhance edges.
- Image Color: Color and Monochrome – To control pixel coloration issues that may contribute image noise.
- Skip Setting - Controls collection speed by skipping data collection lines.

After comparing the images obtained on the tear-drop sample with the different parameters the following optimized parameters were selected:

- Microscope Parameters
  - Mode: Fine, High Resolution (Topography)
  - Magnification: High magnification 40X
  - Measurement Brightness: Auto-80
  - Skip setting of stitched image: Do not skip
  - Specify Z-range: Varies
  - Light sources: Both. Depends on surface reflectivity
- Camera Settings
  - Light: Manual Setting. Depends on surface reflectivity
  - Color Option: Color and Monochrome (collect both for comparisons)
  - Camera image edge enhance: Sample dependent (3.0 used in most samples as it provides a better balance between sharpness and pixilation)
- Other Settings
  - Auto focus (Area size): Small
  - Matrix size: Up to 25 MP (microscope total image size limit)

High resolution images of the tear-drop sample obtained with the LCM and WAMS are shown in Figure 8. The optimized parameters for the LCM image are discussed in reference [6]. The optimized parameters for the WAMS images are those discussed above. Although the image with the LCM shows higher resolution than the WAMS images, the small features can be still identified in the WAMS images. Comparison of the color and monochrome images from the WAMS aided in the identification of cracks and other defects.

FY15 DE02 Section C2 where potential cracks were found was used for additional comparison between the LCM and the WAMS. FY15 DE02 Section C2 is the ICCWR sample where Bellatrix, Cursa Minor and Cursa Major are located [4]. Figure 9 shows the comparison using the images for Bellatrix while Figure 10 shows the comparison using the images for Cursa Minor and Cursa Major. Although the WAMS displays lower resolution, cracking and pitting observed in the LCM can be discerned using the WAMS. The WAMS images were obtained one year after the LCM images, which showed that the samples may have undergone some changes over time. Nonetheless, the WAMS results show that it can be utilized to obtain images for faster screening or identification of corrosion feature on the surface while the LCM can be utilized to obtain higher resolution images of those areas identified by the WAMS.

In FY20 the WAMS was utilized to start the examination of the ICCWR full circumference for FY17 DE02 and FY18 DE03. Appendices A and B show all the images obtained with the WAMS using the optimized parameters discussed above. Although analysis of the data will continue for identification of corrosion features, the WAMS was successfully implemented for faster data collection of the full circumference of the ICCWR. SRNL and the University of South Carolina (USC) have developed methods to extract the data from the WAMS files, without the native software, to be able to apply machine learning and continue working on methods for the analysis of the LCM and WAMS images [10].

