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Innovative Foundations in the Field of Tags, Seals, and Remote Monitoring Systems

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A gap analysis has been completed for passive and active seals currently being used by the International Atomic Energy Agency (IAEA). Several shortcomings of various seals were identified as areas where improvements could be made. In addition, technologies not previously applied to the areas of tags and seals were evaluated for potential use in these applications. These "new" technologies must meet the existing functional requirements and also fill the voids found in current devices. Several of these "new" technologies were selected for further evaluation of implementation feasibility. The most promising item is stressed glass due to its relatively inexpensive cost, high strength, and the possibility of using it for a variety of applications. Using ion exchange, complex shapes of glass can be chemically stressed for specific applications. This process is being considered for improving various components of seals, rather than proposing a brand new design.

1. Introduction

As the nuclear industry grows around the globe, it brings with it a need for more safeguards resources and new technologies to resist nuclear weapons proliferation. Monitoring the equipment and the material present in a given nuclear facility is necessary in order to maintain a continuity of knowledge of the security of the equipment and thereby the material being monitored. The seals used to maintain the integrity of this equipment and material fall into two categories: active and passive. Active seals are used to provide immediate alerts to the proper authority if the item or material has been accessed without authorization. Passive seals do not transmit data. They must be inspected to determine whether their integrity has been compromised. In addition, tags are unique identifiers that correspond to a particular item or piece of equipment. Several technologies used in currently deployed tags and seals were neither actively nor consistently updated in the last ten years; therefore, it is necessary to research new innovations in this area.

The motivation behind this study is to determine the limitations of currently employed tags and seals. To establish the limitations, as well as capabilities of the tags and seals, a gap analysis will be done. Technologies that are not used in the field of tags and seals will be included in this gap analysis to evaluate whether they can be implemented or integrated to fill existing gaps. A comparison between existing devices and 'new' technologies will provide the optimal pairing of both counterparts. Subsequently design recommendations will provide options for improvement to an existing device.

2. Gap Analysis

A gap analysis was performed to evaluate four categories: passive seals, active seals, tags, and 'new' technologies. A gap analysis is a tool to compare the actual performance of a device to its potential performance. Primarily displayed as a matrix, a gap analysis is a simple visual representation of optimal features that were not necessarily addressed by current designs. By understanding the gaps in presently used devices, the capabilities and limitations of 'new' technologies can be evaluated for filling the gap. The tag and seal types selected for the gap analysis are all currently in use or in stages prior to being deployed. The criteria for the 'new' technologies selection included: had not been used in a current design in the field of tags and seals, have a viable application for either a new device or can be integrated into an existing device.

Several subject matter experts (SME) reviewed the analysis and provided input on optimal features and desired capabilities of tags and seals. In addition the SMEs contributed insight on the rankings for each device as well as supplementary comments. Although several of the evaluation criteria are somewhat subjective, based on a series of revisions a consensus was reached, providing a complete analysis.

Once the analysis of the existing tags and seals, along with the 'new' technologies was completed a determination had to be made between the areas for improvement and also which technologies best filled the gaps. Upon preliminary inspection there were several desired capabilities and qualities obviously not being met in each of the four categories. Examining the passive seals yielded no reusable seals, along with questions about security levels. Very detailed and time consuming inspection is required to detect some defeat scenarios for these seals. The analysis of active seals showed limitations only as far as the cost. In order to address this gap measures to maintain existing fulfilled requirements but at a lower cost must be implemented. Evaluating currently employed tags demonstrated the need for (in some cases simpler) on-site verification. In addition, further research was done on the finer design details of currently deployed devices since the information provided by the gap analysis was not sufficient in some instances.

The 'new' technologies being considered for tag and seal applications also extended to a variety of devices used in relation to that field, this included considerations for better securing equipment cabinets and devising better inspection methods. The preliminary eliminations of 'new' technologies were based on cost, readiness level (as defined by NASA), and security level [1]. The cost of the raw materials could not be more than three times the current cost of the least expensive deployed system or device, the readiness level must be five or greater, and the security level must be six or greater. Following this approach fibre optic panels, IR motion detectors, microwave sensors, light sensors, and piezoelectric film were immediately excluded. Fibre optic panels, while secure are exceedingly expensive especially if a replacement is needed. IR motion detectors, microwave sensors, and light sensors can all be spoofed by a determined adversary and have a higher probability of false alarm as compared to other technologies. Piezoelectric film has many desirable properties however; it has not been tested in environments similar to that in which it would be used. All of these technologies were intended to be used in conjunction with monitoring and securing equipment cabinets.

