EVALUATION OF A RF-BASED APPROACH FOR TRACKING UF_6 CYLINDERS AT A URANIUM ENRICHMENT PLANT

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ABSTRACT

Approved industry-standard cylinders are used globally to handle and store uranium hexafluoride (UF_6) feed, product, tails, and samples at uranium enrichment plants. The International Atomic Energy Agency (IAEA) relies on time-consuming physical inspections to verify operator declarations and detect possible diversion of UF_6. Development of a reliable, automated, and tamper-resistant system for near real-time tracking and monitoring UF_6 cylinders (as they move within an enrichment facility) would greatly improve the inspector function. This type of system can reduce the risk of false or misreported cylinder tare weights, diversion of nuclear material, concealment of excess production, utilization of undeclared cylinders, and misrepresentation of the cylinders' contents. This paper will describe a proof-of-concept approach that was designed to evaluate the feasibility of using radio frequency (RF)-based technologies to track individual UF_6 cylinders throughout a portion of their life cycle, and thus demonstrate the potential for improved domestic accountability of materials, and a more effective and efficient method for application of site-level IAEA safeguards.

The evaluation system incorporates RF-based identification devices (RFID) which provide a foundation for establishing a reliable, automated, and near real-time tracking system that can be set up to utilize site-specific, rules-based detection algorithms. This paper will report results from a proof-of-concept demonstration at a real enrichment facility that is specifically designed to evaluate both the feasibility of using RF to track cylinders and the durability of the RF equipment to survive the rigors of operational processing and handling. The paper also discusses methods for securely attaching RF devices and describes how the technology can effectively be layered with other safeguard systems and approaches to build a robust system for detecting cylinder diversion. Additionally, concepts for off-site tracking of cylinders are described.

INTRODUCTION

It is well known that uranium enrichment plants can easily be modified to produce direct-use material for nuclear weapons. The current global resurgence in nuclear power has peaked interest and created demand for constructing uranium enrichment facilities in countries that currently do not have this capability. This resurgence has created concerns and challenges that the International Atomic Energy Agency (IAEA) and global community must address.

The existing safeguards regime for uranium enrichment plants was negotiated as part of the Hexapartite Safeguards Project (HSP) effort completed in 1983 by countries commercializing uranium enrichment technology at the time. It is a system that, for a period, worked well when

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enrichment plant capacities were in the range of up to the 1,000,000 separative work units (SWU)/kg and were limited to a few established corporations and states. However, based on the projected growth required to fuel the current global nuclear renaissance, enrichment capacity requiring safeguards in the next few decades easily will surpass the current capabilities of the IAEA to provide those services. This is particularly true when considering the changing nature of the fuel cycle, current geopolitical dynamics, and the potential for new players to become involved.[1]

The reason it is important to consider tracking uranium hexafluoride (UF_6) cylinders at enrichment facilities is that the contents of these cylinders represent the majority of material inventory available for further enrichment processing. Keeping track of cylinders (in a near real-time manner) as they move around a site allows implementation of methodologies that can provide timely detection of unauthorized material diversion. Implementation of these near real-time tracking technologies also creates options for utilizing remote unattended monitoring methods for inspection, which typically are less intrusive to the facility owner and more cost effective for the IAEA.

To ensure that the IAEA has the capabilities it needs to support this renaissance, effort must be invested in developing and deploying better remote containment and surveillance (C/S) monitoring technology. It is paramount to the global safeguards community that the IAEA have the technologies and methodologies needed to provide timely assurance that significant quantities of nuclear material from peaceful or declared nuclear activities has not been diverted for the manufacture of nuclear weapons.[2]

The current nuclear material accounting and control procedures for tracking UF_6 cylinders typically involve manually entering cylinder data into logbooks or computer databases. This approach is inherently problematic and many times requires follow-up effort(s) to find and correct errors from the manual data entry process. The IAEA also relies on labor-intensive containment verification and surveillance techniques, such as conventional seal and weight checks, to verify UF_6 cylinder contents and establish some level of continuity of knowledge (CofK).

The current inspection regime for enrichment plants under IAEA safeguards consists of physical inventory verification (PIV), performed annually, interim inventory verification (IIV), performed approximately monthly, and a number of limited frequency unannounced inspections (LFUA) performed randomly each year. Annual and periodic scheduled inspections (such as PIVs and IIVs) are intended to establish a material balance for the IAEA to determine whether nuclear material has been diverted by the operator. The risk of detection provides deterrence and mitigation against proliferation and misuse by the facility operator. In order to achieve this, the IAEA spends a significant portion of its inspection efforts at enrichment plants verifying inventories, shipments, and receipts of UF_6 cylinders. These types of efforts will only increase with the future growth in enrichment services, creating a strong need to develop dynamic real-time approaches that improve the efficiency and effectiveness of current efforts.
To this end, the original HSP effort currently is being enhanced. New options to improve the current safeguards regime for enrichment plants were discussed during an IAEA technical meeting in April 2005, and documented in a final report, [3] as well as in the revised model safeguards approach to gas centrifuge plants.[4] These new approaches will improve the efficiency

and effectiveness of safeguards applied to enrichment plants and will close existing gaps in the HSP safeguards. The IAEA's updated model approach outlines the following three safeguards objectives to address proliferation concerns at gas centrifuge enrichment plants:

1. the timely detection of the diversion of significant quantities of natural, depleted, or low-enriched UF_6 from the declared flow through the plant, and the deterrence of such diversion by the risk of early detection;
2. the timely detection of the misuse of the facility in order to produce undeclared product (at the normal product enrichment levels) from undeclared feed and the deterrence of such misuse by the risk of early detection; and
3. the timely detection of the misuse of the facility to produce UF_6 at enrichment higher than the declared maximum, in particular highly enriched uranium (HEU), and the deterrence of such misuse by the risk of early detection.

