Prototype of Tamper Indicating Device for Automated Robotic Application

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1.0 Abstract

To reduce the amount of weapons-grade nuclear waste present in the United States, the Department of Energy (DOE) started an initiative to dilute and dispose of the nation's surplus plutonium. This disposition operation, occurring over the next 30 years, will process upwards of 120,000 Criticality Control Overpack (CCO) containers. Because of the high volume of CCOs being inspected and the duration of the project, the Savannah River Site (SRS) tasked Savannah River National Laboratory (SRNL) with automating the inspection of the CCOs while preserving the level of security in manual inspection operations. The final step in the inspection procedure is applying a Tamper Indicating Device (TID). The TID used in manual operations was unusable when paired with robotic automation, requiring the redesign of the TID and the design of an end-of-arm tool for the robot to apply the TID. Following several prototypes using additive manufacturing and different materials, the latest iteration of the TID consists of two components: a reusable block made of a stainless steel and a replaceable, serialized aluminum pin. With the redesigned pin, the applicator tool, equipped with the block and pin assembly, applies the TID to the drum lid closure ring, presses the pin through the block, and deforms the disposable pin, locking it in place. Once locked, the TID prevents the bolt from being loosened and the lid from being removed unless the aluminum pin is destroyed. The robot captures the serial number, adding it to the data package for the CCO container, which is then verified when removing the TID and reopening the CCO after inspection. This is a custom, mass produced device that, because of its ability to be integrated with the robotic automation process, will allow the last step of the inspection process to be completed without human involvement. The automated installation of the TID ensures the security of the CCOs and that the management of nuclear material is not compromised throughout the disposition process.

2.0 Introduction

Before storing dispositioned surplus plutonium, newly delivered CCOs must be processed through a rigorous inspection [1]. Currently, this inspection includes the manual disassembly of the container and its parts and a visual inspection to verify the integrity of the components and no additional components or defects are found. Once verified, the CCO is reassembled and secured with a TID, which confirms the container has not been opened since passing inspection; the TID will show signs of tampering if there has been an attempt to re-open the CCO after the inspection process before being loaded with material [2].

2.1 Current TID Application Process

Following the completion of a successful manual inspection, one or more operators apply a pull-tight wire cable TID. The wire is wrapped around the CCO lid ring lugs and inserted through a hole in the bolt before being pulled through the locking mechanism. The wrapping of the wire prevents the lid from being loosened while the TID is present. If the cable is cut, the steel wires fray and separate, making the cable unable to be reinserted into the locking mechanism, exhibiting tampering.

Figure 2-1. Pull-tight TID on CCO

2.2 Automating TID Application

The newly automated process utilizes a FANUC robotic arm and Schunk quick-change system to switch between various tooling throughout the inspection. Despite the versatility of these components, the design of the pull-tight TID is not conducive to being installed autonomously; the tooling design, creation, and use of the robotic process would be overly complicated and costly. As a result, the decision was made to develop a new TID that can be easily manipulated, applied, and inspected for tampering both manually and autonomously.

3.0 Design of a New TID and Tooling

The design of the new TID is required to meet the same safeguards of preventing the CCO from being opened and to indicate if there has been a breech in security in a way that is easily recognizable. Additionally, each TID must have a unique serial number that can be autonomously recorded and assigned to the CCO drum it was applied to. The design must also be conducive to a manufacturing process that is reasonably economical for mass production and consumption.

3.1 First Iteration of New TID and Tooling Design

The first iteration of a new TID included a custom housing that was applied over the drum ring bolt and lugs and locked in place with a pin [3]. The design of the housing prevented the drum ring from opening far enough to remove the drum lid without breaking the housing. The TID pin also could not be removed from the housing unless destroyed because of its flared geometry that only allows motion in one direction, similar to the barb of a fishhook.

