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A Distributed Ledger Technology (DLT) Approach to Monitoring UF6 Cylinders: Lessons Learned from TradeLens

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Abstract

Every year thousands of tons of uranium hexafluoride (UF_6) are produced and transported worldwide in international certified containers from conversion plants to enrichment plants to fuel fabrication plants. Although the International Atomic Energy Agency (IAEA) and nuclear industry are effective in monitoring this valuable nuclear material, it still may take several weeks before missing UF_6 cylinders are detected and located. To address these monitoring gaps, the World Nuclear Transport Institute (WNTI) released a guide in 2017 on an industry-wide identification format for UF_6 cylinders. Following the acceptance of the WNTI standard, this paper proposes an additional feature should be included to better monitor UF_6 cylinders—a distributed ledger technology (DLT) system that is utilized across the nuclear industry. By reflecting on the lessons learned from TradeLens—an IBM and Maersk jointly-developed "blockchain-enabled shipping solution", this paper's findings suggest that TradeLens reinforces how DLT may bring transparency, efficiency, real-time monitoring, and security to global supply chains, emphasizing several conditions required for reliable implementation of DLT for monitoring UF_6 cylinders. As an emerging application in the nuclear nonproliferation field, DLT could provide a digital platform that allows the IAEA and the nuclear industry to improve monitoring the UF_6 supply chain, ensure that sensitive material arrives at the final destination through end-user verification, and mitigate pressing proliferation risks by meeting safeguards and export control challenges.

Defining the Problem: The Movement of UF_6 Cylinders

The Risk

As part of the nuclear fuel cycle, uranium hexafluoride (UF_6) is required for the enrichment process that produces the uranium that will be further processed to be used in fuel for nuclear reactors and nuclear weapons. Every year thousands of tons of UF_6 are produced and transported worldwide in Models 48Y and 30B cylinders.[1] The most common model used across the nuclear industry to transport, process, and store natural UF_6 is the 48Y cylinder. Model 30B cylinder is intended to transport and store low enriched uranium (LEU). If diverted, conversion of LEU to highly enriched uranium (HEU) in a clandestine facility could be completed within weeks or months, depending on the scale of a facility.[2] One cylinder containing natural uranium is enough material to produce a significant quantity (SQ) of HEU at 90% enrichment[ii] within 3 months to 1 year. This fast breakout point illustrates the need to effectively monitor the transport and storage of UF_6 cylinders.

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[ii] SQ of HEU at 90% enrichment is defined as 25 kg of U_{235}.

However, monitoring 48Y and 30B cylinders serve as a proxy for monitoring UF_6, since the material itself is vulnerable to misuse or diversion due to the short time needed to produce a SQ of HEU. The attractiveness of this material and gaps in the current International Atomic Energy Agency (IAEA) practices make detection relatively difficult and the monitoring of UF_6 paramount. Although the IAEA and the nuclear industry are effective in monitoring this nuclear material, it still may take several weeks before missing UF_6 cylinders are detected and located. In addition, there is the threat that such cylinders in transit could be diverted or obtained by non-state actors or black market vendors.[3]

Current and Evolving International UF_6 Cylinder Standards

National and international standards for cylinder fabrication have minimum requirements for labeling cylinders. The current international transportation standard requires cylinders to display a metal nameplate with identification information, such as the serial number, owner, and additional certifications.[4] There is also a separate number, or a batch number, that is assigned to the UF_6 contained within the cylinder. The cylinder identification is used for recording and tracking the location of cylinders on-site and during transportation. Despite this information being engraved, it is often difficult to read. Furthermore, these standards lack a unique identification (UID) format that is applied for the entire nuclear industry.[5] Without a standard industry format, inventory inspections require considerable effort and time, and IAEA inspectors lack a systematic way to detect any potential concealment activities, such as nameplate swapping.[6]

To address these issues, the World Nuclear Transport Institute (WNTI) released a guide in 2017 for a standardized, industry-wide identification format for Model 48Y and Model 30B cylinders.[iii] The preferred global identifier is a stainless-steel plate with a 10-character, alpha-numeric identification number.[7] This would consist of four capital letters, followed by six numbers. The first three capital letters would be the "prefix" of the cylinder owner. For example, Urenco would be 'URE'. The fourth capital letter would be reserved for use by the cylinder owner, and the 6-digit number would also be assigned by the cylinder owner. This would also be paired with a 2D barcode of the assigned 10-character identification number.