To help achieve the above goals, the IAEA has expressed interest in developing "smart tags" for monitoring material flow and inventory via the tracking of UF_6 cylinders[3]. Tracking UF_6 cylinders represents one possible way to monitor the flow of uranium throughout the enrichment process. It helps maintain CofK of the material at each stage in the enrichment process, such as the input of natural feed material, the withdrawal of product material (including blending operations), the withdrawal of depleted tails, and the withdrawal of material for sampling.[5] On-going efforts to track protected assets using radio frequency (RF) technology are occurring within the Department of Energy facilities, and this experience is being utilized for this effort.[6]

An RF-Based UF_6 Cylinder Tracking System

Implementing a reliable, automated, and tamper-resistant RF-based cylinder tracking system (CTS) designed to track UF_6 cylinders throughout their entire life cycle will improve domestic accountability of materials and provide the IAEA with a more effective and efficient method for site-level application of safeguards. The CTS also could be part of an overall safeguard system design that integrates data from other systems and sensors (such as radiation detectors, gamma spectrometers, pressure and temperature sensors, accelerometers, limit switches, cameras, accountability scales, and other pertinent devices) that are designed around a site-specific, rules-based architecture. Key benefits of such a system for safeguards applications are discussed in the following section.

Effectiveness vs. Efficiency: How much value can a RF-based CTS add to IAEA safeguards and how effective it is in mitigating proliferation? Effectiveness can be improved by closing gaps in the current HSP safeguards approach such as detecting undeclared feed. Currently the only method the IAEA has to detect undeclared feed is by discovery during unannounced inspections. A CTS can provide improved detection beyond what random inspections offer if (1) all authorized cylinders are tagged, (2) the movement of cylinders into and out of the process areas is monitored, and (3) a surveillance system is in place to detect the presence of an unauthorized cylinder being connected to the feed and withdrawal systems.

Efficiency can be improved by decreasing the amount of time that an IAEA inspector spends at enrichment plants verifying cylinder inventories. A CTS can greatly improve the efficiency of cylinder verification by significantly shortening the time an inspector spends physically verifying a cylinder's identification and containment integrity and reconciling data entry errors. In this way, the inspector is more likely to detect anomalous activities that could indicate material diversions or facility misuse, which would, in fact, also improve safeguards effectiveness.

Wireless vs. Wired Systems: Wireless systems are really the only choice for monitoring assets that move. A RF-based system typically is more cost-effective to install in existing or future facilities when compared with hard-wired installations. Wired installations typically involve wall penetrations, some very long wire runs (that may require physical inspection by inspectors to make sure they are connected to the right device), and additional physical security to monitor materials while existing systems are powered off to support the installation. The costs for maintaining and sustaining wired systems typically are higher than for wireless systems.

System Integration: By providing rules-based tracking with integrated surveillance, site-specific rules can be established to monitor activities at each facility with greater precision. Timely detection of the asset is greatly enhanced, which is critical in today's world of increasing threats where the only way to ensure an appropriate response (for any potential theft or diversion event) is to have near real-time detection at the asset. Effectively tracking UF_6 cylinders within a facility would provide a foundation for other safeguards systems to build upon and thus would become part of an integrated safeguards approach that could provide an improved indication of undeclared activities.

Developing a Path Forward—UF_6 Cylinder Tracking System

The United States is undertaking efforts to improve current safeguards regimes at enrichment plants. The National Nuclear Security Administration (NNSA) is promoting exploration of technologies and approaches that could be applied to advanced safeguards technologies such as a UF_6 CTS. In December 2006, an expert team of representatives from the national laboratories met in Washington, D.C., to formulate a systematic approach to explore the use of RF-based technologies in IAEA safeguards[7]. This team defined the safeguards needs, discussed potential RF-based solutions, identified weaknesses, and vulnerabilities in RF-based technologies, and identified key system design requirements. A draft report, issued in February 2007, summarized the meeting findings and provided recommendations on a path forward[5]. The expert team stated that it would need a thorough understanding of existing commercial-off-the-shelf (COTS) RF technologies that could potentially address IAEA requirements prior to considering new technologies. It is also recommended that any RF-based system be considered within the context of an integrated safeguards system that could be enhanced by other containment and surveillance (C/S) and process-monitoring technologies. To design a system that increases the efficiency and/or effectiveness of IAEA safeguards, the report defined the following paths forward:

1. Identify IAEA needs and requirements. Evaluate existing RF-based technologies, assess performance for meeting needs, and develop a baseline plan for future improvements in safeguards system performance.
2. Based partly on the testing results and other systematic analyses, develop new technologies and approaches to address vulnerabilities and improve system robustness and effectiveness.

Vision for Future CTS Design within Enrichment Plant

A proposed system installed at a gas centrifuge enrichment plant would provide the capability to monitor all cylinder movements within an enrichment facility, including feed cylinders, parent product (or intermediate) cylinders, customer cylinders, sampling containers, and tails cylinders. In the proposed CTS field design, a unique, robust, and tamper-resistant RF tag is attached to each cylinder either before it enters the enrichment facility or at the point of entry. A series of RF interrogators are strategically placed throughout the facility to monitor cylinder movements. The data automatically transmitted from the RF tags to the interrogators provide a positive and unique identification and location of every cylinder.

Movement of UF_6 Cylinders in a Gas Centrifuge Enrichment Plant

As feed cylinders arrive at an enrichment facility, the CTS positively identifies RF-tagged cylinders using an RF interrogator. As cylinders enter the feed storage area, the RF interrogator automatically reads the tag and associates it with all relevant recorded cylinder data, such as tare weights, accountability weights, and any nondestructive analysis (NDA) that has been performed. The CTS registers when the cylinders have moved out of the feed storage area and into the cylinder processing area. (It should be noted that the hypothetical CTS could be integrated with other containment, surveillance, and process data, such as door switches, crane movements, and signals from video cameras.) An RF interrogator automatically identifies cylinders as they are placed into an autoclave/hotbox, where they are attached to a process line. This provides positive identification of cylinders that are attached to the cascade—one of the main needs identified in the IAEA revised model safeguards approach for gas centrifuge plants. Additionally, an integrated system can monitor the operation of the autoclave/hotbox using position limit switches and record the total time that the cylinder is in process. The operation of a feed valve to the cascade, as well as any flow monitors on the feed header also can provide data points for the CTS. When feeding is completed, an operator closes the transfer valve, disconnects the cylinder from the process line, and moves the feed cylinders to an accountability scale. When on the scale, cylinders are identified again by the CTS, and are weighed to determine the UF_6 heels remaining. The mass measurements are automatically entered into the CTS, and the amount of UF_6 that entered into the cascade is determined and logged. The empty feed cylinder then is moved to the storage location and, subsequently, either shipped back to the supplier or used to store tails material. The integrated CTS can monitor all movements described above. It also can track samples taken from the feed cylinders and associate the analysis results automatically with the source cylinders. Figure 1 depicts a conceptual model of a CTS employing RF-based technology for feed cylinders.

