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Development of the Hydra Tamper Indicating Seal and Seal Reader

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Abstract

Savannah River National Laboratory (SRNL) is developing a new loop seal called the Hydra tamper indicating seal. The Hydra Seal is a single-use loop seal with advanced authentication features that are created during seal application and can be verified in-situ. The Hydra Seal was originally conceived by the Savannah River National Laboratory (SRNL), Pacific Northwest National Laboratory (PNNL), the United Kingdom's (U.K.) Atomic Weapon Establishment (AWE) and Milagro Consulting, with most of the development performed by SRNL. The seal has a cubic shape with sides approximately 1.25" long. The external part of the seal is clear plastic, which allows the tamper indicating and authenticating features to be visible to both the monitoring and host parties. As part of the seal development, SRNL is developing a seal reader that assists with seal application and obtains reference and verification images of the seals for authentication and verification. It is envisioned that the Hydra Seal could be used in many applications where a robust low-cost passive seal is required. A vulnerability assessment of the seal design is currently being performed by Argonne National Laboratory and a field test of the seal is currently being performed in the K-Area Material Storage (KAMS) facility at the Savannah River Site (SRS).

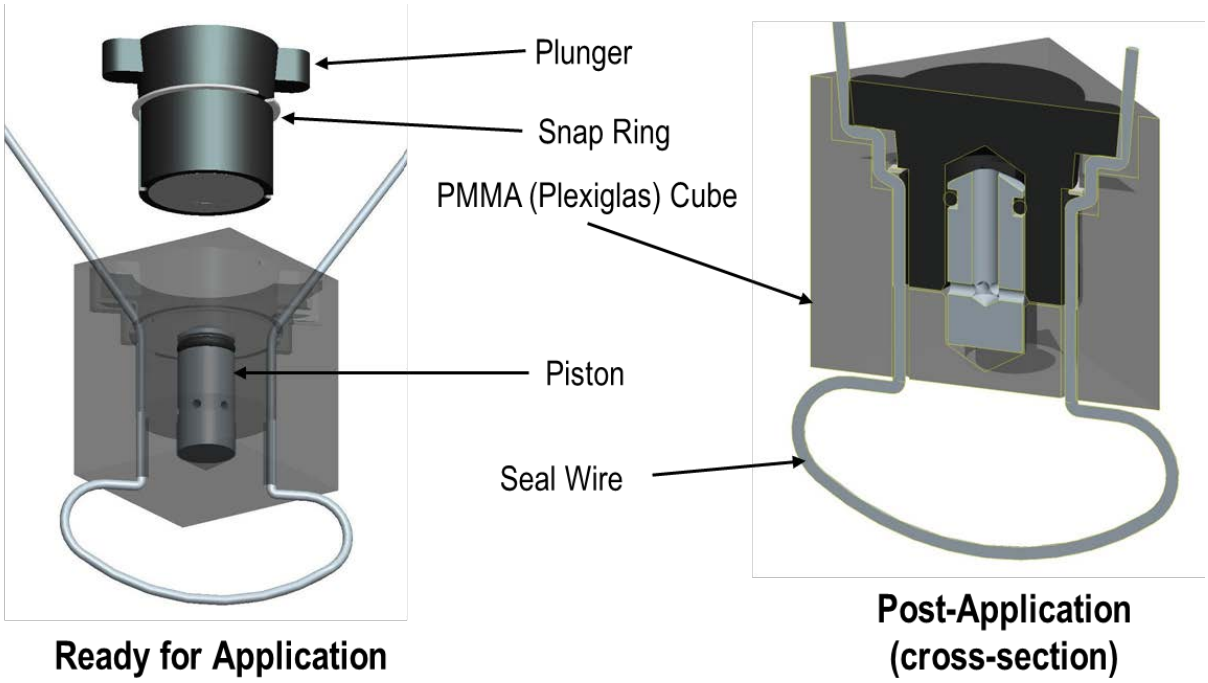
Definition of a Passive Loop Seal

The Hydra Seal is a loop seal, meaning that it has two main components – a loop made of wire that is fed through a hasp or some other means to attach it to an item; and a seal body, which captures both ends of the loop. A seal is a tamper indicating device, not a lock. In other words, a seal is not intended to physically prevent an adversary from opening a container. Rather, a seal is intended to provide evidence that a container has been opened. To be an effective seal, it must not only be tamper indicating, but it must be able to be authenticated – it must have features that are unique to each specific seal and cannot be replaced without the inspecting party knowing that the replacement occurred. The Hydra Seal is considered a passive seal, because it has no electronic components and its status is not monitored and updated periodically via electronic means. The Hydra Seal is designed for use in nuclear arms control treaty verification. In this application, transparency and simplicity are valued by both the host and inspecting parties. For both parties to trust the authenticity of each seal, the seal unique identifier (UID) is ideally created during application of the seal in the host facility.

