Pacific Gas and Electric Company

EPIC Final Report

Program	***Electric Program Investment Charge (EPIC)***
Project	***EPIC 3.46 – Advanced Electric Inspection Tools – Wood Poles***
Reference Name	***Radiography of Utility Wood Poles***
Department	*Asset Risk Management*
Project Sponsor	Jim Gill
Project Business Lead Contact Info	Daniel Rakin EPIC_Info@pge.com
Date	August 23, 2024
Version	Final

Table of Contents

List of Tables

List of Figures

Table of Acronyms (Alphabetized)

ATS	Applied Technology Services
CEC	California Energy Commission
CR	Computed Radiography
DR	Digital Radiography
FEA	Finite Element Analysis
IRRSP	Industrial Radiography Radiation Safety Personnel
IOU	Investment Owned Utilities
kVp	kilovoltage peak
NDE	Nondestructive Examination
mA	milliAmps
mR	milliRoentgen
PG&E	Pacific Gas & Electric
PTT	Pole Test and Treat
RT/ X-Ray	Radiographic Testing

1 Executive Summary

This report summarizes the project objectives, technical results and lessons learned for EPIC Project 3.46 – Advanced Electric Inspection Tools – Wood Poles as listed in the EPIC Annual Report.

Although PG&E has an extensive condition monitoring program for wood poles (pole test and treat (PTT) inspection), the health evaluation is determined from intrusive testing at or near groundline. Intrusive testing may not provide an overall representation of the wood pole condition due to the limited quantity of drill holes made throughout the base of the pole.

The primary objectives of this project are 1) demonstrate that radiographic testing (RT), a nondestructive testing method, can detect degradation in the form of decay and 2) demonstrate that a portable x-ray imaging unit can take place of traditional computed radiography (CR). The portable x-ray unit could then be used as a supplemental inspection method to the current PTT inspection method.

Key Accomplishments

The following summarizes some of the key accomplishments of the project over the project duration:

- Demonstrated that computed radiography can produce high quality x-ray images to identify areas of decay.
- Demonstrated that real-time radiography can produce comparable x-ray images to computed radiography.
- Identifying a safe and low radiation dose real-time x-ray imager that can be used to capture high quality images by trained personnel.
- Designed and built a track system for the x-ray device solving x-ray image quality issues.

Key Takeaways

The following findings are the key takeaways and lessons learned from this project:

- Both computed and real-time radiography can produce high quality x-ray images displaying the extent of decay or voids.
- Portable real-time x-ray imaging devices are not capable of retrieving an image at or below groundline.
- Operationalizing the portable real-time x-ray imaging device and inspection technique would require licensed radiographers to interpret the images of the inspected wood poles.

Challenges and Resolutions

This project faced several challenges in which the most significant is detailed below.

- Real-time x-ray imaging devices are unable to inspect wood poles below groundline or near pole obstructions.
- Radiography provides a 2D image. Quantifying the spatial void or remaining quantity of sound wood present would require several profile clock position x-ray images.
- Only a single viable portable real-time x-ray imaging device was identified and evaluated.
- The x-ray imaging device overheats with high usage.

Recommendations

- The utility pole diameters can be much larger than the current 14-inch DR panel arm diameter capacity. A variation of DR panel arm lengths would accommodate larger diameter poles.

Conclusion
The team identified several significant findings.

- The nondestructive examination method of radiographic testing via computed radiography and real-time radiography imaged the decay in wood poles.
- A viable real-time x-ray imaging device was shown to produce high quality x-ray images comparable to computed radiography.
- Trained and qualified operators using the identified device can produce high quality x-ray images in both a laboratory and field setting.
- The team determined that operationalizing the technology to serve as an alternative inspection method is not feasible. This is driven by the device's inability to inspect below groundline or near obstructions.

PG&E's technical center, ATS, will continue to utilize these radiographic techniques on wood poles. This technology can be utilized to document existing conditions prior to destructive testing. The x-ray images produced provide guidance for destructive testing.

2 Introduction

This report documents the EPIC 3.46 – *Advanced Electric Inspection Tools – Wood Poles* project achievements, highlights key learnings from the project that have industry-wide value, and identifies future opportunities for PG&E to leverage this project.

The California Public Utilities Commission (CPUC) passed two decisions that established the basis for this demonstration program. The CPUC initially issued D. 11-12-035, *Decision Establishing Interim Research, Development and Demonstrations and Renewables Program Funding Level*[1], which established the Electric Program Investment Charge (EPIC) on December 15, 2011. Subsequently, on May 24, 2012, the CPUC issued D. 12-05-037, *Phase 2 Decision Establishing Purposes and Governance for Electric Program Investment Charge and Establishing Funding Collections for 2013-2020*[2], which authorized funding in the areas of applied research and development, technology demonstration and deployment (TD&D), and market facilitation. In this later decision, CPUC defined TD&D as "the installation and operation of pre-commercial technologies or strategies at a scale sufficiently large and in conditions sufficiently reflective of anticipated actual operating environments to enable appraisal of the operational and performance characteristics and the financial risks associated with a given technology."[3]

The decision also required the EPIC Program Administrators[4] to submit Triennial Investment Plans to cover three-year funding cycles for 2012-2014, 2015-2017, and 2018-2020. On November 1, 2012, in A.12-11-003, PG&E filed its first triennial Electric Program Investment Charge (EPIC) Application with the CPUC, requesting $49,328,000 including funding for 26 Technology Demonstration and Deployment Projects. On November 14, 2013, in D.13-11-025, the CPUC approved PG&E's EPIC plan,

---

[1] http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/156050.PDF
[2] http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/167664.PDF
[3] Decision 12-05-037 pg. 37
[4] Pacific Gas & Electric (PG&E), San Diego Gas & Electric (SDG&E), Southern California Edison (SCE), and the California Energy Commission (CEC)

including $49,328,000 for this program category. On May 1, 2014, PG&E filed its second triennial investment plan for the period of 2015-2017 in the EPIC 2 Application (A.14-05-003). CPUC approved this plan in D.15-04-020 on April 15, 2015, including $51,080,200 for 31 TD&D projects.[5] On April 28, 2017, PG&E filed its third triennial investment plan for the period of 2018 – 2020 in the EPIC 3 Application (Application (A. 17-04-028). The CPUC approved this plan in D.18-10-052 on October 25, 2018 including $55,600,000 for 43 TD&D projects[6] .

Pursuant to PG&E's approved 2018-2020 EPIC triennial plan, PG&E initiated, planned and implemented the following project: 3.46 Radiography of Utility Wood Poles. Through the annual reporting process, PG&E kept CPUC staff and stakeholder informed on the progress of the project. The following is PG&E's final report on this project.

3 Project Summary

The primary objective of this project was to demonstrate that radiographic testing (RT), a nondestructive testing method, can detect degradation in the form of decay or voids and provide a more quantitative evaluation of utility wood pole health. The intention was to avoid the need to further weaken or damage the wood pole by performing intrusive testing which requires an inspector to drill into the base of the wood pole. Nondestructive testing may provide an opportunity to better analyze the overall health and condition of wood poles. The nondestructive data collection could further improve the forecasting of wood pole replacements and provide for data driven decisions on wood pole repairs.

3.1 Issue Addressed

PG&E's pole test and treat program oversees the intrusive inspection of approximately 230,000 wooden poles every year among the 2.3 million poles in service. Approximately 4,000 wood poles are replaced annually from failed intrusive inspections.

The primary factors that affect the service life of utility poles are fungi, insects, inadequate impregnation, deep cracks and splits. Currently PG&E's wood pole inspection consists of a visual, sound (hammer test) and intrusive (bore and probe test) inspection. The visual assessment seeks to identify any areas of external damage or deterioration. The sound inspection consists of striking a framing hammer on the surface of the pole near the groundline to as high as can be reached (typically 6 feet) to identify internal voids or hollowness. Decay pockets would be indicated by a dull sound or a less pronounced hammer rebound. An intrusive inspection consists of drilling a hole(s) and using a shell thickness gauge to determine the amount of sound wood is remaining. Drilling commonly takes place up to 20 inches below the groundline; this is the most prone area for decay to occur.

Although PG&E has an extensive condition monitoring program for wood poles, the health evaluation is determined from intrusive testing. Intrusive testing may not provide an accurate overall

---

5 In the EPIC 2 Plan Application (A.14-05-003), PG&E originally proposed 30 projects. Per CPUC D.15-04-020 to include an assessment of the use and impact of EV energy flow capabilities, Project 2.03 was split into two projects, resulting in a total of 31 projects.

[6] CPUC Decision.18-10-052, p. 115

representation of the wood pole health condition due to the limited testing locations at the base of the pole.

3.2 Project Objectives

The following were the primary objectives of the project:

- Validate that computed radiography of utility wood poles can detect degradation in the form of decay, voids or damage.
- Procure a real-time x-ray imaging device that is portable, rugged, and safe to use.
- Validate that real-time radiographic testing can produce similar results in comparison to computed radiography.
  - CR consists of utilizing a film which reacts to emitted radiation to capture an image of the part/ section being tested.
  - Real-time x-ray is produced electronically, rather than on film. This enables an image of the part/ section to be generated in real-time in the field.
- Validate that real-time x-ray can be utilized safely and efficiently as an alternative enhanced internal inspection method without impacting the structural integrity of the wood pole.
- Develop criteria on what types of poles (Pine, Cedar, or Douglas Fir), size and classification of pole can be inspected along with the appropriate settings for each combination.
- Implement supplemental inspection method for Electric field operational use.
- Quantify the decreased rate of wood pole failures.
- Quantify the decreased rate of poles failing prior to replacement.

3.3 Scope of Work and Project Tasks

To achieve the objectives of the project, the scope of work was as follows:

- Proof-of-Concept
- Device Selection and Procurement
- Field Testing
- Scale for Production

3.3.1 Tasks and Milestones

- Procure wood pole samples recently removed from service due to failed pole test and treat inspection.
- Perform computed radiography of the base of the pole at ATS and collect x-ray images at 0 and 90 degrees to identify and locate drill holes or decay.
- Sectionalize previous radiographed sample poles to verify identified areas of drill holes or decay.
- Procure portable real-time x-ray imager and acquire manufacture training.
- Perform real-time x-ray on received failed wood poles and compare images to baseline computed radiography images.
- Test and determine best settings of the device that will yield best results given the pole characteristics or scenario.
- Modify portable real-time x-ray to produce higher quality x-ray images while improving operational ease of use.
- Identify safety precautions and best practices when using real-time x-ray equipment.
- Conduct field demonstration to evaluate effectiveness in comparison to current PTT practices.

- Analyze return-of-investment for technology and inspection implementation.
- Develop endorsement program to qualify electric field inspectors.

4 Project Activities, Results, and Findings

4.1 Technical results and findings – Proof-of-Concept

4.1.1 Technical Development and Methods

Prior to procuring a handheld real-time x-ray imaging instrument, a proof-of-concept was performed to ensure that radiography can successfully detect voids or decay pockets within utility wood poles. ATS collected eight recently removed wood pole samples to test and evaluate.

The assessment included:

- Record review: The PTT inspection reports were the primary records reviewed. PG&E's PTT intrusive inspection determines the remaining strength of the pole. This value is used to determine the Pass/Fail criteria. The PTT reports also contain comments on any identified degradation seen during the inspection.
- As-Received Photographs: The as-received photographs provide an overview of the wood pole butt taken from the field.
- RT imaging: The RT imaging will be used to identify any internal cavities, e.g., woodpecker holes/nests, decay pockets, voids.
- Pole dissection: With the RT images to guide the dissection, appropriate cross-sections will be cut. These cross-sections will be used to validate the RT imagery.

