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Results from a Demonstration of RF-Based UF_6 Cylinder Accounting and Tracking System Installed at a USEC Facility

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Global Nuclear Security Technology Division

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ACRONYMS AND ABBREVIATIONS

CATS	Cylinder Accounting and Tracking System
C/S	Containment and Surveillance
CofK	Continuity of Knowledge
COTS	Commercial off the Shelf
DOE	Department of Energy
EPC	Electronic Product Code
HEU	Highly Enriched Uranium
IAEA	International Atomic Energy Agency
LOTO	Lockout/Tagout
MC&A	Material Control and Accountability
NDA	Nondestructive Assay
ORNL	Oak Ridge National Laboratory
PGP	Pretty Good Privacy (encryption)
PNNL	Pacific Northwest National Laboratory
RF	Radio Frequency
RFID	Radio-Frequency Identification
UF_6	Uranium Hexafluoride
UHF	Ultrahigh Frequency
USEC	United States Enrichment Corporation

ACKNOWLEDGMENTS

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EXECUTIVE SUMMARY

Approved industry-standard cylinders are used globally for storing and transporting uranium hexafluoride (UF_6) at uranium enrichment plants and processing facilities. To verify that no diversion or undeclared production of nuclear material involving UF_6 cylinders at the facility has occurred, the International Atomic Energy Agency (IAEA) conducts periodic, labor-intensive physical inspections to validate facility records, cylinder identities, and cylinder weights. A reliable cylinder monitoring system that would improve overall inspector effectiveness would be a significant improvement to the current international safeguards inspection regime. Such a system could include real-time unattended monitoring of cylinder movements, situation-specific rules-based event detection algorithms, and the capability to integrate with other types of safeguards technologies. This type of system could provide timely detection of abnormal operational activities that may be used to ensure more appropriate and efficient responses by the IAEA. A system of this type can reduce the reliance on paper records and have the additional benefit of facilitating domestic safeguards at the facilities at which it is installed.

A radio-frequency (RF)–based system designed to track uranium hexafluoride (UF_6) cylinders during processing operations was designed, assembled, and tested at the United States Enrichment Corporation (USEC) facility in Portsmouth, Ohio, to determine the operational feasibility and durability of RF technology. The overall objective of the effort was to validate the robustness of RF technology for potential use as a future international safeguards tool for tracking UF_6 cylinders at uranium-processing facilities.

The results to date indicate that RF tags represent a feasible technique for tracking UF_6 cylinders in operating facilities. Additional work will be needed to improve the operational robustness of the tags for repeated autoclave processing and to add tamper-indicating and data authentication features to some of the pertinent system components. Future efforts will focus on these needs along with implementing protocols relevant to IAEA safeguards.

The work detailed in this report demonstrates the feasibility of constructing RF devices that can survive the operational rigors associated with the transportation, storage, and processing of UF_6 cylinders. The system software specially designed for this project is called Cylinder Accounting and Tracking System (CATS). This report details the elements of the CATS rules-based architecture and its use in safeguards-monitoring and asset-tracking applications. Information is also provided on improvements needed to make the technology ready, as well as options for improving the safeguards aspects of the technology. The report also includes feedback from personnel involved in the testing, as well as individuals who could utilize an RF-based system in supporting the performance of their work.

The system software was set up to support a Mailbox declaration, where a declaration can be made either before or after cylinder movements take place. When the declaration is made before cylinders move, the operators must enter this information into CATS. If the IAEA then shows up unexpectedly at the facility, they can see how closely the operational condition matches the declaration. If the declaration is made after the cylinders move, this provides greater operational flexibility when schedules are interrupted or are changed, by allowing operators to declare what moves have been completed. The IAEA can then compare where cylinders are with where CATS or the system says they are located. The ability of CATS to automatically generate Mailbox declarations is seen by the authors as a desirable feature. The Mailbox approach is accepted by the IAEA[*] but has not been widely implemented (and never in enrichment facilities). During the course of this project, we have incorporated alternative methods for implementation.