Hydra Seal Development History

Development of the Hydra Seal began during fiscal year 2011 as part of the U.S.-U.K. Technical Cooperation Program. Initial development included input from SRNL, PNNL, AWE, and Milagro Consulting. SRNL took over development of the seal and seal reader as the other parties focused their attention on preparations for the 2011 U.S.-U.K. Warhead Monitored Dismantlement Exercise (WMD). As an aside, the seal is named "Hydra" after a serpentine water monster in Greek and Roman mythology who had many heads (the seal has four faces). Hydra also follows the serpent theme of previous tamper indicating seals (e.g. Cobra, Python).

Hydra Seal Design



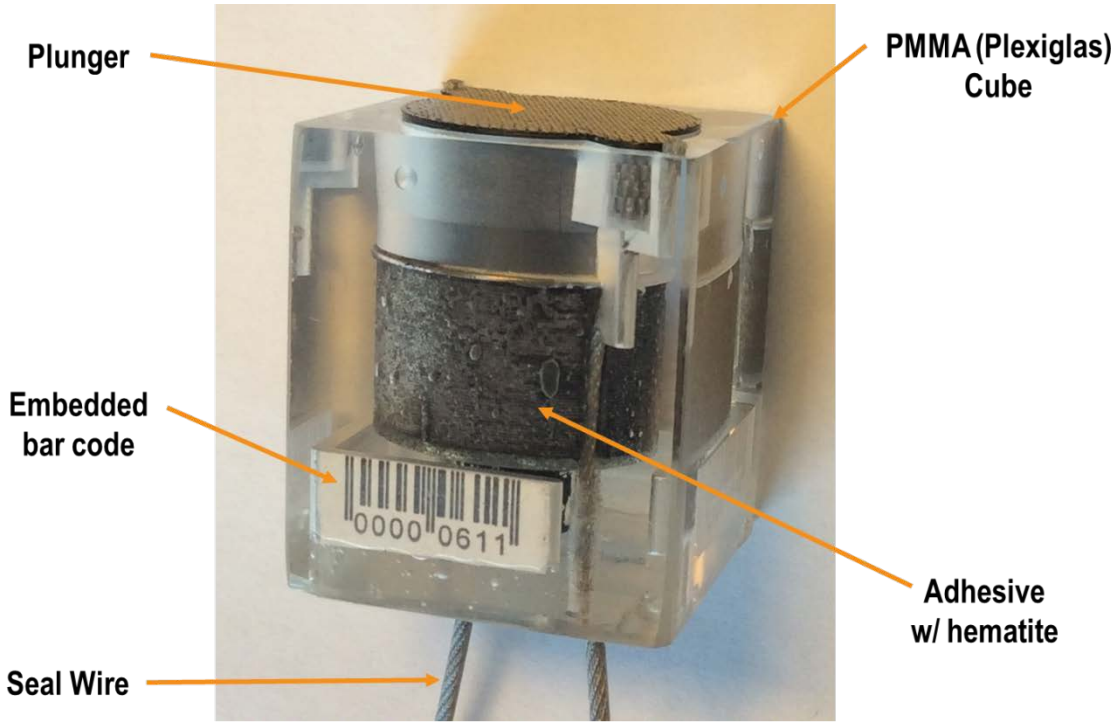


Figure 1: 3-D model of Hydra Seal (top), photo of Hydra Seal (bottom)

The Hydra Seal has three major components: a cube, a plunger, and a seal wire. The cube is made of transparent PMMA (Plexiglas) and is nominally 1-1/4" long in each direction. An internal cavity is machined in the cube to receive the cylindrical black plunger. Also part of the cube assembly is a piston, which is additively manufactured using black polycarbonate/ABS plastic. The plunger is additively manufactured and is composed of black polycarbonate/ABS plastic. Pre-packaged in the plunger cavity is a mixture of UV cured adhesive and specular hematite particles. The plunger also has ears that are used to retain the seal wire. The seal wire is made of stainless steel wire rope and is coated with a translucent plastic coating.