The next eliminations were made based on the gaps found in current devices and systems and the feasibility of using the remaining technologies to fill them. Eddy current mapping has many outstanding qualities; however the ease of conducting on-site verification was not likely without a laptop and a program to compare prior maps to the most current. Eddy current penetration detection is an excellent method for ensuring the integrity of welds or even an entire enclosure.. Inspecting an enclosure in its entirety may take longer than an individual anticipates. Flexible circuit boards can be utilized in a variety of applications due to the fact that they can be easily manipulated into complex shapes. One concern is the durability, if he circuit boards were exposed to heat fluctuations or not sufficiently protected they could be damaged and need continuous maintenance.

The remaining 'new' technology is stressed glass, although it may be more expensive than other technologies its strength, security levels, readiness levels and availability are strong merits. It important to note that there are two ways to stress, or temper, glass: thermally and chemically. Thermal tempering is when the glass is rapidly cooled through the glass-transition temperature using air or liquid jets [2]. The base strength of the glass can be approximately doubled from the generated compressive surface stresses. The process of chemically tempering glass, or the ion-exchange process, is accomplished by exchanging small ions near the glass surface with larger ions [3, 4]. Depending on the exchange time and temperature, which affects the concentration of ions replaced by larger ions, it is possible to achieve high residual compression in the glass, as with thermal tempering [5, 6].

Of these two methods ion-exchange is desired over thermal tempering. This is because any shape and thickness of glass can be accommodated with this process making it an extremely viable technology for a variety of applications. Ion-exchange has become commercially available, being used in cell phone screens, computer screens, car windshields, along with a myriad of other applications. Due to the commercial availability of this process the majority of the expense is the fabrication of the glass component.

In addition, ion-exchanged glass will fragment when subjected to a sizeable point load. The fragmentation occurs as a unique fracture pattern based on the exchange time and temperature. The fracture pattern can be used in post-mortem verification of the glass component. The fracture pattern can be evaluated using image analysis software to ensure only cracks produced by the indentation and corresponding crack branching are analyzed [7]. Furthermore, the number of fragments produced along with the average fragment size can be determined.

Thus, the devices selected to study enhancing with a 'new' technology were the latest generation of electronic seals, such as the electronic optical sealing system (EOSS), and the Remote Monitored Sealing Array (RMSA). This selection was made after conducting further research revealing several ongoing projects that would fill some of the gaps of current devices, and by narrowing down the feasible devices for improvement based on the number of devices currently in use along with the plausibility of designing an improved component or module.

This type of seal monitors the integrity of a fibre optic cable by sending light pulses through the cable. Any opening of the seal would result in a loss of light. All opening and closing events are recorded and reported back to the monitoring system. The stressed glass component would form a boundary around the sensitive electronics to detect any attempt at gaining access inside the seal to allow tampering with the electronic devices or to modify store events. The EOSS currently uses a flexible foil component for this purpose.

3. Design Concept

The redesign consists of replacing the interior foil component with a two-piece component fabricated from ion-exchanged glass. As discussed, using ion-exchanged glass offers several benefits for this specific application. The high strength of the stressed glass is extremely valuable for maintaining the durability of the overall system. Most likely the glass component will be fabricated with rounded edges or in a cylindrical design in order to reduce stress concentrations. Conductive traces will be laid on either side of the glass pieces, increasing the difficulty for an adversary to perform any attack without detection. This component will be a nested design held together with a pressure sensitive adhesive. Inside this glass component there will be a cylindrical metal band housing the additional components of the EOSS. This band will be adhered to the top and bottom pieces of the glass. This singular apparatus will be contained in an outer casing similar to those used in the existing seals.. It is the intent to use as many original seal components and design specifications as possible after the redesign is completed.

4. Future Work

Future work will include determining the optimal fracture pattern based on the desired number of fragments. The appropriate time and temperature for the ion-exchange bath to achieve the desired fracture pattern will be calculated. In addition, any design modifications to existing components of the seals, as a result of the redesigned component, will be addressed A prototype will be fabricated as a proof-of-concept in order to fully evaluate the merits of the replacement component.