Figure 1: Example of the WNTI Preferred Global UID[8]

[iii] In 2014, WNTI established a working group with about 20 cylinder stakeholders, which collaborated to establish the 2017 WNTI Standard for UF_6 Cylinder Identification.

The implementation of these identifiers would ensure their numbering and lettering scheme is not duplicated across the nuclear industry. In addition, the identifiers would be machine-readable, last the entire cylinder life of approximately 40 years, and be independently verifiable by the IAEA.[9] This industry-wide identification format is already being applied with newly fabricated cylinders, and there is optimism for further implementation of this standard.

Following the acceptance of the WNTI preferred global identifier, this paper proposes that an additional feature should be included—a distributed ledger technology (DLT) system that is utilized across the nuclear industry.

DLT as a Unique Solution

Evolving DLT Systems

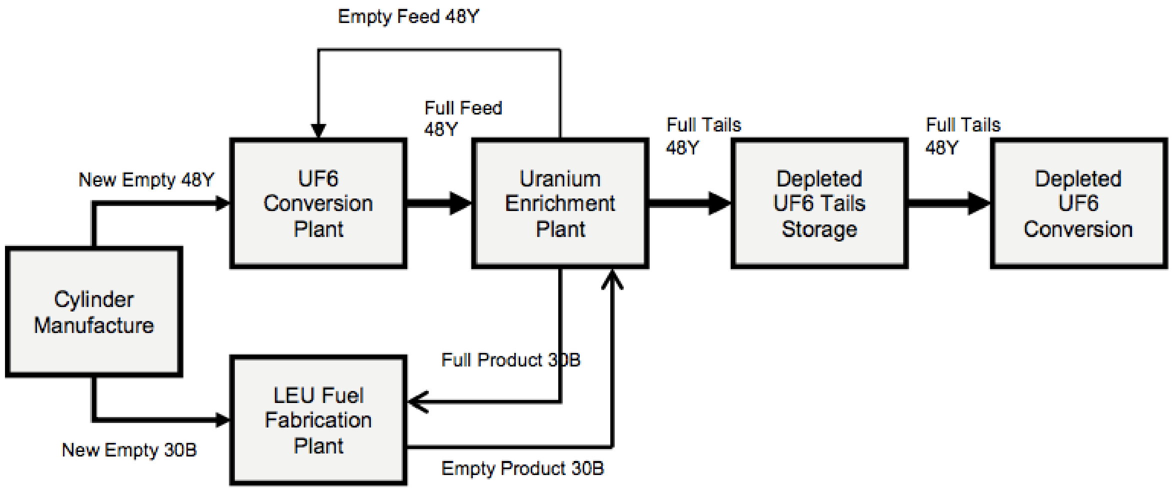
The development of Bitcoin in January 2009 arguably initiated public attention around blockchain technology, however, many remain unfamiliar with the underlying technology of DLT, which enables the storage and transfer of data without the need for a central authority as an intermediary. As a distributed and decentralized database, DLT stores and verifies information using cryptographic protocols.[10] DLT uses independent computers or 'nodes' to record, share, and synchronize transactions. Each transaction is recorded and added to the previous one, resulting in a growing chain of information through "blocks". Transactions in a distributed ledger system are not limited to financial uses. Instead this evolving technology is being applied to several sectors, including the diamond and fishing industries,[11] and can be utilized for item tracking, identity logging, or verifying the completion of an action. For example, in the application of DLT for supply chain management, the digital value of the good (e.g., through a scannable barcode) would pass from one user to the next, with each user verifying the information through a public-private key. These transactions are added to the distributed ledger, enabling participants to monitor the good from the manufacturing phase through distribution, transit, and to the final user.[12]

