FIRST PROTOTYPE OF INTRINSICALLY TAMPER INDICATING CERAMIC SEAL (ITICS)

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ABSTRACT

The Intrinsically Tamper Indicating Ceramic Seal (ITICS) is an advanced capability seal intended to replace the ubiquitous metal cup seal used by both domestic and international security organizations for applications such as treaty verification. Users of the metal cup seal have expressed a need for a new seal for the following reasons: verification of the metal cup seal is labor intensive; seals generally should be updated as adversaries continually advance; and advanced capabilities such as in-situ verification and improved ease of deployment are desired. ITICS will provide in-situ verification of tamper and identity. In the current prototype, tamper indication is evident by examination of the seal body itself, fabricated from frangible ceramic material, and through downloaded messages provided to a handheld reader by the electronics. The authenticity of the seal is also verified in-situ using a handheld reader. This paper will describe the features of the current prototype including advancements in adhesives research, and the research and development underway for the next prototype.

INTRODUCTION

Seals are critical elements of any monitoring regime to detect diversion of nuclear material, equipment tampering, as well as compliance with treaties and agreements. Their continual improvement is required as the adversary advances technically. Additionally, advancing technologies can improve efficiency.

The International Atomic Energy Agency (IAEA) uses approximately 20,000 metal cup seals (Figure 1) per year. Other users include the HEU Transparency Program and EURATOM. The metal cup seal, used since the 1960s, is a conventional passive loop seal useful for single-use applications. While conceptually simple and robust, the seal is cumbersome to deploy. The wire must be secured within the seal, for instance by tying knots in the seal wire and using a crimp connection and tool for termination. Verification of the seal's authenticity is labor intensive and the analysis cannot be performed in-situ. A unique ID is obtained by imaging random scratches on the inside surface of the metal cap and comparing the images before installation and after removal. Due in part to the difficulties in verification and application, users have requested a replacement for the metal cup seal.

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Figure 1: Size comparison of a metal seal (left), rapid-prototype mockup of the ITICS (right), and a U.S. quarter (bottom). Picture courtesy SNL.

The Intrinsically Tamper Indicating Ceramic Seal (ITICS) is a collaborative research effort between Sandia National Laboratories (SNL) and the Savannah River National Laboratory (SRNL). It provides modern security features (tamper indication and unique identification) and efficiency (in-situ verification and ease of application). Its innovation is the integration of these advanced capabilities in a small volume, including easy-to-use wire-cutting features into either the seal itself or an application tool, and a self-securing wire feature; multiple levels of tamper indication via a frangible seal body, surface coatings, and active detection of state through low power electronics; unique electronic identification number verified in-situ through a handheld reader, and physical identification via non-reproducible surface features.

SEAL DESCRIPTION AND OPERATION

ITICS is assembled by threading a wire through the item to be secured and then into holes within the ITICS seal base (as shown in Figure 1). Barbed trenches secure the wire into place as a battery is pushed down into the seal base during deployment. The seal cap is then placed on the seal base and a snap ring and adhesive secures the two halves. A seal application tool is utilized to provide the necessary force to secure the seal. The wire will be cut either within the seal itself during closure or by the seal application tool. Note that the seal when assembled is permanently closed. See Figure 2 and Figure 3 for details.