References

[1] J.C. Mankins. (1995, April 6). *Technology readiness levels: A white paper* [Online]. Available: http:// http://www.hq.nasa.gov/office/codeq/trl/trl.pdf
[2] R. Gardon: Thermal tempering of glass, in *Glass: Science and Technology V*, edited by D.R. Uhlmann and N.J. Kreidl (Academic Press, New York, 1980).
[3] S. Kistler: Stresses in glass produced by nonuniform exchange of monovalent ions. *J. Am. Ceram. Soc.* **47**(2), 59 (1962).
[4] M.E. Nordberg, E.L. Mochel, H.M. Garfinkel, and J.S. Olcott: Strengthening by ion exchange. *J. Am. Ceram. Soc.* **47**(5), 215 (1964).
[5]A.L. Zijlstra and A.J. Burggraaf: Fracture phenomena and strength properties of chemically and physically strengthened glass. *J. Non-Cryst. Solids* **1**(1), 49 (1968).
[6]R. Tandon and S.J. Glass: Controlling the fragmentation behavior of stressed glass, in *Fracture Mechanics*

of Ceramics, Vol. 14: Active Materials, Nanoscale Materials, Composites, Glass, and Fundamentals, edited by R.C. Brandt, D. Munz, M. Sakai, and K.W. White (Springer, New York, 2005), pp. 77-91.
[7]J.E. Kooi, R. Tandon, S.J. Glass, and J.J. Mecholsky Jr.: Analysis of macroscopic crack branching patterns in chemically strengthened glass. *J. Mater. Res.* **23**(1), 214 (2008).

Appendix A: Gap Analysis

Passive Seals Gap Analysis

	METAL CABLE SEAL	E-CUP SEAL	ADHESIVE SEAL	BOLT-TYPE SEALS	COBRA	ULTRASONIC SEALING BOLT
DOES NOT NEED MAINTENANCE ON A REGULAR BASIS	X	X	X	X	X	X
SEAL CAN BE APPLIED WITHOUT SPECIAL TOOLS	X	SOMETIMES	X			
EASY TO VERIFY SEAL INTEGRITY ON-SITE	X		SOMETIMES	NOT ALWAYS	X	X
DURABILITY FOR NORMAL WEAR AND TEAR	X	X		X	X	X
TRAINING REQUIRED FOR USING SEAL		X		X	X	X
DIFFICULT TO REMOVE AND REPLACE WITHOUT TAMPER INDICATION						
DIFFICULT TO REPLICATE		X			X	
REUSABILITY						
READINESS LEVEL (0-9) PENDING OBSOLESCENCE	9	9	9	9	9	9
SECURITY (0-9)	2	5	3	5	8	8
LIFETIME OF SEAL	3 YEARS	2 YEARS	24 HRS	2 YEARS	2 YEARS	2 YEARS
SUITABLE FOR SAFEGUARDS	LOW	HIGH	HIGH	MEDIUM	HIGH	HIGH
SUITABLE FOR ARMS VERIFICATION	LOW	MEDIUM	LOW	LOW	HIGH	POSSIBLY
COST	$	$	$	$	$$$*	$$$$

Active Seals Gap Analysis

	VACOSS	EOSS	TRFS	RMSA
DOES NOT NEED MAINTENANCE ON A REGULAR BASIS	BATTERY NEEDS TO BE CHECKED	BATTERY NEEDS TO BE CHECKED	BATTERY NEEDS TO BE CHECKED	SELF-MONITORING FOR BATTERY LIFE.
SEAL CAN BE APPLIED WITHOUT SPECIAL TOOLS	ONCE ASSEMBLED SPECIAL TOOLS ARE NOT REQUIRED BUT TO CUT THE CABLES TO THE APPROPRIATE LENGTH IS NOT TRIVIAL		X	X
DIFFICULT TO REMOVE AND REPLACE WITHOUT TAMPER INDICATION	X	X	X	X
EASY TO VERIFY SEAL INTEGRITY ON-SITE	X	X	X	X
TRAINING REQUIRED FOR USING SEAL	X	X	X	X
RELIABILITY	X	X	X	?
DURABILITY FOR NORMAL WEAR AND TEAR	X	NEEDS MORE TESTING IN THE FIELD.	X	?
DATA TRANSMISSION OFFSITE	X	X	X	X
DATA TRANSMISSION TO PC ONSITE	X	X	X	X
DATA ENCRYPTION	X	X		X
LOW POWER/BATTERY REQUIREMENTS	X	X	X	X
READINESS LEVEL (0-9) PENDING OBSOLESCENCE	9	9	8	8
LIFETIME OF SEAL	2-3 YEARS	2-3 YEARS	?	?
SUITABLE FOR SAFEGUARDS	HIGH	HIGH	MEDIUM	HIGH
SUITABLE FOR ARMS VERIFICATION	LOW	LOW	LOW	HIGH
COST	$$$$$	$$$$$	$$$	$$$

