IPNDV Working Group 3: Technical Challenges and Solutions
Chain of Custody (7)—Technology Data Sheet

June 12, 2017

Chain of Custody (CoC) Technology Name: Container Integrity Assessment

Physical Principle/Methodology of Technology:

Container Integrity involves techniques and technologies to interrogate containers of interest to establish and to maintain confidence in their integrity at various points within a monitoring regime. Tamper indicating devices and seals may be used to augment confidence; however, these are separate concepts not discussed here.

Container integrity inspection techniques include contact or non-contact interrogation. All applicable techniques may be considered active as they interact with the container as part of a measurement. Technology categories include acoustic, electromagnetic (EM), and optical (including thermal).

Acoustic technologies rely on applying low-power, high frequency (typically greater than 500 kHz) mechanical energy to the container and using the response to determine if the container integrity has been compromised. Commonly used systems rely on contact of the sensor with the container. Pulse-echo systems use a single sensor to both inject mechanical (ultrasonic) energy and record the response. Transmit-receive systems use one sensor to inject energy and one or more separate sensors to record the response. Variations within this technology include mechanically scanning the container surface with the sensor or interrogating large sections of the container using a single sensor (guided waves). Non-contact techniques use stand-off sensors (laser-based sensors) for measuring the responses without making physical contact with the container. Stand-off distances can range from a few millimeters (for electromagnetic acoustic transducer (EMAT)-based sensors) to several meters (for laser-based sensors). These methods directly measure the integrity of the container. Indirect methods typically measure the contents of the container and assure container integrity by confirming that the contents have not changed. An example is a proposed acoustic resonance technique for monitoring gas mixtures in sealed containers; a change in the composition of the gas mixture is indicative of a leak. Other examples include the Swept Frequency Acoustic Interferometer (SFAI) and Ultrasonic Pulse Echo (UPE) instrument, which were investigated[1] for determining the presence or absence of weapons, nuclear components, and HE components in containers (Figure 1).

(1)

(2)

[1] D. N. Sinha and C. T. Olinger, "Acoustic Techniques in Nuclear Safeguards," in *17th Annual ESARDA Symposium on Safeguards and Nuclear Material Management* (Aachen, Germany: May 9–11, 1995); and

Figure 1: Two Acoustic Technologies: (1) Ultrasonic Pulse Echo (UPE) and (2) Swept Frequency Acoustic Interferometer (SFAI) (Photo Credits: (1) Pacific Northwest National Laboratory and (2) Los Alamos National Laboratory)

Electromagnetic (EM) technologies generally apply, using a coil sensor, low frequency electromagnetic energy to the container wall and record the change in coil impedance. The coil impedance changes with a change in the material properties of the container from, for instance, tampering or other damage. At low frequencies, the technology is referred to as eddy current inspection and the sensor is typically scanned over the container to determine if any part of the container has been tampered.[2] Recent advances in EM sensors have resulted in array sensors that reduce the need for mechanical scanning. The technology requires contact between the sensor and the container (Figure 2). Alternative technologies, which do not need contact with the container, use thermal imaging of changes in thermal conductivity to determine if integrity has been compromised. This requires the deposition of a modest heat load into the container wall, which could be done using ambient sources or a heat lamp. Thermo-sonic methods use a high-power ultrasonic source to generate the necessary heat.

Figure 2: Eddy Current Array Probe with Calibration Specimen. (Photo Credit: Pacific Northwest National Laboratory)

Optical methods generally fall into one of three categories: visual imaging using cameras that compare the image of the entire container to a reference image to ensure that integrity has not been compromised; visual imaging of small regions of the container, with the images (still or video) analyzed to determine if the surface shows signs of degradation; and non-contact laser profiling methods (Laser Mapping) that scan the surface of the container and determine if modest changes in surface profile exist, which could be an indication of tampering. A version of laser profiling, Non-Contact Laser Interrogation, has been demonstrated to be capable of detecting tampering that is not apparent when examined visually.[3]

K.J. Bunch, L.S. Williams, A.M. Jones, and P. Ramuhalli, "Electromagnetic Signature Technique as a Promising Tool to Verify Nuclear Weapons Storage and Dismantlement under a Nuclear Arms Control Regime," in *Proceedings of the 53rd Annual INMM Meeting, Orlando, FL July 15‑19, 2012* (Richland, WA: Pacific Northwest National Laboratory, 2012).

[2] K. Tolk and G. Stoker, "Eddy-Current Testing of Welded Stainless Steel Storage Containers to Verify Integrity and Identity," in *Annual Meeting of the Institute of Nuclear Materials Management (INMM)* (Phoenix, AZ, July 25–29, 1999).

[3] B. Bernacki, *Non-Contact Laser Interrogation,* Flyer, PNNL-SA-115700 (Richland, WA: Pacific Northwest National Laboratory, 2016).

Table 1 presents a summary of available technologies that may be readily adapted to assess container integrity.