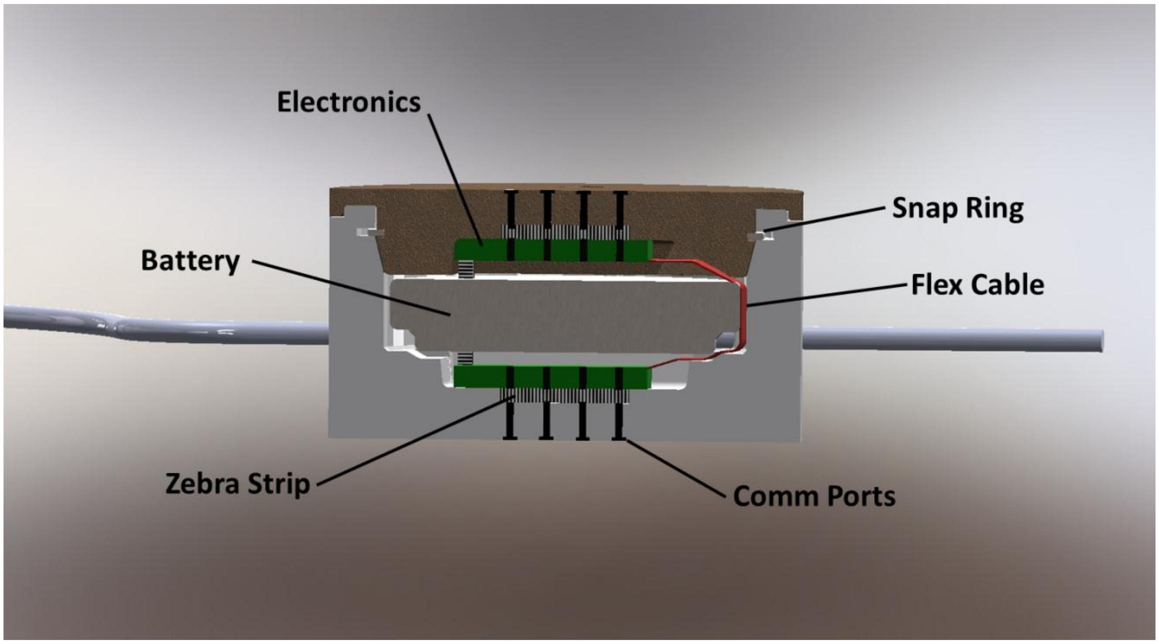

Figure 2: First prototype concept. Image courtesy SNL.

Figure 3: First prototype seal base with wire (left), seal cap with snap ring (right), battery (center), U.S. quarter (bottom) for size comparison. Picture courtesy SNL.

TAMPER INDICATION

The concept for the seal body is a tradeoff between the strength necessary to withstand operational handling and the characteristic to chip or shatter upon tamper attempt. SRNL researched ceramic materials for the seal body and chose alumina based on properties such as tensile strength, frangibility, manufacturability, availability, and compatibility with SNL's brazing materials. Other materials researched include zirconia and Macor™. Additional information on the ITICS seal body materials can be found in references [1] and [2].

As the seal is composed of two separate pieces to allow for insertion of the electronics, battery, and seal wire, a robust joining mechanism is required for the two halves. A snap ring embedded in an internal groove and an adhesive material provides two layers of protection from separation. Figure 4 shows the locations of the snap ring and adhesives.