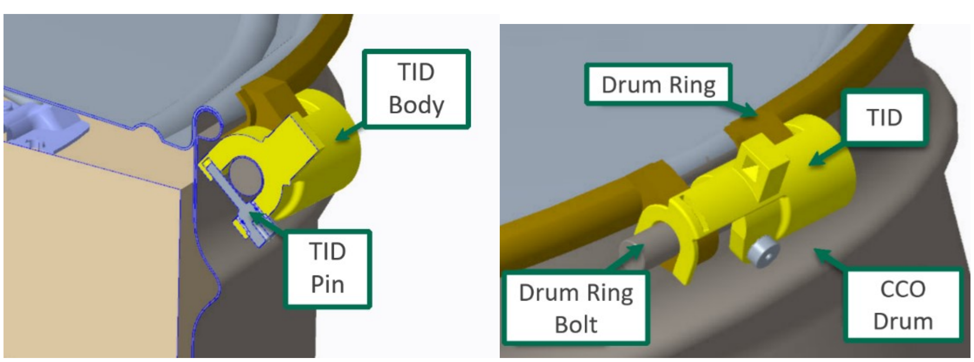

Figure 3-1. First iteration of TID

The housing for the drum ring bolt was held in a parallel two-jaw gripper on the robot, which was positioned over the closure for installation. The robot then actuated a pneumatic cylinder to insert the flared pin and lock the housing in place over the bolt.

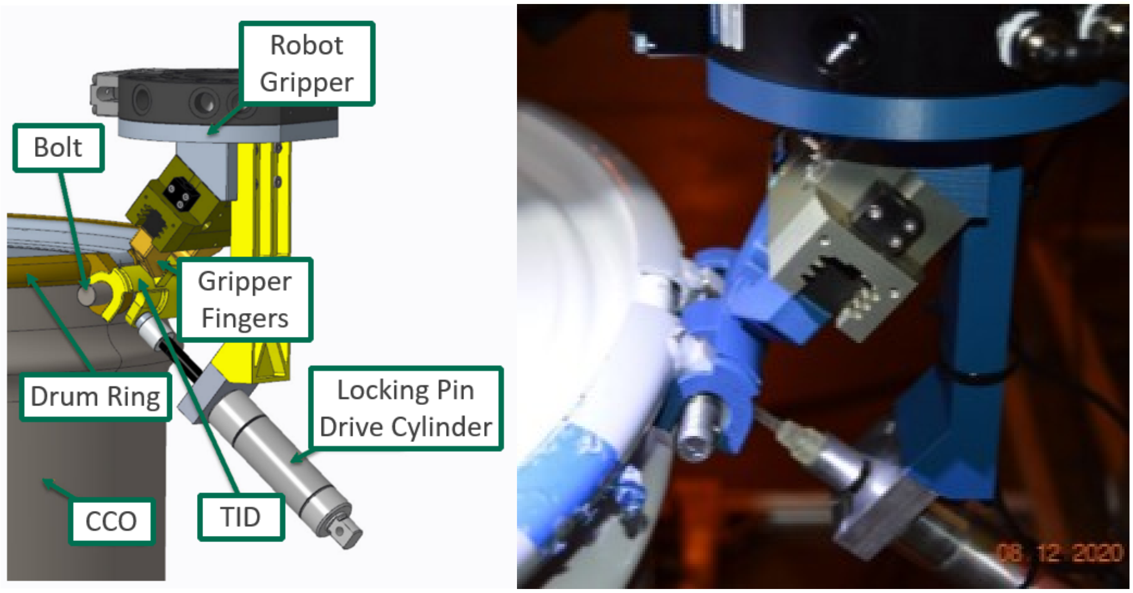

Figure 3-2. First iteration of TID tooling

This first iteration served as a proof-of-concept and, although the concept seemed dependable, there were some flaws in the design. The housing utilized complex geometries that were difficult to machine and not economically reasonable. The tooling design required the pin to be held in a way that led to frequent misalignment during insertion, occasionally damaging the pin. Because of these issues, the robotic process was unreliable and required operator intervention.