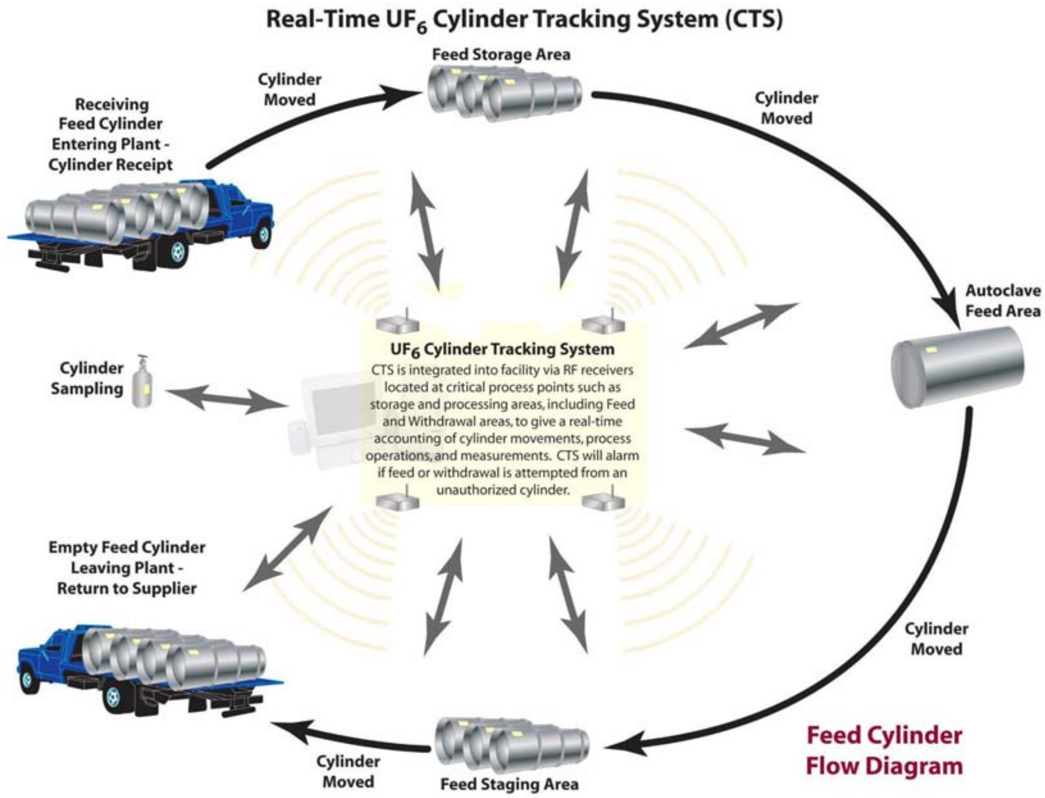
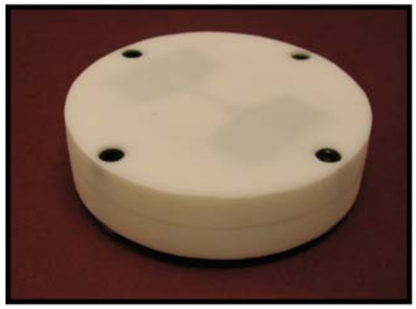


Figure 1: Conceptual RF-based CTS field test.

Field Testing Efforts to Date

Preliminary tests of available RF tags were conducted at Oak Ridge National Laboratory (ORNL) in 2006 under conditions that were representative of worst-case operating conditions at an enrichment plant.[8]. These tags also were tested for read range, orientation with antennas, and physical durability. Many of the COTS tags did not pass the tests, typically failing at the high temperatures. Consequently, ORNL commissioned one of the vendors to create a custom enclosure designed to protect the RF tag in extreme temperatures while providing at least a 2-m read range. The RF tag is a Generation 2 UHF passive tag (i.e., no batteries), shown in its custom enclosure in Figure 2. It affectionately is referred to as the "hockey puck" tag.

The proof-of-concept field test (depicted in Figure 3) is designed to evaluate the feasibility of using RF technology to track cylinders. This test is focused on determining how well the technology (with minimal packaging effort expended to protect it) can survive the conditions of repeated autoclave cycling and repeated operational handling. The test facility for conducting these evaluations is located in Portsmouth, Ohio,



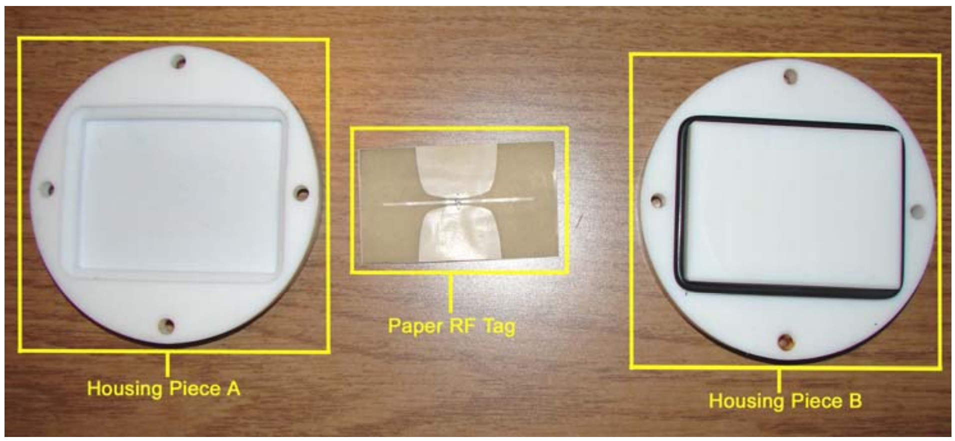


Figure 2: Custom-enclosed "hockey puck" RF tag and its internal components.