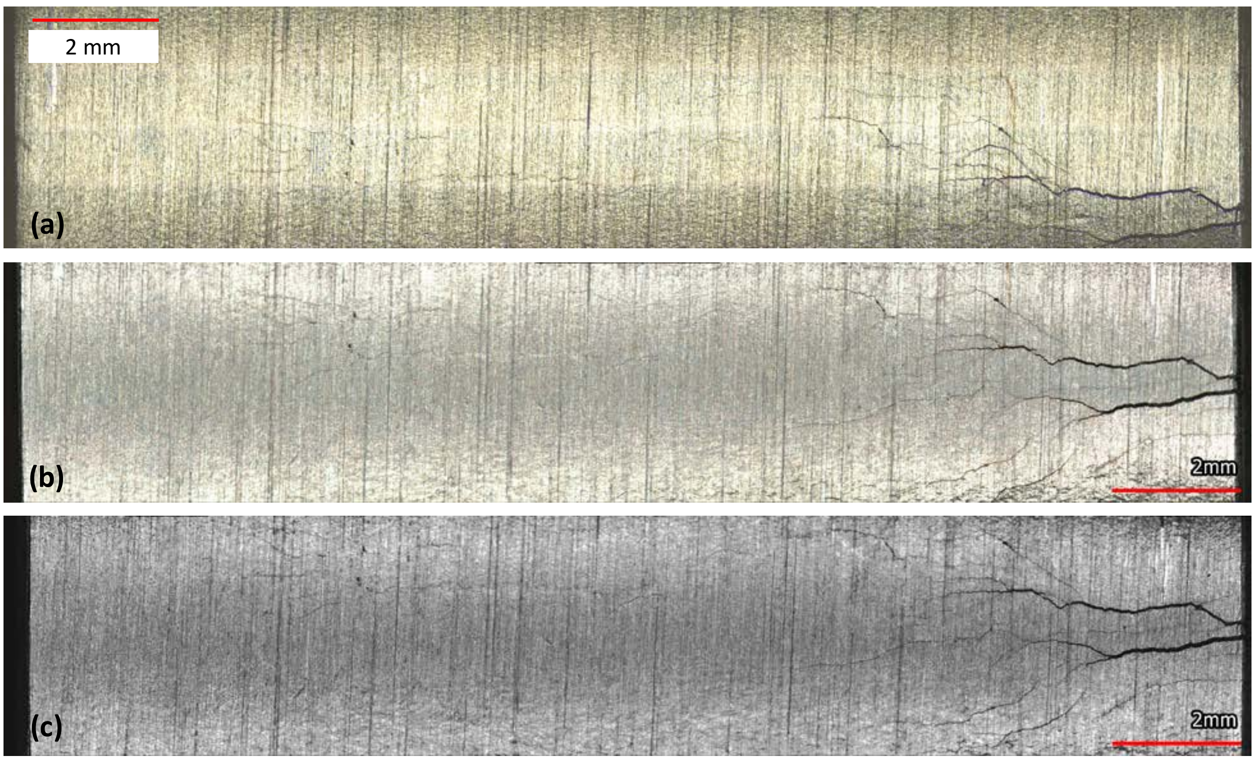

Figure 8. High resolution images of a generic tear-drop type sample containing large and fine SCC fractures. Images obtained with (a) LCM, (b) WAMS in color mode and (c) WAMS in monochrome mode.

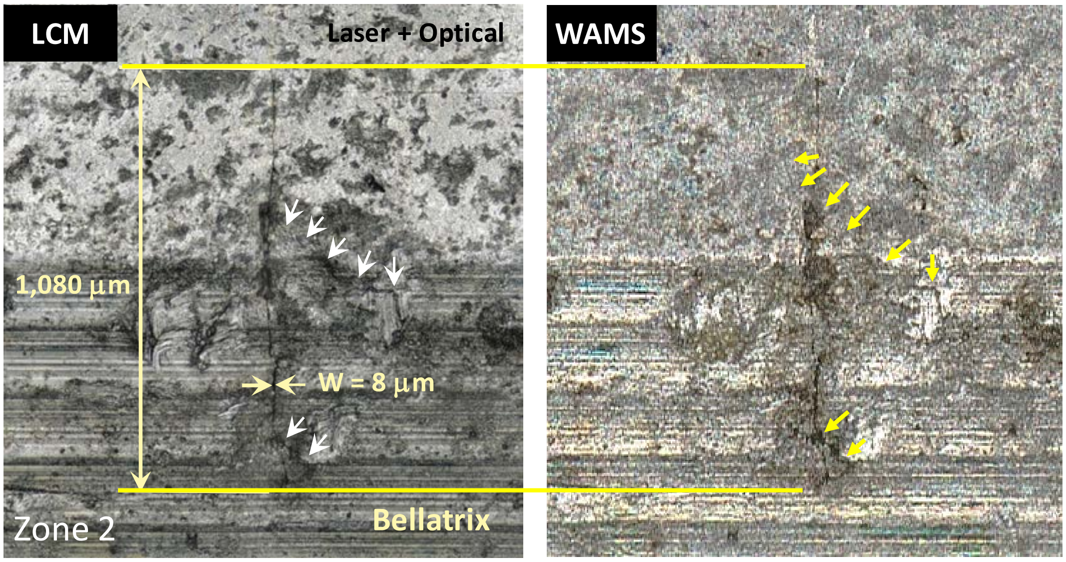

Figure 9. Comparison between the LCM and the WAMS for FY15 DE02 Section C2 containing Bellatrix.