The TIDs would not be inspected for a proper seal until the CCO was removed from the workcell and, if deemed unacceptable, would have to be manually removed and the CCO would have to be reinspected, sacrificing cost, and wasting time. Additionally, the pin flare was in a location that was not visible to the operator, causing a potential security issue. The pin was also inserted into the housing in a way that, if the CCO was roughly bumped, the pin could be damaged because of excessive contact against an adjacent CCO in transportation, falsely indicating tampering. Along with the TID design, the installation tooling was impractical; though simple, the lack of controls and feedback on the gripping and pin insertion mechanisms could cause damage to the TID housing or pin during installation. The tooling was also incapable of reloading itself for the next inspection, requiring operator involvement.

3.2 <u>Second Iteration of New TID and Tooling Design</u>

Following these findings and based on customer feedback, a new housing with simpler geometries, a new pin, and a new application tool were developed to improve autonomy, reliability, and manufacturability [4]. The second iteration of the housing was designed with a more rudimentary geometry that would require less machining time without sacrificing tamper indication. The new pin was designed to have an end that would fit through the hole in the housing with little to no clearance with a flare in the middle that locks the pin in place. This design protects the flare from being damaged from rubbing against the CCO. This pin also had a rectangular tab on the back end for serial number identification. The housing included geometries to protect the pin from sideways forces and to aid in aligning the serial number for scanning and verification.

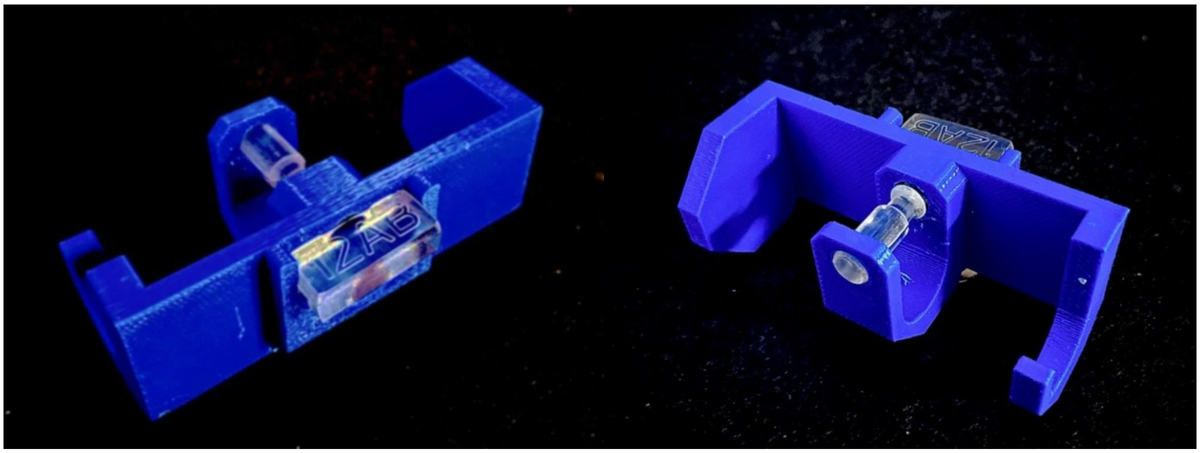

Figure 3-3. Second iteration of TID housing

After successfully testing this iteration, it was determined the pin design would be too expensive to manufacture and the push-through flare would not be repeatable enough to meet security requirements. The hole diameter tolerance required for proper locking of the pin caused approximately 5-10% of pin flares to crack upon insertion. Additionally, autonomously verifying the proper insertion of the pin flare proved to be difficult with it being in the middle of the housing.

The tooling for this TID iteration was designed to increase control over the application process, improve repeatability, and allow the tool to function without operator intervention. The new tool was designed for the TID shown in Figure 3-3 to capture the TID assembly and push the pin through the housing on the bolt.

