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Task 3.1.2 Report – Survey and Assessment of Technologies

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April 2014

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Executive Summary

The National Nuclear Security Administration (NNSA) Office of Nonproliferation and International Security's (NA-24) Next Generation Safeguards Initiative (NGSI) and the nuclear industry have begun to develop approaches to identify and monitor uranium hexafluoride (UF_6) cylinders. The NA-24 interest in a global monitoring system for UF_6 cylinders relates to its interest in supporting the International Atomic Energy Agency (IAEA) in deterring and detecting diversion of UF_6 (e.g., loss of cylinder in transit) and undeclared excess production at conversion and enrichment facilities. The industry interest in a global monitoring system for UF_6 cylinders relates to the improvements in operational efficiencies that such a system would provide. This task is part of an effort to survey and assess technologies for a UF_6 cylinder to identify candidate technologies for a proof-of-concept demonstration and evaluation for the Cylinder Identification System (CIS).

This report evaluates the feasibility and desirability of candidate technologies, commercially available off-the-shelf technologies (COTS) or modifiable off-the-shelf (MOTS) technologies that can be used for unique UF_6 cylinder identification. Candidate technologies were limited to those for which the authors could find sufficient information to make an assessment, which may have biased the selection toward those described in U.S. publications. These technologies were assessed using the screening criteria developed in *Task 3.1.1 Report – Identification System Requirements Development,* (Hockert and Wylie 2014).

The technology assessment found that none of the evaluated technologies is sufficiently well adapted to the UF_6 cylinder environment, nor operationally robust in the context of the requirement set established in Hockert and Wylie (2014). Additionally, none of these technologies is adequately mature to support proof-of-concept testing at this time. However, the assessment identified two commercial, or near-commercial technologies (bar codes and radio frequency identification [RFID] tags) that are capable of meeting the defined requirements, except for those addressing authentication and tamper indication. These technologies, and the absence of any facility operational requirement for authentication or tamper indication, suggest the use of a hybrid approach. This hybrid approach combines one of these two commercial, or near-commercial technologies, with one of the more complex, and less mature, authenticable technologies that could be modified to meet our requirements for a proof-of-concept demonstration. Such an approach would permit a facility to concern itself only with the bar code or RFID tags, largely ignoring the more complex technology. The IAEA applications of the CIS could use the authenticable technology where necessary. Because of potential operational issues with RFID and the industry acceptance of bar codes, a bar code technology is recommended for the technology supporting facility needs, referred to as the base technology.

The information available during this technology review was not sufficient to make a definitive judgment of the relative merits of the recommended authentication technologies from the perspective of the ease of development or the cost of deployment. However, three authentication technologies and hybrid design concepts were identified as sufficiently promising to be considered strong candidates for further product development. In addition, the IAEA has identified some promising tag technologies for their use that might also be useful as the authentication element of our hybrid approach. Those technologies could also be used in a hybrid design, but are not discussed in this paper, pending receipt of information about the technologies. The three promising candidates are described as follows.

- **A combined bar code and reflective particle tag, with a matrix and adhesive that does not degrade in the UF_6 cylinder environment.** Consideration should be given to reflective particle technology development that focuses on software and reader enhancements to permit accurate authentication from angles and distances and in lighting different from the initial enrollment, as well as making sure that the bar code and label do not degrade in the UF_6 cylinder environment.
- **A combined bar code Optically Stimulated Luminescence (OSL) label, with a matrix and adhesive that does not degrade in the UF_6 cylinder environment.** Consideration should be given to OSL technology development that focused on OSL and reader enhancements to improve the accuracy of authentication and permit accurate authentication in ambient lighting.
- **A welded metal bar code tag with digital image or laser weld recognition for authentication.** The bar code tag materials should ensure that the tag does not degrade in the UF_6 cylinder environment. For digital image weld recognition, consideration should be given to development that focuses on software and imaging enhancements to significantly improve the accuracy of authentication and permit accurate authentication from angles and distances and in lighting different from the initial enrollment. For laser weld recognition, consideration should be given to development that focuses on enhancements to permit recognition from greater distances and at greater angular difference from initial enrollment.

Consideration should be given to a program to further develop one or more of the three technology approaches above, or one or more of the promising IAEA-developed authentication tag technologies, which we were not able to include in this report. Promising IAEA-developed technologies will be addressed in a revision to this report to be published later this year. Such a technology development effort should provide a prototype authentication approach that meets IAEA's authentication requirements and is suitable for a proof-of-concept demonstration. The selection of the approaches for serious consideration for further development should consider estimates of development costs; costs to produce and apply the CIS cylinder components and CIS reader modules; input from IAEA, industry, and national regulatory authorities about the usability and merits of the approaches; and the interest of commercial bar code fabricators and vendors in participating in a joint industry-laboratory development program.

Acknowledgments

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Acronyms and Abbreviations

3D-LSA	3 Dimensional Laser Surface Authentication
CIS	Cylinder Identification System
COTS	commercial off-the-shelf
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
EMI	electromagnetic interference
EmSec	Emissions Security
IAEA	International Atomic Energy Agency
INMM	Institute of Nuclear Material Management
IR	infrared
JRC	European Joint Research Center in Ispra, Italy
L2IS	Laser Item Identification System
LED	light-emitting diode
LMCV	laser mapping system for containment verification
MOTS	modifiable off-the-shelf
NA 24	Office of Nonproliferation and International Security
NGSI	Next Generation Safeguards Initiative
NNSA	National Nuclear Security Administration
ORNL	Oak Ridge National Laboratory
OSL	optically stimulated luminescence
PNNL	Pacific Northwest National Laboratory
PoC	proof of concept
RF	radio frequency
RFID	radio frequency identification
RPT	reflective particle tag
SNL	Sandia National Laboratories
UF_6	uranium hexafluoride
UHF	ultra-high frequency
UID	unique identifier
UV	ultraviolet

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1.0 Introduction

1.1 Background

The National Nuclear Security Administration (NNSA) Office of Nonproliferation and International Security's (NA-24) Next Generation Safeguards Initiative (NGSI) and the nuclear industry have begun to develop approaches to identify and monitor uranium hexafluoride (UF_6) cylinders. The NA-24 interest in a global monitoring system for UF_6 cylinders relates to its interest in supporting the International Atomic Energy Agency (IAEA) in deterring and detecting diversion of UF_6 (e.g., loss of cylinder in transit) and undeclared excess production at conversion and enrichment facilities. The industry interest in a global monitoring system for UF_6 cylinders also relates to the improvements in operational efficiencies that such a system would provide. This task is part of an effort to survey and assess technologies for a UF_6 Cylinder Identification and Monitoring System to identify candidate technologies for a proof-of-concept (PoC) demonstration and evaluation for the Cylinder Identification System (CIS) portion of the Cylinder Identification and Monitoring System.

This evaluation describes candidate technologies, including commercially available off-the-shelf (COTS) technologies or modifiable off-the-shelf (MOTS) technologies that can be used for unique UF_6 cylinder identification, and provides an assessment of the feasibility and desirability of the use of these technologies for UF_6 CIS. Candidate technologies were limited to those for which we could find sufficient information to make an assessment, which may have biased the selection toward those described in U.S. publications. These technologies are assessed using the screening criteria for assessment of cylinder unique identification technologies developed in *Task 3.1.1 Report – Identification System Requirements Development* (Hockert and Wylie 2014), which refines and augments the functional requirements developed in ORNL/TM-2013/278, *Preliminary Concept of Operations for a Global Cylinder Identification and Monitoring System* (Whitaker et al. 2013). Finally, this report provides conclusions and recommendations for PoC demonstration and evaluation.

1.2 Approach

For the purpose of this analysis, the CIS is considered to comprise a cylinder element and a reader element. Depending upon the technology being evaluated, the cylinder element may be a cylinder attribute created during cylinder fabrication (e.g., surface micro-roughness fingerprint) or during cylinder enrollment (e.g., information that is engraved on the cylinder). The cylinder element may also be a cylinder component (e.g., an item that, like the nameplate, is affixed to the cylinder, such as a tag, a bar code, a label, or a radio frequency identification device [RFID]) or a combination of a cylinder component and attribute. The reader element comprises a module that "reads" the cylinder element to determine the unique identification of the cylinder (the reader module) and other components that either measure and automatically record information about the UF_6 cylinder (unattended monitoring station) or read the cylinder identification and permit operator entry of additional information about the UF_6 cylinder (reader). The following CIS categories were developed for this analysis:

- A CIS that relies solely on a cylinder component affixed to the UF_6 cylinder will be referred to as "extrinsic CIS."

- A CIS that relies solely on the measurement of one or more unique UF_6 cylinder attributes, created during either cylinder fabrication or enrollment, will be referred to as “intrinsic CIS.”
- A CIS that relies on both intrinsic cylinder attributes and an extrinsic cylinder component will be referred to as “combined CIS.”

This technology evaluation focuses on the cylinder element and reader module. The UF_6 cylinder identification process and technology is independent of the remaining components in the unattended monitoring station or reader, excepting, of course, the possibility of electromagnetic, optical, or other interferences between the reader module and the remaining components. This near independence permits the technology evaluation to focus almost completely on the reader module, leaving the remaining reader or unattended monitoring station components “to be designed.” This relationship is further detailed in Appendix B of Hockert and Wylie (2014).

Section 2 of this report identifies the technologies reviewed, provides a qualitative assessment as to the practicality of their use in a UF_6 cylinder environment, and briefly discusses where the technologies meet the requirements developed in the Task 3.1.1 report (Hockert and Wylie 2014). Finally, this section assesses subjectively whether a system employing the technology could be designed and qualified as able to meet the Task 3.1.1 report requirements or whether it is likely that a modification of the technology would permit it to be used in a design that meets the requirements. None of the technologies assessed at this time have been qualified, by testing or analysis, as able to meet all of the Task 3.1.1 report requirements. The technologies are divided among extrinsic, intrinsic, and combined, although it should be noted that an extrinsic technology such as a bar code can be either an extrinsic or intrinsic technology, depending upon whether the technology is affixed to the cylinder (via a metal or ceramic tag) or applied directly to the cylinder (via laser etching).

Section 3 of this report presents a gap analysis. This analysis provides a qualitative discussion of the challenges that must be overcome to employ the most promising technologies in a CIS suitable for PoC testing. Section 4 of this report presents conclusions and recommendations for additional activities to develop a prototype CIS for PoC testing.

2.0 Candidate Technologies

The technologies reviewed include proven designs, such as bar code identification technologies and others that are much newer, such as laser identification technologies. Where classes of technologies (e.g., RFIDs of various types) all appear similarly close to meeting the requirements for a CIS concept, the technologies are discussed as a class and compared with each other using the requirements developed in Task 3.1.1 (Hockert and Wylie 2014).

2.1 Extrinsic Cylinder Identification Systems

Extrinsic CIS are those that rely solely on an item affixed to the UF_6 cylinder. One important requirement for the candidate technologies is that the item must be affixed to the valve end of a cylinder. The placement of the identifier on the cylinder valve end not only provides the highest level of protection of the item from damage during routine cylinder handing, but also permits the item to be read in numerous operational configurations (e.g., immediately prior to insertion in an autoclave). The technologies considered are: bar codes, RFIDs, reflective paint/particle tags, and nameplates used in concert with optically stimulated luminescence.

2.1.1 Bar Code Technologies

Bar code technologies have been used in general industry for many years and can be readily used to uniquely identify items. Bar code technologies are also used by some government organizations, including the U.S. Department of Defense (DoD), to track items and facilitate inventory. Bar codes are optical machine readable representations of data. They can be either linear (1D), such as the ubiquitous universal product codes found on almost every item available for purchase, or matrix (2D) codes, which can contain far more information than the 1D bar codes (Spielmann 2013). Bar codes can be readily used to identify unique items. Both types of bar codes can be read by smart phones, or by a specialized reader, and both are readily available on the commercial market in any number of formats. Bar codes can be written or engraved on paper, ceramic, or metal tags for attachment to each UF_6 cylinder. The tags can be mechanically attached (e.g., welded) to a cylinder attached using an adhesive, or directly applied to a UF_6 cylinder (See Section 2.2.2). Because any combination of numbers or letters can be used in developing a bar code, the actual information included in these bar codes is not addressed here. The reader is an imager that retrieves, assembles, and transmits data to the database (The Basics 2010). Newer bar code readers have included software that provides error-checking capability (Wray 2007).

Matrix (2D) codes have several advantages over a standard 1D code. Not only can they contain more data than a standard 1D code, but they also can be read omni-directionally, are less likely to be read incorrectly if part of the physical code is damaged or obscured (i.e., the 2D code is either read correctly or cannot be read at all), and they are scalable, that is, they can be easily enlarged to be read from a distance. According to MIL-STD-130, *Identification Marking of U.S. Military Property*, the 2D matrix is the standard for use by DoD for marking many inventory items (DoD 2005). These codes do require specialized readers, but as noted above, a smart phone app can be programed to read the information.

Readers for 1D and 2D bar codes are able to read from the required distances (1-20 ft).[1] These readers can be hand held or unattended and have been used for many years.

Bar codes by themselves have serious limitations in meeting the requirements for authentication, resistance to tampering and resistance to counterfeiting. According to Sandia National Laboratories, *Random Patterns and Biometrics for Counterfeit Deterrence* (Tolk 1993), citing Donald Bauder, who originated the work at Sandia in the 1970s (also see Bauder 1989):

- Any pattern made to a specified design can be duplicated using identical technology.
- Any surface feature can be duplicated. Although there is a limit to the level of detail that can be copied, this has been demonstrated to be true for all magnifications that are practical for field use.
- Any two dimensional pattern can be duplicated, no matter how complicated.
- The most difficult pattern to copy is a multidimensional pattern produced by random processes.

These limitations mean that both 1D and 2D technologies can be duplicated / counterfeited. This issue is the most limiting issue in the use of bar codes. They are otherwise inexpensive,[2] fairly easily applied, and are found in established industries. Therefore, for safeguards purposes,[3] a bar code would need to be paired with an element employing another technology that precludes duplication, undetectable tampering, or counterfeiting.

The harsh environment in which all of these tags must survive constrains the selection of materials employed for their construction. While many of the bar code manufacturers, (e.g., CAMCODE) provide various types of bar code tags (e.g., metal, Teflon® on metal, ceramic barcodes, polyester, etc.) for caustic environments, the available information does not indicate which, if any, of these types would be resistant to the normal operating environment for UF_6 cylinders (AirLink Automation 2013). Figure 2.1 (Friend et al. 2009) shows the wear and damage that metal labels are subject to over time. There is an obvious concern that dirt, paint, or other environmental elements could obscure a bar code and render it unreadable. A key consideration is that the bar code could be incorrectly read (i.e., misidentifying the cylinder) under such circumstances (Hawker 2010).