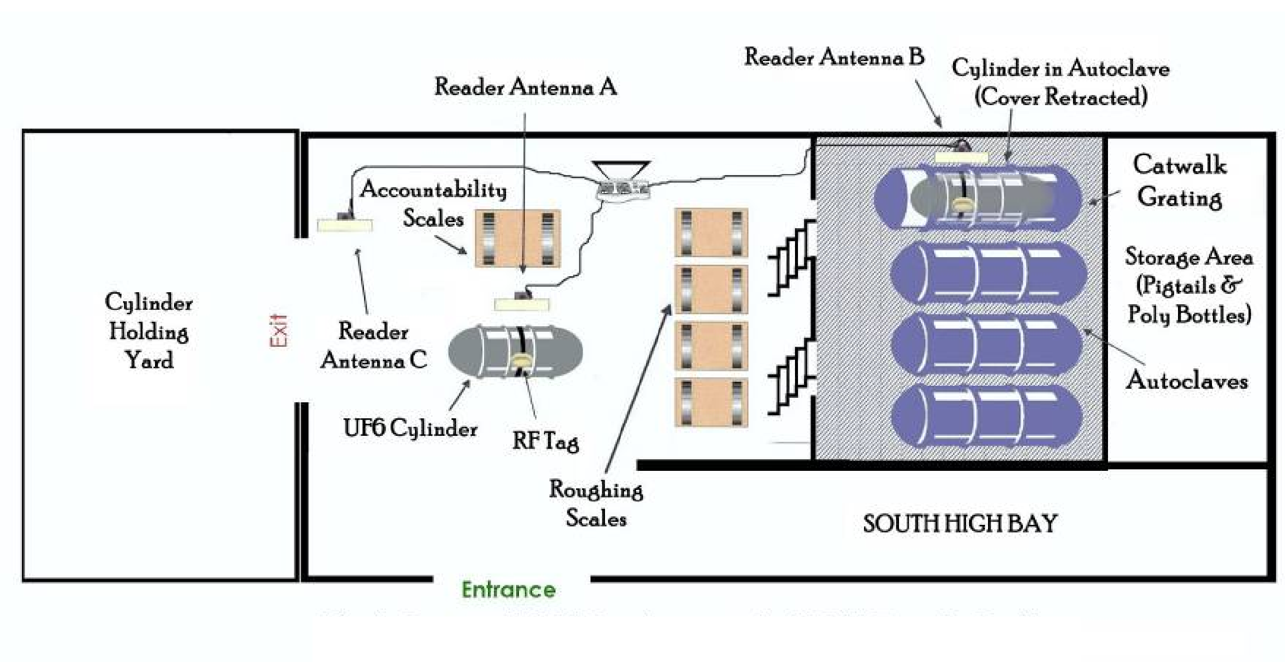


Figure 3: Proof-of-Concept Test Facility for RF-based CTS.

A RF-based system was installed at the Portsmouth, Ohio, enrichment plant in an autoclave facility to determine the operational issues of implementing an RF system in a facility of this type. The initial goal of this effort is to evaluate the feasibility of encased COTS RF technology to withstand plant-operating conditions and to obtain operational knowledge that will help identify what considerations should be included in future efforts.

The proof-of-concept test began with the RF tag being installed on a cylinder arriving into the cylinder staging area (near the entrance depicted in Figure 3). The cylinder is then moved past the first RF antenna (near the area shown in Figure 4) and read as it was raised by RF-controlled crane on its way to the autoclave. The cylinder is then placed in the autoclave, and its tag is read by the antenna mounted at that location. When the door for the autoclave closes, the tag is shielded from the antenna by the metal of the autoclave door. This event starts a clock that can be used to measure "time in the autoclave." When the metal autoclave door re-opens (prior to removing the cylinder from the autoclave), the tag is again readable by the antenna placed near the autoclave. This event stops the clock measuring time in the autoclave. This timing information may be useful for detecting events that violate process rules associated with particular equipment or a facility. The rules-based feature is inherent in the ORNL software and can be used to trigger other safeguard technologies (i.e., cameras) to collect additional data to further support verification.

After the cylinder is removed from the autoclave, it is moved to an accounting scale (see Figure 5), where the tag is read to log the activity, along with the recorded weight of the cylinder. As the cylinder, exits the facility, its tag is read for the last time by the antenna located near the exit (shown in Figure 6).

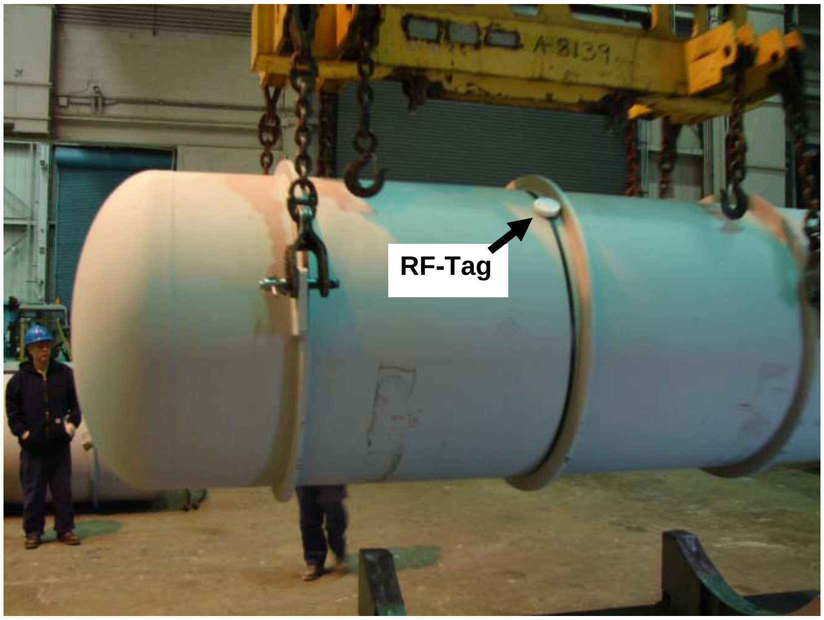


Figure 4: An RF-tagged UF_6 cylinder passing the staging area antenna and being raised on route to the autoclave.