*K. Tolk, T. Capel, M. Aparo, C. Liguori, and A. Alessandrello, “Requirements for Automated Transfer of Operator Declarations,” presented at the 47th Annual INMM Meeting, Nashville, Tenn., July 2006.

1. INTRODUCTION

Uranium enrichment plants can be used 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, possibly in countries that currently do not have this capability. This resurgence has raised safeguards concerns and challenges that the International Atomic Energy Agency (IAEA) and global community must address.

Based on the projected growth required to fuel the global demand for energy, enrichment capacity requiring safeguards in the next decade could surpass the current capabilities of the IAEA to provide adequate safeguards. 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 in the use of nuclear power.[1] To ensure that the IAEA has the capabilities required to support this resurgence, investments will be needed to support the development and deployment of more advanced containment and surveillance (C/S) monitoring technologies. It is paramount to the international safeguards community that the IAEA has the tools needed to provide timely assurance that significant quantities of nuclear material from peaceful programs have not been diverted for the manufacture of nuclear weapons.[2] Thus, a reliable system that can improve the efficiency and increase the effectiveness of detecting diversion or undeclared production of nuclear material at enrichment facilities would be welcome.

2. THE IMPORTANCE OF TRACKING AND ACCOUNTING FOR UF_6 CYLINDERS

A key reason it is important to track UF_6 cylinders at enrichment facilities is that the contents of these cylinders represent the majority of material inventory available for further enrichment processing. The tracking of cylinders (in a near real-time manner) as they move throughout a site provides for the implementation of methodologies that can verify declared movements between material balance areas and thus help to detect undeclared activities. Implementation of near real-time tracking and accountancy technologies also creates options for implementing remote unattended monitoring methods for inspection, which typically are less intrusive to the facility owner and can be more cost-effective for the IAEA.[3]

The authors are aware that current IAEA safeguards efforts do not require the tracking of UF_6 cylinders, but they do require the accounting of material contained in cylinders. Since nearly all the material at enrichment facilities is stored in cylinders, a system as proposed in this report can be designed to meet the goals of the IAEA by providing an automated material accountancy. In addition, this system provides the opportunity to track the cylinders in "real-time" to help identify certain operational activities that could indicate that proliferation was occurring. In this way, the proposed system goes beyond the current safeguards regime and identifies new approaches that can better address the future safeguards challenges facing the IAEA.

For enrichment facility safeguards systems to be effective, they must provide "timely" detection of known indicators that may be associated with

- diversion of declared UF_6,
- undeclared low-enriched production at amounts greater than declared, and
- production of HEU.

Some of these indicators are outlined below:

- — unauthorized feed and withdrawal stations,
- — unauthorized cylinder movements,

— unauthorized alterations to cylinders that modify their weights,
— altered scales or load cells,
— the presence of unauthorized cylinders in the feed and withdrawal areas,
— reduced throughput,
— portable feed and withdrawal equipment/stations in the cascade area,
— extra UF_6 cylinders in the cascade area,
— valve settings,
— piping reconfigurations (e.g., intercascade piping, feed/withdrawal points), and
— radiation measurements or swipes indicating the presence of HEU.

Traditional safeguards practices typically employ technologies and methods listed below during on-site inspections:

- radiation monitoring and nondestructive assay (NDA) measurements,
- sampling,
- application and verification of seals,
- visual observation,
- environmental sampling,
- continuous online enrichment monitors, and
- portable neutron uranium hold-up counter.

It is important to note that tracking UF_6 cylinders does not directly address the detection of operational activities or piping reconfigurations necessary to produce HEU. However, if the clandestine activities involve the use of UF_6 cylinders, a cylinder tracking system would make it more difficult for proliferators to accomplish their task because it would require them to spend additional time to circumvent the system and the associated equipment.