Bar codes etched on aluminum, stainless steel, and other metals can be difficult to read (Nachtrieb 2013). Metal or metalized surfaces will scatter reflected light rather than return it in a predictable linear direction. Metal bar codes can be applied to cylinders using welds or adhesives.[4] As UF_6 cylinders already ship with required metal nameplates, it is not anticipated that the addition of a metal tag containing a bar code would be particularly difficult, at least if it were to be applied at the time of manufacture or recertification. With the exception of an adhesive tag, it is believed that application of a welded or riveted tag at any other point in the lifecycle of a UF_6 cylinder would require verification that

[1] The Symbol LS3408-ER Long Range Barcode Scanner is advertised as able to read bar codes up to 45 ft away (Electronic Imaging Materials 2014).
[2] CAMCODE (2014b) notes that UID labels can be as inexpensive as $ 0.25 per label when ordered in large (1000s) quantities. CAMCODE also provides readers, software, etc.
[3] A bar code that provides an enterprise ID number for a cylinder can be used both by the operator for individual cylinder identification, while the tamper indicating element will provide assurance that the cylinder originally associated with that unique ID is still the cylinder being identified.
[4] It is possible that other metal tags could be applied using adhesives.

the cylinder is still compliant with its pressure vessel requirements. Tags have been developed to be resistant to deterioration by ultraviolet (UV) light for 20 years (CAMCODE 2014a).

Figure 2.1. UF6 Cylinder Label

Various adhesives are available to attach the tag to the item. Adhesive used for this purpose would need to withstand the repeated thermal and humidity cycling associated with UF_6 cylinder autoclaving, the acidic atmosphere resulting from the occasional exposure to HF during operations, as well as the chemicals used during cylinder cleaning operations (White et al. 2012). Adhesive chemistry is a sufficiently mature science that an adhesive meeting these requirements could almost certainly be identified or developed (Fraunhofer 2013). It is less certain that a COTS adhesive could be found that would meet all the requirements.

2.1.1.1 Industry Experience

All cylinders at URENCO facilities have adhesive labels showing a 1D bar code, equipment number, and owner’s number. (Friend et al. 2011). According to Friend 2011, URENCO chose to use bar codes after a review of existing technology in 2008 determined that RFID technologies were not currently able to meet operational needs for reliability and cost. URENCO also established a new cylinder numbering system for use across all three of the European plants based on the Bureau International des Containers et du Transport Intermodal (BIC) number system (Spielmann 2013). In addition to applying the barcode to the cylinder, URENCO has requested that the manufacturer etch the same number on the nameplate welded to new cylinders as the Manufacturer’s Serial Number (Friend et al. 2011). The authors were unable to find out the expected longevity of their adhesive labels; but for their use there would be no requirement for a 10-year design life. As these barcodes are not intended to meet IAEA requirements for authenticable or tamper-indication for safeguards purposes, there would be no additional cost to URENCO associated with replacement of their bar codes if the adhesive failed beyond the time expected in the normal course of business. If an authenticable/tamper-indicating label were to fall off, an additional expected cost to the operator and IAEA would involve the replacement of the label and re-authentication of the cylinder, which would have some operational impact.

Adhesive tags can be read by most readers. A review of the online URENCO facility tour video indicates that the bar codes are read by a handheld reader held about 1 -1.5 ft from the cylinder as shown in Figure 2.2 (URENCO 2013).

Figure 2.2. URENCO Bar Code and Scanner

URENCO installed a new computer system, applied the adhesive tags to all their cylinders, and ensured that all their paperwork reflected the new identification number as well as the owner number (Friend et al. 2011).

2.1.1.2 Bar Code Tag Conclusions

If the concerns related to authentication can be resolved, it would appear that matrix codes would be a simple, cost-effective solution for a CIS. The 2D format has the advantage of carrying more information, is more resistant to damage, as the information can be duplicated within the tag in several areas and can be easily enlarged for reading from a distance. The bar code technology is COTS, with the possible exception that the tag material and the method of attaching the tag to the UF_6 cylinders may need modification to meet environmental and design life requirements. If these items are not COTS, it is very likely that they can be fabricated from MOTS items. It is anticipated that for industry use of a bar code CIS, new computers and readers would be required, and would be necessary for IAEA inspectors.

2.1.2 Radio Frequency Identification Technologies

An RFID system is one that transmits information (usually a serial number) wirelessly using radio waves (Violino 2005c). A microchip is encased in a matrix or embedded in the material of interest. The chip is attached to a radio antenna. A reader with one or more antennas emits radio waves, queries the microchip and receives signals back from the chip. The information is then passed to a computer. In an active RFID system, the chip continuously broadcasts its data to the readers, and must have a power source (Violino 2005b). Some active RFID chips respond only when queried, which helps preserve the battery life. Passive RFID chips only reflect the radio wave back to the reader. Passive RFID chips are cheaper than active chips (Violino 2005b). RFID chips have the advantage that they can be read from a distance, even if the reader is not within a direct line of sight of the tag (Jo 2007, Ward and Rosenthal 2009). This could be helpful for inspectors or anyone who wished to find a cylinder in a cylinder storage yard, where many cylinders may be stacked. However, because RFID chips are readable from a distance and the radio waves can be reflected by items in a facility, it is possible for the RFID reader to detect a tag that it is not pointed toward (i.e., to read the wrong tag). This false directionality might limit the usefulness of an RFID system for locating cylinders in storage.

The read distance for active chips can be up to 300 ft while passive chips can generally be read from no farther away than about 30 ft. The chip can be packaged in many ways, (e.g., as a smart label, or packaged to resist heat or chemicals, etc.) however, the packaging can significantly increase the cost (Violino 2013). RFID chips operate at four different frequency bands: low frequency (generally 124, 125, or 135 kHz), high frequency (13.56 MHz), ultra-high frequency (UHF, anywhere from 860 MHz to 960 MHz), and microwave (Wireless Technology Advisor 2014). The distance from which a chip can be read depends upon the frequency. Low- and high-frequency passive RFID tags use inductive coupling, while passive UHF RFID tags use propagation coupling (Violino 2005b). Low- and high-frequency waves cannot penetrate metal, while UHF and microwave frequencies do not work well through water. Metal will also interfere with both microwave and UHF radio waves. The read range for low- and high-frequency chips ranges from 1 to 3 ft. UHF and microwave chips can be read from 10 ft or more (RFID Technology, Wireless Technology Advisor 2014). Microwave-frequency RFID chips are the newest and most costly chips (Violino 2005a).

Passive UHF chips have other potential concerns, such as detuning, signal attenuation (with distance or type of materials used), and electromagnetic interference (EMI) (Violino 2005b). These issues can generally be handled in a properly installed system, by employing measures such as an air gap to avoid detuning, proper equipment shielding for equipment that might generate EMI, and proper placement of the reader antenna. However, if the reader module needs to generate a high power signal in order to read the tag at the required distances, and the signal that the reader module generates is at a frequency used by plant safety, security, or operational equipment, then EMI will be almost unavoidable.

Neither low-frequency, high-frequency, nor microwave RFID chips appear to be able to meet the requirements identified in the Task 3.1.1 report (Hockert and Wylie 2014). Therefore the analysis is limited to UHF RFID tags. A CIS designed for worldwide use that employs UHF RFID chips creates a separate issue. As shown in Figure 2.3, the UHF frequencies assigned by governments for RFID use vary by country (Repec 2013). Specific countries shown in Figure 2.3 were chosen based upon the location of UF_6 facilities. As indicated by Figure 2.3, there is no single UHF frequency that is permitted for RFID use in all countries where UF_6 cylinders are handled. This means that a passive UHF tag and readers would need to be designed to operate adequately over multiple frequency bands. Although it would be theoretically possible to employ multiple passive RFID tags on cylinders expected to travel between countries or regions with different RFID frequency band allocations, this type of design appears to be operationally impractical. The requirement for passive RFID tags to operate over multiple frequencies reduces the electromagnetic efficiency of the tags so the reader will need to send a more powerful radio frequency (RF) signal to read the multiple frequencies than would be needed for a tag optimized for a specific frequency.

Figure 2.3. Range of permitted UHF RFID frequencies by country

Because most countries limit the reader power output, this lower RF efficiency ultimately translates into a lower maximum distance from which the tag can be read reliably (Hickerson et al. 2009). Operating at or near the maximum permissible power may also increase the likelihood of EMI. The reader design would probably need to be country- or region-specific so that it did not broadcast on unauthorized frequencies.[5] A CIS design that employed an active RFID tag in this situation would need to be country- or region-specific and would need to be changed to one operating in the legal frequency range if the cylinder were shipped internationally. Therefore, operational complexity issues associated with multi-frequency operation preclude the use of active RFID tags and pose significant challenges to the multi-national use of RFID tags.[6]

[5] A single reader module designed to be capable of operating on multiple UHF frequency bands would be theoretically possible. However, there would be significant operational risk that the plant or IAEA would unintentionally operate the reader module on the wrong frequency band for their location, risking EMI or other interference problems.

[6] Obviously such constraints would not affect the use of RFID tags or seals on items that rarely, if ever, left a single facility or remained within a single State,

Emission security (EmSec or TEMPEST) is an issue with any equipment that broadcasts radio signals from a secure area (Online Guide to Security Responsibilities 2013). The facility operator and/or State regulators need assurance that the reader module or active RFID chip is not being employed to transit sensitive facility information to unauthorized persons. In the United States, the U.S. Nuclear Regulatory Commission (NRC) and the U.S. Department of Energy (DOE) have specific TEMPEST requirements, and neither grants blanket approval for the use of wireless transmitting devices in a classified environment. Because enrichment technology is regarded as sensitive information throughout the world, it is anticipated that similar restrictions would be likely imposed at enrichment facilities worldwide. TEMPEST issues have been addressed with the implementation of active RFID tags at the National Geospatial-Intelligence Agency (Whitaker 2014a). In addition to the EmSec considerations related to wireless devices on site, EMI may limit a facility's future modifications or equipment considerations. Although experiments conducted at UF_6 facilities found that the RFID chips did not interfere with digital equipment, these chips did interfere with older, analog equipment. (Pickett et al. 2008). A facility that wished to incorporate new equipment would be constrained by EMI from the installed RFID chips.

The RFID tags need to be designed to prevent counterfeiting. Unless specific protective measures are incorporated, RFID tags are vulnerable to counterfeiting and spoofing by a method referred to as a "man-in-the-middle" attack. In this vulnerability, an unauthorized reader queries a genuine tag and records the response. This response is then used to create a counterfeit tag that provides the same response as the genuine tag. The counterfeit tag could then be employed to disguise the diversion of a registered UF_6 cylinder or to allow an unregistered UF_6 cylinder to masquerade as a registered cylinder. Details of the vulnerability and protective measures are discussed in *Secure, Passive RFID for Safeguards Applications.* (Nekoogar 2012). While technology is available to address spoofing and counterfeiting, use of this technology may increase the cost of any chip.

2.1.2.1 Current Research Using RFID Tags

In 2008, Oak Ridge National Laboratory (ORNL) conducted testing of RFID chips at the Portsmouth Gaseous Diffusion Plant to determine whether they were a feasible technology to be used in UF_6 cylinder monitoring (Pickett et al. 2008).[7] Their evaluation found that eventually all of the RFIDs tested failed to survive repeated autoclave exposure. [8] Additionally, during the test campaign, RF interference issues were discovered. Testing found that the analog portable dosimeter had problems when the RFID system was in operation. However a newer, digital model did not. Likewise, the analog-based equipment on the nondestructive assay (NDA) cart was adversely affected by RF interference, but the digital equipment was not.

In 2009, ORNL published another paper, *Testing Of Commercial High-Temperature RFID Tags For Use In Radiant-Heat Autoclaves,* (Pickett 2009) reporting the results of testing seven RFID tags. The results indicated that the substrate and packaging for the tags continues to be a problem in survivability and usability after heating. The test included reading the various tags at different angles. Some tags performed more successfully than other. Four tags were selected for further testing.[9]

[7] This test was a follow-on test to the results of a test conducted at ORNL in 2006 (Kovacic et al. 2006).
[8] It is noteworthy that the RFID failures were in the mechanical parts of the system (e.g., antenna, tag backing) rather than the electronic components (e.g., failure of the semiconductor component[s]).
[9] William Frick and Company's stick tag, Intermec's small rigid tag, Rafsec's NXP G2XM tag, and Rafsec's short Monza tag.

In 2009, a field test of an RFID system was conducted at Global Nuclear Fuel Americas fuel fabrication plant (Martyn et al. 2011). Passive RFID tags were attached to 30B cylinders upon receipt, tracked throughout the site as they were placed in interim storage, processed in an autoclave and eventually left the site. Upon leaving the site, the tags were removed. Antennas were installed throughout the facility to read the RFID tags. These antennas were connected to the computers which were, in turn, connected via the facility Ethernet network. At least 10, and perhaps more antennas were used for the study. In addition to recording the location of the cylinders, the computers were also able to record weight data in those areas where the weights were recorded. Additionally, handheld readers were used to confirm inventory and verify the automatic records. While it was determined that RFID tags can be used to track cylinders within a facility, several problems were identified. Many of these were software issues, such as the creation of several thousand events in the database when tagged cylinders were left overnight in front of antennas, others related to the distance at which the antenna could read the tags. If the cylinders were placed out of range, they could not be located by the system. Antennas also read the wrong cylinder if there was more than one tagged cylinder in the area.

Other issues related to the format of the test and the apparent re-use of tags without unregistering data. Tags that passed through entryways with antennas did not always get read because of the speed of the forklift. Alternatively, the antenna angle in respect to the RFID tag may have prevented the ability of the antenna to read the tag. Martyn et al. (2011) indicated that there were faulty readings, which may have been the result of the test format, or some other cause. Power fluctuations near one of the antenna locations caused the network to fail frequently.

Martyn et al. (2011) concluded that the RFID tags were helpful in conducting an inventory, but that modifications would have to be made to antenna locations and power in order to reduce the number of events in the database, and confirm that there are no duplicate cylinders or tags. A handheld reader was found to be extremely helpful in tracking the cylinders for an inventory. Unfortunately, the Martyn paper did not discuss the number of times the tags were subjected to the autoclave process. At least 45 cylinders were tagged, but it was not clear that any RFID tag underwent more than one cycle in the autoclave. Because the entire system was designed to be removable, no data could be obtained relating to the sturdiness of the method of attachment, although it was noted that the tags did not interfere in operations. No EmSec issues were discussed.

As a part of IAEA long-term directions and key objectives, which include improving and expanding techniques, tools and procedures for containment verification, the IAEA would like to develop RFID techniques, among others, to be used for stand-off tracking of material containers (IAEA 2011).

2.1.2.2 RFID Conclusions

The RFID technology offers several potential advantages, including the ability to “read” the tags without direct line of sight and when the tag is obscured by dirt or environmental elements. However, the issues associated with EmSec, EMI, and differences in RFID UHF frequency allocation do not appear to have a technical resolution. In addition, the companies in the nuclear industry who would need to voluntarily adopt the CIS technology have been resistant to adopting RFID technology.

2.1.3 Reflective Paint and Particle Tagging

Reflective paint particle tagging is based upon application of paint containing randomly distributed reflective particles. The random location and orientation of the particles on the surface of the item are then used to uniquely identify an item (Tolk 1993). Originally used for weapons control, it was soon extended to protect a document by applying a pattern, and then recording and encrypting the data describing the random pattern and other identifying information (e.g., an assigned number). The record is then compared against the pattern at a later date to determine whether it is the same pattern, to confirm that there has been no tampering. The approach requires a means to generate a suitably complex random pattern, a reader that can read the data from the pattern, a means to store the data for later comparison and a means to compare data sets to be sure the pattern is authentic. These patterns must be stable over a long time, readable, unique, and not duplicable (Tolk 1993).

Reflective particles are easy to apply and to read (Tolk 1993). The paint would include thousands of reflectors, which would make it difficult to reproduce. Other approaches within the same category could include fibers added to paper to create a tag.