Figure 5: RF monitoring as cylinder is moved to scale for post process weighing.

In addition to being able to withstand the operating environment, the authors recognize that future cylinder tags must support tamper resistant attachment without modification to cylinders. The tags will also require tamper resistant packaging and more than likely some form of data authentication. Current work involves following the commercial efforts to provide these types of features along with lab technology development efforts. The rapid progression of theses should make cylinder tracking an attractive option for near-term IAEA consideration.

Figure 6: Detection of cylinder exiting facility into cylinder yard.

The software's user interface for the proof-of-concept testing is shown below in Figures 7 and 8. This interface has been designed for growth. It supports the requirements of modern data management systems and rules-based event processing and is not specific to any particular type of RF technology.

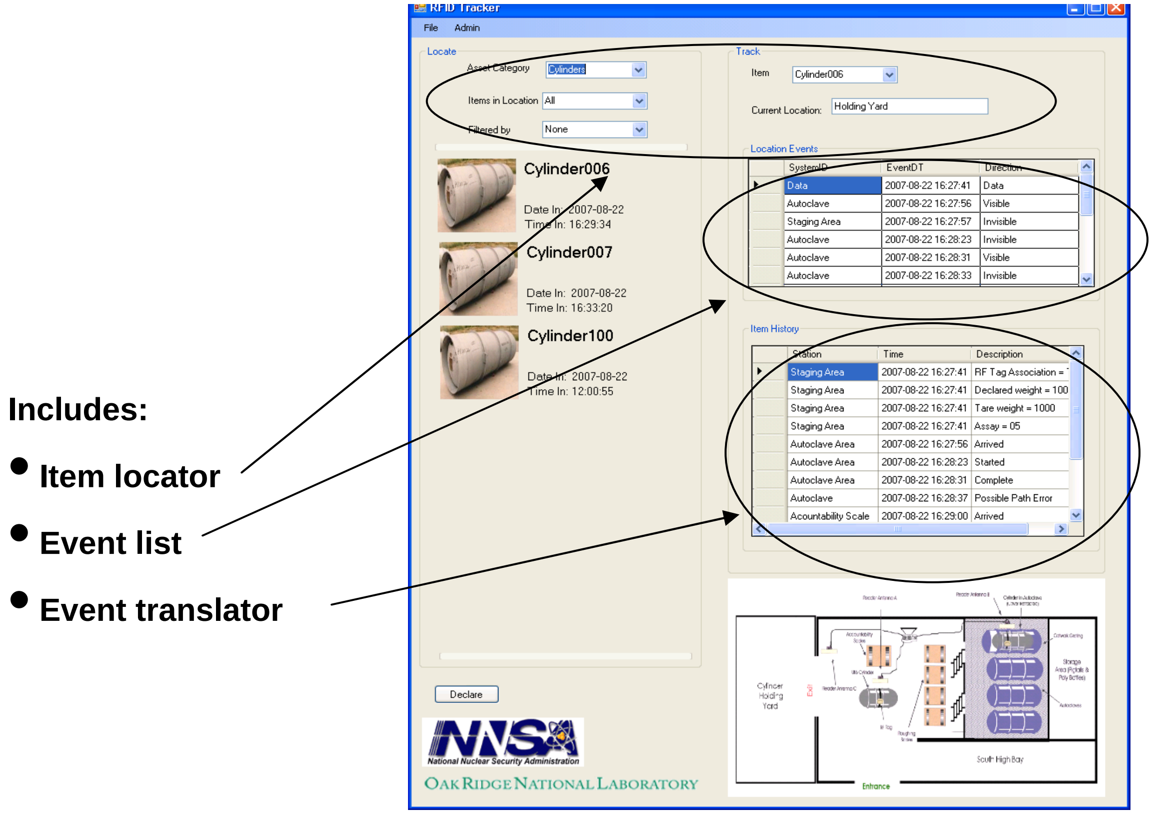
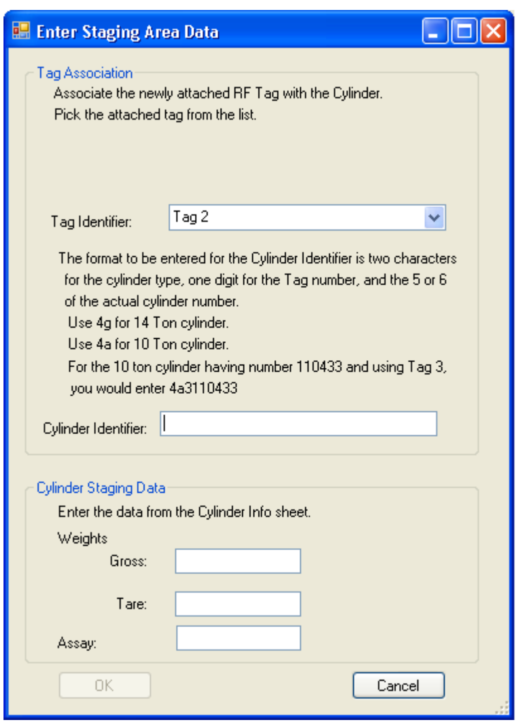
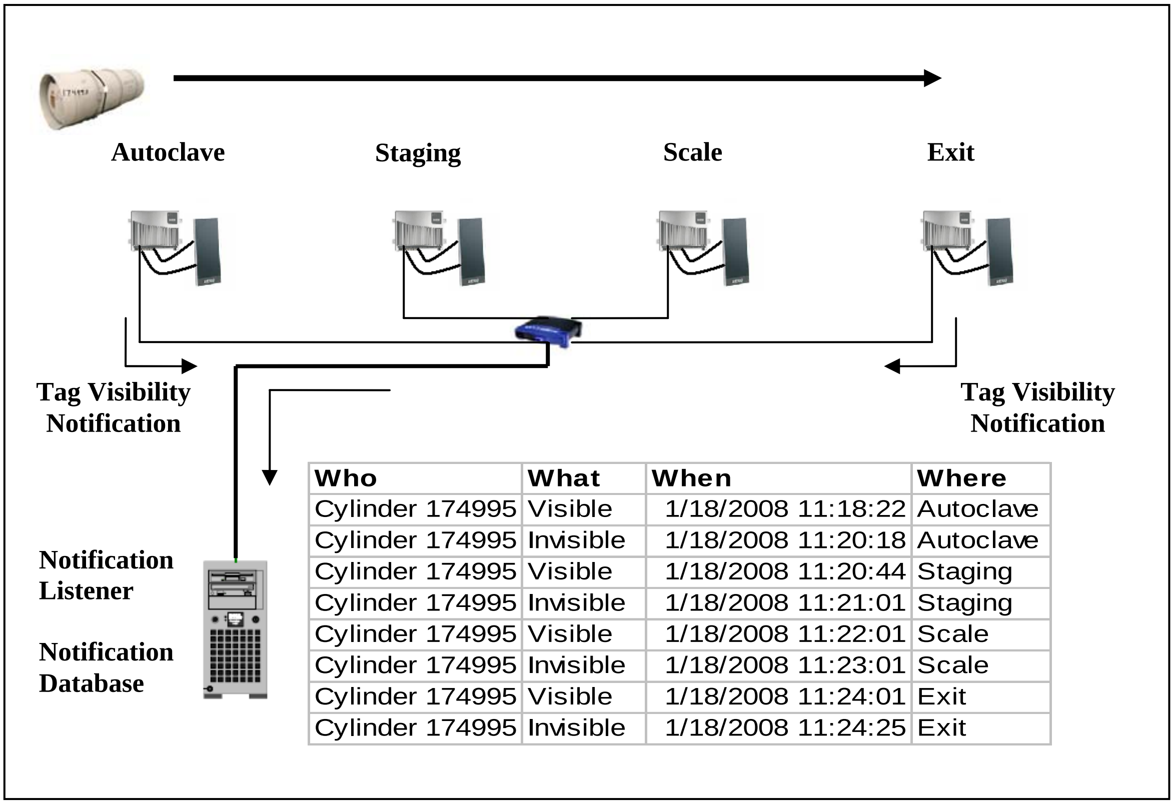