This information management system is superior to other existing databases as it makes the data more available, immediate, transparent, and secure. DLT can help to reinforce the traceability and security of global supply chains since the history of transactions cannot be altered or reversed after it is recorded in the ledger. Instead, each "block" is dependent upon the previous block, which provides users a chronological record of transactions.[13] Not only does this system improve efficiency in inspection, regulatory, and compliance scenarios, but it also allows users to ensure a product reaches the final destination while increasing consumer trust and confidence in the process.

The Concept: DLT for Supply Chain Management of UF_6 Cylinders

Conversion, enrichment, fuel fabrication, and depleted UF_6 deconversion facilities are typically not at the same location, which makes the monitoring and reporting of material very challenging. As seen by Figure 2, the lifespan of a UF_6 cylinder reveals various vulnerabilities as cylinders are transported, emptied, and received for shipment, frequently across different states. However, there may be opportunities to monitor these vulnerabilities through DLT, while increasing confidence in identifying cylinders and reconciling transfers between stakeholders.

Figure 2: The Life Cycle of a UF_6 Cylinder[14]



With the implementation of the WNTI identifier and scannable 2D barcode on each cylinder, data would be easily represented in a machine-readable manner that is reliable and efficient. The barcode would be scanned at each point in the supply chain of the cylinders. For example, the 10-character UID and 2D barcode would be engraved on the cylinder during manufacturing. This would be scanned and would become the first block in the distributed ledger system. Once the cylinder is transported to a conversion plant, it would be scanned again, verifying its receipt at the plant and recorded in the ledger. This process of scanning and recording would continue as the cylinder is transported from conversion to enrichment to fuel fabrication plants.

The barcode would contain important identifying information about the drum, such as whether nuclear material is present, the type of material, shipping name, weight, quantum of radioactivity, point of origin, destination, date, and the names of the individuals handling the container at each point. This digital identification, along with other logistical information, would be uploaded to the distributed ledger and would be cryptographically chained together in blocks. Each transaction, such as the transfers of cylinders and inventories, would be transparent on the entire ledger, providing a means to monitor the movement of the cylinder.[15] Moreover, this trackable process would enable more reliable end-user verification to determine that the UF_6 cylinder arrived at the final destination.

Though this is currently only a concept, the utilization of a digital ledger for supply chain management has increasingly grown over the past several years. Specifically, the digital platform TradeLens—an IBM and Maersk jointly-developed “blockchain-enabled shipping solution”—offers a noteworthy case study for how the nuclear industry and the IAEA may utilize DLT to help overcome current monitoring gaps in the global nuclear trade.

A Case Study of TradeLens: Lessons Learned

A New Global Trade Platform

For decades, one of the key challenges in the shipping industry has been the ability to track where a shipping container might be in the world and which government agency possess the containers. It may take weeks to gather the paperwork necessary to identify where a container has been, from factory to market.[16] For years, the shipping industry has been trying to digitize these processes to increase efficiency in the shipping workflow.

In January 2018, IBM and global shipping leader, Maersk, announced an initiative to create a new global trade platform built on blockchain.[17] TradeLens is a digital platform that provides businesses and authorities along the supply chain with a single, secure source of shipping data. As of May 2019, participants on the ledger included more than 100 organizations, including more than 40 worldwide ports and authorities.[18] Due to the evolving nature of DLT for global trade, TradeLens offers the following lessons that highlight the advantages of using DLT as a system to monitor UF_6 cylinders.