The reflective particle tag (RPT) can provide visual evidence of tampering, as well as being uniquely identifiable as explained in Gonzales et al. (2009). These tags are made up of an adhesive polymer mixed with specular hematite particles. As tested by Sandia National Laboratories (SNL), the tag is cured in the field with a battery powered UV light-emitting diode (LED) curing tool. A two-component epoxy resin system was selected for future evaluation to simplify field application in the future (Merkle et al. 2010). SNL's image-based verification was used to verify that the gallery image and the probe image are sufficiently similar to provide certainty that the item in question is the expected item (Gonzales et al. 2009). Digital images of the tag using lighting from different directions are taken and recorded as references. Initial testing provided confidence that the algorithm was able to determine whether the two images were of the same RPT in the same lighting, but it could not determine whether small areas of the RPT had changed.[10] In addition, RPT tags were tested in an autoclave and were found to have undergone physical distortion that potentially compromised their authenticability (Whitaker 2014b).[11] It is likely that this problem could be resolved by embedding the reflective particles in a different matrix, such as glass, that is less subject to physical distortion under heat than the hardened resin used in the autoclave tests. SNL has been able to show that a change in the lighting will be as different as two different tags taken using identical lighting. (Merkle et al. 2010) The latest version of the tag reader is a digital camera with a fixed lighting assembly on a rigid body. When inspected, the tag and reader must be in the same relative positions as when the reference image was obtained (Merkle et al. 2010). In order to achieve this orientation, a laptop computer is used to display alignment lines that correspond to alignment targets on the tag. In the field, the alignment fiducial would be located within the particle field (Merkle et al. 2010). This would make it more challenging to easily use this technology in the field, although not impossible.

2.1.3.1 Reflective Particle Trials

The latest version of the RPT comes with a frame for mechanical alignment, a cover, an alphanumeric tag label, and resin and hardener with particles. The resin/hardener/particle mixture is dispensed from a single

[10] SNL planned to attempt to address this issue and obtain more confidence in their results.
[11] Such changes would add to the difficulty in using the RPT tag alone for identification, but might not impact the tag if used only for authentication purposes. Further research would be needed.

use bubble pack. SNL performed pull strength tests and found that the pull strength varied as a function of temperature and that there were difficulties in achieving uniform mechanical properties in the UV-cured resin (Merkle et al. 2010). Pull tests had not been performed on the epoxy. The reader used a laptop to control the lights and digital camera. The laptop provided an inspector interface to acquire the reference and actual images. An optical character reader (OCR) was used to read the tag labels. In testing the prototype, the system failure rate was 14%, with the majority of the failures because of the software failing to acquire or recognize the image. The researchers believe that a more reliable barcode identifier and custom software will increase reliability.

2.1.3.2 Reflective Particle Tag Conclusions

The technology appears promising; however, the development to date has focused mainly on the RPT in seals, rather than tags useable for a unique identifier (UID) on a cylinder.[12] The areas of concern relative to the CIS requirements and evaluation criteria follow.

- The reflective pattern recognition approach requires that the identification scan and the reference scan be performed at the same distance from the reflective particle tag, the same angle relative to the surface normal, and the same lighting. This limits the use of the RPT to a standard layout at all facilities. Work proceeds in the area of developing a stand-off reader for an RPT.
- Although the RPT scanner itself is relatively small and man-portable, the equipment necessary to ensure that enrollment and identification scans are performed at a standard distance and angle from the RPT under standard lighting, significantly affects ease of use and operational flexibility. The RPT scanner must be precisely aligned and the proper lighting must be applied in order to authenticate the pattern.
- The 14% recognition failure rate in the prototype trials is far from the required 1% failure rate or less required to achieve 99% reliability. The trials did not provide any information regarding the false identification rate which the CIS requirements limit to no more than 0.1%.

This technology is more cumbersome than others, such as the bar code, for routine cylinder identification. However, with continued development this technology might be useful in providing authentication and tamper indication to the cylinder component.

2.1.4 Optically Stimulated Luminescent Materials in combination with Nameplates

2.1.4.1 Concept Overview

Pacific Northwest National Laboratory (PNNL) has demonstrated a counterfeit-resistant surface coating (Miller et al. 2010), intended to provide a method for inspectors to use a portable device to detect tampering with a container or seal. Known as optically stimulated luminescent (OSL) materials, these materials are passive, and have multiple emission wavelengths and spectral width, permitting the use of various light sources and filters to provide for the optimal combination.[13] The use of OSL materials is

[12] The IAEA staff has mentioned development of frangible glass reflective particle tags; but was not able, on short notice ,to provide documentation of the technology that was approved for release.
[13] Miller notes that future research might include infrared absorbent materials as well.

discussed in greater detail in *Container Verification Using Optically Stimulated Luminescence*, (Tanner et al. 2008). OSL materials will fluoresce at specific wavelengths when illuminated by another (known) wavelength band. An irradiated crystal is used to produce the luminescence, which is proportional to the dose and amount of light. OSL materials exhibit multiple emission peaks from a single material. The relative intensity of the emission peaks can be controlled and manipulated according to PNNL, leading to a unique position and spectral width of the infrared optically stimulated luminescent emission peak.[14] An item coated with OSL material can therefore be authenticated by subjecting it to the known wavelength band and confirming that the wavelength emitted is the expected wavelength. PNNL suggests that alphanumeric text or patterns could be encoded using the OSL materials. (Tanner et al. 2008).

2.1.4.2 Trials

PNNL used a 30% by weight infrared grade OSL phosphor and added it to powdered paint. The blend was then milled to achieve uniformity and prevent clogging of the paint gun. The paint was sprayed on metal and allowed to cool and cure. Using a 460 nm peak emission blue LED cluster, an infrared camera, an incandescent white light source and an infrared (IR) light source, the team took digital and IR pictures of paint with and without the OSL phosphor. Only the OSL-treated paint emitted bright light in the IR range. The team then drilled a hole in the OSL-treated metal plate, and then repaired it. Under the IR light the tampering was visible (Miller et al. 2010).

Various studies have been conducted on the OSL emissions using irradiated LiF, which was chosen because it has been used with dopants in radiation dosimetry and its emission peaks were well known to be stable at room temperature over time (Miller et al. 2010). The crystals are stable up to 600 °C. Light exposure does not reduce the OSL emission intensity. The materials used by PNNL are proprietary, but have been found to be environmentally stable after manufacture. Many studies using these materials have been performed as a part of dosimetry studies. Although LiF is soluble in water, if the irradiated powder is encapsulated in a polymer, it remains stable even after immersion in water for days (Miller et al. 2010).

Experiments have shown that the OSL material can be irradiated to a desired brightness prior to use, or an electron beam can be used to encode a fluorescent pattern after application of the OSL material (Miller et al. 2011). A handheld reader is being developed to determine whether material can be used for seals. After development issues have been resolved, a vulnerability assessment would be performed. Should the effort prove successful, readers could be developed for a wide range of applications, because of the variety of optical signatures. Specifically, it is anticipated that the OSL materials could be applied in such a way as to provide differeing optical features for various security measures. Random placement of OSL particles could provide another level of security.

2.1.4.3 Conclusions

Although this is a step forward in providing an inspector with the ability to see tampering using a digital camera and IR lighting, it does not purport to be unique. Nevertheless, it is possible that the paint technique could be used in conjunction with a numbered tag, such as a bar code that cannot be shown to be tamper-free. It is not apparent that the approach can be used for authentication purposes at this time. As noted, the decay of the luminescent paint might be used to authenticate a tagged item. Because of the

[14] Temporal luminescent decay is also unique for the OSL materials used in the experiment and might be further investigated.

need for IR light, the limited data available and the need to take additional pictures (e.g., both infrared and digital pictures) this approach is not likely to be useful at this time. The only situation where it might have utility would be in combination with another identified technology that cost effectively met all requirements except for the requirement to be tamper-indicating.

2.2 Intrinsic Cylinder Identification Systems

2.2.1 Laser Item Identification System

2.2.1.1 System Overview

The Laser Item Identification System (L2IS) was developed for the IAEA by the European Union Joint Research Centre (JRC) at Ispra, Italy, to identify UF_6 cylinders. L2IS uses one or more class 3R lasers mounted on a rotation stage and permits the "mapping" a range of cylinders (30B, 48Y, and 48Z) rapidly and accurately. Cylinders are enrolled by performing a reference scan of the entire head of each cylinder of interest with the scanner in a defined distance and orientation to the cylinder. This reference scan provides a unique "fingerprint" of the cylinder and results from the cylinder's intrinsic surface micro-roughness. This information would be retained in a reference database. The identity of the cylinder can then be authenticated at strategic points within a process by using a fixed instrument to read the cylinder attributes and match them to the known database. Figure 2.4 depicts a typical setup of L2IS. Figure 2.5 provides an example of such a comparison. The comparison algorithms are designed to distinguish and filter out small marks, scratches and dents in order to minimize the false alarm probability. The verification reliability can be further increased by the use of standard surveillance methods at the screening stage to ensure that measurements are unimpeded. (Sequeira et al. 2010; Monteith et al. 2010).

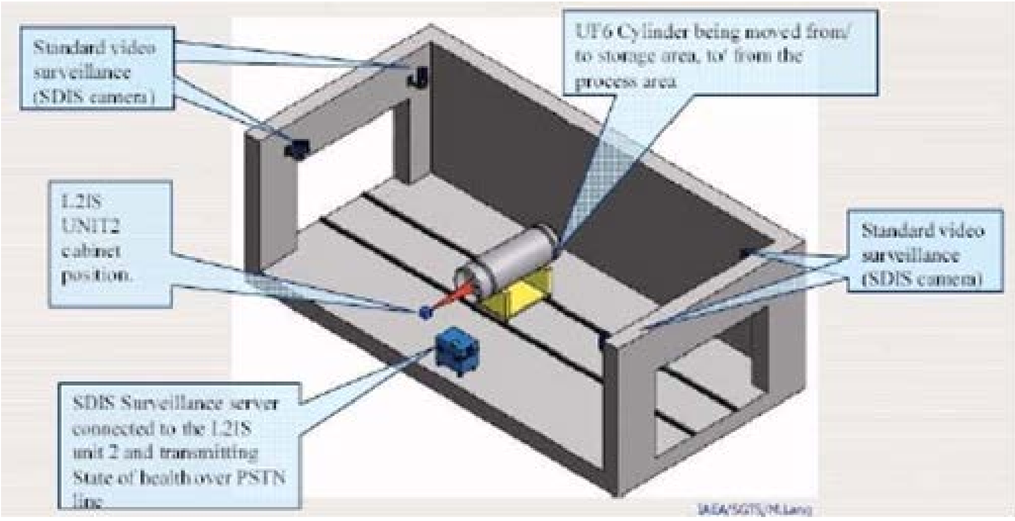

Figure 2.4. L2IS set up (Poirier et al. 2010)

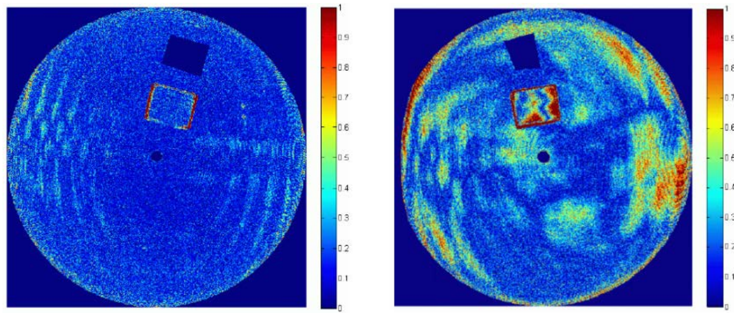

Figure 2.5. Matching scan (left) and non-matching scan (right) (Monteith et al. 2010)

The 3 Dimensional Laser Surface Authentication (3D-LSA) employs laser triangulation (illustrated in Figure 2.6). As explained by Poirier et al. (2010),

> "A sheet of light is projected onto the interrogated object using a laser diode and a cylindrical lens. Where this sheet of light intersects with the object surface, it creates a laser line which is viewed by a digital camera from a different angle. The camera is equipped with a bandpass filter adapted to the laser wavelength so as to minimize the influence of ambient light. The shape of the laser line 'seen' by the camera depends upon the shape of the object (surface). Assuming that the system is properly calibrated, each point of the laser line recorded by the camera yields the coordinates of one point in the laser plane. Each camera image therefore yields a profile which is the intersection between the laser plane and the object surface. By moving the object or the scanner in a controlled manner, a sequence of profiles can be acquired, producing a dense cloud of 3D points on the object surface."

The line scanner that projects the laser beam is a COTS item. The L2IS project uses reliable, mainly standardized and commercially available components and is implemented in a standard IAEA cabinet, offering IAEA standard data retrieval media and procedures to the inspectors, which minimizes the need for additional training, supplies, and maintenance.

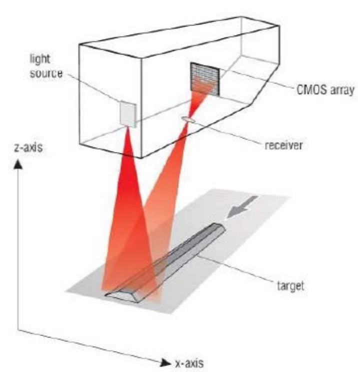

Figure 2.6. Triangulation Principle (Poirier et al. 2010)

2.2.1.2 Field Trial Experience

Several trials of the L2IS technology have been conducted initially at BNFL Springfields, Rokkasho enrichment plant, and at Pierrelatte (Sequeira et al. 2010). The IAEA continued to field test this system with an estimated completion toward the end of 2012 (IAEA 2011). The Rokkasho trial was able to identify about 96% of 48Y and about 98% of 30B cylinders (Yao et al. 2011). In-plant field tests of L2IS were limited to Rokkasho enrichment plant, which is small and moves cylinders along a single corridor. Therefore, concerns remain about the ability to deploy L2IS in enrichment plants larger and more crowded than Rokkasho. Serious concerns also remain about the effectiveness of L2IS as an authentication approach because of its limited ability to distinguish among precisely manufactured cylinders.

2.2.1.3 L2IS Conclusion

The L2IS technology meets many of the requirements for a CIS. The L2IS concept has been deployed in field trials. The areas of concern relative to the CIS requirements and evaluation criteria follow.

- The L2IS triangulation approach requires that the identification scan and the reference scan be performed at the same distance from the cylinder surface, and the same angle relative to the surface normal. This limits the use of the L2IS to a standard layout, such as the one shown in Figure 2.4 at all facilities.
- There would appear to be no time savings in identifying cylinders in the yard as they would have to be subjected to the L2IS process for identification purposes.
- The L2IS scanning configuration depends upon the cylinder diameter, so two different scanners or a single dual head scanner would be required to scan both 30B and 48Y UF_6 cylinders.[15]
- Although the L2IS scanner itself is relatively small and man-portable, the equipment necessary to ensure that enrollment and identification scans are performed at a standard distance and angle from the cylinder surface significantly affects ease of use, operational flexibility, and portability.
- The uniqueness of the L2IS reference spectrum (fingerprint) was only demonstrated for the relatively small population of cylinders involved in the field trial application (i.e., the set of cylinder expected to be used at one facility during a material balance period). Discussions with IAEA staff indicated serious concerns about its effectiveness as an authentication approach because of its limited ability to distinguish among precisely manufactured cylinders In the field tests this was shown by the lower accuracy of identification of smaller intermediate product cylinders (nominal 35.5 in diameter) manufactured to high accuracy (Yao et al. 2011).
- It is not clear that the cylinder surface would be sufficiently unchanged following process cycles, protected against the environment over any period of time, or during recertification procedures. In particular, there may be a need to re-enroll cylinders after refurbishing.