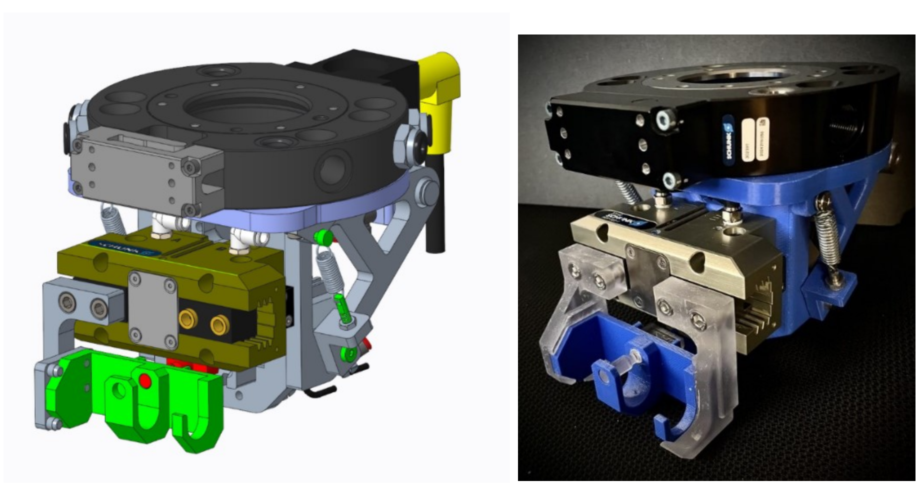

Figure 3-4. Second iteration of TID tooling

While this tool functioned, because of the changes required for the TID pin and the desire for more control, the tool had to be refined and improved upon.

3.3 Current Iteration of New TID and Tooling Design

The housing was slightly redesigned and simplified to accept a square aluminum pin with an unflared end and the serial number on all four sides for more affordable manufacturing, more reliable insertion, and easier verification. The pin is pushed through the housing with minimal clearance and is not deformed upon insertion. After installation, the tool flares the end of the pin, allowing the FANUC and operators to clearly inspect the outwardly exposed flare. The geometry of the two parts allows the flare to sit recessed, preventing it from being damaged by interaction with the CCO or being removed without indicating tamper.

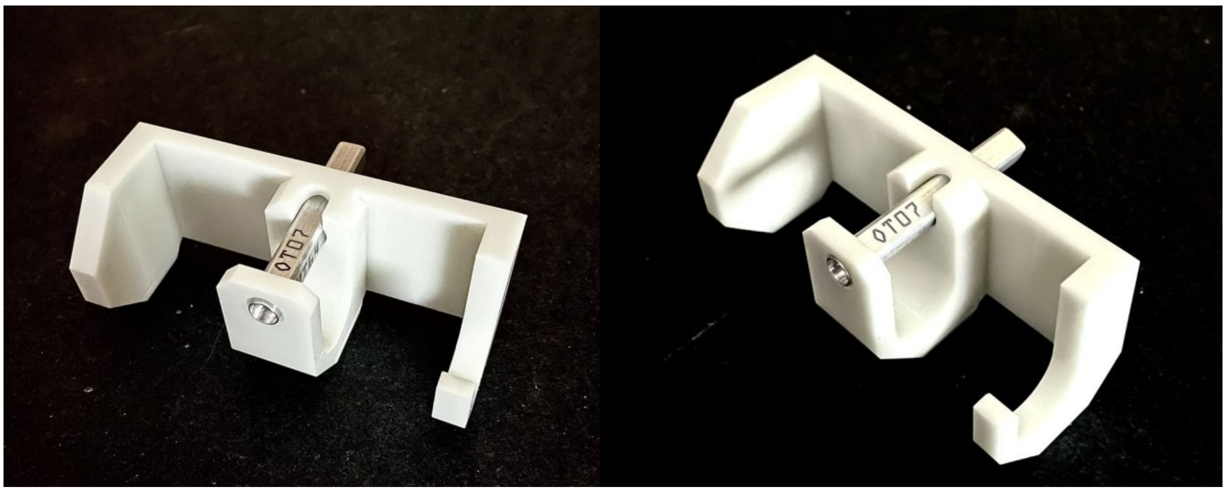

Figure 3-5. Current TID iteration

This design also clearly displays the flare of the pin and the serial identification number for autonomous verification and recognition for the operator and data package.