4.1.2 Challenges

The proof-of-concept effort encountered the following challenges:

- The initial challenge was sample collection. This was primarily from managing and coordinating the sample collection efforts across multiple departments.
- The second challenge was quantifying the spatial void or remaining quantity of sound wood present. Radiography provides 2D images. To represent a 3D structure, such as a void or decay pocket, several profile x-ray images in multiple clock positions is required. Interpreting the results of multiple x-ray images quantitatively is not practical.
- The third challenge was associated with the process of computational radiography. CR cannot generate a single continuous x-ray scan. To create a single clock position profile image of a wood pole, several incremental x-ray images along the length of the pole had to be stitched together digitally. The inability to obtain a single overall profile x-ray image efficiently was not solved.

4.1.3 Results and Observations

An example pole will be used to provide insight into the assessment results. Sample pole 1 results are provided in the section of the report.

Records Review:

The PTT results for all the poles is provided in Table 1, below. The sample #1 pole assessment indicated it did not Pass and had shell rot/decay.

Table 1 – Summary of PTT Results for Wood Pole Samples

Sample #	PTT Results	PTT Comments
1	Fail	Shell Rot / Decay
2	Pass	Shell rot at base of pole
3	Fail	Internal decay at ground line
4	Fail	Shell Rot / Decay
5	Fail	Shell Rot / Decay
6	Pass	Shell Rot / Decay
7	Pass	Shell rot detected at ground line
8	Pass	Shell Rot / Decay

As-Received Photographs:
Figure 1 represents the as received photographs of the Sample 1 pole. The remaining poles are shown in Appendix B.

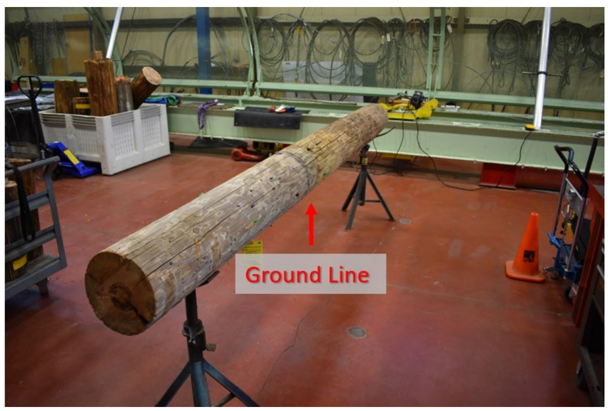


Figure 1 - Sample 1 As Received Photo

RT Imaging Setup:
The CR test set up is shown in Figure 2, below. This location is the ATS Radiography shooting cell used for generating high dose radiation in a safe environment. A profile radiographed x-ray image via computed radiography was captured for each pole in the ATS Radiography shooting cell.

Figure 2 - ATS Radiography Shooting Cell Setup

The capture media of the x-ray image was on a phosphor image plate in which the shots were taken in small sections for the entire length (~10 ft) of the sample pole. The x-ray images were then stitched together to get a continuous view of the internal condition of the length of the sample pole, see Figure 3. The pole sections were from the base of the pole (pole butt) up to 1 ft above groundline.

When viewing x-ray images, the less dense areas will appear darker, and the denser areas will appear lighter. In reviewing Figure 3 below, it is apparent that there is a void at the bottom half of the pole, circled in red.

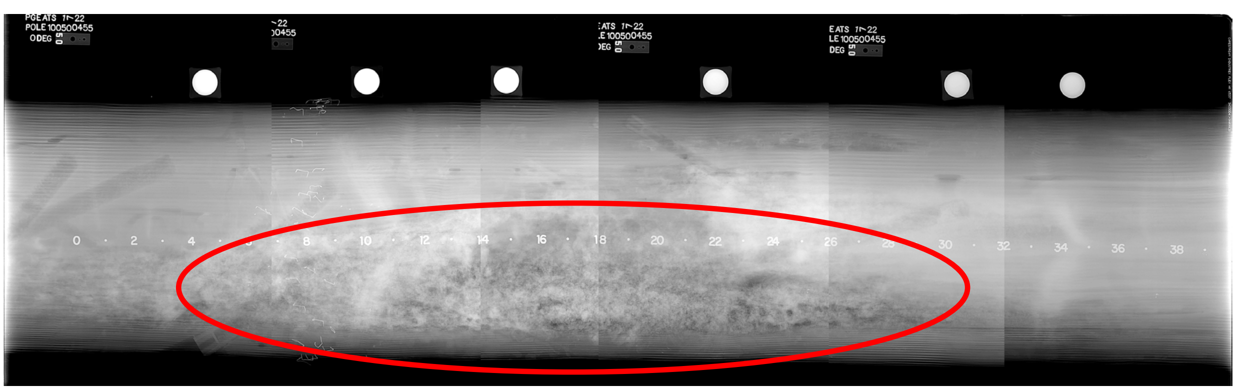


Figure 3 - Stitched Radiographic Image

<u>Pole dissection</u>:
The samples were then dissected circumferentially into 4-inch sections to validate the voids detected within the x-ray image. Figure 4 shows the cross-sections; the numbers in the upper left are inch designations to identify each cut section of the Sample #1 wood pole. The -7-0 is the above ground section, 0-4 is the first 4 inches below ground, then 4-8 is the next 4-inch section and so on. These identifiers are used to track the locations and compare to the x-ray imagery.
Upon comparing the x-ray images to the dissected cross-section of the wood pole samples, ATS confirmed that there was a good correlation.

In evaluating the sample pole 1, an observer can visually see the variations of grey shade in the x-ray image, Figure 3, as compared to Figure 4 of the dissected sections of the same pole.

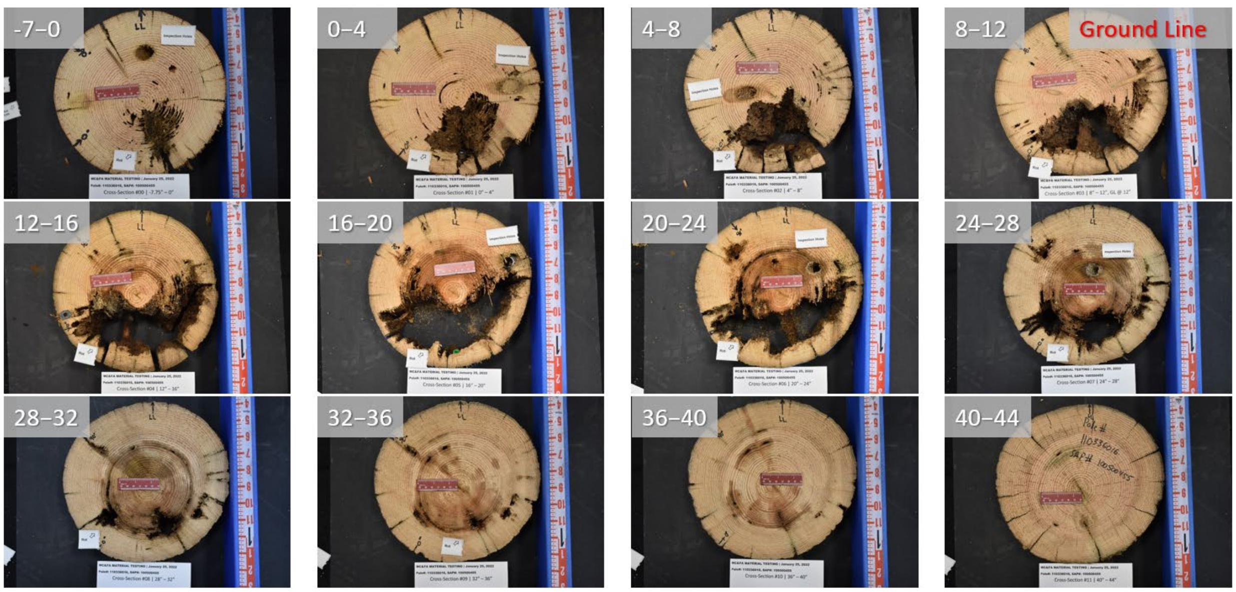


Figure 4 - Pole Dissection

<u>Sample Pole Assessment Summary</u>:
To bring the analysis together, the three data sets have been stacked to better show the correlations. As can be seen in Figure 5 below, the correlation between the x-ray image and the dissections is readily seen. This view has been created for each of the sample poles and is presented in Appendix B.

The results of the 8-wood pole study has satisfied the proof-of-concept scope of work by validating that radiography can positively detect internal rot/ voids. The conclusion of this phase prompted enough evidence to move onwards to the next phase of this project.

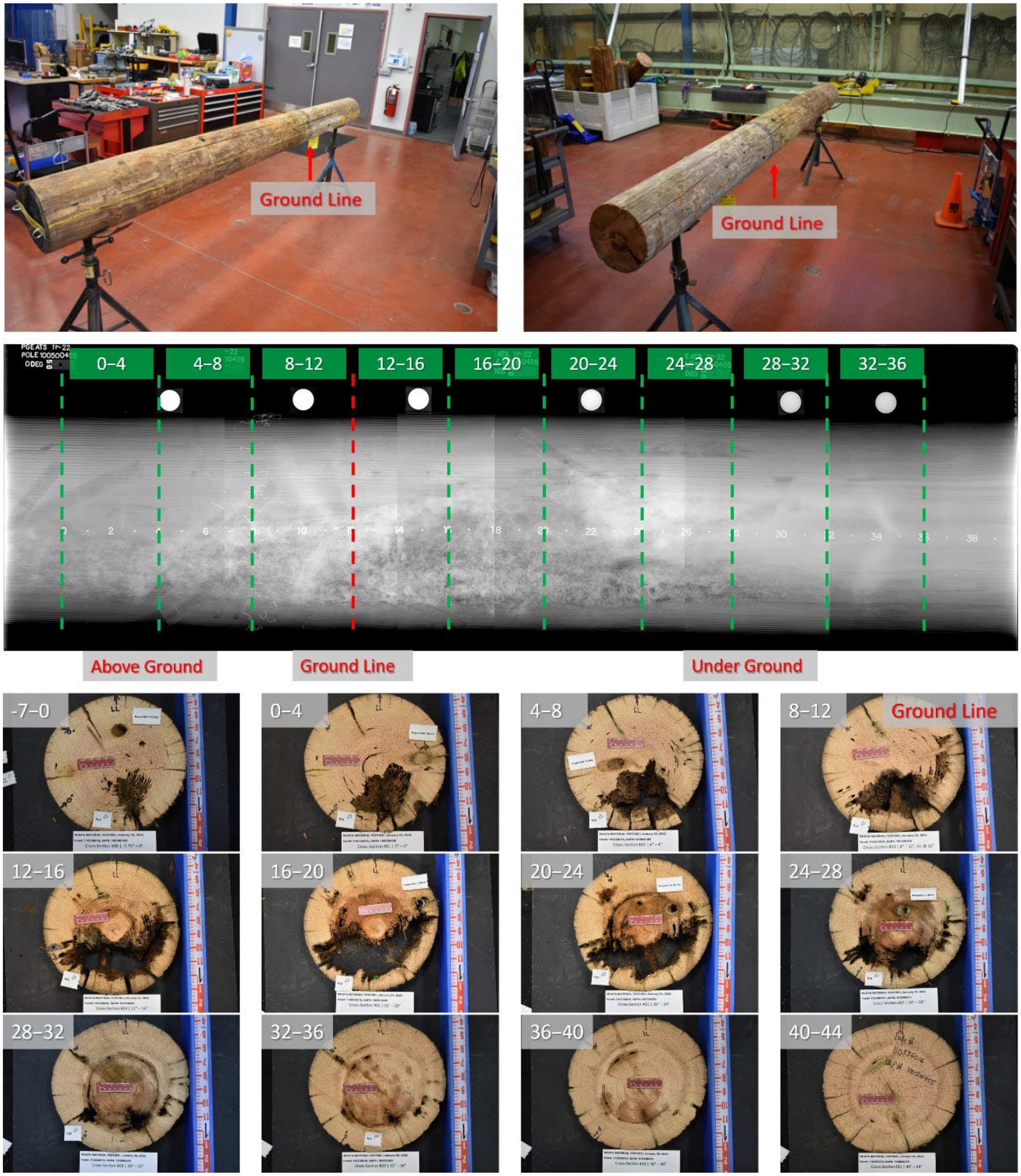


Figure 5 - Sample Pole 1 Summary Image

4.2 Technical results and findings – Device Selection and Procurement

4.2.1 Technical Development and Methods

Given that computed radiography was successful in the detection of internal decay of wood poles, this method of radiography served as the baseline of acceptable imagery when seeking to evaluate portable real-time x-ray imaging devices. The feasibility criteria for determining if a real-time x-ray imaging devices was viable, included:

- Portability: This aspect of a tool is essential for use in the field. Inspectors/Technicians need to carry devices to remote locations easily.
- Ease of use: The ability to operate the device easily, obtain and export useful information. This will identify the level of training the operator will need.
- Capable to scan a wood pole in-service: The ability of the device to scan and produce an x-ray image real time of the interior of an in-service wood pole.
- Radiation dosage: The level of radiation dosage needed to obtain useful images. Furthermore, the dosage will identify the level safety precautions that will be needed to operate the device in the field.
- Regulatory requirements: The limitation of radiation being exposed to a non-monitored person (member of the public) is 2 milliRoentgen (mR) per hour or 100mR per year. Higher dosage levels generated by a device would disqualify the device.
- Overall Viability: Based on the above five criteria, a final overall viability of use in the field will be determined. Should a device be deemed viable the device will move to the next phase.