Hydra Seal Installation and Validation Process

Below is a brief summary of the process for installing a Hydra Seal on an item of interest:

1. Cut a length of seal wire and route it through device to be secured so that both ends of the wire are accessible.
2. Insert both ends of the seal wire into the Hydra Seal cube.
3. Insert the plunger into the cube. Note: during this step, the piston breaks the seal that retains the adhesive/hematite mixture and as the plunger is further inserted into the cube, the mixture is expressed into the annular space between the cube and the plunger.
4. After inserting the Hydra Seal into the Hydra Seal Reader (see Figure 2), the seal adhesive is cured using UV LEDs internal to the reader.
5. The reader automatically acquires images of the seal after the adhesive is cured. The reader acquires eight images of the seal – one image of each face while illuminated from the right side and one image of each face while illuminated from the left side (see
6. Figure 3). These eight images are called reference images. The reader also reads the bar codes that identify each face of the seal.

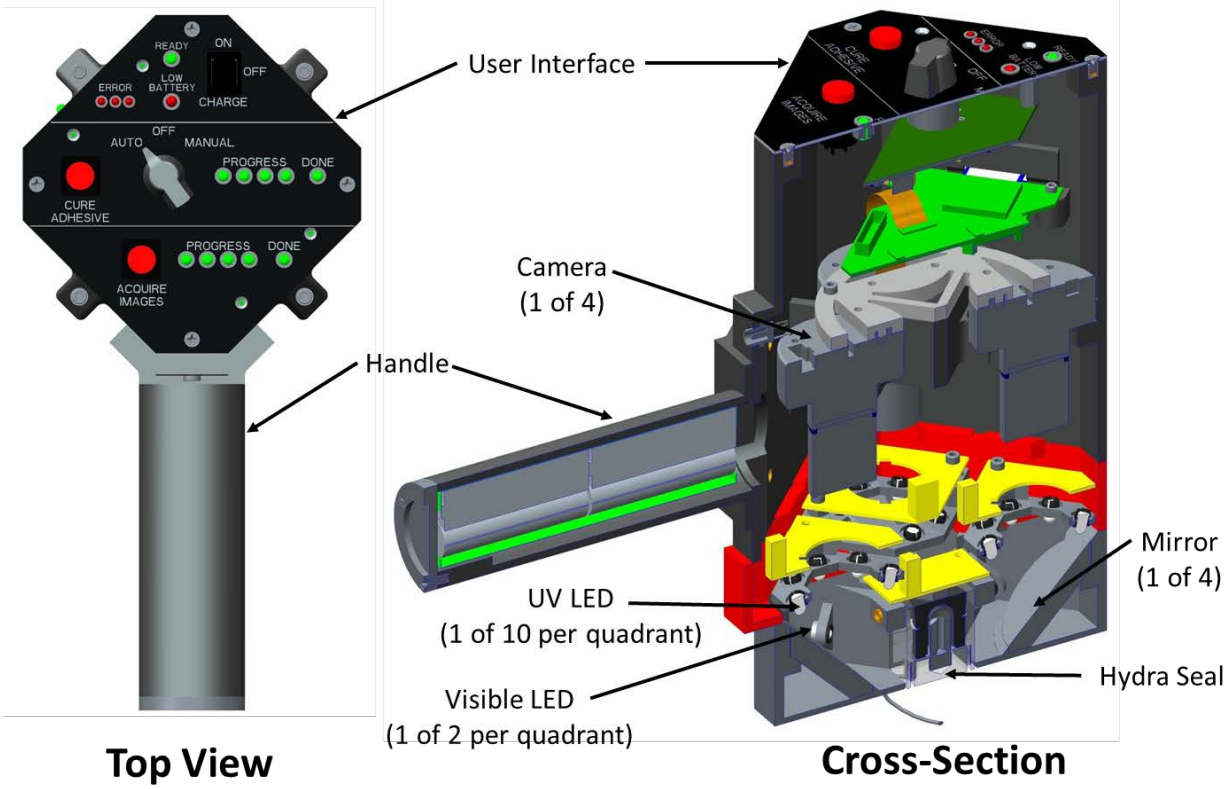


Figure 2: Hydra Seal Reader

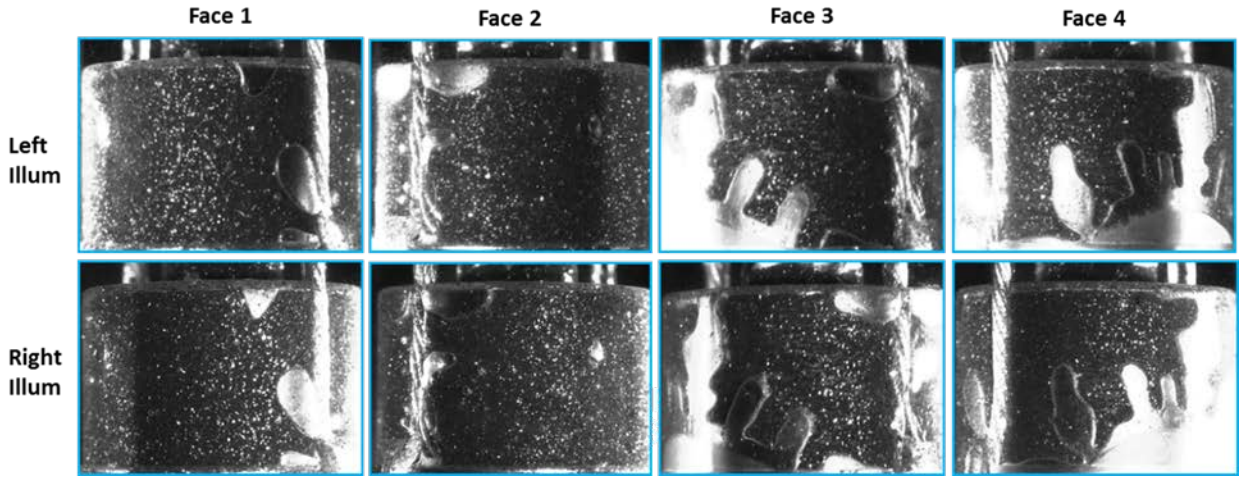


Figure 3: Images Taken by Hydra Seal Reader

On some regular basis, an inspector will repeat the image acquisition process that was performed during installation. These subsequent images are called validation images in our software (same as verification images) and are compared to the reference images for the purposes of authentication and tamper indication. The image information is written to two SD cards installed in the reader. The operational concept is that the host facility personnel have the option of taking