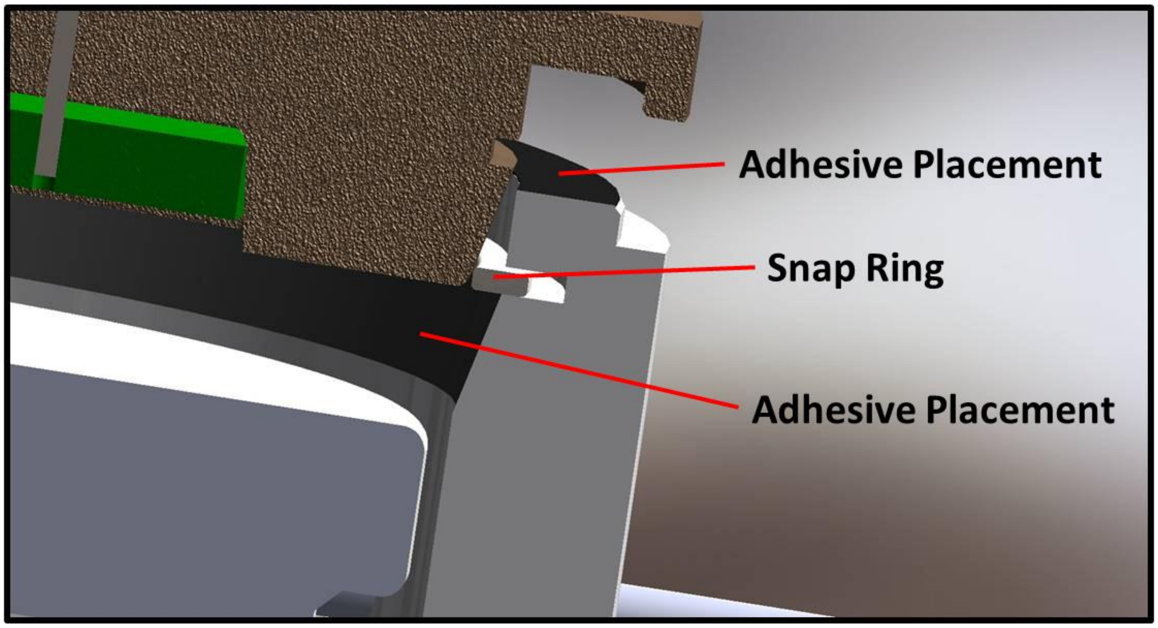

Figure 4: Seal closure and environmental barrier mechanisms. Image courtesy SNL.

The primary purpose of the adhesive, however, is as an environmental barrier. Adhesives must be identified that have the following characteristics: the ability to bond with the seal materials, that afford the appropriate packaging or delivery scheme within the seal, attain adequate bond strength with no "in field" surface preparation, that bond only at the time of installation, exhibit shelf life commensurate with seal deployment, and that maintain bond strength in a broad range of ambient conditions.

SNL initially tested three COTS adhesive systems (all acrylic based): (1) 3M VHB, an acrylic based pressure sensitive adhesive (PSA) serving as a baseline, (2) Avery Dennison (AD) S8755 PSA unfilled, and (3) AD S8756 PSA unfilled, 0.25 micron $Al(OH)_3$. None performed as needed for this specific application. Thus, SNL has been collaborating with Avery Dennison on the development of a unique adhesive system (Figure 5) that will provide increased bond strength, improved chemical resistance to organic solvents, and provide the necessary environmental robustness.

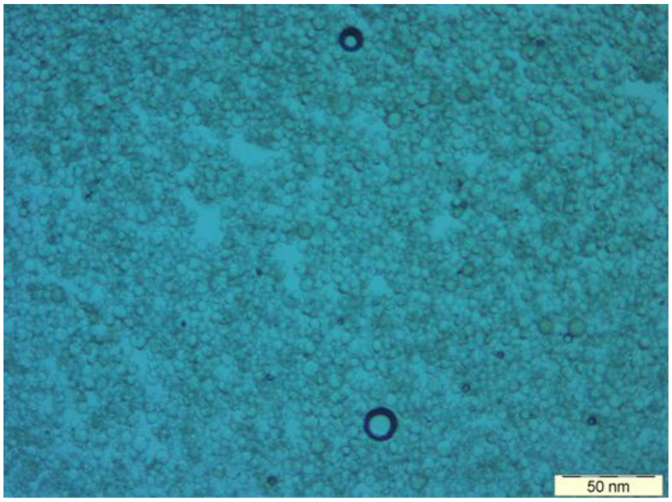

Figure 5: Example adhesive system under development by Avery Dennison. Top picture shows two capsules of epoxy adhesive in the acrylic carrier matrix. Bottom picture shows an example of crushed capsules at a different location. Pictures courtesy Avery Dennison.

Other tamper indicating technologies designed in the seal are fluorescent coatings – passive measures sensitive to surface modifications of the seal body [3, 4]. SRNL is developing these technologies and they will be included in the second prototype.