Figure 7: Current user interface to RF-based CTS.



Tag registration ensures that a specific protocol is followed and verified to ensure appropriate cylinder-tag association.

Figure 8: Tag registration dialog box.



Who	What	When	Where
Cylinder 174995	Visible	1/18/2008 11:18:22	Autoclave
Cylinder 174995	Invisible	1/18/2008 11:20:18	Autoclave
Cylinder 174995	Visible	1/18/2008 11:20:44	Staging
Cylinder 174995	Invisible	1/18/2008 11:21:01	Staging
Cylinder 174995	Visible	1/18/2008 11:22:01	Scale
Cylinder 174995	Invisible	1/18/2008 11:23:01	Scale
Cylinder 174995	Visible	1/18/2008 11:24:01	Exit
Cylinder 174995	Invisible	1/18/2008 11:24:25	Exit

Figure 9: Reader Visibility Notification System Architecture.

System Design: Tag Tracking Notification and Event Capturing

The RF tag readers are being used implement a notification mechanism for reporting the visibility events of tags that they "see." The notification mechanism for multiple readers and a notification listener connected via a network is shown in Figure 9. This mechanism is TCP/IP based and relies on a computer that is listening on a specified port for event notifications. The antenna readers are continuously scanning for tags and keep a cache of tags that they detect.

When a tag is detected either that a reader does not already have cached or a tag that is cached is not detected, a visibility notification event is sent to the listening application. The listening application processes this notification, and records the pertinent event information in an event database for future use. If a tagged cylinder were to travel past all the readers from the autoclave reader, to the staging reader, to the scale reader, and out into the cylinder year passing the exit reader, the acquired visibility events would be as shown in the table of Figure 10,. Figure 10 shows the data from each antenna reader as visibility (data event) pairs— where the cylinder is seen and then not seen at each antenna reader location.

Visibility Event Filtering and Processing

One feature built into the reader's visibility event notification system is filtering very short duration events. It is expected that as a tag approaches a reader, there could be a burst of visibility (data) events at the fringe of the reader/tag range where a tag is briefly seen and then not seen in quick succession. It is also expected for a number of reasons that tags well within the range of a reader, may not respond to a particular scan although they will respond and be detected by subsequent scans. Software filtering ensures that these effects are properly handled before a visible notification is generated. For this particular installation, the filtering parameters were specifically configured for each antenna based on facility operations.

Knowing the process parameters, such as the path that a cylinder will be taking, the time spent at each location, and the travel time required between locations, site-specific software rules could be developed to appropriately monitor cylinder movements. If a cylinder followed the wrong path, missed an operation, spent too much or too little time in a particular place visibility events could generate system notifying the appropriate party of the potential deviation...

The operation of the system has provided valuable insight into the importance of balancing the power levels of the readers with their filtering parameters and the filtering software particularly in an environment with multiple antennas set up in close proximity... The main effect was short duration, overlapping notifications from other readers, which was handled by modifying gain settings and system software. Future site systems would require that this effect, be better evaluated and addressed.