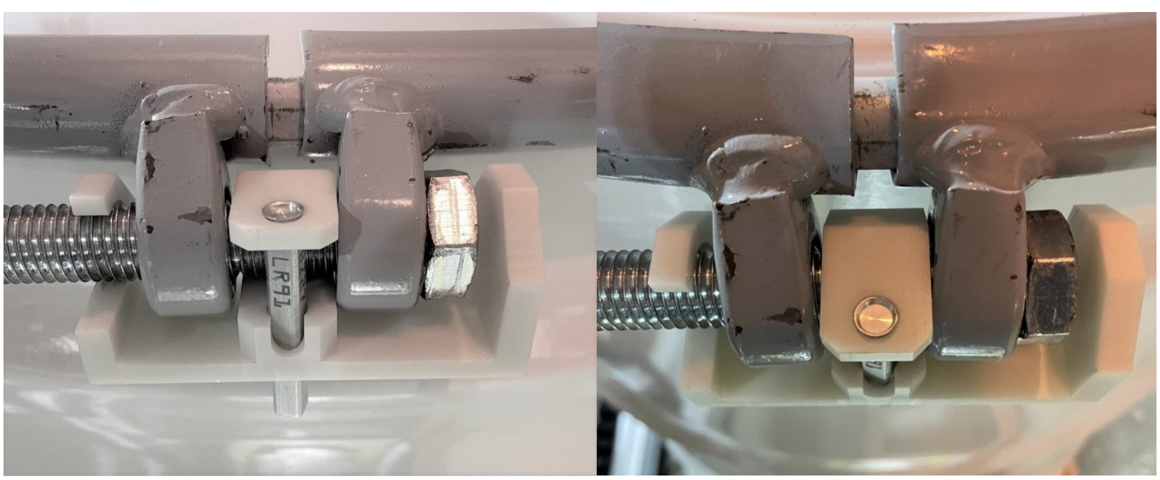

Figure 3-6. Current TID installed on CCO

In order to deform the end of the square aluminum pin, the unflared end had to be accessible to the tool. This crimping action also had to be used in conjunction with the gripping of the TID housing and pushing the pin through the housing once the bolt is encapsulated. Signal feedback to ensure the TID housing and pin had the correct positioning throughout the process was essential. This led to the development and addition of a control box, a pneumatic pressure regulator manifold, and an electric solenoid bank for the tool itself rather than utilizing the limited pneumatic controls from the robot.