4.2.2 Challenges

The only significant challenge in this phase was that only two potential devices met the feasibility criteria.

4.2.3 Results and Observations

Searching the available instruments on the market that meet the criteria, the team only identified two real-time imaging devices. These are refereed here as Device 1 and Device 2. The assessment of this devices follows the above critical criteria described in Section 4.2.1.

Device 1: Shown in Figure 6.

Figure 6 - Identified Real-Time Portable X-Ray Imaging Device 1

- Portability: **PASS**
  This device was relatively light (9.6 lbs) to carry and had two handles for ease of operation. The device also included a wheelable pelican case with custom foam inserts for ease of transportation and security.
- Ease of use: **PASS**
  A demonstration of the x-ray imager was held at ATS to showcase the ease-of-use and capabilities prior to purchasing. To acquire the highest quality real-time x-ray image, the operator must scan at a rate of 6 inches per second while not exceeding the 30 second operating time limit. Device 1 requires a minimal level of training for the operator to be successful. The operating system was fairly easy being an android based system which allowed for quick exporting of the data via memory card.
- Capable to scan a wood pole in-service: **PASS**
  Device 1 has two scanning modes, transmission and backscattered. Both scanning modes were demonstrated at ATS during the demonstration session. The results of this demonstration provided enough confidence that the x-ray imaging instrument would be capable of detecting the internal features (e.g., voids, decay pocket, knots) of a wood pole via either transmission or backscatter mode.
  - Transmission mode: X-ray source and detector (DR panel arm) are separated. The X-rays are emitted from the source, transmitted through the object, and are detected by the detector.
  - Backscatter mode: X-ray source and detector are integrated into one device. The object under examination only needs to be accessible from one side. This allows for more flexibility in scanning but decreases the image quality when compared to transmission mode because it relies on small amounts of radiation scattering back from the object to the device's sensor.
- Radiation dosage: **PASS**
  The design output is 140 kV at .000050 mA and the measured radiation dose 12 inches in front of the x-ray tube source was 0.208 mR which creates a small radiation field. The operator will need to be trained. However, with a trained operator, there are no additional safety precautions or radiation monitoring equipment needed when operating the instrument. The image quality during the initial assessment was poor and would require some modifications. It was apparent Device 1 can capture high-quality images.
- Regulatory requirements: **PASS**
  No regulatory requirements due to the low dosage generation of Device 1.
- Overall viability: Device 1 is viable for use in the field.

Device 2: Shown in Figure 7.

Figure 7 - Identified Real-Time Portable X-Ray Imaging Device 2

- Portability: **PASS**
  This device is relatively light (12.8 lbs) and has a single handle to carry. The unit comes with a custom rollable carrying case.
- Ease of use: **PASS**
  For a trained radiographer, this device is compact and relatively easy to use. The device can be mounted on a tripod to perform stationary x-ray shots. The unit is compatible with numerous digital imaging systems to view and evaluate the x-ray images.
- Capable to scan a wood pole in-service: **PASS**
  Device 2 provides exceptional radiation penetration as it can penetrate up to one inch of steel which is far more dense of a wood pole.
- Radiation dosage: **FAIL**
  The alternative option is a pulsed x-ray tube with a design output of 270 kilovoltage peak (kVp) and 2.6 mR/HR per pulse at 12 inches from the source. The typical shot of Device 2 consists of 99 to 200 pulses which creates a radiation dose field of 17.16mR to 34.32mR around any individual(s) at 12 inches. As the radiation exposure is greater than 2 mR, the operator of the instrument must have a thermoluminescent dosimeter (film badge), pocket dosimeter, rate alarm, and survey meter of the ionization type during operation.
- Regulatory requirements: **FAIL**
  In addition, the operator would need to have an Industrial Radiography Radiation Safety Personnel (IRRSP) card which requires 180 hours of x-ray tube experience with a trainer and to be monitored by a Radiation Safety Officer (RSO) program.
- Overall viability: This device was removed from consideration due to the safety precautions and requirements an individual would need to operate the instrument.

Device Assessment Summary:

Of the two devices identified, only one was deemed viable for field use; that was Device 1. While the image quality is dependent on the operator's skill, a few potential modifications may provide the needed stability for very high-quality images. The next phase of the EPIC 3.46 program is a field test of Device 1. Additionally, some simple modifications will be evaluated to stabilize the operability and potentially increase its field capabilities.

4.3 Field Testing of the X-Ray Imaging Device 1

4.3.1 Technical Development and Methods

Upon procurement of the viable x-ray imaging unit (Device 1), several PG&E ATS personnel received manufacture training in order to operate the instrument. To validate that real-time radiographic testing can produce similar results in comparison to computed radiography, the following tasks were performed.

- Field Testing: Field testing of in-service poles will provide a baseline data set to compare against the CR method.
- Device Enhancements: Identify and implement process improvements to obtain high quality x-ray images.

4.3.2 Challenges

- The most significant and unresolved challenge encountered during the project was the inability to perform real-time radiography at/below groundline or near pole obstructions that restricted the DR panel arm from being utilized.
- The second unresolvable challenge was the inability to capture x-ray images of poles with obstructions that restrict access of the device (e.g., fences, stubs, trees).
- The third challenge is associated with freehand control of the device. The image quality decreased due to the unsteady movements and inconsistent scan rate by the operator. Process enhancements were developed and described below.
- Limitations:
    - First limitation is associated with utilizing the DTX arm. The arm is limited to inspecting pole diameters of approximately 14 inches and below. Wood poles of larger diameters can be inspected by backscatter mode; however, this reduces the x-ray image quality.
    - The second limitation is that it overheats with high usage. This resulted in reducing continuous usage of the device to avoid overheating that increased the overall duration of inspection of multiple wood poles.

4.3.3 Results and Observations

Field Testing:

Seven (7) in-service utility wood poles were radiographed with Device 1 from groundline to approximately 6 ft above grade. A lead numbering belt spaced in inch increments was affixed to each pole to 1) provide a reference point and 2) determine the quality of the x-ray image. It was originally planned to acquire x-ray images of each pole via backscatter and transmission mode, however, the device overheated during the first pole test. This led to an unresponsive display and unexpectedly malfunctioned the transmission mode. After the device cooled, x-ray images of each pole were captured via backscatter mode which is viewable within Appendix C below. Figure 8 and Figure 9 displays the best and worst real-time x-ray images, respectively.

Figure 8, Sample 1 Field Pole, was easily accessible to scan from any quadrant. However, it is evident from the image that the scan rate of the wood pole was not consistent. This resulted in the spacing of the lead belt numbers to not be uniform. The operator, PG&E ATS Radiographer, attempted to scan at the recommended 6 inches per second. The challenge is managing the 10-pound device from above the shoulders to groundline in a consistent manner. The waviness of the image originates from left and right drift during scanning.

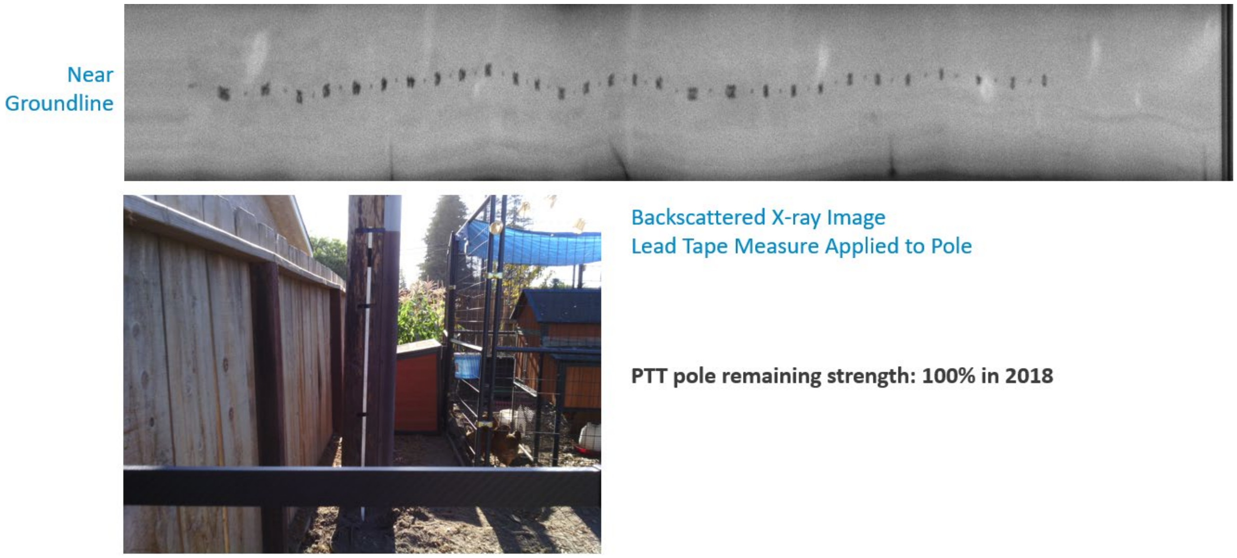


Figure 8 - Sample 1 Field Pole

Figure 9, Sample 2 Field Pole, challenges with scanning the sample 2 field pole consisted of obstructions due to steel climbing hardware, stub (brace) and banding as seen in the site image. The steel results in the dark/black areas associated with the obstructions. These obstructed areas limit the visibility of the presence of decay.

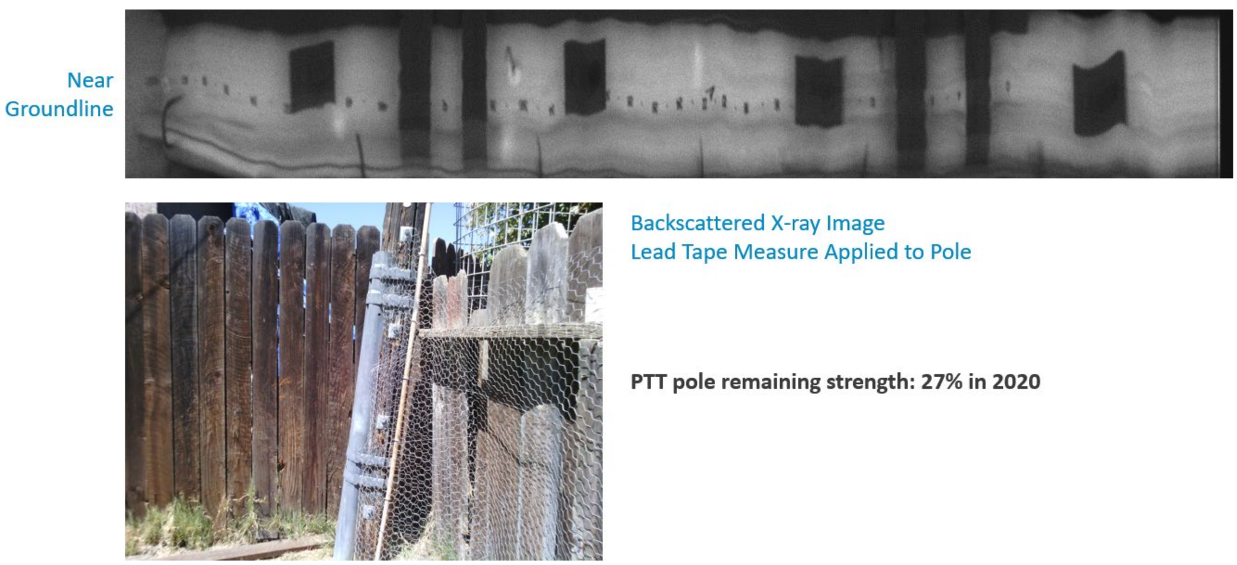


Figure 9 - Sample 2 Field Pole

<u>Device Enhancements:</u>

At the conclusion of field testing, the operator recommended a roller attachment to be designed and mounted to the device. This would lessen the impact of the challenges of scanning.