The electronics provide active tamper indicating features. In the first prototype, the seal body contains two microcontroller units (MCU), one contacting each pole of the battery. Each MCU is logically identical and is, in fact, programmed with the same firmware. At a random interval, a MCU wakes up from a low power sleep state, generates a unique message, and sends it to the other MCU. All communicated messages are authenticated using AES-128 secret key cryptography to prevent an adversary from tampering with the data. Upon disassembly of the seal or when changes to state of health are detected, the secret keys are destroyed and replaced with a default set of keys. A laptop or desktop computer is currently used to download status and event messages.

The current research for implementation in the second prototype is focusing on low-temperature co-fired ceramic (LTCC) for the electronics packaging. LTCC builds the ceramic body up in thin layers and allows printing of the passive electronics directly into the ceramic. An advantage of the LTCC approach is that the electronics footprint is reduced as the passive components are integrated with the ceramic. Fabrication using LTCC is consistent with the coatings research at SRNL, and causes increased surface roughness for the seal body which could enhance the applicability of the Laser Surface Authentication (LSA) method of identification.

UNIQUE ID

ITICS has two methods for unique identification – an active measure using the electronics, and a passive measure using LSA. SRNL has been researching LSA for unique identification; however, the first prototype seal body was not "roughened" during manufacturing and thus LSA will not be utilized as a unique identification method until the second prototype.

The second method for unique identification is via the electronics. Each seal has a 4-byte unique identifier stored in non-volatile flash memory, which is programmed as part of the firmware. Currently, a reader, comprising a laptop and connector, are attached to the serial communication contacts on the seal body for in-situ verification of identity. The seal's identifier, coupled with an incrementing message count, is used to create unique message authentication codes (MAC) appended to each communicated message. Since each seal has its own identifier number, the generated MAC for each message will be distinct.

EASE OF DEPLOYMENT

An issue with the metal cup seal is the effort involved in securing the wire inside the seal and cutting the wire. The wire in the ITICS seal is self-securing (shown in the barbed trenches of Figure 3) and the wire will either be cut inside the seal itself or with the application tool. A manual pull test has been performed to confirm that the wire is secured within the seal, and more rigorous tests will be performed by the vulnerability review team.

The decision as to whether the wire will be cut within the seal or by the application tool may be driven by the required force and wire alignment. SRNL is researching and developing the application tool, while SNL has been researching a cutting edge within the seal itself by joining metal to ceramic via brazing [1]. The challenges involved with implementing a cutting edge into the seal are brazing joint strength adequate to cut through the wire, optimizing the cutting edge shape, and optimizing the shear interface. SNL has successfully cut wire with a tungsten carbide cutting feature brazed to a ceramic fixture, but this has not yet been tested within the seal itself. Next steps will test alternate cutting methodologies. The joint SNL-SRNL team will decide the optimal wire cutting method for the second prototype after the results of the alternate cutting methodologies are collected.

NEXT STEPS

The design of the seal will continue to evolve over the next year as lessons learned from the development of the first prototype are incorporated into the next prototype. SNL will specifically incorporate guidance from the vulnerability review team, test the new adhesive developed with Avery Dennison, develop the electronics packaging using LTCC, and continue to enhance the electronics.

SNL's vulnerability review team, a separate entity from the design team, performed both a systems-level analysis of the seal as well as an analysis of various components of the seal. Their recommendations for improvement will be taken into consideration for the second prototype.

During an assembly attempt of one of the first prototype seals, the seal base fractured (Figure 6) and seal assembly was unable to be completed. SNL is analyzing this failure for remediation in the second prototype. One possible scenario is that the snap ring was not properly seated in the lower body groove, indicating a possible need for tighter design tolerances and dimensions around the snap ring.

A second possibility is that the clamping force used to close the seal caused the failure as it was applied towards the outer diameter of the seal body to avoid damage to the prototype communication connectors. These connectors were test fixtures only and will not be implemented in subsequent prototypes. In a typical seal closing, the clamp would distribute the force evenly across the surface of the seal.