3. ASSET TRACKING STRATEGY

Implementation of a reliable, automated, and tamper-indicating radio-frequency (RF)–based Cylinder Accounting and Tracking System (CATS)—designed to track uranium hexafluoride (UF_6) cylinders throughout their life cycle—will improve domestic accountability of materials and provide the IAEA with improved detection of material diversion and undeclared production. CATS was designed to be part of an integrated safeguard system that can support both domestic and international needs through effective integration of inputs from other monitoring systems and sensors such as radiation detectors, gamma spectrometers, pressure and temperature sensors, accelerometers, limit switches, cameras, accountability scales, and other pertinent devices.

Many current nuclear material accounting and control procedures for tracking UF_6 cylinders typically involve manual entry or bar-code scanning of 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 visual container inspections, to verify UF_6 cylinder contents and to establish some level of continuity of knowledge (CofK) assurance.

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.[4] Tracking UF_6 cylinders represents one possible approach for monitoring the flow of uranium throughout an enrichment facility. It helps maintain CofK of material location at each step in the enrichment process.[5] Ongoing efforts to track other protected assets using RF technology are occurring within the Department of Energy (DOE) facilities, and experiences from these efforts were utilized for this project.[6]

4. TAG EVALUATIONS FOR OPERATIONAL DEPLOYMENT

Early in the project, the team identified radio-frequency identification (RFID) technology as a feasible solution for tracking UF_6 cylinders, if the RF device could survive the extreme conditions of autoclaves and support read ranges of 8 ft. Oak Ridge National Laboratory (ORNL) conducted numerous tests of commercially available tags that were candidates for surviving multiple runs through a steam autoclave and that had the operational durability and read range needed for tracking cylinders as they moved throughout a processing facility.[7] An environment of a steam autoclave was chosen because it represent the worst-case environmental condition that an RF tag is likely to experience. The photos below depict some of the testing that occurred in the environmental chamber and in the laboratory to determine read range and performance on metal containers. In all cases, the tags were first evaluated under ideal laboratory conditions to obtain a benchmark for future reference before performing additional testing

1. in an environmental test chamber for heating and cooling cycles as would be experienced in a steam-heated autoclave [see Fig. 1(a)], and
2. in various orientations in air and on metal containers to determine read range and antenna/reader performance [see Fig. 1(b)].

(a) **(b)**

Fig. 1. Examples of Laboratory RFID tag testing: (a) Environmental chamber results after heating and (b) measurement of read distance.

After testing in the environmental chamber, each tag was checked and compared with its previous (prechamber) data to determine if performance had been changed or diminished substantially by the elevated temperatures and humidity that would be experienced in a steam-heated autoclave. The only condition that the environmental chamber could not easily simulate is the pressure associated with steam-heated autoclaves. This would have to be tested and evaluated in the field.

Only a few tags survived the testing [as can be seen in the results shown in Fig. 1(a)]. The tag that was chosen for use at the Portsmouth United States Enrichment Corporation (USEC) facility was a tag that had been specially packaged and designed by a vendor to survive these conditions. The tag is an Electronic Product Code (EPC) Generation 2 ultrahigh-frequency (UHF) passive (i.e., no batteries) paper RF tag packaged in plastic enclosure and sealed with an O-ring. The tag is shown in Fig. 2. Four tags of this type were procured and utilized for the initial proof-of-concept testing at Portsmouth. This design had some flaws (i.e., an O-ring seal applied to a rectangular plug and gaps