- <u>Custom Bracket and Wheel Attachment:</u>

A custom bracket would further improve the real-time x-ray image quality along with reducing the physical effort to operate the instrument, The ATS 3D scanning team designed (Figure 10) and 3D printable bracket and added purchased wheels. The design allowed the operator to manage the scanning operation more consistently.

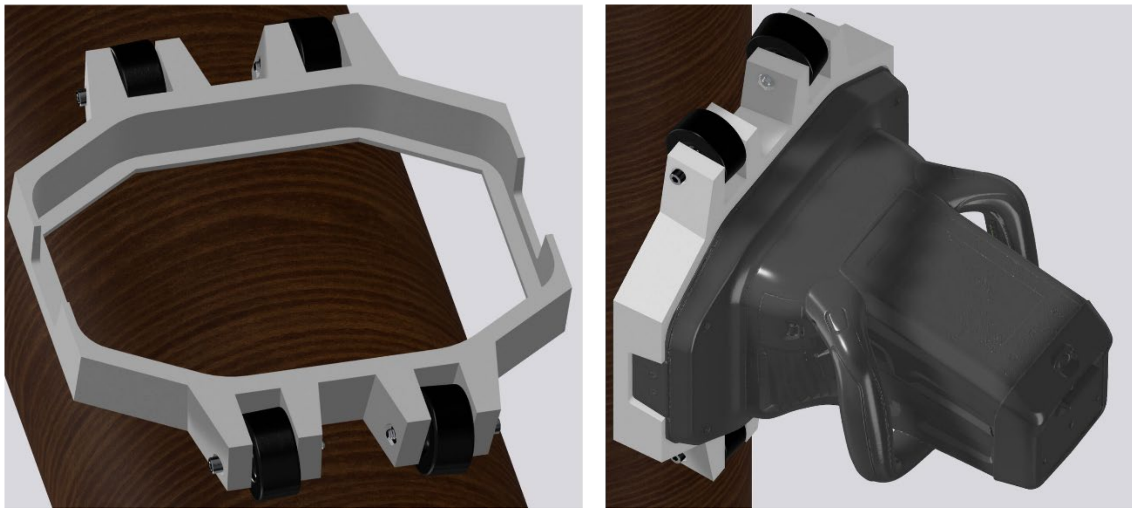


Figure 100 - 3D Design of Bracket with Wheels

Testing with the new 3D printed attachment was performed on seven (7) received damaged poles where real-time x-ray images were taken at 0 and 90 degrees. The first of which is shown in Figure 11. The x-ray images were noticeably better in comparison to all prior handheld x-ray images. The usability was also significantly improved as the operator x-rayed all damaged samples collecting 14 x-ray images with higher efficiency. The remaining sample pole images can be seen in Appendix D. In reviewing all of the x-ray images, it was apparent that the images had a consistent brightness variation throughout the scan, seen as horizontal lines. The variations were due to the wheels traveling along the uneven wood surface. In addition, some x-ray images had a waviness due to the wheels interacting with the wood pole. Although the bracket wheels improved the x-ray images, they were not comparable to computed radiography.

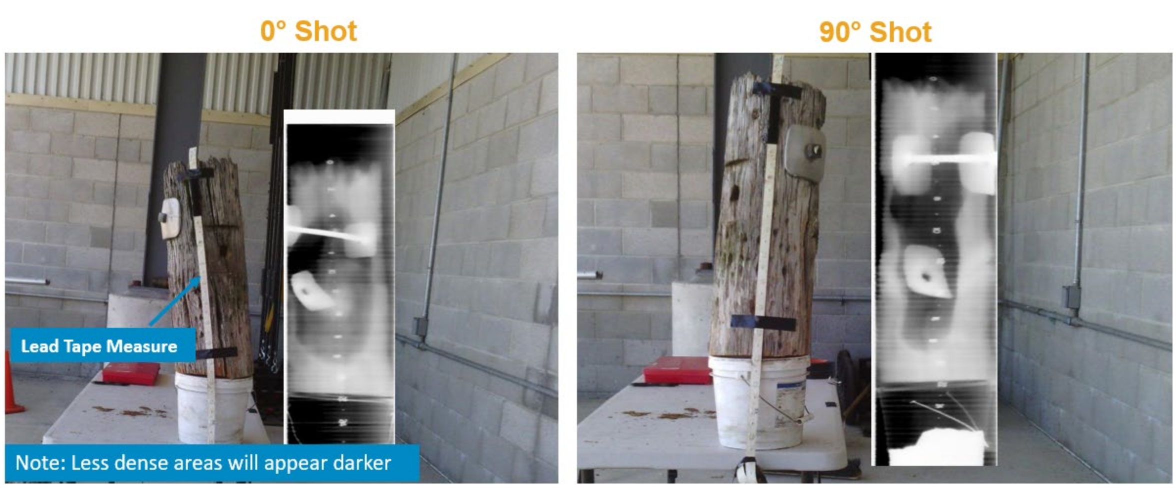


Figure 111 - Sample 1: Damaged Pole

- <u>Track System:</u>

The second attempt to increase the quality of the x-ray images, was to develop a track system. The ATS project team fabricated a track system that can be utilized in the field or in a laboratory setting. The track system consists of a track, ratchet straps, the 3D printed bracket mount and custom mounting hardware (Figure 12). The track system allows for mobile field testing of in-service wood poles. In a laboratory setting, the track system setup consists of the same components but requires pole support. These supports were horizontal attachments on each end (Figure 13).

Figure 122 - Field Track System Setup

Figure 133 - Laboratory Track System Setup

The track system was tested on a pole with below groundline decay and significant woodpecker damage. The pole was cut into eight sections (Figure 14) for ease of transport and handling. Seven of the eight sections were x-ray imaged with the track system. The top section of the pole was not x-ray imaged as there were no evident signs of internal defects. In review of all the x-ray images, the team confirmed that the track system produced comparable image quality to conventional radiography. As shown in Figure 15, the location and overall size of the voids can be clearly seen.

Figure 144 - Pole Sample with Groundline Decay and Woodpecker Hole Damage

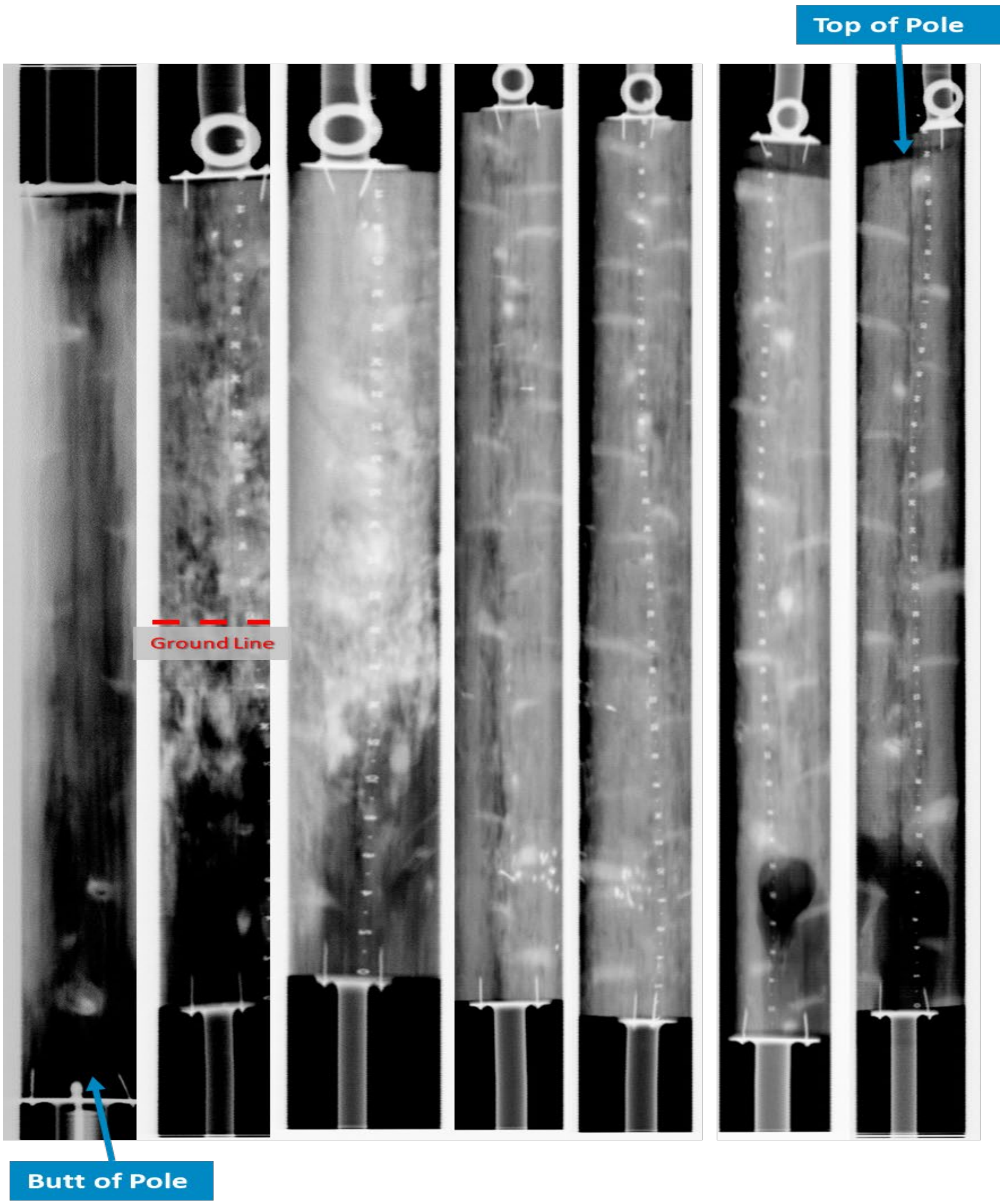


Figure 155 - X-Ray Images of Sampled Pole with below and above grade defects

4.4 Technical results and findings – Scale for Production

4.4.1 Results and Observations

The track system developed for the device did improve the usability and quality of x-ray images. However, the team unanimously agreed that the device cannot be used as a supplemental wood pole inspection method for the following reasons:

- The initial testing of the handheld x-ray imaging device confirmed that below groundline inspections were not possible without digging to expose the pole.
- Secondly, quantifying the void size to calculate the wood pole remaining strength would require a significant amount of effort.
- Lastly, the interpretation of x-ray images produces would require an individual to be certified in radiography. This is not practical for electric operations personnel to acquire the need training to achieve such a certification.

5 Value proposition

The purpose of EPIC funding is to support investments in technology demonstration and deployment projects that benefit the electricity customers of PG&E, San Diego Gas and Electric (SDG&E), and Southern California Edison (SCE). EPIC 3.46 Radiography of Wood Poles has demonstrated that conventional and real-time radiography can successfully detect wood pole voids caused by decay or woodpecker holes.