Permission-Based Distributed Ledger

DLT systems can be permissionless (public) or permissioned (private).[19] A public DLT is open for anyone to join and would not be feasible in the UF_6 cylinder context, as a specific group of stakeholders would need to have access to this data for security and proprietary reasons.[20] With sensitive data like the movement of UF_6 cylinders, a permission-based ledger, like TradeLens, would be the most secure type of system.

TradeLens is a platform model that is based on Hyperledger Fabric, or a permissioned ledger that only includes authorized users. Verified stakeholders, such as ocean carriers, ports, inland transportation, and customs authorities, can participate on the platform.[21] While participants are anonymous on a permissionless system, a permission-based DLT includes known entities who are authorized to join, view, and publish data. Permissionless ledgers rely on computationally intensive consensus algorithms to validate transactions, which presents a high risk of sabotaged blocks.[22] In contrast, permission-based consensus allows transactions to be endorsed by relevant participants. Therefore, decision-making is authorized to specific members, providing controlled data consistency and preventing of any illegitimate blocks or conflicts on the ledger.[23]

Through contractual agreements, UF_6 cylinders are shipped both internationally and domestically under strict regulations that address safety, security, and safeguards issues. In theory, this system could allow stakeholders in the global nuclear supply chain, such as States, the nuclear industry, and the IAEA, to verify the origins of the UF_6 cylinders, monitor its movements, and verify the end-users.

Cybersecurity and Privacy

Another insight that TradeLens offers is that DLT can provide a high degree of cybersecurity assurances and mechanisms to accommodate multiple degrees of privacy. Security and privacy of this type of data are especially critical as the nuclear industry is concerned with sabotage and potential theft. In addition, nuclear companies, like shipping companies, need a fair amount of privacy in order to remain competitive in their respective industries. TradeLens portrays how each transaction in a network can be secure by using advanced cryptography, so only specific parties can submit, edit, or approve related data.[24] In this system, each participant would have a private key to protect and secure their own data.

A DLT system can also allow users to create private collections of data and channels of communication. For example, the IAEA could communicate and exchange sensitive information only with a State Party, or a nuclear company could communicate privately with another company, despite being on a shared network with the IAEA. Not only is it clear which organizations are on the ledger, but it is possible to control and limit access according to the specific user.

Real-Time Monitoring

As the main authority that monitors UF_6 worldwide, the IAEA conducts nuclear material accountancy, inspections, and transit matching of shipments and receipts. In accordance with each Member States' safeguards agreement, the IAEA has the right to verify inventory and shipments and receipts of this nuclear material.[25] All Non-Nuclear Weapons States (NNWS) with a comprehensive safeguards agreement are required to report the inventory or transfer of all UF_6 material, which covers imports, exports, and domestic movements.[26] These reports include any transfer of an empty cylinder, as well as inventory changes on the site. INFCIRC/207 also provides Nuclear Weapons States (NWS) a reporting mechanism to inform the IAEA of all exports and imports of nuclear material, which are subject to safeguards prior to the export.[27] However, real-time reporting of this information is currently not a requirement for international safeguards.[28]

TradeLens demonstrates that with the development of a reliable, automated, and tamper-resistant system, real-time monitoring of UF_6 cylinders may be possible and would improve the challenges with reporting, including the inspector function.[29] As Marie Wieck, general manager for IBM Blockchain, states, "Every participant [of TradeLens] can check any aspect of the flow in real time, or an auditor or other authority can easily track the entire process from start to finish by clicking on a block in the blockchain instead of requesting data from each entity manually."[30]

Increased Efficiency

Another lesson that the TradeLens case highlights is that DLT is capable of providing consistent document exchanges, reducing cumbersome manual processes, and improving reporting. Monitoring shipping containers has traditionally been a largely paper-intensive and manual process. According to IBM and Maersk, paperwork and documentation may be exchanged over 100 times for a single container shipment.[31] In addition, The World Economic Forum estimates that document processing accounts for 20% of the total transportation costs within global trade.[32] Therefore, by digitizing the shipping document workflow, TradeLens is saving billions of dollars for businesses and trade authorities globally. This increased efficiency in the shipping workflow has resulted in some of the top shipping companies adopting DLT, such as the TradeLens platform.