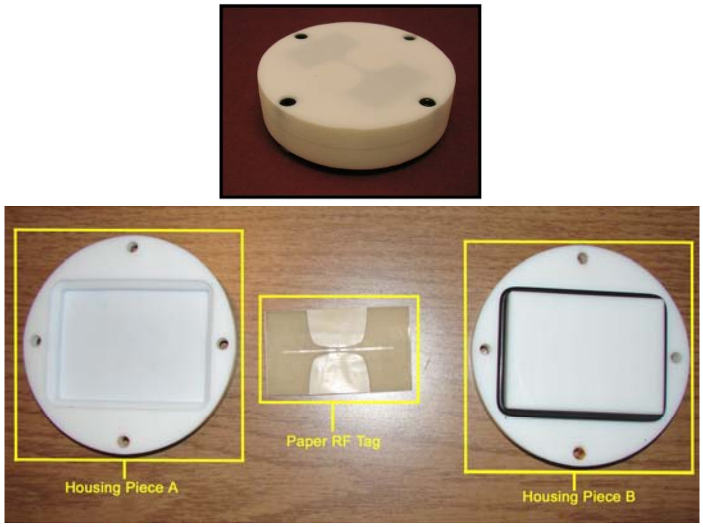


Fig. 2. Custom-encased "Hockey Puck" RF tag and its internal components.

between the plastic pieces that did not close uniformly when assembled). Such flaws became apparent during the initial autoclave testing, but after minor modification, the tag package functioned very well over the test period.

A second tag type, tested in later autoclave runs, had survived the environmental chamber testing but always exhibited diminished performance after being cycled through the autoclave. Discussions with the vendor indicated that there were some quality control problems with the manufacturer that as of the date of this report have still not been determined. A new supply of these tags has been received; however, they have not been tested at the time of the writing of this report.

In the early phases of the project, the RFID commercial market was rapidly expanding and the new product development cycle was not keeping up with demand. It was very hard at that time to find many "true" high-temperature tags; therefore, custom-packaged options became the best choice for this project. Recently, the commercial sector has matured and produced a variety of robust choices for high-temperature tags, some of which are illustrated below. These tags are specially designed and packaged for high-temperature applications; many are hermetically sealed and include direct attachment options. The set shown in Fig. 3 are currently being evaluated by ORNL for future cylinder tracking efforts.

Fig. 3. Next-generation high-temperature RF tags.

5. SYSTEM IMPLEMENTATION

5.1 SYSTEM COMPONENTS

The CATS implementation at the USEC facility in Portsmouth, Ohio, utilized four networked Motorola XR400 UHF RF readers, attached to four Motorola AN400 high-performance area antennae; a Windows XP computer system with keyboard, mouse, and monitor; a six-port Ethernet network hub; two types of high-temperature RF tags; and various mounting hardware for the readers, antennae, and computer. A facility layout of the system is shown in Fig. 4.