either SD card and the inspector takes the other card. This approach enhances transparency between the host and inspecting parties and provides assurance against tampering, counterfeiting and accusations of cheating by either party. The inspector then compares the reference and validation images using SRNL-developed image comparison software (see Figure 4). The image comparison algorithm is adapted from the algorithm developed by Dr. Keith Tolk for Reflective Particle Tag image comparisons. An image comparison results in a value we called the "Keith Tolk Factor" or KTF, in honor of Dr. Tolk's contribution. A KTF of 1.0 is a perfect match. Figure 4 shows a comparison between reference and validation images of the same seal face. Note that the KTF is > 0.996. In the image comparison software, each pixel is assigned a value 0 and 255 based based on its brightness (0 is black and 255 is saturated white). The image comparison software allows for thresholding of images, which sets all pixels to zero (black) if they are darker than the threshold value. This theoretically highlights the bright reflections from the hematite, but the utility of thresholding needs to be investigated further to determine whether it improves the image comparison. Image registration (alignment of the reference and validation images relative to each other to account for reader variability) and normalization are also performed. In addition to the automated image comparison performed by the software, the right hand window in Figure 4 labeled "Absolute Difference" illustrates that the software also allows an inspector to perform a visual comparison between the reference and validation images. White areas in the Absolute Difference window highlight where the validation image does not match the reference image and is a powerful tool for drawing attention to a tamper event.