5.1 Primary Principles

The primary principles of EPIC are to invest in technologies and approaches that provide benefits to electric ratepayers by promoting greater reliability. This EPIC project contributes to these primary principles in the following ways:

- Greater reliability: Real-time radiography of wood poles allows for a nondestructive method to further evaluate questionable wood poles, validate the presence of decay or confirm the results of PTT.

5.2 Accomplishments and Recommendations

5.2.1 Key Accomplishments

The following summarize some of the key accomplishments of the project over its duration:

- Demonstrated that computed radiography can produce high quality x-ray images to identify areas of decay.
- Demonstrated that real-time radiography can produce comparable x-ray images to computed radiography.
- Identifying a safe and low radiation dose real-time x-ray imager that can be used to capture high quality images by trained personnel.
- Designed and built a track system for the x-ray device solving x-ray image quality issues.

5.2.2 Key Recommendations

- The utility pole diameters can be much larger than the current 14-inch DR panel arm diameter capacity. A variation of DR panel arm lengths would accommodate larger diameter poles.

5.3 Technology transfer plan

5.3.1 IOU's technology transfer plans

A primary benefit of the EPIC program is the technology and knowledge sharing that occurs both internally within PG&E, and across the other IOUs, the CEC and the industry. In order to facilitate this knowledge sharing, PG&E will share the results of this project in industry workshops and through public reports published on the PG&E website.

5.3.2 Adaptability to other Utilities and Industry

The following findings of this project are relevant and adaptable to other utilities and the industry:

Radiography of wood poles can provide added visibility of the internal condition of the pole without having to intrusively examine the area of interest. Radiography can also be used as an alternative nondestructive method to evaluate questionable wood poles.

5.4 Data Access

Upon request, PG&E will provide access to data collected that is consistent with the CPUC's data access requirements for EPIC data and results.

6 Conclusion

The team identified several significant findings.

- The nondestructive examination method of radiographic testing via computed radiography and real-time radiography imaged the decay in wood poles.
- A viable real-time x-ray imaging device was shown to produce high quality x-ray images comparable to computed radiography.
- Trained and qualified operators using the identified device can produce high quality x-ray images in both a laboratory and field setting.
- The team determined that operationalizing the technology to serve as an alternative inspection method is not feasible. This is driven by the device’s inability to inspect below groundline or near obstructions.

PG&E’s technical center, ATS, will continue to utilize these radiographic techniques on wood poles. This technology can be utilized to document existing conditions prior to destructive testing. The x-ray images produced provide guidance for destructive testing.

Appendix A: Real-Time X-Ray Imager Specification Details

Device Specifications

Weight	9.6 lbs. (4.35 kg) including battery pack for the base system (no options)
Size	11.75" (298 mm) x 10.75" (273 mm) x 7.0" (178 mm)
Scan Speed	Up to 12" (30 cm) per second
Batteries	Rechargeable Li-ion battery pack 4 hours with typical duty cycle
Display	Color touchscreen LCD
Operating Conditions	-40° F (-40° C) to 140° F (60° C)

Device Features, Accessories & Options

Lead (Pb) Detection	Configuration Option
Wingbar-Tab	Option – 12.5" remote tablet accessory
X-Ray Generator	140 keV X-Ray Source
Imaging	Image stitching, Auto-contract, Histogram enhancement, Image Compare
Connectivity	USB-C, Bluetooth, WiFi
Standard Accessories	Lockable waterproof case Adjustable safety strap 110/220 V AC battery charger and space battery pack

Device Imaging Performance (Steel and Steel Equivalent Penetration)

Steel	5mm (0.20")
Aluminum	23mm (.89")
Concrete	26mm (1.03")
Carbon Fiber	56mm (2.19")
Plastic	89mm (3.49")
Drywall / Sheetrock	46mm (1.92")
Wood	128mm (5.04")
Ceramic Tile	17mm (.69")
Rubber	89mm (3.49")

Appendix B: Pole Samples

The below photos are of the eight (8) wood poles that were evaluated for nondestructive and destructive testing.