Traditionally, DLT systems consist of structured data, however, TradeLens demonstrates that it is possible to share over 18 types of unstructured and structured documents with the platform.[33] Through TradeLens, structured documents, like digital bills of invoices, as well as unstructured documents, like scanned copies of packing lists, can be shared on the platform. Because existing cylinders are consistently being emptied, re-certified, and reused, the designed ledger for the cylinders would need to be able to share structured and unstructured data. Currently, when a cylinder is cleaned and re-certified, the tare weight may change, but the new tare weight is engraved on the nameplate.[34] As TradeLens highlights, this data could be shared as structured data on the ledger, instead of in file folders, hard drives, or email inboxes throughout the supply chain. Specifically, by utilizing the IBM Cloud, TradeLens allows participants on the platform to seamlessly share documents to other members around the world.[35]

In addition, the nuclear industry and the IAEA currently manually read and transcribe the serial numbers from the nameplate of a UF_6 cylinder. Specifically, the IAEA relies on time-consuming physical inspections to verify operator declarations and detect possible diversion of UF_6. While it is unclear what the financial costs are for these activities, it is evident that these verification activities remain time extensive and laborious since the inspectors manually read each cylinder. Moreover, transcription errors often require additional time to resolve. By coupling DLT with the standardized UF_6 cylinder identifier format, the IAEA's reporting could improve by reducing reading and transcription errors. This scannable barcode could reduce the time required for the IAEA to verify cylinder inventories during on-site inspections.

Think Big, but Start Small

While DLT for supply chain management offers several benefits, there are many challenges in its adoption. In the 2018 Review of Maritime Transport, the UN Conference on Trade and Development (UNCTAD) highlighted that a key challenge for adoption in the shipping industry will be to establish interoperability, so data can be exchanged seamlessly. The UNCTAD also emphasized that it will be critical to ensure cybersecurity and the protection of commercially sensitive and private data.[36] Such challenges will be similar for the nuclear industry.

The WNTI estimates that there are approximately 20,000 cylinders in active circulation, and 100,000 cylinders in long-term storage.[37] Therefore, it would be best to start with newly manufactured cylinders that adopt the WNTI standard UID, and later scale up to cylinders during the re-certification process.[iv] In addition to testing the functionality of a DLT system, it will be critical to test the system's cryptographic guarantees. For example, it would be essential to test if a stakeholder could somehow manipulate an item in the supply chain or if privacy is guaranteed between permissioned stakeholders.

[iv] Industry is already working on an implementation plan for installing the WNTI standard identifier during the re-certification process.

DLT is a rapidly developing area, garnering the attention of the IAEA and nuclear companies. Therefore, it is critical to engage the key industry stakeholders. One concern with this engagement is the fact that the entire nuclear industry and the IAEA are facing economic challenges, which is limiting the ability to implement any sort of technological solution. Therefore, it is critical to start small and get buy-in from major stakeholders. Any potential applications will likely be incremental, slowly easing in stakeholders. By implementing this in phases and easing in industry leaders, there may be an opportunity to conduct a pilot project, starting with a few of the key stakeholders.

Building Trust and Transparency

Overall, the TradeLens case portrays that DLT has the potential to strengthen confidence and efficiency related to monitoring UF_6 in the front end of the fuel cycle. A ledger for monitoring UF_6 cylinders would provide direct and credible assurances to the suppliers, regarding end-user verification, and would have several benefits for increasing the effectiveness and efficiency of nuclear safeguards. Real-time monitoring of UF_6 cylinders through DLT could provide the IAEA with more comprehensive information for nuclear material used in civilian nuclear programs, and as well as a more accurate and efficient transit matching process for UF_6 shipments and receipts.[38] Because DLT provides a fully auditable history that is maintained and updated on the ledger, this also has the potential to increase trust and transparency across the nuclear supplier industry and the IAEA. Most importantly, the distributed ledger could enhance collaboration between the IAEA and nuclear industry, in that if the industry detects a problem with the supply chain using real-time DLT reporting, it can immediately bring that to the attention of the IAEA.