Visibility Event Data Analysis and Performance

For each tagged cylinder that is processed and tracked, for a manual data log was kept by operators. This manual data log was used for comparative purposes to the visibility events that were recorded by the readers and computer system. A typical comparison is provided for the data of cylinder 173624 where the times and actions from the log sheet (last column) are provided in the last column as shown in Figure 10.

Reader	Event	EventDT	Time Between Events	Log Sheet Info
Data	Data	1/28/2008 16:02:35		Tag Attached 16:15
Staging Area	Visible	1/28/2008 16:17:02	0:14:27	Staging Area 16:20
Staging Area	Invisible	1/28/2008 16:17:08	0:00:06	
Autoclave	Visible	1/28/2008 16:20:49	0:03:41	Placed into Autoclave 16:23
Autoclave	Invisible	1/28/2008 16:31:55	0:11:06	Shell Closed 16:35
Autoclave	Visible	1/29/2008 00:43:23	8:11:28	Shell Opened 00:50
Autoclave	Invisible	1/29/2008 00:58:23	0:15:00	Cylinder Removed 1:00
Staging Area	Visible	1/29/2008 00:59:31	0:01:08	
Staging Area	Invisible	1/29/2008 00:59:36	0:00:05	
Weighing	Visible	1/29/2008 01:01:04	0:01:28	On accountability scale 1:00
Weighing	Invisible	1/29/2008 01:02:12	0:01:08	
Weighing	Visible	1/29/2008 01:04:17	0:02:05	
Weighing	Invisible	1/29/2008 01:05:06	0:00:49	
Portal	Visible	1/29/2008 01:21:21	0:16:15	Exits 01:25
Portal	Invisible	1/29/2008 01:21:28	0:00:07	

Figure 10: Typical comparison of tracking events and manual log sheet.

Times between consecutive events are provided to show travel times and dwell times for the cylinder during different process stages. The initial event is a data event that is generated during tag registration that assigns a specific tag to a cylinder (see Figure 8). This tag registration event can occur at a time different from when the tag was actually attached to the cylinder, since the tag attachment and data entering may be conducted by the same people. Any agreement with these times would be coincidental. The location where a tag is attached could also be outside the range of an antenna reader and therefore an immediate event from a reader would not be generated. For cylinder 173624, the tag was attached and registered in a location where a reader was not present. The cylinder was initially detected at the staging antenna as it was transported to the autoclave. The autoclave reader then detected the cylinder as it was lowered into the autoclave. The autoclave reader does not see the tag when the shell is closed. The full retraction of the autoclave shell was detected when the tag was seen again 8 hours and 11 minutes after the initial shell closing. After the cylinder was removed from the autoclave, it passed by the staging antenna as it was transported to the accountability scale. The antenna at the accountability scale detected the cylinder when it is loaded on to the cart that moves onto the accountability scale. Sometimes, the antenna will "lose" the cylinder when the cart is actually on the scale. As the cylinder cart returns back from the scale, the cylinder is seen again by the antenna. The cylinder is then transported to the exit and passes the exit antenna on its way to the cylinder yard.

A summary of the manual log data and the system's data are provided in Figure 11. Correlation between the actual data captured and the manual logs has been very good.

Additional work will include developing the following specifications for the attached RF device:

- ability to withstand washing in cylinder cleaning facilities
- survivability from repeated heating and cooling cycles at temperatures expected in an operating environment
- best location for attachment
- survivability after exposure to hydrogen fluoride gas and to other corrosive gases
- functionality in the presence of electromagnetic/radiofrequency interferences and ac/dc magnetic fields
- survivability from operational (vibration, dropping, and rough) handling at the plant and during transport
- resistance to software viruses
- resistance to tampering
- multiyear durability, including long battery life, if applicable.

Issues and Vulnerabilities of RF-Based CTS

Continuous monitoring of an asset or sensitive material using RF-based technology is recognized as capable of providing direct security benefits through timely detection of diversion activities[6]. However, in moving forward with a proposed CTS concept, it is important that issues and vulnerabilities be clearly identified. The effectiveness and added benefits of RF technology as a security measure needs to be evaluated at the safeguards systems level. Diversion path analysis and evaluation of effectiveness and efficiencies of RF technology in actual safeguards applications will help delineate requirements necessary to design a robust system. Vulnerability

Cylinder Number	Notes	Time the Tag was attached	Tag Attached	Placed At Staging	Placed Into Autoclave	Shell Closed	Shell Opened	Removed From Autoclave	Acountability Scale	Cylinder Exits Facility
175101 RF	Empty Test Cylinder to optimize tag and Autoclave antenna alignment. Therefor lots of Autoclave events. No log sheet was kept for this run	1/17/2008 13:48	3							
175101 Log										
174995 RF		1/18/2008 10:46	2	11:08	11:10	11:31	1:17	1:30	1:33	1:40
174995 Log		1/18/2008 10:00		10:46	11:15	11:30	1:17	1:30	1:35	2:25
Practice RF	No log for this exercise									
Practice Log										
001879 RF		1/18/2008 22:31	4	22:34	1:39	1:54	12:53	13:13	13:16	13:35
001879 Log		1/18/2008 22:30		22:35	1:42	1:53	12:55	13:15	13:16	13:42
002476 RF	Tag 1 Failed after autoclave	1/19/2008 12:49	1	13:21	13:30	13:40	*	*	*	*
002476 Log		1/19/2008 12:45		13:23	13:30	13:40	2:18	2:34	2:40	2:45
002222 RF	Tag 3 has issues	1/20/2008 3:04	3	*	*	*	*	*	16:59	17:02
002222 Log		1/20/2008 3:00		3:05	3:21	3:45	13:05	16:35	16:50	17:10
174017 RF		1/24/2008 9:59	4	10:29	10:34	11:32	3:05	3:20	8:20	8:26
174017 Log		1/24/2008 9:59		10:29	10:34	11:40	3:10	3:25	8:23	8:30
001551 RF		1/25/2008 10:39	2	10:41	15:59	16:23	14:42	15:03	15:05	15:13
001551 Log		1/25/2008 10:35		10:44	16:05	16:25	14:30	15:05	15:00	15:15
002463 RF		1/26/2008 14:48	4	15:16	15:18	15:33	16:59	17:13	17:24	17:27
002463 Log		1/26/2008 14:50		15:15	15:17	15:50	17:00	17:15	17:25	17:30
PP5031 RF		1/27/2008 16:58	2	17:31	17:34	19:40	15:15	15:49	15:51	15:56
PP5031 Log		1/27/2008 15:35		17:32	17:35	19:43	15:15	15:45	16:00	16:03
173624 RF		1/28/2008 16:02	2	16:17	16:20	16:31	0:43	0:58	1:01	1:21
173624 Log		1/28/2008 16:15		16:20	16:23	16:35	0:50	1:00	1:00	1:25
002161 RF		1/29/2008 0:52	4	1:10	1:12	1:44	22:31	22:45	8:01	8:04
002161 Log		1/29/2008 0:10		1:12	1:15	1:50	22:33	22:48	8:03	8:15
001988 RF		1/30/2008 22:50	2	22:51	22:54	23:09	1:15	1:47	1:50	1:59
001988 Log		1/30/2008 22:00		22:51	22:54	23:20	1:15	1:38	1:50	2:00