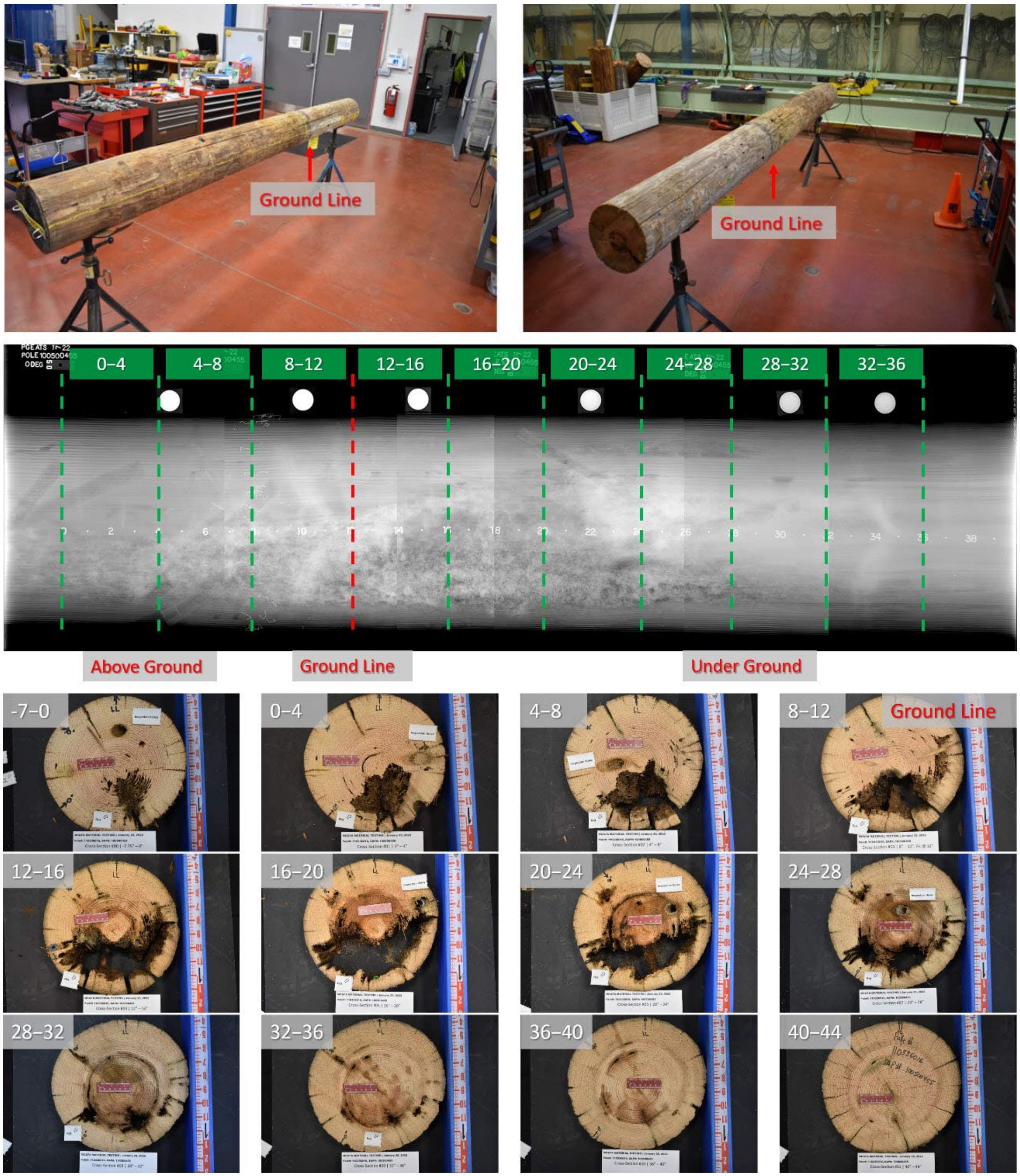


Figure 166 - Sample Pole 1 Summary Image

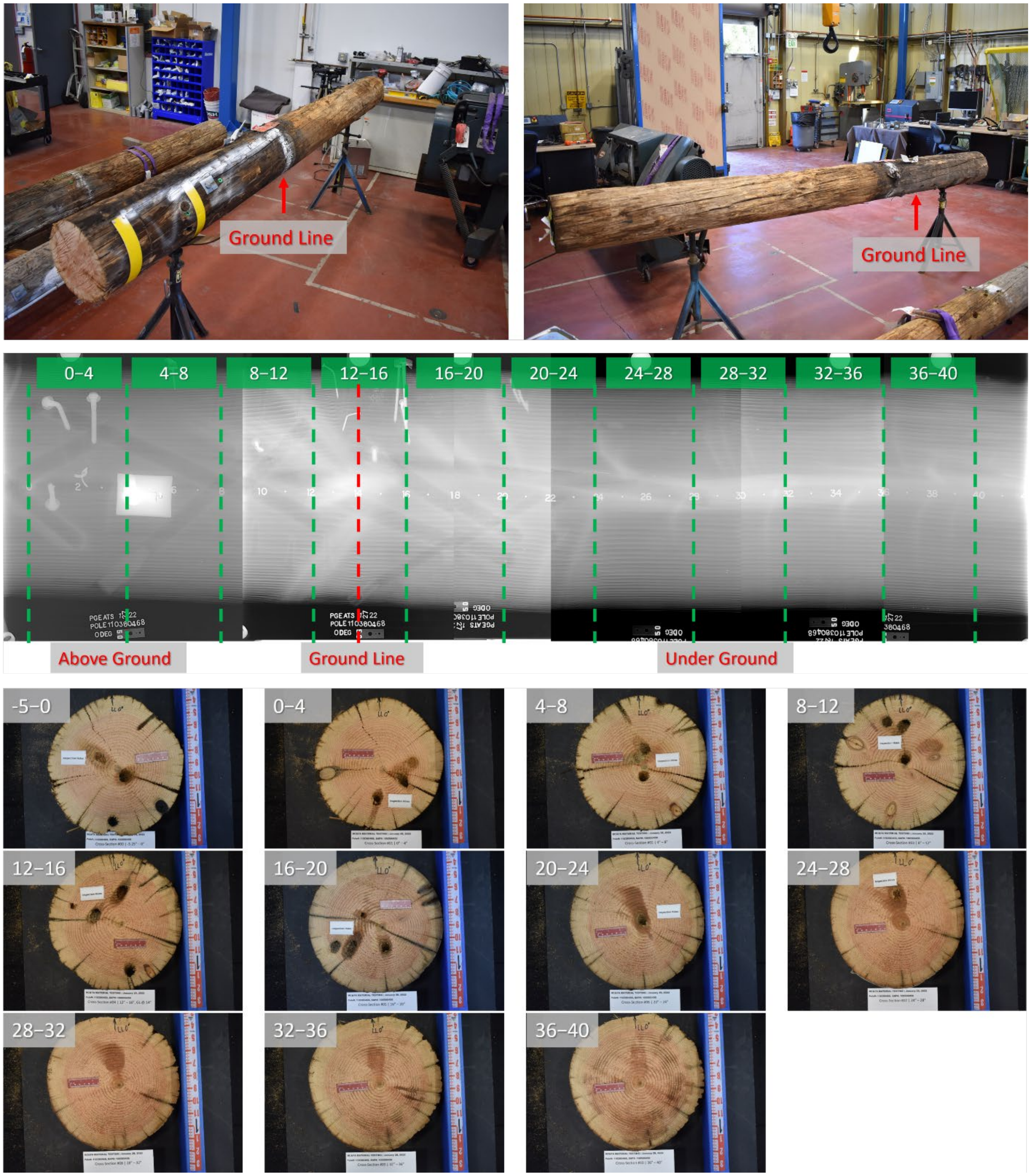


Figure 1717 - Sample Pole 2 Summary Image

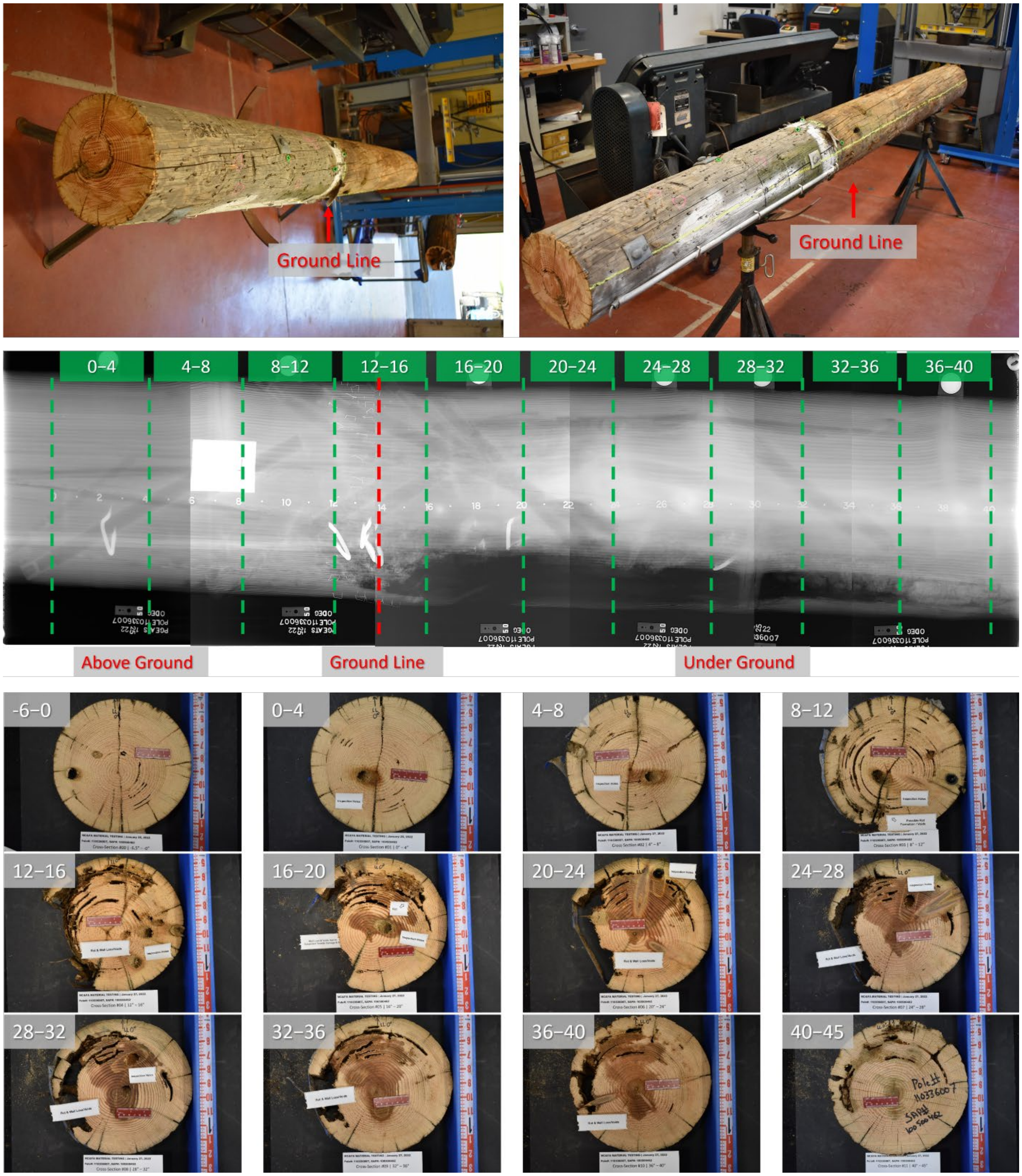


Figure 1818 - Sample Pole 3 Summary Image

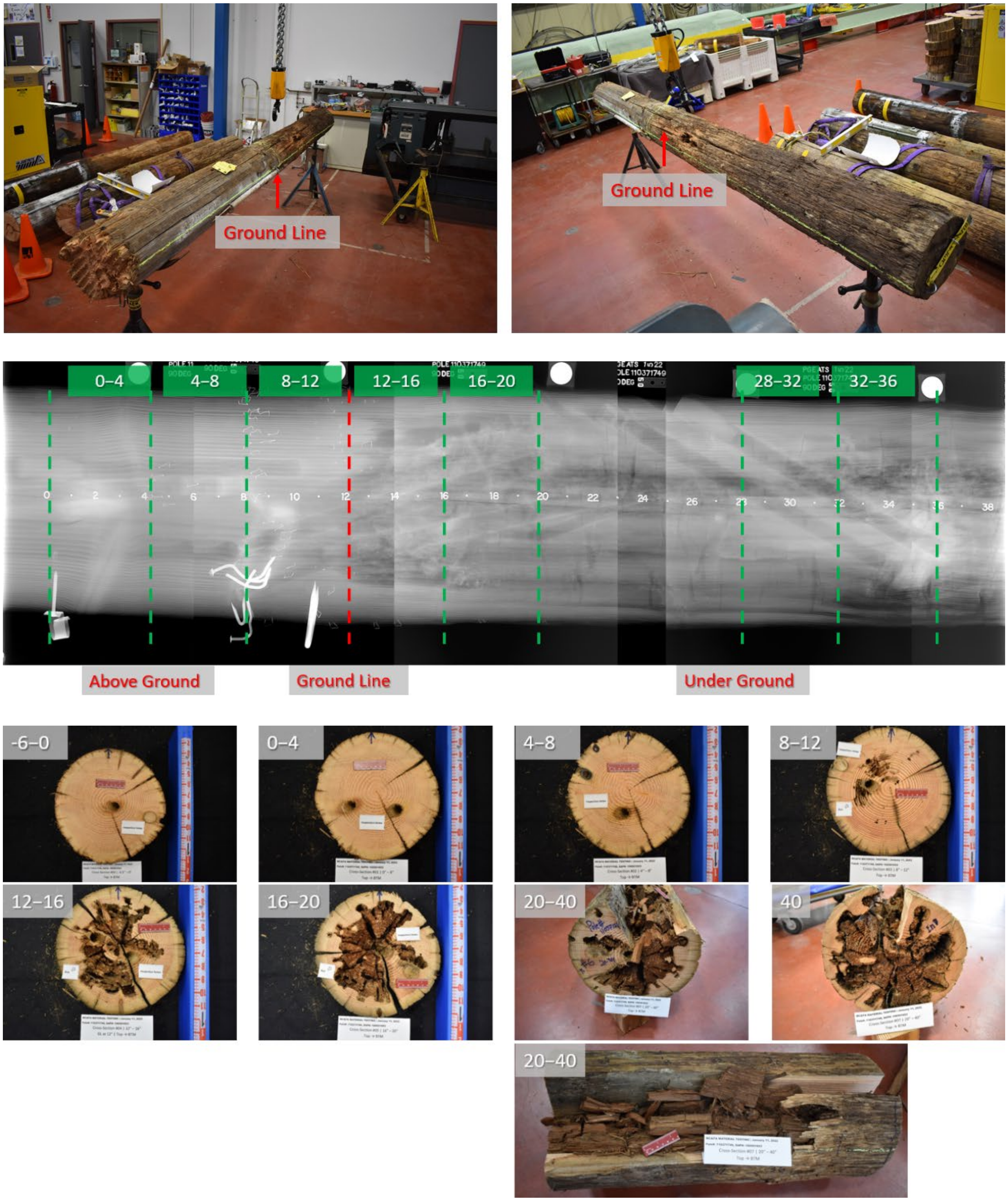


Figure 19 - Sample Pole 4 Summary Image

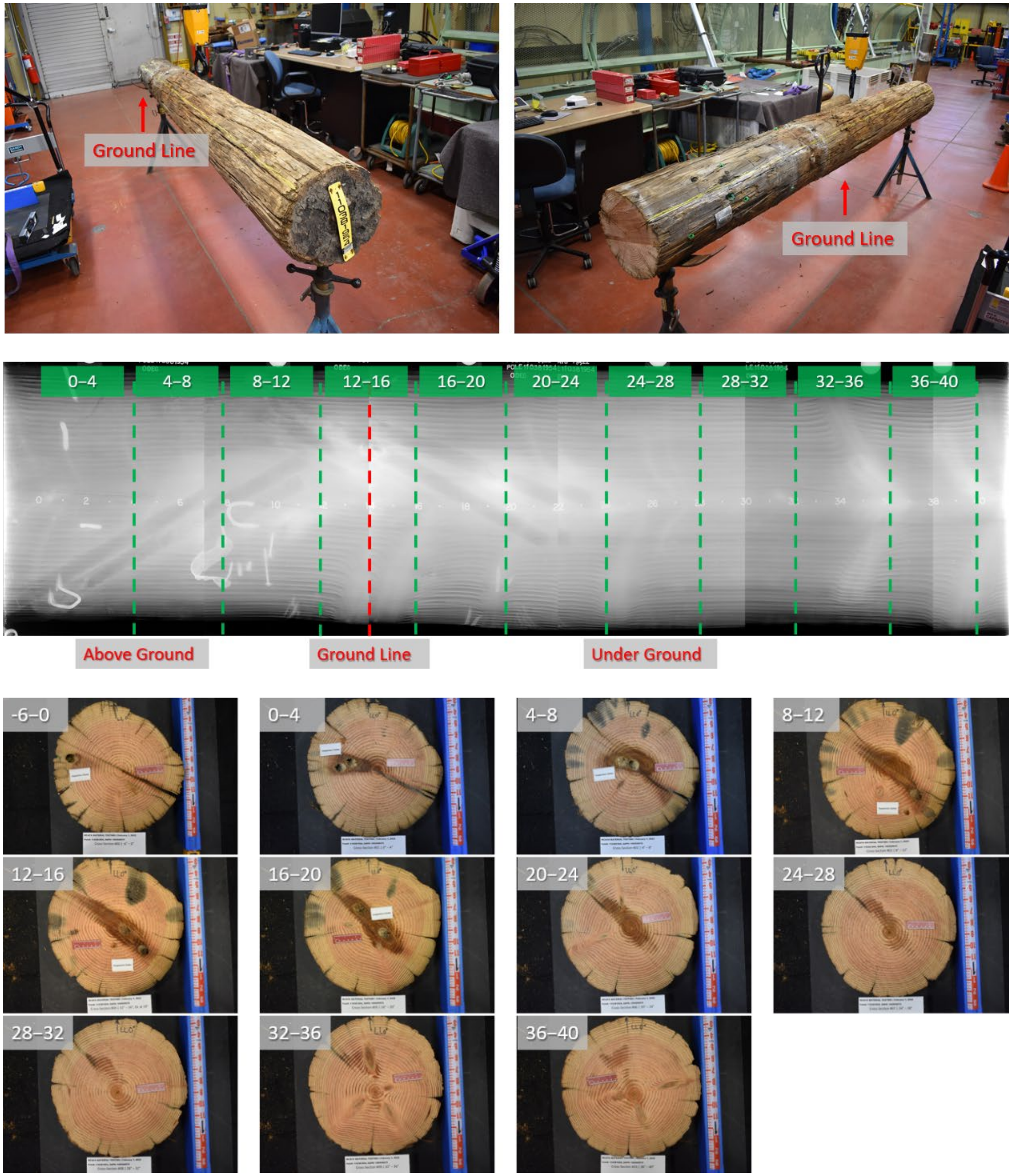


Figure 20 - Sample Pole 5 Summary Image