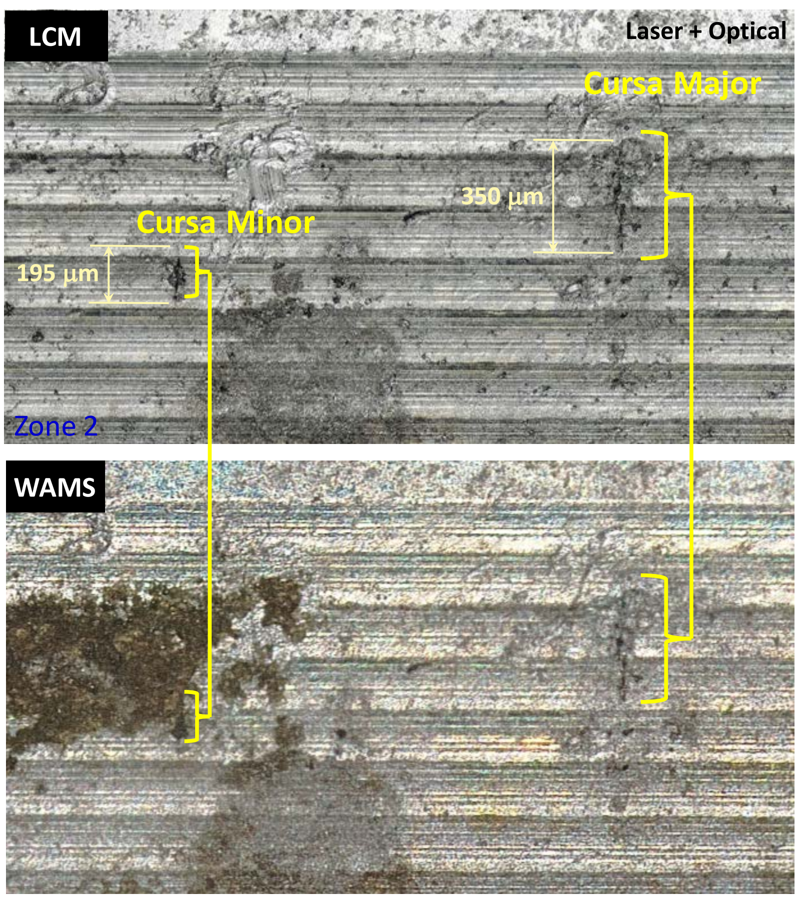

Figure 10. Comparison between the LCM and the WAMS for FY15 DE02 Section C2 containing Cursa Major and Cursa Minor.

6.0 Conclusions

In FY20, the introduction of the Keyence Wide Area 3D Measurement System (WAMS) model VR-5000 was tested as a method for faster inspection of the ICCWR. Optimization of the WAMS parameters for data collection was carried out using a generic tear-drop type sample containing large and fine SCC fractures and high resolution images were compared to the image obtained with the LCM. Although the image with the LCM shows higher resolution than the WAMS images, the small features can be still identified in the WAMS images. Comparison of the color and monochrome images from the WAMS aided in the identification of cracks and other defects. The advantage of collecting data for the full circumference using the WAMS is that it can take about a week to complete, which represents 1/16 of the time needed with the LCM. Nonetheless, both systems offer capabilities that combined can be utilized to expedite the examination of the ICCWR. The WAMS can be utilized to obtain images for faster screening or identification of corrosion features on the surface while the LCM can be utilized to obtain higher resolution images of those areas identified by the WAMS.

The use of the WAMS represented an opportunity to improve the ICCWR examination protocol. This consisted in eliminating the use of the stereo microscope from the examination protocol for performing a panoramic assembly of the ICCWR, and executing the SEM/EDS of the archive sample and the dye penetrant of the surfaces of the samples on an as-needed basis. The panoramic assembly, using the stereo microscope images, is a slow and cumbersome process with low visibility of corrosion features due to corrosion products still present on the surface. Similarly, performing the SEM of the archive sample before cleaning the corrosion products may not show corrosion features that could be present underneath. Although, SEM can be performed after the corrosion products have been removed, it is not an efficient method to screen larges areas for cracks. Also, although EDS has been used to identify chloride species on the surface, it has been more efficient to determine the presence of chlorides using the citric acid washes and ion chromatography. For the case of the dye penetrant test, a better evaluation of the surface to distinguish potential cracks can be performed by using the WAMS. In general, the WAMS results in an efficient overall process with higher magnification images and better visibility of the ICCWR surface for identifying corrosion features. The implementation of these changes contributes to move the samples faster down the ICCWR examination workflow.