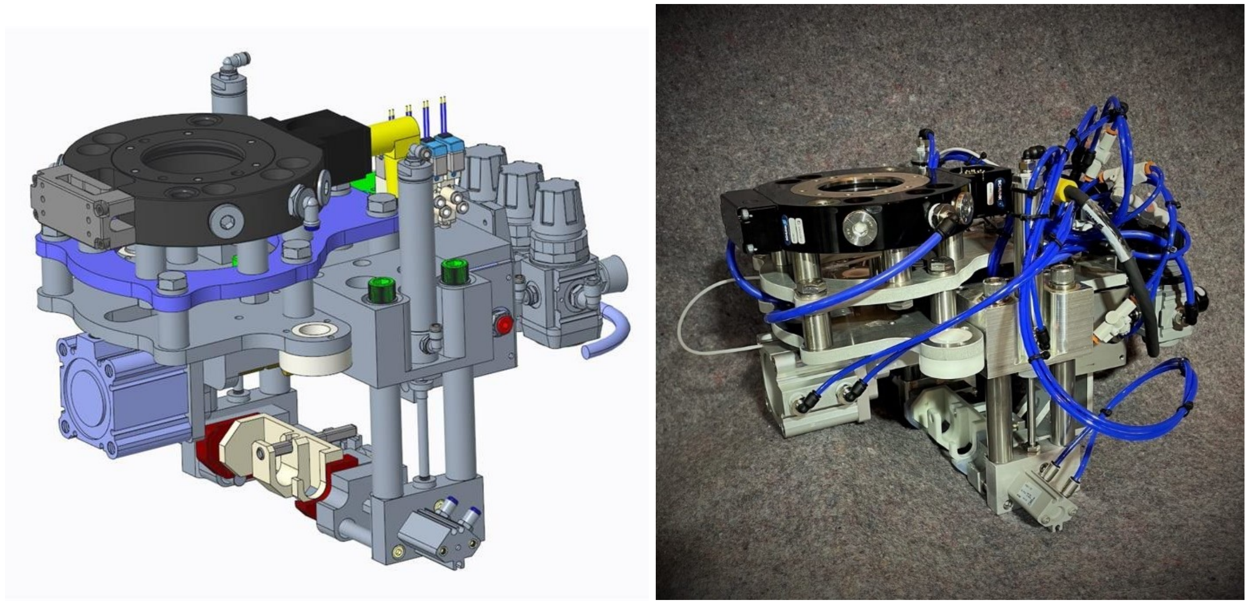

Figure 3-7. Current iteration of TID tooling

4.0 Testing Process

4.1 Robot Pathing

For the TID tool to be able to apply a TID to a CCO, the robot is required to perform complex maneuvers to orient the TID assembly properly. The robot motion and pneumatic processes were initially hard coded to ensure the pathing and functionality was possible. Once proven, the movements were made more robust with vision processes that find the location of the bolt on the drum ring. The hard coded robot motions are offset based on the position of the bolt found in the vision processes to certify the tool and TID approach the bolt properly.

Because of the geometry of the TID and tooling, the pin application occurs at a different angle than the angle required to encapsulate the bolt. Once the bolt is encapsulated, the robot rotates the tool to the position required for flaring the pin. Through testing, the pneumatic controls of the TID application have become more robust, surpassing the original hard coded solution. Sensors in the tool and pneumatic cylinders prevent the robot from transitioning to the next phase in the process until each step has been verified; this verification enhances the reliability of the application without excessive additions to process time. Multiple sensors are utilized throughout the process, including an inductive sensor to ensure the TID block is in the proper position before deformation and sensors embedded along the pneumatic cylinders to confirm the pin is compressed properly. With this sensor feedback, physical verification is present throughout the application process.

4.2 Application Verification

Several methods of verification are measured to ensure the successful application of the TID because of security requirements. Once the TID is applied with no negative sensor feedback, the robot changes tools from the TID applicator to a Keyence laser profiler. The scanner passes over the TID to verify the pin is present and collects and records the TID serial identification for the data package.