Table 1: Summary of Container Integrity Assessment Technologies

Measurement Method	Phenomenology	Sensor Type(s)	Measurement Approach	Container Coverage Using:	Comments
Direct Measurement of Container Integrity	Acoustic	Piezoelectric, EMAT	Pulse-echo	Mechanical scanning	Same sensor used to apply energy to container wall and record response. Change in container material (from tampering/welding/etc.) reflect increased energy back to probe.
		Piezoelectric, EMAT	Transmit-receive	Mechanical scanning	Two sensors used; one to apply energy and one to record response. Change in container material (from tampering/welding/etc.) block energy propagation from transmit probe to receive probe.
		Piezoelectric, EMAT	Pulse-echo, transmit-receive	Guided waves	Energy propagation over long distances (several meters). Received signal has information on changes in container integrity at one or more locations.
		Piezoelectric array	Pulse-echo	Mechanical scanning or guided waves	Array is electronically steered; enables faster scans on container
		Piezoelectric	Acoustic resonance	Modal analysis of container	Vibration modes of container used to assess integrity.
		Laser vibrometer	Acoustic resonance	Scanning laser head or (less frequently) mechanical scanning	Recording only; may be used in conjunction with piezoelectric or EMAT sensor for injecting energy. This is a non-contact measurement.
	EM	Single Coil—Eddy Current	Inductance, resistance of coil	Mechanical scanning	Impedance (resistance and inductance) change related to change in container material due to tampering.
		Antenna—Millimeter Wave (single or array)			Only applicable for non-metallic containers. Non-contact.
		Antenna—terahertz (single or array)			Only applicable for non-metallic containers. Non-contact bus stand-off distances are small (several mm or less).
	Optical	Direct (eyes-on) visual	Direct visual assessment	Visual assessment	Visually evaluating container for evidence of loss of integrity. Can be non-contact.

		Large format camera (still or video)	Image acquisition	Mechanical scanning across container	Image analysis for loss of integrity. Analysis can be manual or comparison to a template. Non-contact.
		Boroscope	Image acquisition	Mechanical scanning	Same as above.
		Laser	Topography	Mechanical or scanning laser head	Use surface changes to identify locations where container integrity was compromised. Non-contact.
		IR Camera	Thermal conductivity	Image of container; mechanical scanning if needed	Thermal conductivity changes may be indicative of container wall material changes from loss of integrity. Flash, thermo-acoustic, or other heat sources may be used to impart heat load. Non-contact.
Measurement Method	Phenomenology	Sensor Type(s)	Measurement Approach	Container Coverage Using:	Comments
Indirect Measurement of Container Integrity	Acoustic	Piezoelectric, laser	Verification of contents	N/A	Verify integrity of contents. Gas composition, mass distribution inside container, etc. Requires coupling energy inside the container.
	EM	Coil	Verification of contents	N/A	Verify contents have not changed. Contents must be electrically conductive.

Potential Monitoring Use Cases (e.g., chain of custody, nuclear material detection, explosives detection, etc.):

To verify that the container itself has not been physically tampered with in a way that would allow the contents to be diverted, substituted, or otherwise subverted without being detected.

This is necessary because a seal on the door or lid of a container can be bypassed by penetrating the actual walls of a container.

Physical Description of Technology (e.g., approximate size, weight):

Equipment used to check container integrity can be on the order of hand-held devices to sensors/probes connected to larger data collection instruments on the order of a few cubic feet. Most of these sensors and instrumentation are typically designed for nondestructive inspection of components and therefore are designed to be man-portable and to meet size, weight, and power constraints in typical field inspections. Most of these instruments (with the exception of high-power systems) are generally available with a battery option. Mechanical scanners, if used for improving the repeatability of the scanning and measurement process, can be heavier. However, this is a function of the size of the scanner and is generally less than a few kilograms. Scanners are typically attached temporarily to the container; as a result the weight of the scanner is of concern mostly for shipping, installation, and dismantling only and not during operation of the measurement system.

Time Constraints (e.g., measurement times, time to install the equipment):

Nothing is permanently installed; rather, the container to be inspected needs to be interrogated or scanned, which usually involves attaching a small sensor to the container in one or more locations or scanning the entire surface of the container. This can take anywhere from a few seconds to a few minutes. In some cases, a mechanical fixture may be used to make the scanning process more repeatable. Such fixtures can usually be installed and dismantled in less than half an hour.

Technology Complexity (e.g., hardware, software, and ease of use by personnel):

Container integrity techniques are more complex than tamper indicating devices and enclosures as they tend to be active (apply energy to the container wall) and rely on complex signals to indicate a loss of integrity. When techniques are adapted to work on multiple types of materials and geometries, the complexity of the overall system increases. The complexity is also a function of the measurement phenomenology, with typical acoustic and EM systems being relatively simple to operate but with complex data analysis methodologies. Direct visual inspection techniques are also relatively simple while laser-based systems being more complex to setup, measure, and analyze. In all cases, personnel training will be necessary not only to operate the instrument but also to analyze the resulting data (or interpret the results of an automated analysis system).