The enrollment process is time-consuming and labor-intensive, which could limit industry voluntary acceptance and might lead to a protracted delay in enrolling a sufficient number of cylinders to provide

[15] For some of the field trial configurations, a three-head scanner was used to permit scanning of 30B, 48Y, and intermediate product cylinders. The three-head scanner was fabricated from three COTS scanners that were fastened together and calibrated.

significant safeguards benefits. Although the L2IS technology is part of a system that has been field tested at one plant, the results do not provide sufficient assurance that cylinders can be distinguished from other cylinders, particularly as manufacturing accuracy increases. The utility of the L2IS technology for a CIS would be significantly enhanced if software modifications or other approaches could be developed so that the reference scan and identification scan could be performed at different distances or angles from the cylinder surface. The possibility that the L2IS reference spectrum may not be unique could be addressed by engraving a bar code or other unique information on the cylinder surface. These enhancements should be pursued before accepting the L2IS technology for the CIS.

2.2.2 Bar Codes Applied Directly to the Cylinder

2.2.2.1 System Overview

This system is essentially the same as that discussed in Section 2.1.1. The only difference is that the bar code or matrix would be applied directly to the cylinder, rather than be attached to the cylinder. As such, this is an intrinsic rather than an extrinsic system.

2.2.2.2 Laser Etching

The code can be applied using direct laser marking (e.g., such as an Ostling Marking System) which etches a groove, vaporizing the material. The marking depth can be up to 50 µm (Ostling Marking Systems 2014). Other methods such as material abrasion, annealing colors or color changes are not appropriate for the UF_6 cylinders and will not be discussed.[16] Initial testing of laser marking, reported in 2008, indicated that the fatigue effects from laser marking appeared to act as an ordinary fatigue crack in the material tested (Davis et al. 2008). Laser marking techniques are now portable (Control Micro Systems 2014). These systems permit an operating window of 1-6 ft off the ground, and can be suspended by a boom that operates in a 15-ft by 20-ft area.

2.2.2.3 Other Marking

Electromagnetic dot peen or pneumatically actuated scribing can also be used to directly mark surfaces. With electromagnetic dot peen marking, such as the Technomark Multi4-ModularMarking tool (Technomark 2014), a hand-held tool can be used to mark the cylinder directly using an oscillating stylus. The pneumatic scribing technique uses pneumatic pressure to create continuous line characters. Either of these two methods could be used to directly mark a number and or data code on the cylinder itself. The unit can be installed as a bench unit as well.

2.2.2.4 Analysis and Conclusion

The strengths and weaknesses of a directly laser-engraved bar code or 2D code are essentially the same as those discussed in Section 2.1.1. Additional observations follow.

[16] These rely on changes in color in the material when exposed to oxygen, removal of metal layers such as anodized aluminum to reveal a different color, or changing colors in lacquers and plastics.

- Because these approaches directly engrave or otherwise mark the cylinder, it may be possible to use optical methods that would enable verification of the authenticity of the UID, once placed on the cylinder.
- While the laser engraving system is portable, the system is also offered with a lifting arm that operates in a rather large footprint area. It can be assumed that for repeated marking, the boom would be required to avoid worker fatigue.
- Dot peen and pneumatically scribed systems could also require a similar boom or constructed bench to avoid worker fatigue.
- The integrity of the cylinder would have to be verified.

This approach would be quite promising if an approach to authentication of the bar code could be developed. It is worth pursuing in coordination with the approach discussed in Section 2.3.1.

2.2.3 Forgery-proof Laser-holographic Product Identification

A recent approach to addressing the problems associated with forged products was developed by a consortium consisting of 3D-Micromac AG, Laser-Laboratorium Göttingen e.V., the University of Applied Sciences Bielefeld, Kappa opto-electronics GmbH, SURA Instruments GmbH, and OLPE Jena GmbH (Industrial Laser Solutions Editors 2012). The ZIM-project “perfekt” aimed to develop an unforgeable approach to marking high-end metal or silicon product surfaces. The process uses an ultrashort-pulse laser system and different diffractive optical elements to shape the laser beam using the optical system in 3D-Micromac’s microSTRUCT laser micromachining system. The diffractive optical elements create a characteristic interference pattern that is transferred to the surface of the component when the laser beam passes through the elements. Rotation and movement of the diffractive optical elements creates an individual unique pattern that is decipherable with a portable reader. The depth of the marking is 100 - 200 nm, and purports to resist reverse engineering efforts because it is not possible to determine the kind of diffractive optical elements or their position to each other from the pattern (Industrial Laser Solutions Editors 2012)

2.2.3.1 Analysis and Conclusion

While the microSTRUCT device is available on the commercial market, it is not apparent that this process has passed beyond the test phase.

- No information was available on the number of various pattern changes available, or whether they could be used in conjunction with a data code that could be read with any reader while only a special reader could be used to read the unique pattern.
- If only a limited number of patterns were available, it is possible that these patterns could be used to provide authentication and tamper-indicating data, even if they could not be used as a unique identification number.

- 3DMicromac is a company that specializes in micromachining for industrial applications and R&D. This technology may not be transferable to a larger-scale pattern without losing the resistance to reverse engineering.[17]

This technology is sufficiently promising that additional communication with the vendor is warranted.

2.3 Combined Cylinder Identification Systems

2.3.1 Nameplate and Weld Digital Imaging

2.3.1.1 Concept Overview

In 2010, PNNL performed a preliminary investigation of the use of high-definition digital photos for cylinder identification employing a form of pattern recognition (Danielson et al. 2010). The concept requires a digital camera and a computer to process the algorithm and act as secure storage device. The camera is used to take a picture of the head end of the cylinder. The computer algorithm singles out and rotates the image of the nameplate, compares the nameplate with imagery in storage, and positively identifies the cylinder using commercially available fractal algorithms. The concept was tested using a commercial camera 2272 x 1704 resolution to produce Joint Photographic Experts Group (JPEG) images. The cylinders were photographed from different distances and angles and the images were digitally processed to level the illumination. The image was then processed using a fractal analysis algorithm to generate 440 fractal dimension digital signature.

2.3.1.2 Test of Concept

The recognition testing consisted of determining whether the fractal algorithm could successfully match the digital signature developed from a photograph selected from the 48 cylinders photographed with its reference digital signature in the 48-cylinder database. With preprocessing to select the nameplate and surrounding weld (done manually in the analysis but possible digitally) and digital adjustment of the illumination to a standard level, the concept recognized 80% of the images (Danielson et al. 2010). The digital recognition algorithm might have been even more effective had it employed raw format image files as the JPEG compression algorithm makes subtle alterations in an image (Austin 2014).

2.3.1.3 Nameplate and Weld Digital Imaging Conclusions

The concept is promising because it was moderately successful in varying lighting conditions employing photos taken with a commercial camera from various distances and angles. However, the test of concept failed to demonstrate the capability to identify a cylinder by comparing an identification photo taken from one distance and angle with a reference photo taken from a different distance and angle. The testing also failed to demonstrate the uniqueness of the 440 fractal dimension digital signature for a sample larger than the 48 cylinders photographed. The 80% recognition rate was significantly lower than the 99.9%

[17] To the extent that the resistance to reverse engineering relies upon the difficulty of machining a complex micro-design, enlarging the design would reduce this resistance unless the same level of micro-detail could be maintained over a larger area. However, it is not apparent that micro-detail of this complexity could be read with sufficient accuracy from the longer distances required for the CIS.

recognition rate required for the CIS. The concept has not really reached the prototype stage yet and would require significant additional development and independent vulnerability assessment before being considered for the CIS. Although the geometric limitations are basically the same as those of L2IS, the use of off-the-shelf equipment and a single photograph in lieu of a laser scan appear to make it easier, quicker, and cheaper to use than L2IS.

The concept is sufficiently promising that a focused small scale industry-laboratory development program, including consideration of its use in combination with a welded bar code plate or other identifier, may be appropriate. Because this is essentially a two-dimensional image recognition approach, an independent vulnerability assessment to ascertain its robustness against counterfeiting and tampering would be especially important.

2.3.2 Nameplate and Reflective Particle Tagging

A reflective particle could be applied to a nameplate in such a manner as to provide for authentication of the nameplate. While this would address a significant problem with the use of a nameplate technology, the difficulties associated with the use of the reflective particle tagging remain.[18]

2.3.2.1 Analysis and Conclusion

This approach has little to commend it over the combination of a bar code and reflective particle tag. The limitations of using the name plate for cylinder unique identification have been discussed.

2.3.3 Bar Code and Laser Digital Imaging

2.3.3.1 Concept Overview

The IAEA employed laser mapping to verify that welded closures on nuclear material containers have not been tampered with. This approach, laser mapping system for containment verification (LMCV), could potentially be used to verify the absence of tampering with etched bar codes or welded bar code plates. Tampering is detected because the removal and re-welding of the welded plate or modification of the etched bar code would change the weld reflow pattern or the three-dimensional structure of the cylinder surface surrounding the etched bar codes or welded plate. The approach uses a laser triangulation scan, like that employed for L2IS to generate a set of weld profiles (see Figure 2.7 from Kravtchenko 2013). The length of each profile and the resolution (point-to-point distance in a profile) vary with the distance between the scanner and the surface.

[18] Research into a standoff reader for RPT is ongoing.

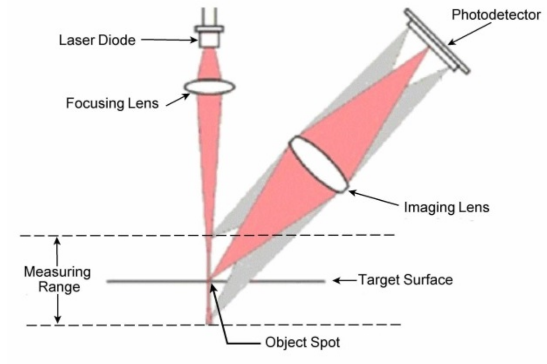

Figure 2.7. Imaging approach

The weld scan produces multiple profiles as shown in Figure 2.8 (from Busboom et al. 2007). The color on the image illustrates the metal height, as shown on the scale at the side of the figure. Once a reference scan and a verification scan of a weld have been acquired, they need to be compared to each other to determine whether tampering has taken place.

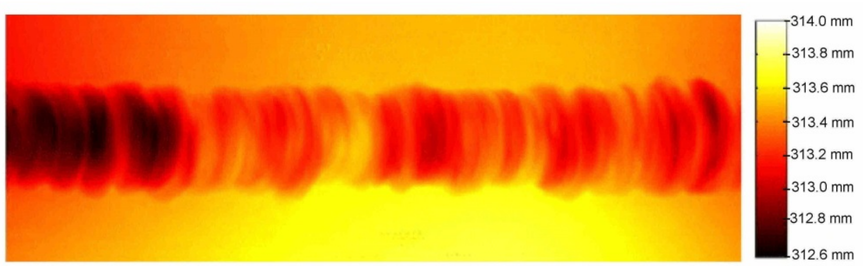

Figure 2.8. Raw scan image

A direct point-to-point comparison of the profile would only be possible in a situation of perfect mechanical alignment between the two scans. However, a practical system needs to be able to make accurate comparisons with a manual setup without calibration or high-precision mechanical adjustment. Therefore, the comparison approach must remain accurate with variations in the distance of the scanner from the surface, the point along the weld where the scan is started, and the position and orientation of the scanner with respect to the surface between the reference and verification scans. This is accomplished by algorithmically normalizing the distance between the scanner and the surface and the angle between the scanning direction in both the reference scan and the verification scan. The analysis algorithm extracts a three shape characteristics for each profile: profile width, profile height, and profile area, as illustrated in Figure 2.9 (Busboom et al. 2007). The variation of each of these characteristics along the weld provides a characteristic function. Testing has shown that these three characteristic functions provide a unique "fingerprint" of the pattern of the weld. The variations of these three characteristics along a weld are shown in Figure 2.10 (Busboom et al. 2007).

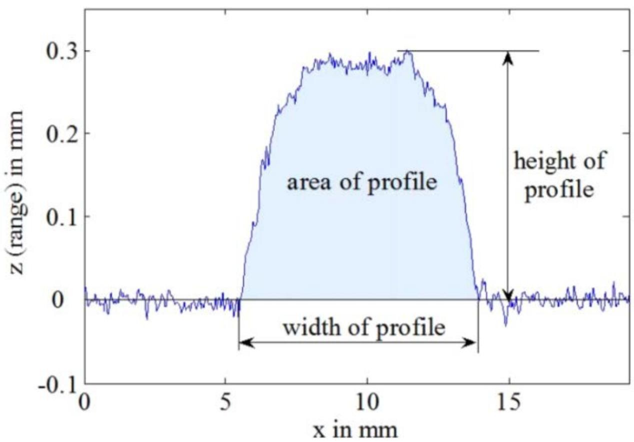

Figure 2.9. Profile shape characteristics

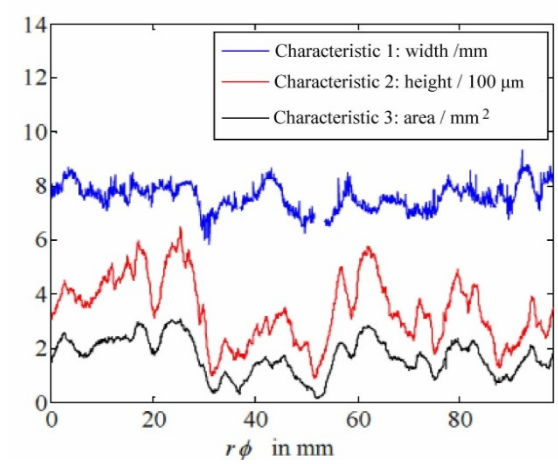

Figure 2.10. Weld characteristic functions

Figure 2. 11(Busboom et al. 2007) shows the difference (error function) between the characteristic functions for the reference scan and a validation scan of the same weld. As the figure shows, all three of the characteristic functions exhibit a very pronounced minimum at the same shift of approximately $\boldsymbol{r\,\phi}$ = 40 mm. Note that the vertical axis is scaled logarithmically and the minima are almost two orders of magnitude below the "noise floor." Ideally, the error function would be zero at the matching position—the remaining error stems from the measurement uncertainty of the scanner and any error residuals from the preprocessing and feature extraction steps. The errors at the non-matching positions result from the variation of the reflow pattern of the weld itself.

In laboratory tests performed with six plutonium canisters, the combined comparison of the three weld characteristic functions typically showed separations of three orders of magnitude between a matching and a non-matching weld. The closest two nonmatching welds came was still almost two orders of magnitude. These tests indicated that the minimum weld length that needs to be scanned during verification was 30 mm. Below this value, the risk of a false match (i.e., the system accepts two welds as matching even though they are not identical) increases significantly. These tests also indicated that, for the welds tested the separation distance between weld profiles could be increased to about 700 µm without a substantial loss in performance. This makes it possible to increase the scanning speed to about 87.5 mm/s, which would permit a verification scan to be completed in around 340 ms (Busboom et al. 2007).