Tags Gap Analysis

	IMAGE PATTERNS	ULTRASONIC	RFID
DOES NOT NEED MAINTENANCE ON A REGULAR BASIS	X	X	X
SEAL CAN BE APPLIED WITHOUT SPECIAL TOOLS	X	X	X

EASY TO VERIFY ON-SITE	EYES TYPICALLY ARE NOT GOOD ENOUGH		
DURABILITY FOR NORMAL WEAR AND TEAR	X	X	
TRAINING REQUIRED FOR USING SEAL	X	X	X
DIFFICULT TO REPLICATE	X	X	
REUSABILITY		X	
READINESS LEVEL (0-9)	5 – 8	9	9
SECURITY (0-9)	4 – 8	9	4
LIFETIME OF TAG	AS LONG AS RECORDS ARE KEPT	AS LONG AS RECORDS ARE KEPT	2 YEARS
SUITABLE FOR SAFEGUARDS	HIGH	HIGH	LOW
SUITABLE FOR ARMS VERIFICATION	HIGH	MEDIUM	LOW
COST	$-$$$	$$$	$$

'New' Technologies Gap Analysis

	EDDY CURRENT MAPPING	EDDY CURRENT PENETRATION DETECTION	RESISTIVE MEMBRANES	IR MOTION DETECTION	MICROWAVE SENSORS	LIGHT SENSORS
DOES NOT NEED MAINTENANCE ON A REGULAR BASIS	X	X	X	X	X	X
SPECIAL TOOLS REQUIRED TO ATTACH SEAL	X	X	X			
EASY TO VERIFY SEAL INTEGRITY ON-SITE		HIGH	HIGH	MEDIUM	MEDIUM	MEDIUM
DURABILITY FOR NORMAL WEAR AND TEAR	HIGH	HIGH	MEDIUM	HIGH	MEDIUM	HIGH
TRAINING REQUIRED FOR USING SEAL	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	LOW
DIFFICULT TO REPLICATE	HIGH	HIGH	MEDIUM	LOW	LOW	LOW

REUSABILITY	X	X		X	X	X
RELIABILITY	HIGH	HIGH	MEDIUM	MEDIUM	MEDIUM	MEDIUM
READINESS LEVEL (0-9)	7	8	6	4	4	7
SECURITY (0-9)	8	8	7	5	6	6
LIFETIME OF TECHNOLOGY	?	LIFETIME OF APPLICATION	2 YEARS	2 YEARS	2 YEARS	2 YEARS
SUITABLE FOR SAFEGUARDS	HIGH	HIGH	HIGH	MEDIUM	MEDIUM	MEDIUM
SUITABLE FOR ARMS VERIFICATION	HIGH	MEDIUM	HIGH	MEDIUM	MEDIUM	MEDIUM
COST	$$$	$$	$$	$$$	$$	$$

‘New” Technologies Gap Analysis Continued

	STRESSED GLASS	STRESSED GLASS WITH PRINTED CIRCUIT BOARD	FLEXIBLE CIRCUIT BOARD	PIEZOELECTRIC FILM	FIBER OPTIC PANELS
DOES NOT NEED MAINTENANCE ON A REGULAR BASIS	X	X	X	X	X
SPECIAL TOOLS REQUIRED TO ATTACH SEAL	X	X	X	X	X
EASY TO VERIFY SEAL INTEGRITY ON-SITE	HIGH	HIGH	HIGH	MEDIUM	HIGH
DURABILITY FOR NORMAL WEAR AND TEAR	HIGH	HIGH	MEDIUM	MEDIUM	MEDIUM
TRAINING REQUIRED FOR USING SEAL	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM
DIFFICULT TO REPLICATE	MEDIUM	HIGH	MEDIUM	MEDIUM	HIGH
REUSABILITY	X	X			
RELIABILITY	HIGH	HIGH	MEDIUM	MEDIUM	HIGH
READINESS LEVEL (0-9)	8	7	8	3	6
SECURITY (0-9)	8	8	7	7	8
LIFETIME OF TECHNOLOGY	10 YEARS	10 YEARS	5 YEARS	5 YEARS	5 YEARS
SUITABLE FOR SAFEGUARDS	HIGH	VERY HIGH	HIGH	MEDIUM	HIGH

SUITABLE FOR ARMS VERIFICATION	HIGH	VERY HIGH	HIGH	MEDIUM	HIGH
COST	$$	$$-$$$	$$	$$	$$$$$