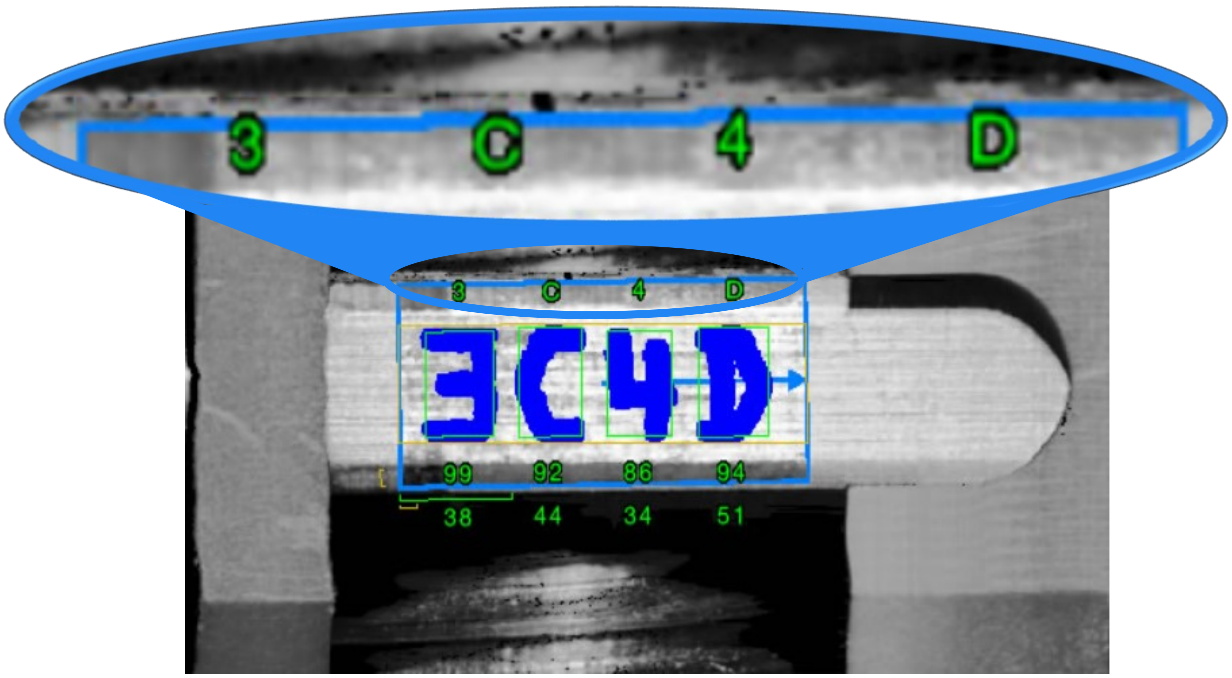

Figure 4-1. Optical character recognition of TID serial identification

The laser then scans the deformed end of the pin to ensure a proper seal. By identifying the diameter of the depressed pin, the automated software determines if the pin was properly flared during installation. This program can recognize both whether the pin was fully compressed using a predetermined diameter tolerance and if a section of the pin did not flare out properly using a flaw detection algorithm on the circle; to pass the verification process, the inspection must meet both metrics. This verification gives a benchmark reference for the manual inspection of the TID upon receipt of the CCO within a secured facility.