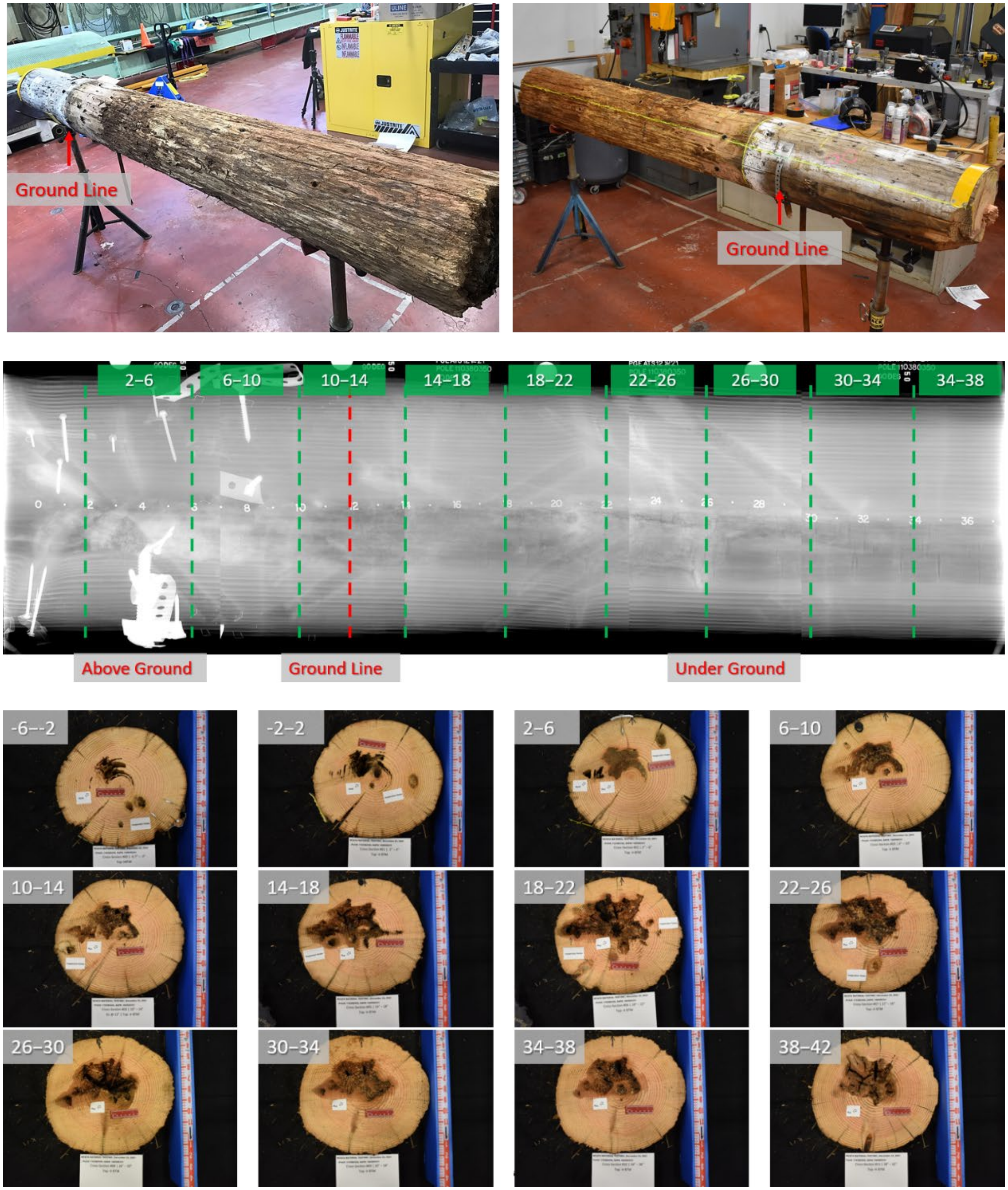


Figure 211 - Sample Pole 6 Summary Image

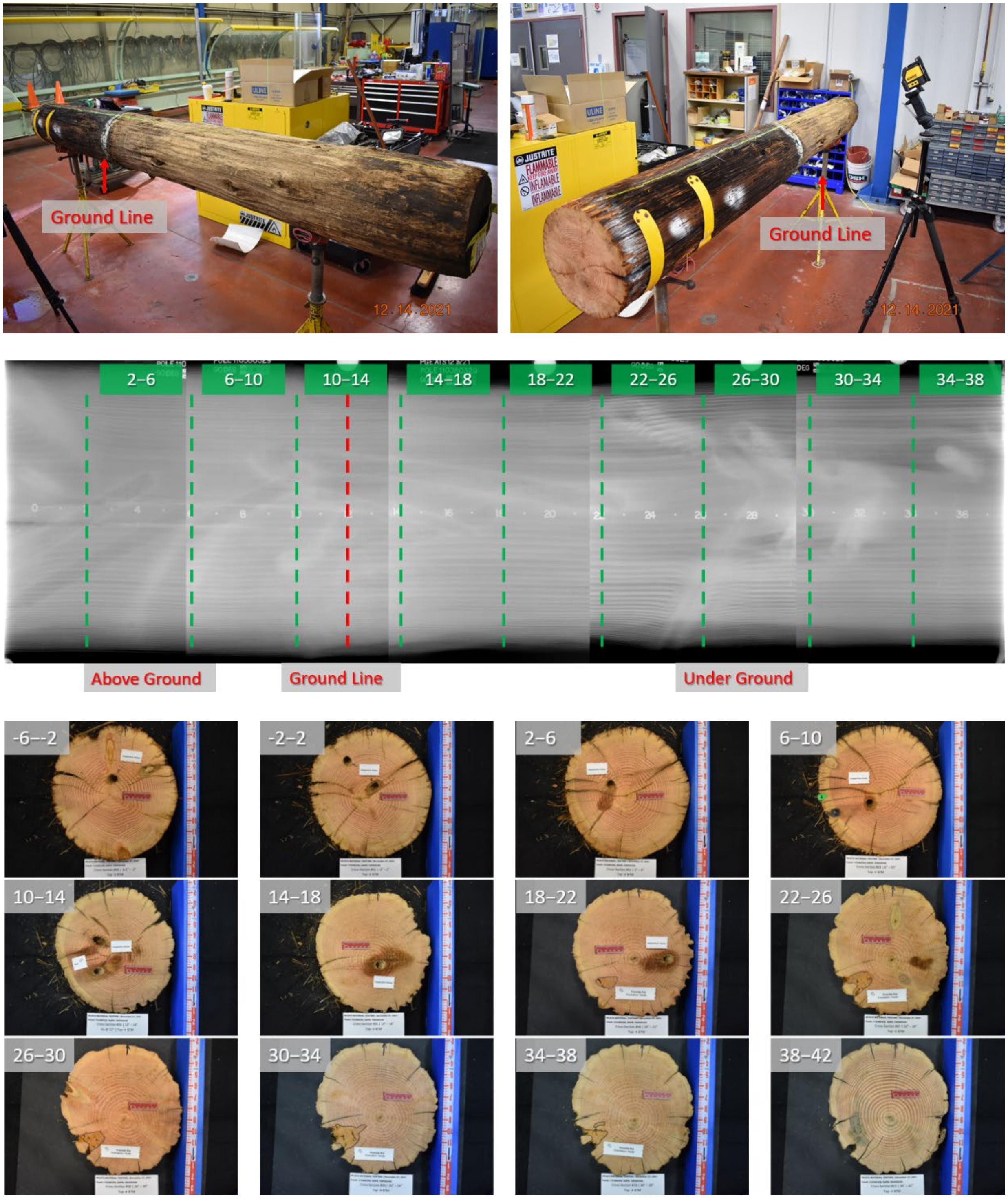


Figure 222 - Sample Pole 7 Summary Image

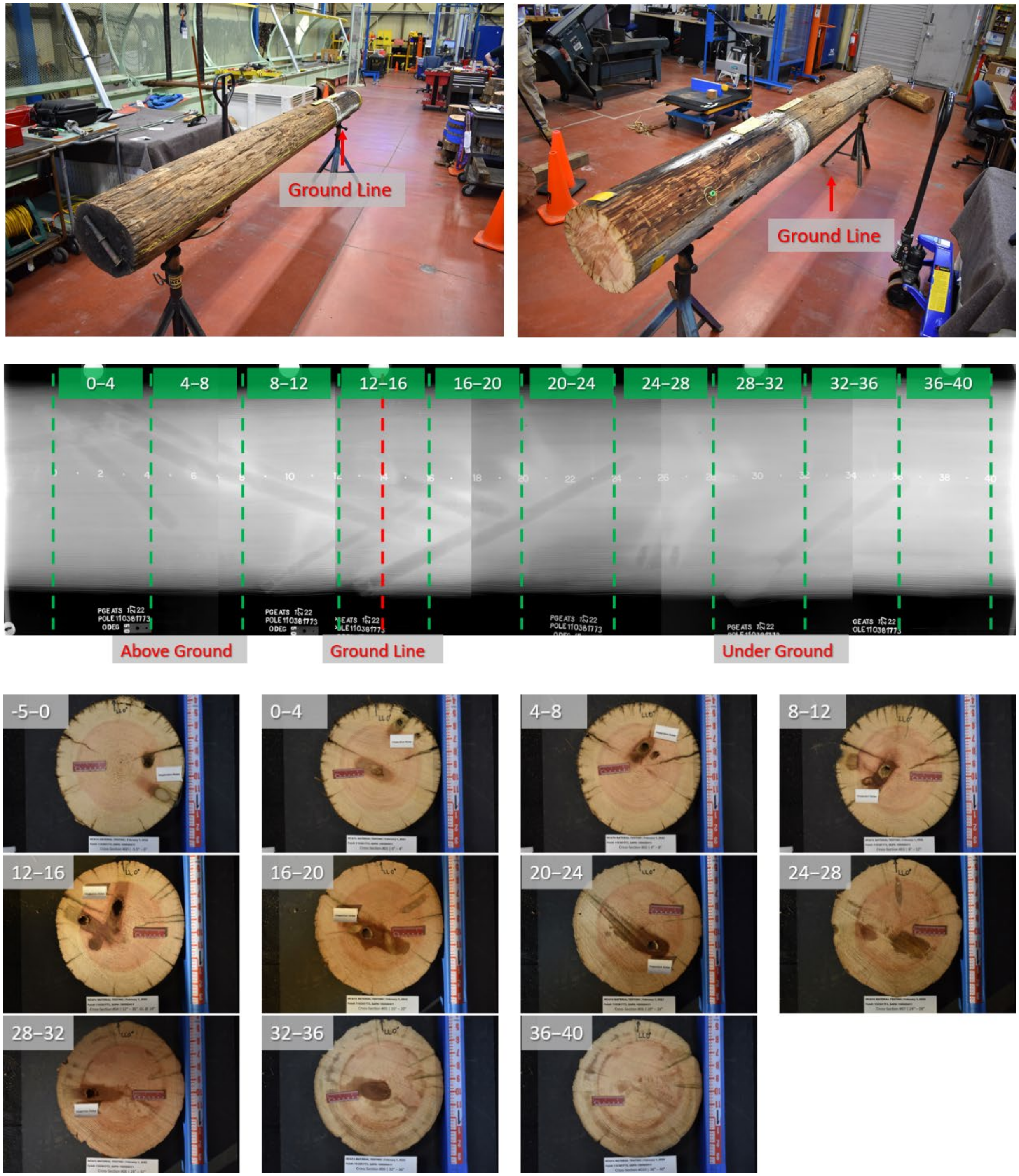
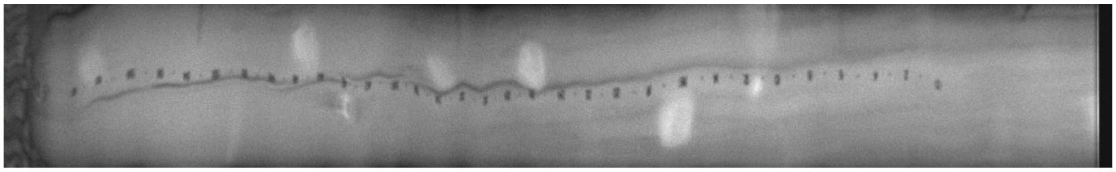


Figure 233 - Sample Pole 8 Summary Image

Appendix C: Field Testing of Device 1

Below are the remaining five (5) of the seven (7) in-service wood poles inspected with Device 1 via backscatter mode.