While this technological solution has not been developed yet for the IAEA and the nuclear industry, TradeLens provides several lessons that may be applied to the case of monitoring UF_6 cylinders. The TradeLens case highlights that DLT may be superior to existing information management technologies due to its ability to control and limit access, increase efficiency, and seamlessly share structured and unstructured data. The most critical question posed in this paper is who the specific participants should be on a UF_6 DLT system. It will be fundamental for the IAEA and the nuclear industry to agree upon who would need to participate on the ledger. Since this DLT is quickly evolving, waiting for the “perfect” DLT solution may mean missing an opportunity to help to shape future distributed ledger designs. Therefore, it is critical to engage in continued and sustained dialogues that examine how to shape DLT to meet the IAEA’s strategic objectives, enhance the nuclear industry’s ability to monitor sensitive material and technology, and address the gaps in the non-proliferation regime.

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[1] Heinonen, Olli. “Why the Monitoring of Movements of UF6 Cylinders Matters,” Opening remarks at the Global Cylinder Identification and Monitoring System Stakeholder Meeting, Washington, DC., 29 April, 2014

[2] Boyer, Brian D, Michael J. Whitaker, Jessica L. White-Horton, and Karyn R. Durbin. “Next Generation Safeguards Initiative: Overview and Policy Context of UF6 Cylinder Tracking Program,” LA-UR-12-22934, Institute for Nuclear Material Management 53rd Annual Meeting, July 15-10, 2012. Orlando, Florida. Pg. 1.

[3] Whitaker, M., M. Farnitano, B. Wishard, O. Heinonen, K. Durbin and E. Wonder. “How the international safeguards regime can benefit from efforts to enhance the identification method used for UF6 cylinders,” Institute for Nuclear Material Management Conference, October 20-24, 2014. pg. 2.