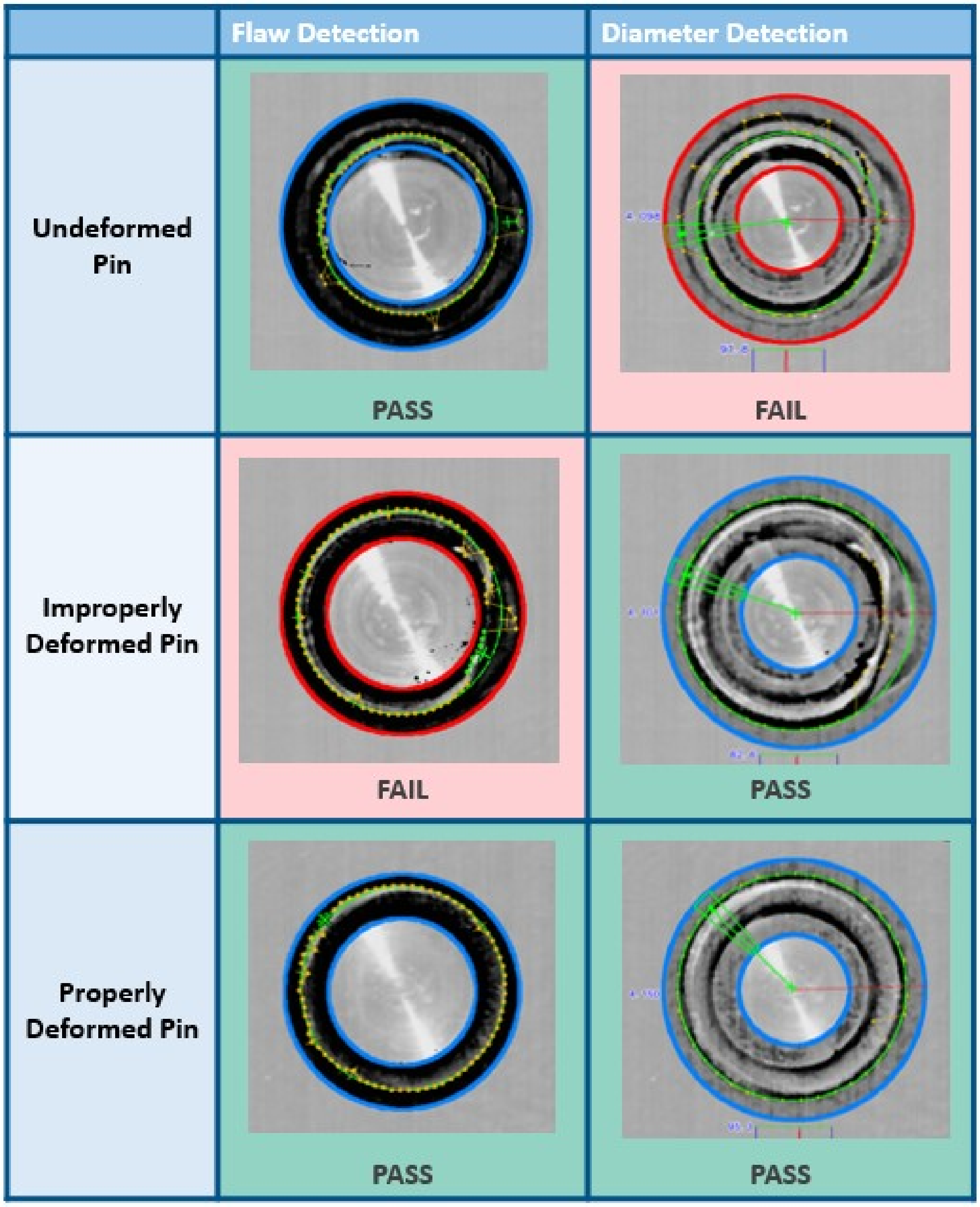

Figure 4-2. Detection scans of TID pins

5.0 Future Work and Implications

While testing and practicing the robotic application, a few concerns have been identified to improve upon to increase the consistency of the tool. Upon installation, because of the robotic maneuvers, the pin tends to become misplaced in the TID assembly. Modifications are being made to the tool to maintain control of the pin during TID and pin installation. The design of the CCO has also changed to have a 5-inch bolt instead of a 4-inch bolt, requiring dimensional changes of the tooling to account for the increased bolt length.

There are several options being explored regarding the manufacturing of the TID housing; while the pin will always be single-use, the housing has the potential to either be single-use or reusable.

If reusable, the housing would be machined from a chromium-nickel austenitic alloy. This would make the housings more durable and would produce less waste but would also require a periodic inspection plan of the housings. If single use, the housing would be made using plastic injection molding; this would allow for several material options and, although upfront tooling would be costly, production of the housings would be inexpensive. This option, although it produces waste, would eliminate the periodic inspection and inventory tasks that would be associated with reusable housings, saving additional funds.

All serial number and pin scanning has been proof-of-concept; after finalizing a production-ready TID housing and pin, the structure of the existing software will be used to create a more robust vision verification system. These improvements will include teaching the optical character recognition (OCR) alphabet to interpret the serial number font, determining the diameter threshold for a failed deformation, refining the flaw detection algorithm to ensure failed pins are identified, and being able to compensate for imperfect scanning conditions.

To make the OCR more reliable, multiple real-world scans of each letter will be added to a reference library. The reference scans will be taken from different angles and rotations to overcome skewed aspect ratios. Additionally, the scans will be tested with different controllable factors, such as lighting, to establish the ability to adapt to changing environmental conditions. To ensure the TID maintains its security requirement, the diameter threshold of the deformation will need to be determined with the customer. The number of test pin scans will increase exponentially as the tooling and TID design is finalized, allowing for the improvement of the flaw detection.

Overall, the TID, tooling, and the integration of these components have been improved upon throughout the duration of the project with positive feedback from the Savannah River Site customers. Finalized designs will be selected and implemented into testing within the next year. The timeline of the TID and tooling improvements coincide with the Department of Energy disposition efforts. These developments will be executed in the autonomous inspection process for the remaining duration of the disposition operation.

6.0 References

[1] SRNS, *Project Overview Surplus Plutonium Disposition Project,* Savannah River Nuclear Solutions, 2021.

[2] R. Koenig, *K-Area Six-Year Automation Plan: Year Two Update,* Aiken, SC: Savannah River Nuclear Solutions 2022.

[3] M. Dalmaso, et al., *Robotic Inspection of the Criticality Control Overpack,* Aiken, SC: Savannah River National Laboratory, 2020.

[4] N. Spivey, et al., *Refining and Testing of the Criticality Control Overpack Robotic Inspection,* Aiken, SC: Savannah River National Laboratory, 2022.