Figure 11: Processing and tracking summary (to date).

issues such as sniffing, spoofing, transfer, and cloning need to be evaluated relative to the effectiveness of RF tags at the systems level. Vulnerabilities of tags, seals, and surveillance systems currently in use by the IAEA should be analyzed to gain a perspective of the IAEA's existing and future safeguards requirements.

Implementation of acceptable encryption and authentication methods may require some development to address the management of cryptographic keys in IAEA monitoring scenarios. Diversion path analyses and "red/blue teaming" to highlight weaknesses and corrective actions of proposed safeguards approaches should be performed to provide credible tools for meeting the requirements of international safeguards. The following are some additional issues and concerns that must be addressed.

- **Security and Cultural Issues—**Wireless systems need to be evaluated to determine whether they constitute an inventory or a security risk. Cultural resistance to using wireless technologies exists, largely because of questions regarding security and reliability. The IAEA and the host country must be assured that the RF system will work as specified. The RF technologies must be compared with current approaches and existing systems to demonstrate clear advantages.

- **Vulnerability Issues—**Vulnerabilities include spoofing, counterfeiting, transfer, and cloning. The extent to which system design can mitigate these concerns will be an important aspect of this study.

- **RF Interferences—**RF signals may interfere with existing systems and equipment. This interference depends on the RF band selected, which also can be a site-specific or a state-specific issue.

- **Frequency Limitation—**Frequencies allowed for use at a facility or in a country must be known and factored into a system using RF.

- **Tags Versus Seals—**Criteria for when to use RF-based tags versus RF-based seals are needed. These criteria should include a design-based-threat type of analysis and a cost-versus-performance evaluation.

- **Reliability—**Reliability of RF technologies must be compared with current approaches and existing systems. Tags must be sufficiently durable to survive the environmental and operational environments at a facility.

- **IAEA Authentication—**The system must be certified in a manner that assures the IAEA that the system is operational and the data are trustworthy.

CONCLUSION

As outlined in this paper, RF-based CTS can provide the IAEA with technologies that improve timely detection of diversion by providing a method to help verify the processing and storage of uranium at an enrichment plant. To achieve this, vulnerability concerns surrounding RF-based cylinder tracking will have to be addressed and the system will have to demonstrate reliability for providing enhanced data and remote monitoring capabilities to the IAEA. If successful, RF-based monitoring systems have the potential to revolutionize the tools available to the IAEA for conducting international safeguards inspections.

Current work has indicated that an RF device can be fabricated that will survive the operating conditions of the autoclave and be durable enough to survive the indoor and outdoor conditions associated with moving and storing cylinders. Future efforts will include efforts to utilize RF technology for tracking UF_6 cylinders as they are transported. One concept for accomplishing this task will be to install an RF reader on a cylinder transport vehicle and track the vehicle via a global positioning system (GPS). This concept is shown in Figure 12. The RF reader on the transport vehicle detects the identity, presence, or absence of the cylinder.

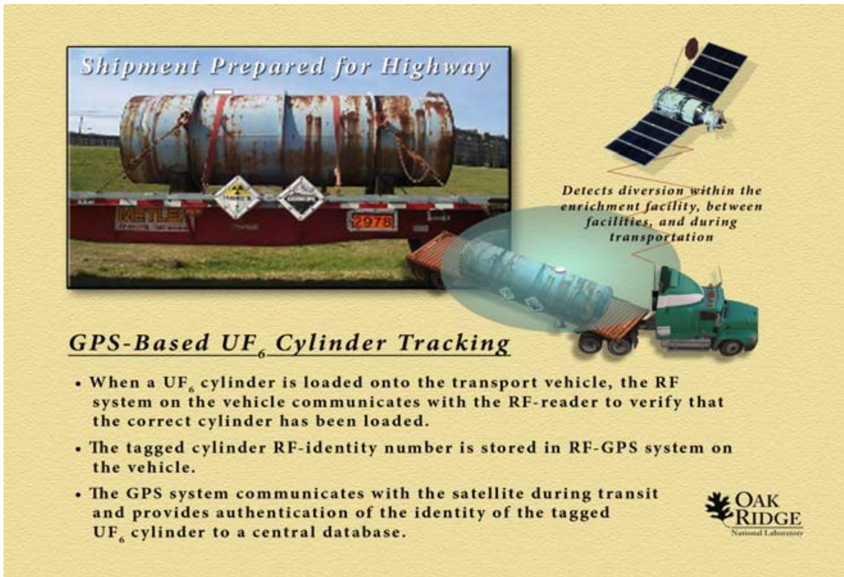


Figure 12: GPS-based cylinder-tracking concept.

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