Evaluation of DE containers from FY13 through FY18, excluding FY15 DE07, FY15 DE08 and FY16 DE05, was performed to select candidates to start processing DEs from the backlog for the full circumference analysis of the ICCWR. The recommended finalist group consisted of FY15 DE06, FY16 DE02, FY17 DE04, FY18 DE03 and FY17 DE02. In FY20, the WAMS was utilized to complete the data collection of the ICCWR full circumference for FY17 DE04 and FY18 DE03. Although analysis of the data will continue for identification of corrosion feature, the WAMS was successfully implemented for faster data collection of the full circumference of the ICCWR. SRNL and the USC have developed methods to extract the data from the WAMS files, without the native software, to be able to apply machine learning and continue working on methods for the analysis of the LCM and WAMS images.

7.0 References

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Appendix A. WAMS of ICCWR Sidewall Sections of FY17 DE04

Figure A.1. High resolution image obtained with the WAMS for FY17 DE04 Sidewall Section A1.

Figure A.2. High resolution image obtained with the WAMS for FY17 DE04 Sidewall Section A2.

Figure A.3. High resolution image obtained with the WAMS for FY17 DE04 Sidewall Section B1.

Figure A.4. High resolution image obtained with the WAMS for FY17 DE04 Sidewall Section B2.

Figure A.5. High resolution image obtained with the WAMS for FY17 DE04 Sidewall Section C1.

Figure A.6. High resolution image obtained with the WAMS for FY17 DE04 Sidewall Section C2.

Figure A.7. High resolution image obtained with the WAMS for FY17 DE04 Sidewall Section D1.

Figure A.8. High resolution image obtained with the WAMS for FY17 DE04 Sidewall Section D2.

Appendix B. WAMS of ICCWR Sidewall Sections of FY18 DE03

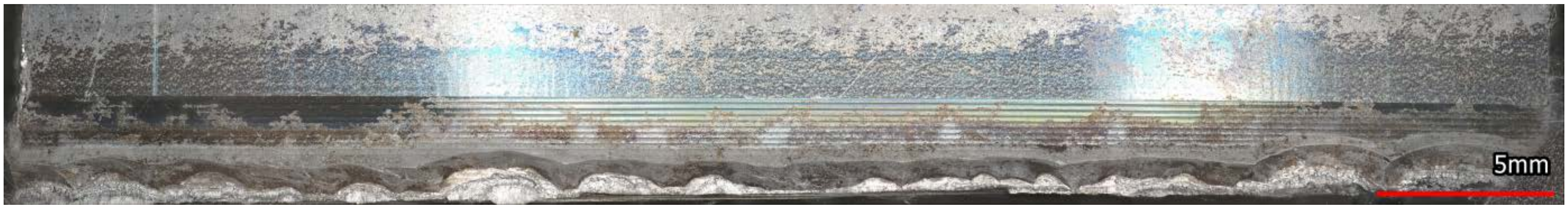

Figure B.1. High resolution image obtained with the WAMS for FY18 DE03 Sidewall Section A1.

Figure B.2. High resolution image obtained with the WAMS for FY18 DE03 Sidewall Section A2.

Figure B.3. High resolution image obtained with the WAMS for FY18 DE03 Sidewall Section B1.

Figure B.4. High resolution image obtained with the WAMS for FY18 DE03 Sidewall Section B2.

Figure B.5. High resolution image obtained with the WAMS for FY18 DE03 Sidewall Section C1.

Figure B.6. High resolution image obtained with the WAMS for FY18 DE03 Sidewall Section C2.

Figure B.7. High resolution image obtained with the WAMS for FY18 DE03 Sidewall Section D1.

Figure B.8. High resolution image obtained with the WAMS for FY18 DE03 Sidewall Section D2.