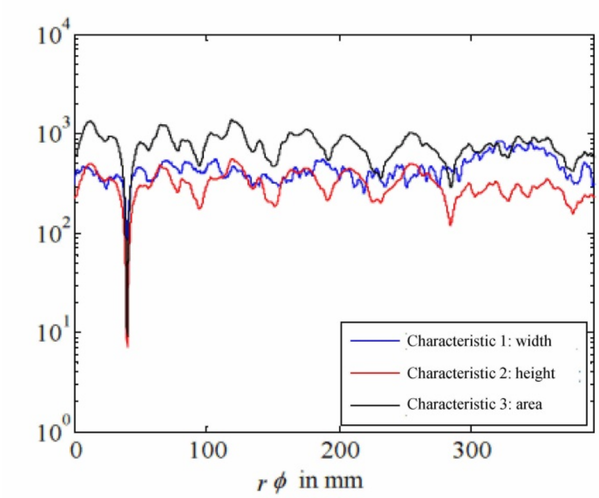

Figure 2.11. Scan function comparison

Thus, the laser digital imaging has the capability of verifying the integrity of scanned welds and detecting tampering. In combination with an etched or welded on bar code, this approach can, in theory, authenticate the UF_6 cylinder bar code identification. Note that, because the laser digital identification is combined with a unique bar code, the weld "fingerprint" only need be sufficiently distinctive to identify weld tampering. It need not be sufficiently distinctive to uniquely identify a single UF_6 cylinder out of tens of thousands registered in worldwide registry.

2.3.3.2 Field Trial Experience

The IAEA demonstrated that this approach is can be used to verify the integrity of dry storage cask confinement. The IAEA developed an LMCV weld scanner that could be attached to the dry storage cask to verify the flange weld. The scanner unit is shown in Figure 2.12 (Kravtchenko 2013). This unit attaches to the dry storage cask as shown in Figure 2.13 (Kravtchenko 2013) to scan the flange weld. The scanner employs a weld comparison algorithm that provides the inspector with a match or no-match indication, eliminating the need for the inspector to make any kind of comparison of images or digital fingerprints. This approach has passed vulnerability assessments and been successfully demonstrated in the field for dry storage cask welds. The field demonstration showed that the comparison was reliable even if the verification scan began at a different point on the weld and the scan angle differed to the extent permitted by the design of the scanner unit (Kravtchenko 2013).

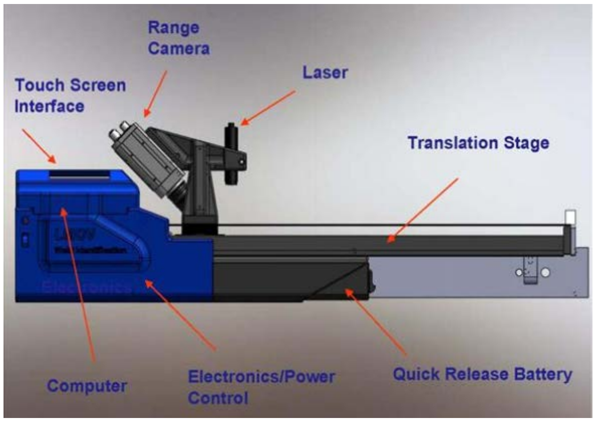

Figure 2.12. LMCV scanner unit

Figure 2.13. LMCV scanner attached to cask

2.3.3.3 Analysis and Conclusion

The LMCV approach is powerful and has been proven effective for verification of container welds. The complication of this design for the CIS Reader Module is that the scanner must be quite close to the weld being verified.

- In the LMCV Scanner Unit for dry casks, the scanner is required to be within 10 mm of the weld. It is not apparent that the approach can extended to permit weld verification from the 20-ft distance specified in the requirements in the Task 3.1.1 report. If the LMCV method cannot be used effectively unless the reader is very close to the weld, this approach would only be useful if the monitoring equipment where authentication is required could be redesigned to permit the LMCV weld scanner to be close to the weld.
- The bar code portion of the CIS cylinder component and its associated reader could be designed to read the bar code information from the required 20-ft distance.
- Research related to the possibility that welds might deteriorate over time and exposure to the UF_6 container environment would be required to ensure that the welds continue to be readable over time.

3.0 Gap Analysis

3.1 General Observations

None of the technologies identified and discussed in this report meets all the requirements established in the Task 3.1.1 report (Hockert and Wylie 2014). The technologies reviewed generally fit into two categories.

The first category comprises technologies that are well commercialized, flexible, and easy to use, but cannot meet the requirements for tamper indication and authentication. These include bar code labels, engraved bar codes, and RFID technologies. Bar code labels or engraved bar codes are perhaps the easiest and most inexpensive solution. Bar code technology is well developed and deployed commercially and the readers are readily available. The gaps for a CIS are qualification of the technology to UF_6 cylinder operating environment and providing authentication and tamper indication, either by modification of the bar code technology or by integration of the bar code technology with a separate authentication technology, such as reflective particle tagging, or some type of digital imaging.

RFID technology is also well developed and deployed commercially. The RFID chips also have the advantage that, if adjusted appropriately, they are most capable of reading information from a tagged cylinder from a distance. This could provide significant efficiencies for IAEA inspection. However, RFID technology has several major challenges. The varying frequencies allowed worldwide require that the RFID chip be capable of responding to more than one range of UHF frequencies. The matrices for RFID chips have not yet been shown to successfully withstand repeated exposure to autoclave or other heating. RFID chips may also interfere with existing facility technology; although tests indicated that analog technology is most vulnerable to this interference. Many RFID tag designs appear to have "man-in-the-middle" attack spoofing vulnerabilities. In addition to potential interference from existing technology, the likelihood exists that RFID would not be permitted at enrichment and other facilities because of EmSec concerns. It is not apparent that the majority of these challenges can be surmounted by additional technological development of RFID chips and tags.

The second category of technologies comprises those that have potential to meet the requirements related to tamper indication and authentication. These are less developed, more complex, have not been commercialized, and appear to be much more difficult to use in day-to-day operations than tag technologies that do not provide these capabilities. These include reflective particle paints and tags, OSL paint and tags, L2IS, and weld recognition. The technologies for reflective particle and OSL paint tagging have not yet progressed to even the prototype stage where they can be reasonably evaluated. In addition, both technologies seem to require extensive care in imaging to authenticate tags. Authentication of reflective particle paint or tags appears to require taking multiple (at least two) images from fixed angles and distances under fixed lighting conditions. Authentication of OSL paint and tags appears to require specific lighting conditions and the capability for authentication may degrade if the paint or tags are exposed to radiation. The L2IS technology has the advantage that it relates directly to the physical properties of the UF_6 cylinder. However, it requires that the cylinder identification authentication be performed in a fixed geometry and requires a different detector geometry for different size cylinders. There are also concerns whether the cylinder properties measured are sufficiently distinct that there would be no duplication among thousands of UF_6 cylinders. The possibility that the L2IS reference spectrum may not be unique could be addressed by engraving a bar code or other unique information on the cylinder surface. These enhancements should be pursued before accepting the L2IS technology for the CIS.

Weld recognition could be employed to provide authentication and tamper indication in combination with a welded bar code or nameplate. Authentication of this technology, like the authentication of reflective particle paint or tags appears to require taking multiple (at least two) images from fixed angles and distances under fixed lighting conditions. All of these technologies would benefit from improvements to the authentication process that would eliminate the requirement for geometric precision and specified lighting conditions.

Another potentially promising technology is forgery-proof holographic laser engraving. However, this technology has barely advanced to the prototype stage, has not been independently tested, and the published data about its performance are quite limited. The consortium developing this technology should be contacted for additional information

The relatively natural separation of the technologies into the two categories described above and absence of any facility operational requirement for authentication or tamper indication, suggests the use of a hybrid approach that combines bar code labels, engraved bar codes, or RFID tags with one of the authenticable technologies. Under this approach the facility would concern itself only with the bar code or RFID tags. The IAEA applications of the CIS could use the authenticable technology where necessary.[20]

3.2 Gap Analysis

None of the technologies reviewed meet all of the requirements (see Appendix A). Both the bar code and RFID technologies need to demonstrate that they can withstand the various environmental insults and stresses associated with the UF_6 cylinder operating environment. There may be commercially available items that can meet these requirements. If there are not, it is likely that such items could be obtained with little additional development. The cost of the development of the item and its manufacture would depend upon whether there was a larger commercial market for the item. To be useful the RFID technology would also need to resolve the frequency spectrum, EMI, and EmSec issues discussed above. Given these additional issues and the current industry acceptance of bar codes, some type of bar code technology is the most desirable choice for the element of the CIS cylinder component that does not provide authentication or tamper indication.

The candidate technologies for the component of the CIS that provides authentication and tamper indication, with the possible exception of OSL, all have a similar shortcoming—the need to employ specific geometries for authentication measurements. With the exception of L2IS, all of these technologies also need to have specific lighting for authentication measurements. It may be possible to resolve some of the geometry and lighting issues through enhancement of the software used to compare authentication measurements. The current software appears to make an unsophisticated comparison of image files or, in the case of L2IS, laser scan results. It appears that OSL technology is not significantly geometrically constrained; but, by its nature, requires a light source of an appropriate type for

[20] It might even be possible for the IAEA to limit its use of the authenticable technology to a statistical sample of its cylinder identification to cut costs and increase efficiency, such a sampling approach provided the requisite enhancement of assurance that diversion or misuse was not taking place. Such a strategy might reduce the cost and effort associated with deploying and using the selected CIS authentication technology.

authentication. The adequacy of OSL authentication and tamper indication under operational conditions, including ambient lighting and anticipated radiation exposures, would need to be demonstrated.

4.0 Conclusions and Recommendation

4.1 Overall Conclusions

This technology assessment has identified two commercial or near-commercial technologies (bar codes and RFID tags) that seem able to provide all of the required features except for authentication, tamper indication, and in the case of RFIDs, longevity. These technologies and the absence of any facility operational requirement for authentication or tamper indication, suggest the use of a hybrid approach that combines one of these two commercial or near-commercial technologies with one of the more complex and less mature authenticable technologies. Such an approach would permit the facility to concern itself only with the bar code or RFID tags, largely ignoring the more complex technology. The IAEA applications of the CIS could use the authenticable technology where necessary. Because of potential operational issues with RFID and the industry acceptance of bar codes, a bar code technology is recommended for the technology supporting facility needs, referred to as the base technology. This element of the CIS cylinder component would need to be designed and qualified to resist the environmental insults and stresses associated with the with the UF_6 cylinder operating environment.

The L2IS technology and some tag technologies developed by IAEA, which are not discussed in this paper because information about them had not been approved for general release, are the only technologies, providing authentication and tamper indication, that have advanced to the prototype stage.[1] All of these technologies, with the possible exception of OSL, impose severe geometric constraints on the authentication measurement process. A key consideration in the recommendations for additional development is a qualitative assessment of the likelihood that these geometric constraints can be overcome by additional research and development. It appears that several of these authentication technologies may be able to achieve the requisite adaptation to the UF_6 cylinder environment, operational robustness, and maturity with a limited technology development program. Therefore, a limited development program for one or more of the following concepts is recommended. The information available during this technology review was not sufficient to make a definitive judgment of the relative merits of the recommended concepts from the perspective of the ease and of development or the cost of deployment. Any development program undertaken should be a joint industry and laboratory program, with industry participation solicited from the vendors of the base technology to be developed. Laboratory leadership should be selected based upon experience with the authentication technology to be developed.

- **A combined bar code and reflective particle tag, with a matrix and adhesive that does not degrade in the UF_6 cylinder environment.** Consideration should be given to reflective particle technology development that focuses on software and reader enhancements to permit accurate authentication from angles and distances and in lighting different from the initial enrollment, as well as verifying that the bar code and label do not degrade in the UF_6 cylinder environment.
- **A combined bar code and OSL label, with a matrix and adhesive that does not degrade in the UF_6 cylinder environment.** Consideration should be given to OSL technology development that focuses on OSL and reader enhancements to improve the accuracy of authentication and permit accurate authentication in ambient lighting.

[1] The L2IS technology, while it has reached the prototype stage, was reported by IAEA staff to have failed to demonstrate acceptable authentication capability in subsequent testing.

- **A welded metal bar code tag with digital image or laser weld recognition for authentication.** The bar code tag materials should ensure that the tag does not degrade in the UF_6 cylinder environment. For digital image weld recognition, consideration should be given to development that focuses on software and imaging enhancements to significantly improve the accuracy of authentication and permits accurate authentication from angles and distances and in lighting different from the initial enrollment. For laser weld recognition, consideration should be given to development that focuses on enhancements to permit recognition from greater distances and at greater angular difference from initial enrollment.

The first two technology alternatives would impose the least cost and operational impact on facilities for cylinder enrollment. The labels could, and probably should, be centrally manufactured with distribution controlled by IAEA or an international consortium. During enrollment, the facility would be responsible for applying the tag and reporting to the registry that the tags had been applied. The facilities where enrollment takes place would also be responsible for establishing a program to secure, account for, and control the tags, similar to existing programs for securing, accounting for, and controlling seals and tamper-indicating devices. The third alternative would require the facilities to weld the bar code tag onto the cylinder and photograph the weld during enrollment. This welding program would need to meet quality assurance standards in order to ensure that the enrollment activities would not jeopardize the UF_6 cylinder certification. This alternative would also require establishment of a program to control and account for the metal bar code tags. Because this approach employs the combination the bar code and weld recognition, the control and accounting requirements for the bar code tags would not need to be as stringent as the tag control program needed for the first two alternatives.

4.2 Recommendation

The NNSA should consider sponsoring a joint industry-laboratory program for one or more of the three technology approaches discussed in Section 4.1, or one or more of the promising IAEA-developed authentication tag technologies, which the authors were not able to include in this report. These technologies will be discussed in a revision to this report to be published later this year. Such a technology development effort should provide a prototype authentication approach that meets IAEA's authentication requirements and is suitable for a PoC demonstration. The selection of the approaches for serious consideration for further development should consider estimates of development costs, costs to produce and apply the CIS components, and CIS reader modules; input from IAEA, industry, and national regulatory authorities about the usability and merits of the approaches; and the interest of commercial bar code fabricators and vendors in participating in a joint industry-laboratory development program.

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Appendix A

Detailed Technology Evaluations

Appendix A

Detailed Technology Evaluations

This appendix presents the assessment of the candidate technologies using the requirements and evaluation criteria derived in the Task 3.1.1 report (Hockert 2013). The assessments are captured in Tables A.1 through A.6. In many cases, the assessments are based on engineering judgment regarding whether or not the technology is likely to meet a specific requirement because the type of test or qualification data needed to demonstrate compliance was unavailable. It would have been helpful to have more objective data about all of the technologies. However, this somewhat judgmental assessment provides a basis for identifying the most promising candidate technologies and the engineering challenges that must be met to develop them to a stage where proof of concept testing can be profitably conducted. Discussions in the “Notes” row highlight the major uncertainties and some of the more important technical challenges associated with demonstrating compliance with the identified requirement.