Near Groundline

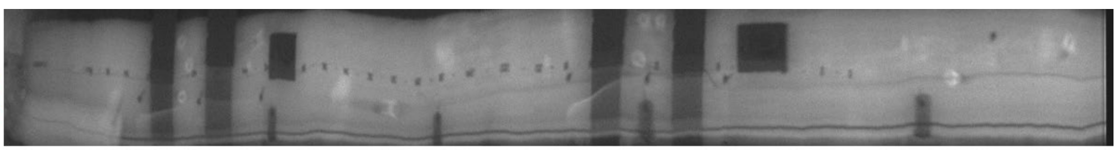


Backscattered X-ray Image
Lead Tape Measure Applied to Pole

PTT pole remaining strength: 93% in 2019

Figure 244 - Sample 3 Field Pole

Near Groundline

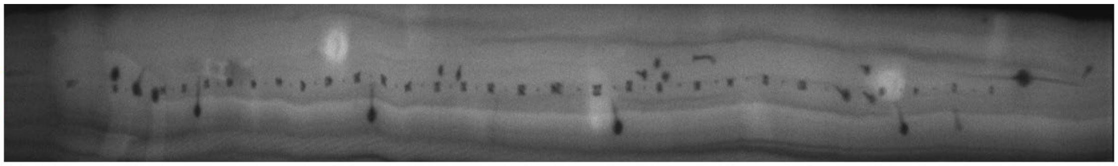


Backscattered X-ray Image
Lead Tape Measure Applied to Pole

PTT pole remaining strength: 100% in 2018

Figure 255 - Sample 4 Field Pole

Near Groundline

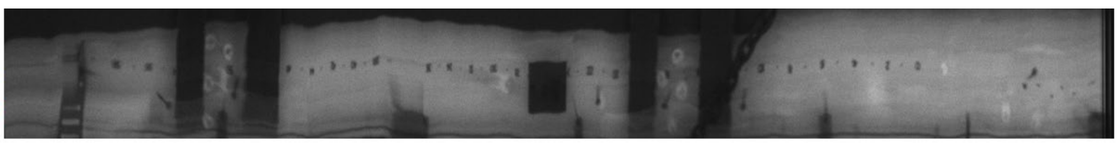


Backscattered X-ray Image
Lead Tape Measure Applied to Pole

PTT pole remaining strength: N/A

Figure 266 - Sample 5 Field Pole

Near Groundline

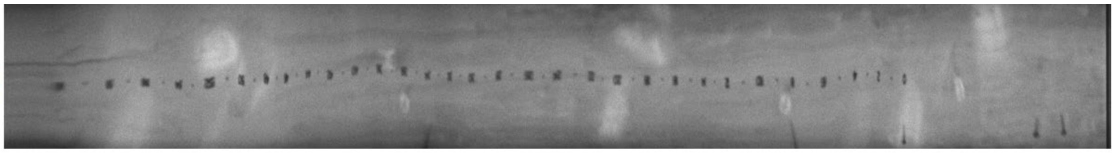


Backscattered X-ray Image
Lead Tape Measure Applied to Pole

PTT pole remaining strength: 100% in 2018

Figure 2727 - Sample 6 Field Pole

Near Groundline



Backscattered X-ray Image
Lead Tape Measure Applied to Pole

PTT pole remaining strength: 56% in 2019

Figure 28 - Sample 7 Field Pole

Appendix D: Real-time X-Ray Analysis of Damaged Poles

Below are the remaining images of the real-time x-ray imaging of damaged poles of each separate pole at 0 degrees and 90 degrees utilizing the custom bracket with rollers.

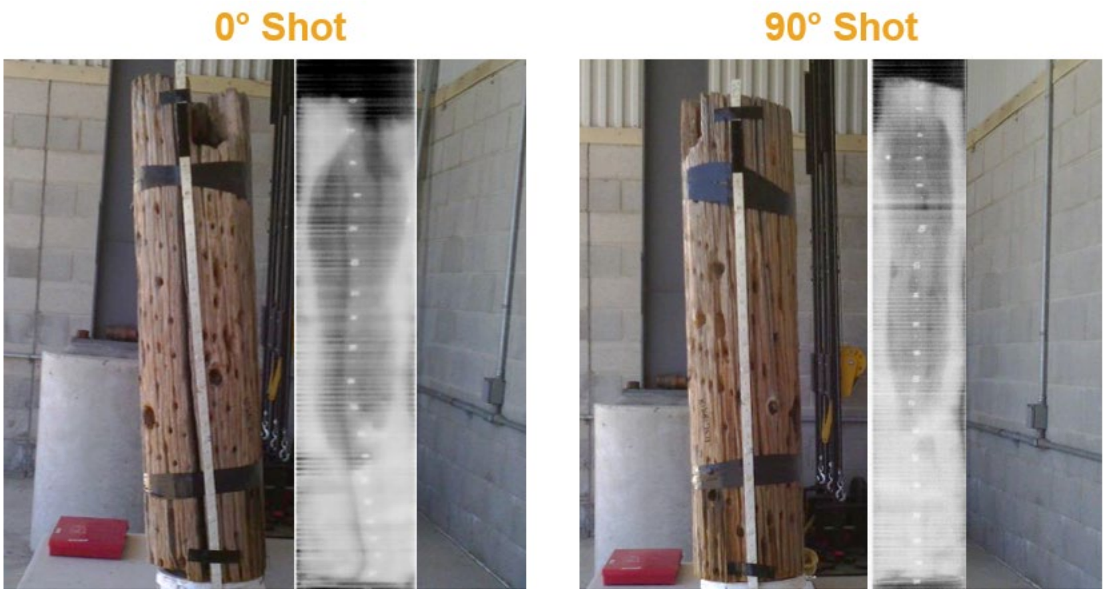


Figure 29 - Sample 2: Damaged Pole

Figure 300 - Sample 3: Damaged Pole

Figure 311 - Sample 4: Damaged Pole

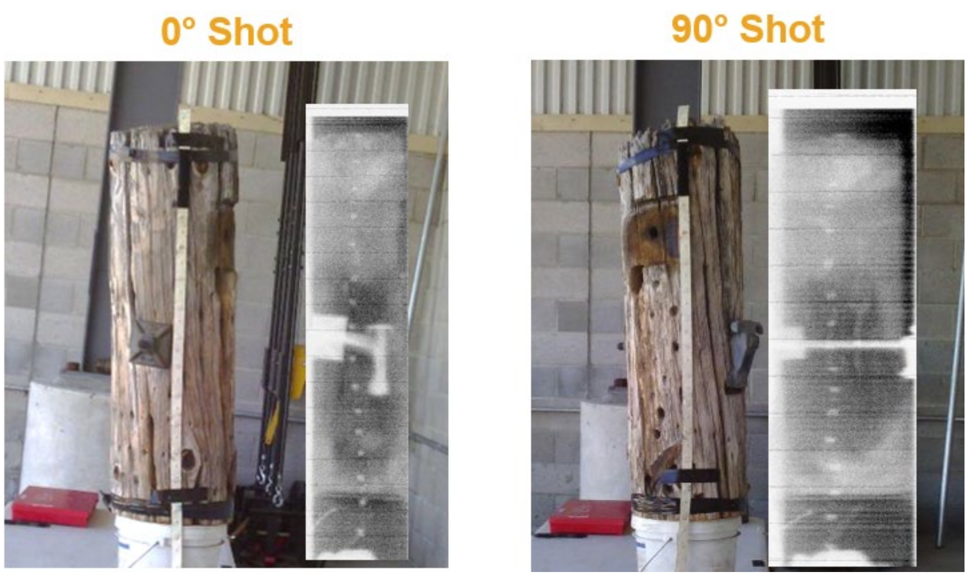


Figure 322 - Sample 5: Damaged Pole

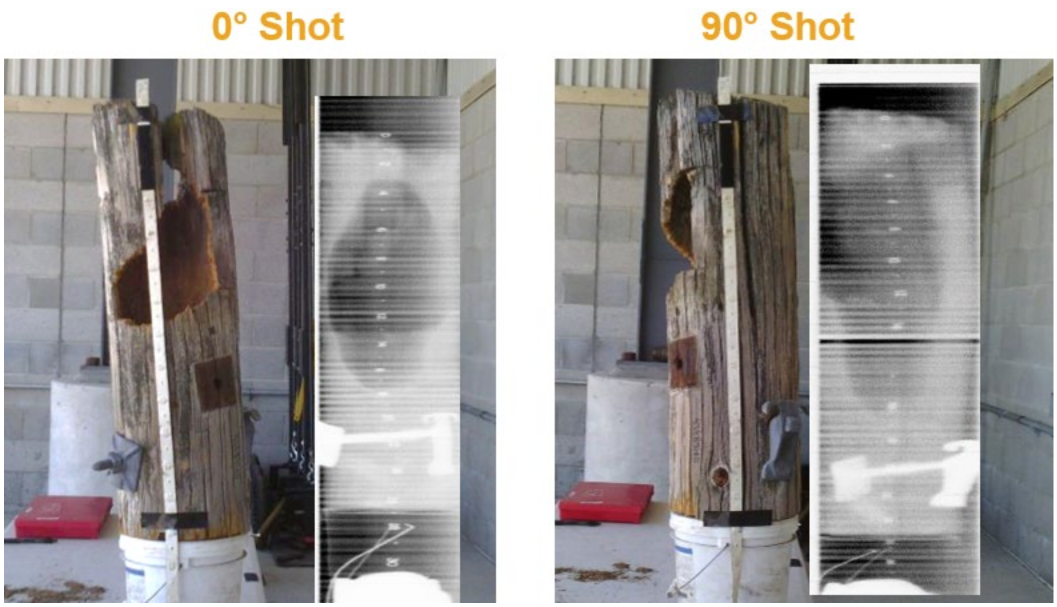


Figure 333 - Sample 6: Damaged Pole

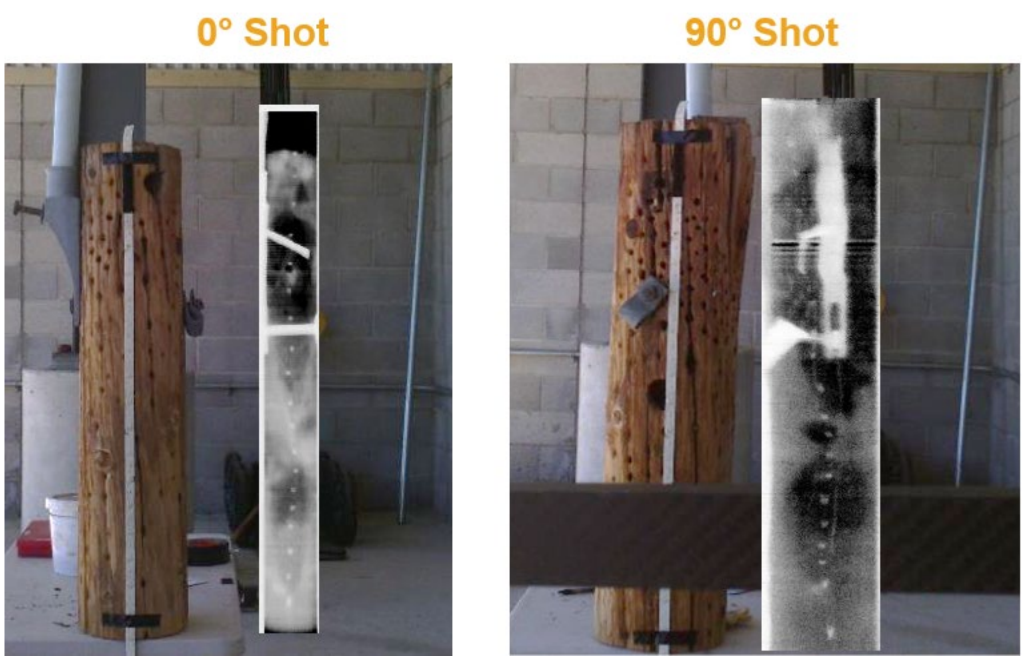


Figure 344 - Sample 7: Damaged Pole