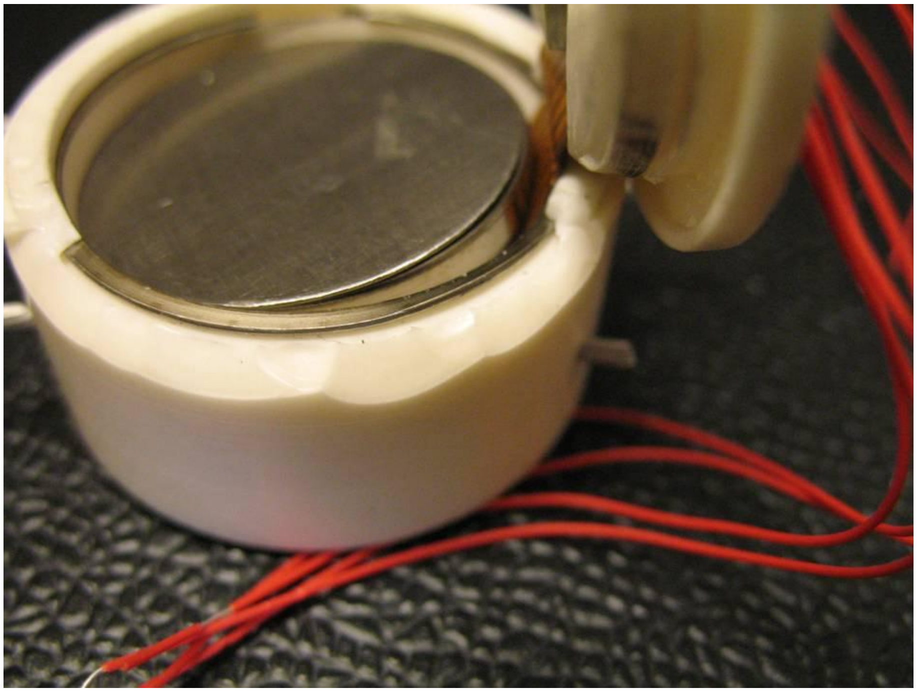

Figure 6: Seal base fracture during assembly. Picture courtesy SNL.

The new adhesive being developed with Avery Dennison as an environmental barrier will be tested at SNL and considered for incorporation into the second prototype. This new adhesive utilizes microencapsulated liquid epoxied resin which reacts with a dispersed co-reactant in a PSA acrylic carrier. This is very unique and provides for a potential bond strength increase as well as solvent resistance.

Finally, as discussed previously, research is ongoing regarding packaging of microelectronics using LTCC. Passive components can be embedded directly into the ceramic body, while active components will be surface mounted into the body (internal to the seal). The result will be a more integrated device with more internal space available for future expansion of capabilities or a smaller volume device. SNL expects the LTCC version to be used in the second prototype. As discussed earlier in this paper, the LTCC has increased surface roughness which should enhance the applicability of LSA for unique identification and is compatible with the SRNL-developed coatings for tamper indication.

ACKNOWLEDGEMENT

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REFERENCES

1. C.A. Walker and V.C. Hodges, “Comparing Metal-Ceramic Brazing Methods,” *Brazing Journal*, 87 (10), 2008.
2. H.A. Smartt et al., “Intrinsically Tamper Indicating Ceramic Seal (ITICS),” in *Proc. Institute Nuclear Materials Management*, Palm Desert, CA, 2011.
3. A.E. Mendez-Torres et al., “Synthesis and Characterization of Smart Functional Coatings by Chemical Solution Deposition Methods,” in Proc. Institute Nuclear Materials Management, Palm Desert, CA, 2011.
4. R.M. Krishna et al., “Characterization of Transparent Conducting Oxide Thin Films Deposited on Ceramic Substrates,” *Materials Letters*, vol. 65, no. 1, 2011.