Table A.1. Extrinsic system technologies requirements

Requirement	RCU-01 The CIS cylinder component shall be designed to be affixed to the valve end of the cylinder near the valve / name plate location.	RCU-02 The CIS cylinder component shall include identification information (e.g., a number) readable without the CIS reader equipment at a distance of 5 feet, but not from more than 30 feet.	RCU-03 If a specialized design is required for the CIS cylinder component, it shall employ only proven design approaches.	RCU-04 The CIS cylinder component shall be designed and placed on cylinders such that it is readable by reader module at the required distance when cylinders are stacked in any of the commonly used configurations for feed, product, or tails cylinders.
Technology				
Bar Code Technologies	Y	Y	Y	Y
RFID Technologies	Y	N	Y	Y
Reflective Paint Particle Tagging	Y	N	N	N
Optically Stimulated Luminescent Materials	Y	N	N	N
NOTES		Note that the RFID chip matrix would need to have the number added on the matrix as would the reflective particle tag. This is good practice anyway, due to reading the wrong cylinder errors.	The latter two are not sufficiently tested to be considered proven.	2D bar codes can be read from various angles. The question is: can they be read in the stack? Maybe.

Table A.1. contd.

Requirement	RCU-05 The design of the CIS cylinder component shall permit its application at cylinder fabricators, conversion plants, enrichment plants, fuel fabrication facilities, and during cylinder recertification.	RCU-06 The application of the CIS cylinder component shall not conflict with current regulatory standards (ANSI N14.1 2001/ISO 7195-2005) for, or void certification, of cylinders, including permitting use of current nameplates.	RCU-07 The CIS cylinder component shall not radiate energy at unauthorized frequencies or frequencies that interfere with facility or IAEA safeguards equipment.	RCU-08 The CIS cylinder component shall have a minimum design life of 10 years.
Technology				
Bar Code Technologies	Y	Y	Y	Y
RFID Technologies	Y	Y	N	N
Reflective Paint Particle Tagging	Y	Y	Y	N
Optically Stimulated Luminescent Materials	Y	Y	Y	N
NOTES		Assumes application of tag will not affect standards.	Without testing, RFID cannot guarantee no interference.	The RFID has not successfully passed tests in the UF_6 environment, leading to a "No" answer here. The reflective paint particle technology still is fairly new, and design life of the paint is unknown.

Table A.1. contd.

Requirement	RCU-09 The CIS cylinder component shall allow maintenance, repair, replacement, updates, and changes to be made without requiring cylinder recertification.	RCU-10 The CIS cylinder component shall be functional throughout the temperature range from -25°F to 140°F.	RCU-11 The CIS cylinder component shall remain functional under exposure to weather conditions when tested in accordance with a weathering program equivalent to a 10-year period, in accordance with applicable standards.	RCU-12 The CIS cylinder component shall be functional and undamaged after (but not necessarily operational during) 100 repeated cycles between -60°F and 250°F, including a 96-hour period at -60°F.	RCU-13 The CIS cylinder component shall be functional and undamaged after exposure to a saturated steam environment in steam autoclave at 250°F for 96 hours.
Technology					
Bar Code Technologies	Y	Y	Y	Y	Y
RFID Technologies	Y	Y	NEED TO TEST	N	NEED TO TEST
Reflective Paint Particle Tagging	Y	Y	NEED TO TEST	N	NEED TO TEST
Optically Stimulated Luminescent Materials	Y	Y	NEED TO TEST	NEED TO TEST	NEED TO TEST
NOTES		Will need to test RFID, Reflective Paint Particles, and OSL Materials.	With the exception of the bar code technologies, this needs to be tested. Although nearly all technologies need to be tested, the "NEED TO TEST" comment is reserved for those technologies where there was so little data or performance information that an engineering judgment "Yes" or "No" was not possible.	The RFID has not successfully withstood such a test. The matrix containing the reflective paint particles may not survive the test.	The RFID has not successfully withstood such a test. The matrix containing the reflective paint particles may not survive the test.

Table A.1. contd.

Requirement	RCU-14 The CIS cylinder component shall remain functional with limited degradation under exposure to an atmosphere of 50 ppm of hydrogen fluoride at 90°F and 90% humidity for a period of 96 hours.	RCU-15 The CIS cylinder component shall remain functional under exposure to nearby lightning strikes (i.e., withstand indirect lightning effects).	RCU-16 The CIS cylinder component shall be compatible with the material of cylinder construction to which it is affixed or with which it comes in contact and shall be designed and emplaced on the cylinder so that its functionality is not impaired by cylinder corrosion.	RCU-17 The CIS cylinder component shall be undamaged by, or readily protected from, the cylinder painting, resurfacing, and cleaning that are performed at a nominal 5-year interval.
Technology				
Bar Code Technologies	NEED TO TEST	Y	Y	Y
RFID Technologies	NEED TO TEST	NEED TO TEST	Y	Y
Reflective Paint Particle Tagging	NEED TO TEST	Y	Y	Y
Optically Stimulated Luminescent Materials	NEED TO TEST	Y	N	Y
NOTES			All - Assumes corrosion does not cause the affixed material to fall off. RFID - Assumes corrosion does not affect antenna. OSL - Assumes corrosion probably affects paint (peels).	Assumes all can be easily covered.

Table A.1. contd.

Requirement	RCU-18 The CIS cylinder component shall remain functional under levels of shock (up to that produced by a 1.2-meter drop of the attached UF_6 cylinder onto an unyielding surface) and vibration associated with normal operations and occasional mishandling of a cylinder.	RCU-19 The CIS cylinder component shall remain functional when exposed to a radiation field of 50 mR/hr (1% neutron and 99% gamma) for a 30-day period.	RCE-01 The CIS cylinder component shall be tamper-indicating.	RCE-02 The CIS cylinder component shall be resistant to counterfeiting.
Technology				
Bar Code Technologies	Y	Y	N	N
RFID Technologies	Y	Y?	N	N
Reflective Paint Particle Tagging	Y	Y	Y	Y
Optically Stimulated Luminescent Materials	Y	Y	Y	Y
NOTES		These will need to be tested. RFID is most likely to have a problem here, but the OSL material may be adversely impacted as well.		

Table A.1. contd.

Requirement	RCE-03 The CIS cylinder component identification and authentication information shall be readable by the reader module at distances between 1 foot and 20 feet at all angles up to 20 degrees off the cylinder surface normal at the point of attachment of the CIS cylinder component.	RCE-04 The cost of the CIS cylinder component and its application to the cylinder shall not exceed $300/cylinder.	RRU-01 The CIS reader module shall employ encryption meeting the Advanced Encryption Standard (i.e., FIPS 197 or equivalent) for transmitting, receiving, and storing sensitive information.	RRU-02 The CIS reader module shall be designed to prevent reverse engineering to "counterfeit" authentication information.	RRU-03 If a specialized design is required for the CIS reader module, it shall employ only proven design approaches.	RRU-04 The CIS reader module shall be tamper-indicating.	RRU-05 The operation of the CIS reader module shall not violate site safety/security requirements or compromise or otherwise interfere with site safety, security, or operations systems.
Technology							
Bar Code Technologies	Y	Y	Y	N	Y	Y	Y
RFID Technologies	Y	Y	Y	N	Y	Y	N
Reflective Paint Particle Tagging	N	Y	Y	Y	Y	Y	N
Optically Stimulated Luminescent Materials	N	Y	Y	Y	Y	Y	Y
NOTES	Current technology requires that the camera and light arrangement for the reflective paint particles be precisely aligned with the tag.	Costs for the reflective paint particle tagging technology and OSL paint are not available. It is believed these technologies would be less than $300/cylinder, including application.	Assume they can.			Assume this can be required in the RFP; less difficult than the actual cylinder component.	Note that RFID readers are limited in frequency across countries and may be limited based on EmSec, as well as specific facilities. Based on the need to properly align a reflective paint particle tag, this could adversely affect site operations.

Table A.1. contd.

Requirement	RRU-06 The CIS reader module shall be configurable to permit its use as a component of unattended monitoring stations or readers installed at strategic facility operating locations.	RRU-07 The CIS reader module shall be functional throughout the temperature range: from -25°F to 140°F.	RRU-08 The CIS reader module shall remain functional when exposed to a radiation field of 1 mR/hr (1% neutron and 99% gamma) for a 30-day period.	RRU-09 The CIS reader module shall be designed to be operable in the electromagnetic interference environment found in enrichment, conversion, and fuel fabrication facilities and in those portions of cylinder fabrication or certification facilities where cylinders are registered.	RRU-10 The CIS reader module shall have an availability of 0.999.
Technology					
Bar Code Technologies	Y	Y	Y	Y	Y
RFID Technologies	Y	Y	Y	N	Y
Reflective Paint Particle Tagging	N	Y	Y	Y	N
Optically Stimulated Luminescent Materials	N	Y	Y	Y	Y
NOTES	Both reflective paint particle tagging and OSL materials need proper lighting to obtain the correct pictures. It is doubtful that the light could be set properly for either. Furthermore, reflective paint particle tagging requires careful alignment to recreate the exact position used for the reference picture.	There is no reason to believe these readers would not function.	There is no reason to believe these readers would not function.	RFID readers have been shown to interfere with some (older) equipment. National frequencies are limited.	

Table A.1. contd.

Requirement	RRU-11 The CIS reader module shall be configurable to permit its use in portable CIS readers for use in routine operational activities (e.g., cylinder yards and inspections).	RRE-01 All information necessary to authenticate the cylinder and any sensitive information useful for targeting specific cylinders (e.g., UF_6 weight or uranium enrichment) shall be readable from the CIS cylinder component by only the specialized CIS reader module.	RRE-02 The CIS reader module shall be able to read the identity and authentication information on the CIS cylinder component at distances between 1 foot and 20 feet at all angles up to 20 degrees off the cylinder surface normal at the point of attachment of the CIS cylinder component.	RRE-03 The system comprised of the CIS cylinder component and CIS reader module shall have a probability of reporting incorrect cylinder identification and authentication information less than 10-3 per reading.
Technology				
Bar Code Technologies	Y	N	Y	Y
RFID Technologies	Y	N	Y	Y
Reflective Paint Particle Tagging	Y	Y	N	N
Optically Stimulated Luminescent Materials	Y	N	N	NA
NOTES		Note that neither RFID or bar code technologies are authenticable, thus the information necessary to authenticate the cylinder cannot be authenticated. As it currently exists, OSL can be seen under any infrared light, and only provides tamper indication	Both bar code technologies (particularly 2D) can be read at an angle and at a distance. RFID also can be read at a distance. RFID may be readable at a greater distance. Reflective paint particle tagging is far more difficult to read even at a distance of a foot as the light and angle must be precisely the same to authenticate the tag. OSL materials must be subjected to the proper light and provide no additional information.	No information as to authenticated data. However, bar code readers and RFID have been able to read data accurately. Reflective paint particles have not yet reached that probability. Not applicable to OSL.

CIS = Cylinder Identification System
EmSec = Emissions Security
FIPS = Federal Information Processing Standards
IAEA = International Atomic Energy Agency
OSL = optically stimulated luminescence
RFID = radio frequency identification

Table A.2. Extrinsic system technologies evaluation criteria

Criterion	ECU-01 The CIS cylinder component should be inexpensive to fabricate and apply (e.g., less than $100 per cylinder).	ECU-02 The CIS cylinder component should be commercially available.	ECU-03 The CIS cylinder component should have a long design life (e.g., 30 years or more).	ECU-04 The CIS cylinder component should be easy and inexpensive to maintain, repair, replace, update, and change.	ECU-05 The CIS cylinder component should have minimal requirements for preventive maintenance and be designed for reliability to minimize corrective maintenance requirements.
Technology					
Bar Code Technologies	Y	Y	Y	Y	Y
RFID Technologies	Y	Y	N	Y	Y
Reflective Paint Particle Tagging	N	N	Y	Y	Y
Optically Stimulated Luminescent Materials	N	N	N	Y	Y
NOTES	Almost certainly correct as to bar codes; less certain, but probable, as to RFID. No data available for the last two.		If the proper material is selected, the bar code should last. As for RFID, it is less likely. The reflective paint should last, but it will depend on the matrix. Unless protected, OSL paint is not expected to survive 30 years in environmental conditions and treatment of the cylinder.	No real data available for paint particles or OSL.	

Table A.2. contd.

Criterion	ECU-06 The CIS cylinder component should be designed to provide indication of degradation or impending failure.	ECU-07 The CIS cylinder component should have the capacity to have status information about the cylinder (e.g., nuclear material inventory) input to it, to store such information, and output the information to the CIS reader.	ECU-08 The CIS cylinder component should be materials, information, and process compatible with identification systems in current use in the nuclear industry.	ECU-09 The CIS cylinder component identification and authentication information should be readable by the reader module at distances greater than 20 feet or at angles greater than 20 degrees off the cylinder surface normal at the point of attachment of the CIS cylinder component.
Technology				
Bar Code Technologies	Y	N	Y	N
RFID Technologies	Y	Y	N	Y
Reflective Paint Particle Tagging	Y	N	N	N
Optically Stimulated Luminescent Materials	Y	N	N	N
NOTES	It is believed that difficulty in reading would provide indications of need for replacement prior to failure. For the line-of-sight tags, visual inspection would lead to warning signs.	Note that this only works for an active chip.		It is possible that a data code could be readable from a distance greater than 20 feet (not known).

Table A.2. contd.

Criterion	ERU-01 The CIS reader module should be designed for high reliability using techniques such as risk /reliability analysis, failure modes, and effects analysis (e.g., single failure proof, fail reliable).	ERU-02 The CIS reader module should be light in weight and small in size.	ERU-03 The CIS reader module should minimize power consumption.	ERU-04 The CIS reader module should be inexpensive to procure.	ERU-05 The CIS reader module should be commercially available.	ERU-06 The CIS reader module should have a long design life.
Technology						
Bar Code Technologies	Need design information	Y	Y	Y	Y	
RFID Technologies	Need design information	Y	Y	Y	Y	
Reflective Paint Particle Tagging	Need design information	N	N	N	Y	
Optically Stimulated Luminescent Materials	Need design information	N	N	N	Y	
NOTES	No information about how these technologies were designed. it is most likely that the bar codes are the most reliable.	Because light sources are required for the latter two, they are less likely to be lightweight or small.	No information on any; likely that none require much power, but the bar codes and passive RFID are less likely than the latter two.	To the extent that all COTS technologies were modified, these are expected to be inexpensive. However, reflective paint particle and OSL readers would be more expensive to modify and acquire.	To the extent that all COTS technologies were modified, these are available.	No information.

Table A.2. contd.

Criterion	ERU-07 The CIS reader module should be easy and inexpensive to maintain, repair, replace, update, and change.	ERU-08 The CIS reader module should permit fabrication of easy-to-use CIS readers.	ERU-09 The CIS reader module should have minimal requirements for scheduled preventive maintenance.	ERU-10 A single CIS reader module design should be useable at all facilities and in all countries where cylinders are used or stored, including permitting international transport of CIS reader modules.	ERU-11 The CIS reader module should be information and process-compatible with readers for identification systems currently used in the nuclear industry.
Technology					
Bar Code Technologies	Y	Y	Y	Y	Y
RFID Technologies	Y	Y	Y	N	N
Reflective Paint Particle Tagging	N	Y	Y	Y	N
Optically Stimulated Luminescent Materials	N	Y	Y	Y	N
NOTES	Cameras have changed. While cameras used in reflective paint particle and OSL tagging likely will remain similar, the shape of these cameras could change, leading to maintenance difficulties in the event of a need to replace them, particularly in an unattended reader.	Judgment based on minuscule information.	Judgment based on minuscule information.	Note that various frequencies are permitted in different countries throughout the world.	