Infrastructure Requirements (e.g., electrical, liquid nitrogen, etc.):

All systems usually require a power supply in the form of an electrical connection to 110V–240V mains or batteries. This includes any reader and any data processing module such as a laptop or integrated computer. Depending on the system, materials for improved coupling of energy to the container or for enhancing the response may be needed. For instance, liquid gel-like materials are usually used to improve the measured signal quality for acoustic technologies.

Technology Limitations (e.g., detection limits for nuclear material, operational temperature range):

The limit of detection for the breach of a container will depend on the technology and the specific scanning technique deployed. A pin-hole penetration of a container will be much harder to detect than a large cut that is repaired through welding or splicing. All of the systems are designed to operate in typical environments encountered (temperature ranges usually less than 50°C, no limitations from humidity or dust other than general equipment care). Visual techniques may be limited in their ability to detect loss of integrity in the presence of thick coatings (paint, etc.) whereas EM techniques are sensitive to coating thickness (high coating thickness reduces effectiveness). Acoustic techniques, although not sensitive to coating thicknesses, require application of liquids (gel) for efficient coupling of energy to the container wall.

Technology Development Stage (e.g., commercially available, development stage):

Almost all of the technologies described are commercially available (TRL 9) but need some adaptation to be ready to use on warhead and warhead component containers (TRL 7–for adaption). The adaptation is usually in the form of sensor modification to ensure adequate coupling of energy into the warhead container, and modification of analysis approaches to detect the desired size breach.

Cost Estimate:

Most acoustic and electromagnetic inspection systems cost approximately USD $20,000 and up. For example, an eddy current scanning system used for inspecting welds and joints in metals costs about USD $25,000 and includes the sensor and instrument for measurement. Acoustic inspection systems for the same application are also in the same ballpark range. Laser vibrometry devices, on the other hand, are generally in excess of USD $100,000 for a higher-frequency capable stand-off device.

Additional System Functionality (e.g., outside the monitoring use case):

Most container integrity inspection systems are based on technology used for quality assurance and quality control (QA/QC) in industrial applications such as welding, and for periodic inspections of components to determine if their structural integrity has degraded during operation. Many of these systems could also be adapted to provide unique identifiers for containers or to determine if a container had been opened previously.

References:

Keith Tolk and Gerald Stoker, "Eddy-Current Testing of Welded Stainless Steel Storage Containers to Verify Integrity and Identity," INMM July 1999.

P. Ramuhalli, *Eddy Current Identifier for Intrinsic Unique Identification,* Flyer, PNNL-SA-115229 Rev.1, (Richland, WA: Pacific Northwest National Laboratory, 2016).

R.F. Miller, M.J. Pechersky, and P.K. Raju, *American Society of Mechanical Engineers' Winter Annual Meeting* (Chicago, IL, 1994): 4.

K.J. Bunch, A.M. Jones, P. Ramuhalli, J.M. Benz, and L.S. Denlinger, "Supporting Technology for Chain of Custody of Nuclear Weapons and Materials throughout the Dismantlement and Disposition Processes," *Science and Global Security* 22, no. 2 (2014): 111–34.

K.J. Bunch, L.S. Williams, A.M. Jones, and P. Ramuhalli, "Electromagnetic Signature Technique as a Promising Tool to Verify Nuclear Weapons Storage and Dismantlement under a Nuclear Arms Control Regime," in *Proceedings of the 53rd Annual INMM Meeting, Orlando, FL July 15-19, 2012* (Richland, WA: Pacific Northwest National Laboratory, 2012).

M. Watkins, K. Bunch, P. Ramuhalli, and M. Jones, "Guided Elastic Waves: The Potential for Containment and Surveillance Applications," presented at the *INMM International Workshop on Containment and Surveillance Concepts for the 21st Century* (June 10, 2010).

P. Daborn, P. Hayden, H. White, and P. Ind, "The Use of Modal Testing within Nuclear Weapon Dismantlement Verification," *Science and Global Security* 22 (2014).

D. N. Sinha and C. T. Olinger, "Acoustic Techniques in Nuclear Safeguards," in *17th Annual ESARDA Symposium on Safeguards and Nuclear Material Management* (Aachen, Germany: May 9–11, 1995).

C. T. Olinger, T. Burr, and D. R. Vnuk, "Acoustic Resonance Spectroscopy Intrinsic Seals," in *35th Annual INMM Meeting* (Naples, FL: July 17–20, 1994).

R. Kouzes and K. Geelhood, *Composite Signatures of Nuclear and Non-Nuclear Technologies for Weapons Material and Component Measurement*, Technical Report, PNNL-13861 (2002).

R.M. Meyer, A.F. Pardini, B.D. Hanson, and K.B. Sorenson, *Review of NDE Methods for Detection and Monitoring of Atmospheric SCC in Welded Canisters for the Storage of Used Nuclear Fuel*, Technical Report, FCRD-UFD-2013-000085 (PNNL-22158) (2013).

International Partnership for Nuclear Disarmament Verification Working Group 3 Chain of Custody (2), Technology Data Sheet: 3D Identification and Containment (2016).

B. Bernacki, *Non-Contact Laser Interrogation,* Flyer, PNNL-SA-115700 (Richland, WA: Pacific Northwest National Laboratory, 2016).