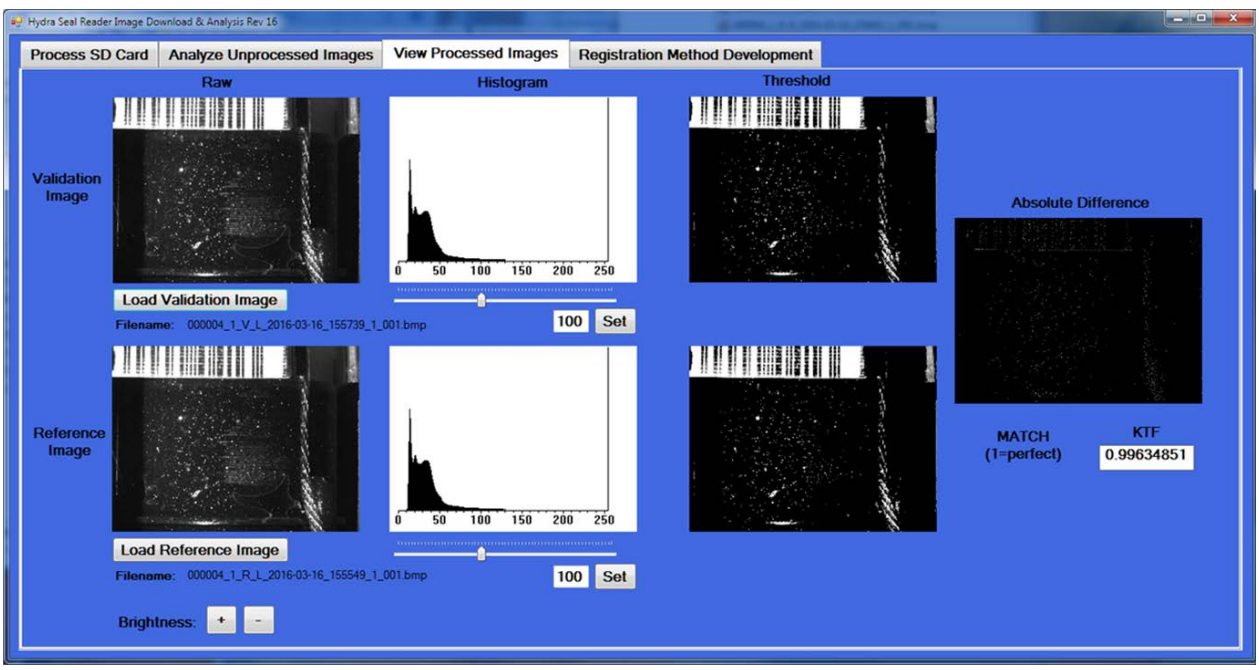


Figure 4: Image Comparison Software

KAMS Testing

Field testing of the Hydra Seal began in June, 2016 and is currently being performed in the K-Area Material Storage facility (KAMS) at the Savannah River Site (SRS). KAMS is a facility that stores excess plutonium and other special nuclear materials (SNM) that were produced at SRS and other Department of Energy sites. The materials are packaged in 9975 packages,

stacked three high, and the exterior containment of each package is a 35 gallon stainless steel drum. The KAMS facility is indoors, but not climate controlled. It is a high security area and is subjected to stringent nuclear regulations.

Testing is being performed in KAMS to subject Hydra Seals to a real world scenario and determine how the seal can be improved for use in support of nuclear arms control treaty verification. Deploying seals in KAMS presents many of the security and safety considerations that are encountered when deploying seals on items in a weapons dismantlement facility. Testing in KAMS also subjects the seals to temperature and humidity fluctuations as well as long term exposure to neutron and gamma radiation. KAMS testing is scheduled to conclude in June, 2017.

Below are the basic parameters for the KAMS testing:

- 25 seals were applied to 9975 packages (one seal per package)
- Thermoluminescent dosimeters (TLDs) with neutron and beta/gamma detection capabilites were installed on every 9975 package where Hydra seals were applied
- The seals were installed at three positions in KAMS (9 in one position and 8 each in the other two positions). Temperature and humidity data loggers were installed at each of the three positions.
- Validation images are being obtained on a periodic basis