Table A.2. contd.

Criterion	ERU-12 The CIS reader module should be self-testing; reporting error information indicative of item/component failure, impending item/component failure, or significant item/component degradation (Note: the capability of the CIS reader module to be automatically tested by other CIS reader components should also be acceptable).	ERU-13 The CIS reader module should be able to read the cylinder unique identification and authentication information at distances greater than 20 feet or at angles greater than 20 degrees off the cylinder surface normal at the point of attachment of the CIS cylinder component or attribute location.	ERU-14 The CIS reader module should have the capability to read the cylinder unique identification and authentication information when cylinders are stacked in any of the commonly used configurations for feed, product, or tails cylinders.
Technology			
Bar Code Technologies	Y	Y	Y
RFID Technologies	Y	Y	Y
Reflective Paint Particle Tagging	N	N	N
Optically Stimulated Luminescent Materials	N	N	N
NOTES	Not 100% sure on the RFID, but they are on the bar codes	Not for 1D bar codes, but suitable for 2D.	

CIS = Cylinder Identification System
COTS = commercial off-the-shelf
OSL = optically stimulated luminescence
RFID =radio frequency identification

Table A.3. Intrinsic system technologies requirements

Requirement	RAU-01 The creation of cylinder attributes shall not conflict with current regulatory standards (ANSI N14.1 2001/ISO 7195-2005), or void certification of, UF_6 cylinders.	RAU-02 The selected or created cylinder attribute(s) shall remain readable under exposure to weather conditions when tested in accordance with a weathering program equivalent to a 10-year period, in accordance with applicable standards.	RAU-03 The selected or created cylinder attribute(s) shall remain readable after exposure to a saturated steam environment at 250°F for 96 hours.	RAU-04 The selected or created cylinder attribute(s) shall remain readable after a 10-year accumulation of cylinder corrosion.	RAU-05 The selected or created cylinder attribute(s) shall be readable by a reader module at the required distance when cylinders are stacked in any of the commonly used configurations for feed or product cylinders.
Technology					
Laser Identification System	Y	Y	Y	Y	N
Bar Codes Applied Directly to Cylinder	Y	Y	Y	Y	Y
Forgery-proof Laser-holographic Product Identification	Y	Y	Y	Y	N
NOTES	Note that for the latter two, this will need to be confirmed.	Will need confirmation.	Note that for the latter two, this will need to be confirmed. However, there is no reason to believe they would not survive this test.	It is assumed that the attributes will remain readable, but it is not known precisely how quickly cylinder corrosion issues arise for cylinders in use.	2D bar codes can be read at a distance. Insufficient information is available for holographic identification.

Table A.3. contd.

Requirement	RAU-06 The selected or created cylinder attribute(s) shall remain readable after exposure to an atmosphere of 50 ppm of hydrogen fluoride for a period of 96 hours.	RAU-07 Any equipment used to create the cylinder attribute(s) during the registration process shall be usable at cylinder fabricators, conversion plants, enrichment plants, fuel fabrication facilities, and during cylinder recertification.	RAU-08 If a specialized design is required for equipment used to create the cylinder attribute(s) during the registration process, it shall employ only proven design approaches.	RAU-09 Any equipment used to create the cylinder attribute(s) during the registration process shall be tamper-indicating.	RAU-10 The selected or created cylinder attribute(s) shall remain readable after levels of surface marring or deformation resulting from normal cylinder handling; occasional cylinder mishandling; and cylinder cleaning, repainting, and refurbishing operations of the type performed every one to five years.
Technology					
Laser Identification System	Y	Y	Y	Y	NEED TO TEST
Bar Codes Applied Directly to Cylinder	Y	Y	Y	Y	Y
Forgery-proof Laser-holographic Product Identification	Y	Y	N	Y	NEED TO TEST
NOTES	Assumes no changes to the engraved items.		No information about the approach for the holographic identification.	Would need to program the latter two. This may be challenging for them.	The first needs more study or testing. 2D codes are more likely to be readable after some damage to a code. The third also requires more testing.

Table A.3. contd.

Requirement	RAU-11 The attribute shall be created on, or the selected attribute shall be read from valve end of the cylinder.	RAI-01 The cost of creating the cylinder attribute(s) shall not exceed $300/cylinder.	RAI-02 The selected or created cylinder attribute(s) shall be tamper-indicating.	RAI-03 The selected or created cylinder attribute(s) shall be readable and authenticable by the reader module at distances between 1 foot and 12 feet.	RAI-04 The selected or created cylinder attribute(s) shall be resistant to counterfeiting.	RAI-05 The nature of the selected or created attribute(s) shall permit the selection or creation of at least 2 million uniquely recognizable configurations of the attribute with recognition error rates of less than 10-3.
Technology						
Laser Identification System	Y	Need design information	Y	Y	Y	N
Bar Codes Applied Directly to Cylinder	Y	Y	N	Y	N	Y
Forgery-proof Laser-holographic Product Identification	Y	Y?	Y	Y	Y	Y
NOTES		No cost information available.		Need to confirm for the latter.		

Table A.3. contd.

Requirement	RAI-06 The enrollment process shall incorporate special equipment capable of creating or modifying cylinder attribute(s) to provide unique intrinsic identification should cylinders with identical configurations of the attribute(s) be identified during registration.	RRU-01 The CIS reader module shall employ encryption meeting the Advanced Encryption Standard (i.e., FIPS 197 or equivalent) for transmitting, receiving, and storing sensitive information.	RRU-02 The CIS reader module shall be designed to prevent reverse engineering to “counterfeit” authentication information.	RRU-03 If a specialized design is required for the CIS reader module, it shall employ only proven design approaches.	RRU-04 The CIS reader module shall be tamper-indicating.
Technology					
Laser Identification System	N	Y	Y	Y	
Bar Codes Applied Directly to Cylinder	Y	Y	N	Y	
Forgery-proof Laser-holographic Product Identification	Y	Y	Y	Y	
NOTES		Assume the reader will be designed with this in mind.		Assume developed this way; no contradictory evidence.	Unclear; no contradictory evidence.

Table A.3. contd.

Requirement	RRU-05 The CIS reader module operation shall not violate site safety/security requirements or compromise or otherwise interfere with site safety, security, or operations systems.	RRU-06 The CIS reader module shall be configurable to permit its use as a component of unattended monitoring stations or readers installed at strategic facility operating locations.	RRU-07 The CIS reader module shall be functional throughout the temperature range, from -25°F to 140°F.	RRU-08 The CIS reader module shall remain functional when exposed to a radiation field of 1 mR/hr (1% neutron and 99% gamma) for a 30-day period.	RRU-09 The CIS reader module shall be designed to be operable in the electromagnetic interference environment found in enrichment, conversion and fuel fabrication facilities and in those portions of cylinder fabrication or certification facilities where cylinders are registered.
Technology					
Laser Identification System	Y	Y		Y	Y
Bar Codes Applied Directly to Cylinder	Y	Y		Y	Y
Forgery-proof Laser-holographic Product Identification	Y	Y		Y	Y
NOTES	Because of the need to stop cylinder movement for the time to read/scan the cylinder, there may be some interference with site operations, as well as space issues for the reader's location.	Laser identification systems require a larger footprint area and setup than a bar code reader.	No information available. L2IS systems have been implemented at some facilities by IAEA.	If properly shielded, it is assumed that a radiation field would not affect the reader.	

Table A.3. contd.

Requirement	RRU-10 The CIS reader module shall have an availability of 0.999.	RRU-11 The CIS reader module shall be configurable to permit its use in portable CIS readers for use in routine operational activities (e.g., cylinder yards and inspections).	RRI-01 The CIS reader module shall be able to measure the attributes necessary to generate cylinder identification and authentication information at distances between 1 foot and 20 feet at all angles up to 20 degrees off the cylinder surface normal at the attribute location.	RRI-02 The CIS reader module shall have sufficient redundancy and error detection capability, and the attribute measured shall be sufficiently distinct that the probability of reporting incorrect cylinder identification and authentication information is less than 10-3 per reading.
Technology				
Laser Identification System	NEED TO TEST	N	N	N
Bar Codes Applied Directly to Cylinder	Y	Y	Y	Y
Forgery-proof Laser-holographic Product Identification	NEED TO TEST	Y	NEED TO TEST	NEED TO TEST
NOTES	The first and third technologies have not been deployed/developed sufficiently to make an availability determination.	Note that for laser identification, the reader must be properly aligned, and it has a larger footprint than a bar code reader. It is not obviously portable.	The forgery-proof laser-holographic product ID was developed as a micro approach. It is unknown if the engraving can be enlarged.	Insufficient information for the laser identification. No information on holographic process.

Table A.3. contd.

Criterion	EAU-01 The created cylinder attribute should be inexpensive to generate (e.g., less than $100 per cylinder).	EAU-02 The equipment required to create cylinder attributes should be commercially available.	EAU-03 The selected or created cylinder attribute should be resistant to wear and environmental conditions, remaining readable for a long period (e.g., 30 years or more).	EAU-04 The selected or created attribute should be readable, including permitting generation of authentication information by the reader module at distances greater than 20 feet or at angles exceeding 20 degrees off the cylinder surface normal at location of the attribute.
Technology				
Laser Identification System	Y	Y	Y	N
Bar Codes Applied Directly to Cylinder	Y	Y	Y	N
Forgery-proof Laser-holographic Product Identification	Need design information	N	Y	N
NOTES		With respect to the forgery-proof equipment, it is apparently available, but it is not clear that the holographic piece is available.	Assumption.	Note: the 2D bar code might be readable at this distance.

CIS = Cylinder Identification System
FIPS = Federal Information Processing Standards
IAEA = International Atomic Energy Agency
ID = identification
L2IS = Laser Item Identification System
RFID =radio frequency identification

Table A.4. Intrinsic system technologies evaluation criteria

Criterion	ERU-01 The CIS reader module should be designed for high reliability using techniques such as risk /reliability analysis, failure modes, and effects analysis (e.g., single failure proof, fail reliable).	ERU-02 The CIS reader module should be light in weight and small in size.	ERU-03 The CIS reader module should minimize power consumption.	ERU-04 The CIS reader module should be inexpensive to procure.	ERU-05 The CIS reader module should be commercially available.	ERU-06 The CIS reader module should have a long design life.
Technology						
Laser Identification System	Y	N	Need design information	Need design information	Y	Need design information
Bar Codes Applied Directly to Cylinder	Y	Y	Need design information	Y	Y	Need design information
Forgery-proof Laser-holographic Product Identification	Y	Need design information	Need design information	Need design information	N	Need design information
NOTES	These can be done; not sure if it is. Needs testing.	Insufficient information with respect to the holographic product identification.			No information on reader availability.	No information on reader availability.

Table A.4. contd.

Criterion	ERU-07 The CIS reader module should be easy and inexpensive to maintain, repair, replace, update, and change.	ERU-08 The CIS reader module should permit fabrication of easy-to-use CIS readers.	ERU-09 The CIS reader module should have minimal requirements for scheduled preventive maintenance.	ERU-10 A single CIS reader module design should be useable at all facilities and in all countries where cylinders are used or stored, including permitting international transport of CIS reader modules.	ERU-11 The CIS reader module should be information and process-compatible with readers for identification systems currently used in the nuclear industry.
Technology					
Laser Identification System	Need design information	Y	Need design information	Y	Y
Bar Codes Applied Directly to Cylinder	Need design information	Y	Need design information	Y	Y
Forgery-proof Laser-holographic Product Identification	Need design information	Need design information	Need design information	Need design information	Need design information
NOTES	No information.	No information on reader availability. Answer is based on limited available information.	No information on maintenance for reader.	No information on reader availability. Answer is based on limited available information.	No information on reader availability. Answer is based on limited available information.

Table A.4. contd.

Criterion	ERU-12 The CIS reader module should be self-testing; reporting error information indicative of item/component failure, impending item/component failure, or significant item/component degradation. (Note: the capability of the CIS reader module to be automatically tested by other CIS reader components should also be acceptable).	ERU-13 The CIS reader module should be able to read the cylinder unique identification and authentication information at distances greater than 20 feet or at angles greater than 20 degrees off the cylinder surface normal at the point of attachment of the CIS cylinder component or attribute location.	ERU-14 The CIS reader module should have the capability to read the cylinder unique identification and authentication information when cylinders are stacked in any of the commonly used configurations for feed, product, or tails cylinders.
Technology			
Laser Identification System	Need design information		
Bar Codes Applied Directly to Cylinder	Need design information		
Forgery-proof Laser-holographic Product Identification	Need design information		
NOTES	No information.		

CIS = Cylinder Identification System

Table A.5. Combined system technologies requirements

Requirement	RCU-01 The CIS cylinder component shall be designed to be affixed to the valve end of the cylinder near the valve/nameplate location.	RCU-02 The CIS cylinder component shall include identification information (e.g., a number) readable without the CIS reader equipment at a distance of 5 feet, but not from more than 30 feet.	RCU-03 If a specialized design is required for the CIS cylinder component, it shall employ only proven design approaches.	RCU-04 The CIS cylinder component shall be designed and placed on cylinders such that it is readable by a reader module at the required distance when cylinders are stacked in any of the commonly used configurations for feed, product, or tails cylinders.	RCU-05 The design of the CIS cylinder component shall permit its application at cylinder fabricators, conversion plants, enrichment plants, fuel fabrication facilities, and during cylinder recertification.
Technology					
Nameplate and Weld Digital Imaging	Y	N	Y	N	Y
Nameplate and Reflective Particle Tagging	Y	N	N	N	Y
LMCV and Bar Code	Y	N	Y	N	Y
NOTES			To the extent that reflective paint particle technology is unproven, this requirement cannot be met.		

Table A.5. contd.

Requirement	RCU-06 The application of the CIS cylinder component shall not conflict with current regulatory standards (ANSI N14.1 2001/ISO 7195-2005) for, or void certification of, cylinders, including permitting use of current nameplates.	RCU-07 The CIS cylinder component shall not radiate energy at unauthorized frequencies or at frequencies that interfere with facility equipment or IAEA safeguards equipment.	RCU-08 The CIS cylinder component shall have a minimum design life of 10 years.	RCU-09 The CIS cylinder component shall allow maintenance, repair, replacement, updates, and changes to be made without requiring cylinder recertification.	RCU-10 The CIS cylinder component shall be functional throughout the temperature range, from -25°F to 140°F.
Technology					
Nameplate and Weld Digital Imaging	Y	Y	Y	Y	Y
Nameplate and Reflective Particle Tagging	Y	Y	N	Y	Y
LMCV and Bar Code	Y	Y	Y	Y	Y
NOTES			Need to confirm for reflective paint particle.	Pending confirmation that everyday use does not change the weld.	

Table A.5. contd.

Requirement	RCU-11 The CIS cylinder component shall remain functional under exposure to weather conditions when tested in accordance with a weathering program equivalent to a 10-year period in accordance with applicable standards.	RCU-12 The CIS cylinder component shall be functional and undamaged after (but not necessarily during) 100 repeated cycles between -60°F and 250°F, including a 96-hour period at -60°F.	RCU-13 The CIS cylinder component shall be functional and undamaged after exposure to a saturated steam environment in a steam autoclave at 250°F for 96 hours.	RCU-14 The CIS cylinder component shall remain functional with limited degradation under exposure to an atmosphere of 50 ppm of hydrogen fluoride at 90°F and 90% humidity for a period of 96 hours.	RCU-15 The CIS cylinder component shall remain functional under exposure to nearby lightning strikes (i.e., withstand indirect lightning effects).
Technology					
Nameplate and Weld Digital Imaging	Y	Y	Y	Y	Y
Nameplate and Reflective Particle Tagging	Y	Y	Y	Y	Y
LMCV and Bar Code	Y	Y	Y	Y	Y
NOTES	Need to confirm for reflective paint.	Need to confirm for reflective paint.	Need to confirm for reflective paint and LMCV.	Need to confirm for reflective paint and LMCV.	