[4] “WNTI Standard: UF6 Cylinder Identification,” World Nuclear Transport Institute, 2017. Pg. 5.
[5] Charette, Marc-André. “WNTI Working Group on UF6 Cylinder Identification,” World Nuclear Transport Institute, November 2017.
[6] Vestergaard, Cindy. “Better Than a Floppy: The Potential of Distributed Ledger Technology for Nuclear Safeguards Information Management,” *Policy Analysis Brief*, The Stanley Foundation, October 2018.
[7] “WNTI Standard: UF6 Cylinder Identification,” Pg. 11.
[8] “WNTI Standard: UF6 Cylinder Identification,” Pg. 21.
[9] Charette, Marc-André. “WNTI Working Group on UF6 Cylinder Identification”.
[10] Jaikaran, Chris. “Blockchain: Background and Policy Issues,” Congressional Research Service, February 28, 2018, Pg. 2; “Blockchain & Distributed Ledger Technology (DLT),” The World Bank, April 12, 2018.
[11] Refer to Fish Coin and Diamond Time-Lapse Protocol; Arnold, Aaron. “Blockchain: A New Aid to Nuclear Export Controls?” *The Bulletin of Atomic Scientists*, October 19, 2017; Colasante, Luis and Taniga Krish. “How Blockchain is Transforming the Energy Industry,” *Energy Post,* October 31, 2017.
[12] Jaikaran, Chris. “Blockchain: Background and Policy Issues,” Pg. 11.
[13] *Ibid.* Pg. 4.
[14] Boyer, Brian D, Michael J. Whitaker, Jessica L. White-Horton, and Karyn R. Durbin. “Next Generation Safeguards Initiative: Overview and Policy Context of UF6 Cylinder Tracking Program,” Pg. 4.
[15] Bal, Meghan. “Preventing proliferation: Tracking Uranium on the blockchain,” ORF Issue Brief, Issue No. 235, April 2018, Pg. 9.
[16] Miller, Ron. “IBM-Maersk blockchain shipping consortium expands to include other major shipping companies,” Tech Crunch, May 28, 2019.
[17] Scott, Todd. “TradeLens: How IBM and Maersk Are Sharing Blockchain to Build a Global Trade Platform,” IBM, November 27, 2018.
[18] Gronholt-Pedersen, Jacob. “MSC, CMA CGM to board Maersk's shipping blockchain platform,” *Reuters,* May 28, 2019.
[19] Vestergaard, Cindy. “Better Than a Floppy: The Potential of Distributed Ledger Technology for Nuclear Safeguards Information Management”.
[20] Gasser, Paige KW. “Monitoring UF6 Cylinders and Enhancing Nuclear Safeguards: A Use Case for Distributed Ledger Technology (DLT),” Presentation for the INMM Central Regional Chapter Meeting, Emerging Information Analysis Concepts for Nuclear Nonproliferation and Security, University of Michigan, October 15, 2018.
[21] “An Introduction to Hyperledger,” July 2018, Pg. 4.
[22] Salimitari, Mehrdad and Mainak Chatterjee, “A Survey on Consensus Protocols in Blockchain for IoT Networks,” March 2019, pp. 7-12.
[23] Biazetti, Ana, “Setting Trade Free with Permissions,” *TradeLens Blog*, February 12, 2019.
[24] *Ibid.*
[25] Frazar, SL., Schanfein, MJ., Jarman, KD., West, CL., Joslyn, CA., Winters, ST., Kreyling, SJ. and Sayre, AM. “Exploratory Study on Potential Safeguards Applications for Shared Ledger Technology,” February 2017, Pacific Northwest National Laboratory, PNNL-26229, Pg. 30 https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-26229.pdf
[26] Babcock, R.A., Whitaker, J.M., Murphy, J. and Oakberg, J. “Benefits of an International Database for UF6 Cylinders,” Institute for Nuclear Material Management Conference. LLNL-CONF-405276. Nashville, TN. July 10, 2008. Pg. 3.
[27] *Ibid.*
[28] Frazar, SL., Schanfein, MJ., Jarman, KD., West, CL., Joslyn, CA., Winters, ST., Kreyling, SJ. and Sayre, AM. “Exploratory Study on Potential Safeguards Applications for Shared Ledger Technology”, Pg. 30.
[29] Pickett, Chris A, James R. Younkin,Donald N. Kovacic, Mark D. Laughter, B. Jairus, and Brain M. Boyer. “Evaluation of a RF-Based Approach for Tracking UF6 Cylinders at a Uranium Enrichment Plant,” International Conference on Facility Operations- Safeguards Interface; Portland, OR, May 2008.
[30] Miller, Ron, “IBM-Maersk blockchain shipping consortium expands to include other major shipping companies”.
[31] Biazetti, Ana, “What does a digitized supply chain look like?” *TradeLens Blog,* March 26, 2019.
[32] *Ibid.*
[33] *Ibid.*
[34] “WNTI Standard: UF6 Cylinder Identification”, World Nuclear Transport Institute, 2017. Pg. 5.

[35] "The TradeLens Solution," Accessed 28 May 2019.
[36] United Nations Conference on Trade and Development, "Review of Maritime Transport," 2018, New York: NY, Pg. 42.
[37] "WNTI Standard: UF6 Cylinder Identification", Pg. 7.
[38] Gasser, Paige KW. "Monitoring UF6 Cylinders and Enhancing Nuclear Safeguards: A Use Case for Distributed Ledger Technology (DLT)".