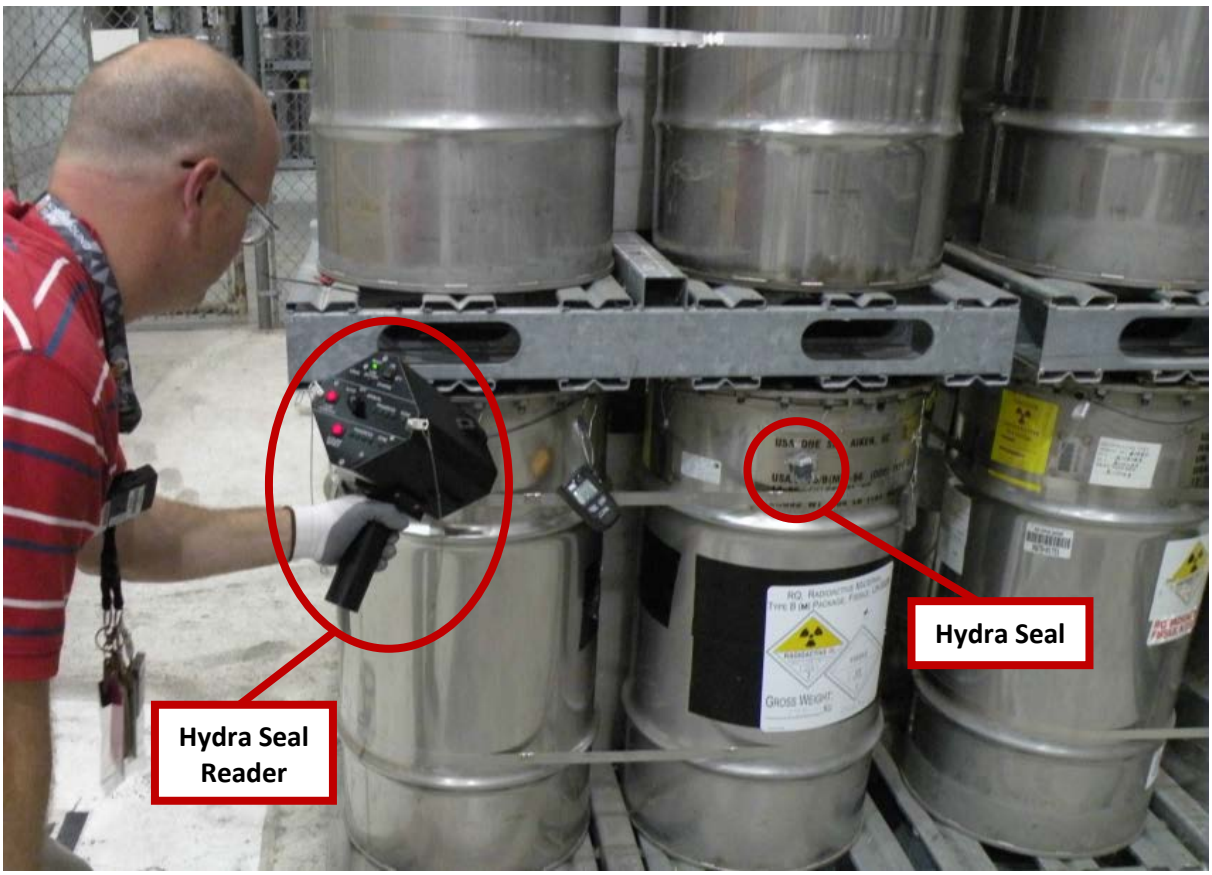


Figure 5: Hydra Seal Reader with Hydra Seal Applied on 9975 Package and Inserted into Hydra Seal Reader

Figure 6: Hydra Seal Reader Hanging from 9975 Package for Installation Process

Vulnerability Assessment

Argonne National Laboratory is performing a vulnerability sssessment (VA) of the Hydra Seal and seal reader. The VA began in April, 2016 and will conclude in September, 2016. SRNL delivered 20 unassembled seals and one reader for ANL to use for the evaluation. In April, SRNL trained ANL on seal application and reader operation. The seals can used by ANL as needed in support of the VA (including destructive tests and examinations). The reader is to be returned to SRNL after completion of the VA.

Path Forward

For fiscal year 2017, SRNL has proposed to the NNSA Office of Nuclear Verification further refinement of the image analysis software. At this stage, the software requires a user to interpret the data it produces to determine whether a seal has been counterfeited or tampering has occurred. SRNL proposes to further analyze and interpret the data produced by the software. This analysis will lead to implementation of software parameters that will allow the reader to indicate to an inspector that the seal image being verified is either a match with the reference image, a non-match, or a potential match requiring further verification to determine its status.

The current version of the Hydra Seal does not incorporate any means for performing advanced wire loop verification (methods of interrogating the wire loop to determine whether it has been replaced or cut/repaired). SRNL and PNNL have proposed to investigate other wire loop options such as fiber optic or other metal wire options that would better facilitate loop verification. Also proposed were advanced methods for seal loop interrogation and verification.

Acknowledgement
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