Table A.5. contd.

Requirement	RCU-16 The CIS cylinder component shall be compatible with the material of cylinder construction to which it is affixed or with which it comes in contact and shall be designed and emplaced on the cylinder so that its functionality is not impaired by cylinder corrosion.	RCU-17 The CIS cylinder component shall be undamaged by, or readily protected from, the cylinder painting, resurfacing, and cleaning that is performed at a nominal 5-year interval.	RCU-18 The CIS cylinder component shall remain functional under levels of shock (up to that produced by a 1.2-meter drop of the attached UF_6 cylinder onto an unyielding surface) and vibration associated with normal operations and occasional mishandling of a cylinder.	RCU-19 The CIS cylinder component shall remain functional when exposed to a radiation field of 50 mR/hr (1% neutron and 99% gamma) for a 30-day period.
Technology				
Nameplate and Weld Digital Imaging	Y	Y	Y	Y
Nameplate and Reflective Particle Tagging	Y	Y	Y	Y
LMCV and Bar Code	Y	Y	Y	Y
NOTES		Assumes it is possible to cover the paint chip and welds on the nameplate, and weld is not damaged.		

Table A.5. contd.

Requirement	RCC-01 The CIS cylinder component in combination with the measured intrinsic attribute shall be tamper-indicating.	RCC-02 The CIS cylinder component in combination with the measured intrinsic attribute shall be resistant to counterfeiting.	RCC-03 The CIS cylinder component in combination with the measured intrinsic attribute shall be readable, including permitting generation of authentication information, by the reader module at distances between 1 foot and 20 feet at all angles up to 20 degrees off the cylinder surface normal at the point of attachment of the CIS cylinder component or at the attribute location.
Technology			
Nameplate and Weld Digital Imaging	Y	Y	Y
Nameplate and Reflective Particle Tagging	Y	Y	N
LMCV and Bar Code	Y	Y	N
NOTES			

Table A.5. contd.

Requirement	RAU-01 The creation of cylinder attributes shall not conflict with current regulatory standards (ANSI N14.1 2001/ISO 7195-2005) for, or void certification of, UF_6 cylinders.	RAU-02 The selected or created cylinder attribute(s) shall remain readable under exposure to weather conditions when tested in accordance with a weathering program equivalent to a 10-year period in accordance with applicable standards.	RAU-03 The selected or created cylinder attribute(s) shall remain readable after exposure to a saturated steam environment at 250°F for 96 hours.	RAU-04 The selected or created cylinder attribute(s) shall remain readable after a 10-year accumulation of cylinder corrosion.	RAU-05 The selected or created cylinder attribute shall be readable by a reader module at the required distance when cylinders are stacked in any of the commonly used configurations for feed, product, or tails cylinders.
Technology					
Nameplate and Weld Digital Imaging	Y	Y	Y	Y	N
Nameplate and Reflective Particle Tagging	Y	Y	N	Y	N
LMCV and Bar Code	Y	Y	Y	Y	N
NOTES		Need to confirm for reflective paint and LMCV.	Need to test; will depend on matrix and glue.	Need to test; will depend on matrix for RPT and weld for LMCV.	Possibly readable at a distance, not necessarily authenticable. The 2D bar code could be read, but could not be authenticated.

Table A.5. contd.

Requirement	RAU-06 The selected or created cylinder attribute(s) shall remain readable after exposure to an atmosphere of 50 ppm of hydrogen fluoride for a period of 96 hours.	RAU-07 Any equipment used to create the cylinder attribute(s) during the enrollment process shall be usable at cylinder fabricators, conversion plants, enrichment plants, fuel fabrication facilities, and during cylinder recertification.	RAU-08 If a specialized design is required for equipment used to create the cylinder attribute during the enrollment process, it shall employ only proven design approaches.	RAU-09 Any equipment used to create cylinder attribute(s) during the enrollment process shall be tamper-indicating.	RAU-10 The selected or created cylinder attribute(s) shall remain readable after levels of surface marring or deformation resulting from normal cylinder handling; occasional cylinder mishandling; and cylinder cleaning, repainting, and refurbishing operations of the type performed every one to five years.
Technology					
Nameplate and Weld Digital Imaging	Y	Y	Y	Y	Y
Nameplate and Reflective Particle Tagging	Y	Y	Y	Y	Y
LMCV and Bar Code	Y	Y	Y	Y	Y
NOTES	Need to test; will depend on matrix.				Less likely for the reflective paint particle tag.

Table A.5. contd.

Requirement	RAC-01 The combined cost of the cylinder component, application of the cylinder component, and creation of the cylinder attribute shall not exceed $300/cylinder.	RAC-02 The created cylinder attribute(s) in combination with the cylinder component shall be tamper-indicating.	RAC-03 The created cylinder attribute(s) in combination with the cylinder component shall be readable and authenticable by the reader module at distances between 1 foot and 12 feet.	RAC-04 The created cylinder attribute(s) in combination with the cylinder component shall be resistant to counterfeiting.	RAC-05 The nature of the selected or created attribute(s) shall permit the selection or creation of at least 2 million uniquely recognizable combinations of cylinder component and attribute configurations, with recognition error rates of less than 10-3.
Technology					
Nameplate and Weld Digital Imaging	Y	Y	Y	Y	Y
Nameplate and Reflective Particle Tagging	Y	Y	N	Y	Y
LMCV and Bar Code	Y	Y	N	Y	Y
NOTES					

Table A.5. contd.

Requirement	RRU-01 The CIS reader module shall employ encryption meeting the Advanced Encryption Standard (i.e., FIPS 197 or equivalent) for transmitting, receiving, and storing sensitive information.	RRU-02 The CIS reader module shall be designed to prevent reverse engineering to "counterfeit" authentication information.	RRU-03 If a specialized design is required for the CIS reader module, it shall employ only proven design approaches.	RRU-04 The CIS reader module shall be tamper-indicating.	RRU-05 The operation of the CIS reader module shall not violate site safety/security requirements or compromise or otherwise interfere with site safety, security, or operations systems.
Technology					
Nameplate and Weld Digital Imaging			Y	Y	Y
Nameplate and Reflective Particle Tagging			Y	Y	Y
LMCV and Bar Code			Y	Y	Y
NOTES	Assume that both can use this to transmit to computer and access to database?	The IAEA reader module probably will need this. The module used by facilities does not.	Reader technology is proven. However, custom recognition/authentication software (based on proven algorithms) would be required.	Assume can be designed as such.	To the extent that these technologies require stopping and alignment of cylinders, this could adversely impact site operations.

Table A.5. contd.

Requirement	RRU-06 The CIS reader module shall be configurable to permit its use as a component of unattended monitoring stations or readers installed at strategic facility operating locations.	RRU-07 The CIS reader module shall be functional throughout the temperature range from -25°F to 140°F.	RRU-08 The CIS reader module shall remain functional when exposed to a radiation field of 1 mR/hr (1% neutron and 99% gamma) for a 30-day period.	RRU-09 The CIS reader module shall be designed to be operable in the electromagnetic interference environment found in enrichment, conversion, and fuel fabrication facilities, and in those portions of cylinder fabrication or certification facilities where cylinders are registered.	RRU-10 The CIS reader module shall have an availability of 0.999.
Technology					
Nameplate and Weld Digital Imaging	N	Y	Y	Y	Y
Nameplate and Reflective Particle Tagging	N	Y	Y	Y	Y
LMCV and Bar Code	N	Y	Y	Y	Y
NOTES	Probably difficult to operate any of these in an unattended mode. As work on stand-off readers precedes, the likelihood of unattended monitoring and authentication increases.				

Table A.5. contd.

Requirement	RRU-11 The CIS reader module shall be configurable to permit its use in portable CIS readers for use in routine operational activities (e.g., cylinder yards and inspections).	RRC-01 All CIS cylinder component and measured cylinder attribute information necessary to authenticate the cylinder and any sensitive information useful for targeting specific cylinders (e.g., UF_6 weight or uranium enrichment) shall only be readable by the specialized CIS reader module.	RRC-02 The CIS reader module shall be able to aggregate the measured cylinder intrinsic attribute used for authentication with the number on the cylinder component during cylinder enrollment and reading for later upload to the registry.	RRC-03 The CIS reader module shall be able to read the CIS cylinder component and measure the cylinder attribute used for authentication at distances between 1 foot and 20 feet at all angles up to 20 degrees off the cylinder surface normal at the point of attachment of the CIS cylinder component or at the attribute location.
Technology				
Nameplate and Weld Digital Imaging	Y	Y	Y	N
Nameplate and Reflective Particle Tagging	Y	Y	Y	N
LMCV and Bar Code	Y	Y	Y	N
NOTES				

Table A.5. contd.

Requirement	RRC-04 The system comprising the CIS cylinder component, the cylinder attribute measured for authentication, and the CIS reader module shall have a probability of reporting incorrect authenticated cylinder identification data of less than 10-3 per reading.
Technology	
Nameplate and Weld Digital Imaging	?
Nameplate and Reflective Particle Tagging	N
LMCV and Bar Code	Y
NOTES	

CIS = Cylinder Identification System
FIPS = Federal Information Processing Standards
IAEA = International Atomic Energy Agency
LMSI = laser mapping system for containment verification
RAPT = reflective particle tag

Table A.6. Combined system technologies evaluation criteria

Criterion	ECU-01 The CIS cylinder component should be inexpensive to fabricate and apply (e.g., less than $100 per cylinder).	ECU-02 The CIS cylinder component should be commercially available.	ECU-03 The CIS cylinder component should have a long design life (e.g., 30 years or more).	ECU-04 The CIS cylinder component should be easy and inexpensive to maintain, repair, replace, update, and change.	ECU-05 The CIS cylinder component should have minimal requirements for preventive maintenance and be designed for reliability to minimize corrective maintenance requirements.
Technology					
Nameplate and Weld Digital Imaging	Y	Y	Y	N	Y
Nameplate and Reflective Particle Tagging	?	N	NEED TO TEST	N	Y
LMCV and Bar Code	Y	Y	NEED TO TEST	N	Y
NOTES		The particles are available (e.g., hematite), but the mix may not be.	Testing is needed.	Anticipate difficulty repairing. Replace only.	

Table A'S. contd.

Criterion	ECU-06 The CIS cylinder component should be designed to provide indication of degradation or impending failure.	ECU-07 The CIS cylinder component should have the capacity to have status information about the cylinder (e.g., nuclear material inventory) input to it, to store such information, and to output information to the CIS reader.	ECU-08 The CIS cylinder component should be materials, information, and process compatible with identification systems in current use in the nuclear industry.	ECU-09 The CIS cylinder component identification and authentication information should be readable by the reader module at distances greater than 20 feet or at angles greater than 20 degrees off the cylinder surface normal at the point of attachment of the CIS cylinder component.
Technology				
Nameplate and Weld Digital Imaging	Y	N	Y	N
Nameplate and Reflective Particle Tagging	Y	N	Y	N
LMCV and Bar Code	Y	N	Y	N
NOTES	Probably when it did not scan? Looked chipped or changed? Depends on design details validated by vulnerability testing.			

Table A'S. contd.

Criterion	EAU-01 The created cylinder attribute should be inexpensive to create (e.g., less than $100 per cylinder).	EAU-02 The equipment required to create cylinder attributes should be commercially available.	EAU-03 The selected or created cylinder attribute should be resistant to wear and environmental conditions remaining readable for a long period (e.g., 30 years or more).	EAU-04 The selected or created attribute should be readable, including permitting generation of authentication information by the reader module at distances greater than 20 feet or at angles greater than 20 degrees off the cylinder surface normal at location of the attribute.
Technology				
Nameplate and Weld Digital Imaging	N	Y	Y	N
Nameplate and Reflective Particle Tagging	N	N	Y	N
LMCV and Bar Code	N	Y	Y	N
NOTES	Not sure, but unwilling to assume it is that cheap; mostly in the research expense?	The reflective paint particle tags are not sold as COTS. However, the ingredients are COTS.	Based on minimal information. Testing would be required.	

Table A’S. contd.

Criterion	ERU-01 The CIS reader module should be designed for high reliability using techniques such as risk/reliability analysis, failure modes and effects analysis (e.g., single failure proof, fail reliable).	ERU-02 The CIS reader module should be light in weight and small in size.	ERU-03 The CIS reader module should minimize power consumption.	ERU-04 The CIS reader module should be inexpensive to procure.	ERU-05 The CIS reader module should be commercially available.	ERU-06 The CIS reader module should have a long design life.
Technology						
Nameplate and Weld Digital Imaging	Y	N	Need design information	Need design information	Y	Need design information
Nameplate and Reflective Particle Tagging	Y	N	Need design information	Need design information	Y	Need design information
LMCV and Bar Code	Y	N	Need design information	Need design information	N	Need design information
NOTES		The equipment needed is believed to be heavier and larger than a simple bar code reader, for example.			To the extent that the cameras used are COTS; however, the software is not.	

Table A'S. contd.

Criterion	ERU-07 The CIS reader module should be easy and inexpensive to maintain, repair, replace, update, and change.	ERU-08 The CIS reader module should permit fabrication of easy-to-use CIS readers.	ERU-09 The CIS reader module should have minimal requirements for scheduled preventive maintenance.	ERU-10 A single CIS reader module design should be useable at all facilities and in all countries where cylinders are used or stored, including permitting international transport of CIS reader modules.	ERU-11 The CIS reader module should be information and process-compatible with readers for identification systems currently used in the nuclear industry.
Technology					
Nameplate and Weld Digital Imaging	Y	N	Y	Y	Y
Nameplate and Reflective Particle Tagging	Y	N	Y	Y	Y
LMCV and Bar Code	N	N	Y	Y	Y
NOTES		The module itself seems as if it would be fairly bulky.	Design information would be required.		To the extent that the readers would read the nameplate and not the tamper indicating/authenticable portions.

Table A'S. contd.

Criterion	ERU-12 The CIS reader module should be self-testing; reporting error information indicative of item/component failure, impending item/component failure, or significant item/component degradation (Note: the CIS reader module's ability to be automatically tested by other CIS reader components also should be acceptable).	ERU-13 The CIS reader module should be able to read the cylinder unique identification and authentication information at distances greater than 20 feet or at angles greater than 20 degrees off the cylinder surface normal at the point of attachment of the CIS cylinder component or attribute location.	ERU-14 The CIS reader module should have the capability to read the cylinder unique identification and authentication information when cylinders are stacked in any of the commonly used configurations for feed, product, or tails cylinders.
Technology			
Nameplate and Weld Digital Imaging	Y	N	N
Nameplate and Reflective Particle Tagging	Y	N	N
LMCV and Bar Code	Y	N	N
NOTES	The reader for the nameplate portion certainly is. It is unclear if the weld imaging or reflective paint particles would be.		

CIS = Cylinder Identification System
COTS = commercial off-the-shelf
LMSI = laser mapping system for containment verification

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