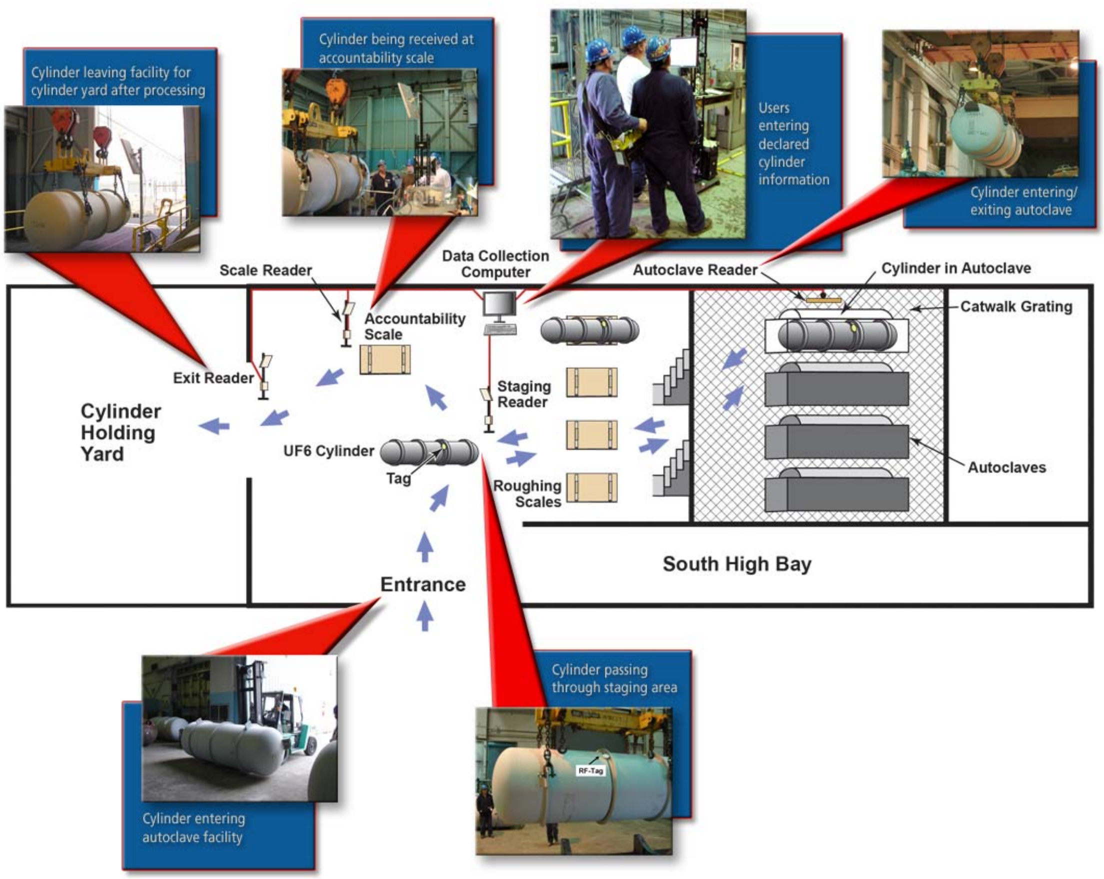


Fig. 4. RF-based CATS as installed within the USEC autoclave facility.

Antenna/reader pairs were strategically installed at four predetermined locations within the autoclave facility. The data were transmitted automatically from the RF tags to the readers to the CATS data collection computer. By using this reader/antennae pairing, cabling to the CATS computer was simplified, allowing readers to be connected via an Ethernet network hub. By utilizing this type of connectivity, the integrity of the RF signal can be maintained over long cable runs, with the only requirement being a need to supply power at each reader/antenna location.

5.2 BASIC OPERATION OF THE RF-BASED CATS TEST BED

The main objective of this project was to investigate the durability and feasibility of using encased commercial off-the shelf (COTS) RF technology to track UF_6 cylinders as they move throughout a processing facility. An autoclave process was chosen since it represents one of the harshest exposure environments for the RF technology. The autoclave facility environment tests the ability of the RF tags to withstand high temperatures and survive the operating conditions associated with heavy equipment moves of cylinders as they enter and exit the facility. This facility provided the ability to evaluate the operational impacts of using RF technology and was an excellent test bed for identifying additional system and equipment requirements for future efforts.

As each RF tag moves through the RF field generated by the reader/antenna pair, it is energized to transmit back its serial number, which is interpreted or "read" by the antenna/reader pair. The proof-of-concept test began with an RF tag being installed on a cylinder as it arrived in the facility near the entrance depicted in Fig. 4. (A tag association procedure is described in detail in Sect. 6.5 of this report.) The declared cylinder weight from accounting records is manually entered at this tag with the tag and cylinder serial numbers. The cylinder then moves as indicated by the arrows in Fig. 4 past the first RF reader/antenna, labeled "staging" area. The RF tag is read by the staging-area reader/antenna as a radio-controlled crane raises the cylinder and it moves toward the autoclave (see Fig. 5). The cylinder is then placed in the autoclave, and the tag is read by the autoclave reader/antenna. When the shell for the autoclave closes, the tag is shielded from the autoclave reader/antenna by the metal of the autoclave shell. This event starts a clock that can be used to measure "time in the autoclave." When the metal autoclave shell reopens (prior to removing the cylinder from the autoclave), the tag is again readable by the autoclave reader/antenna. The time stamps of these two events provide a method for determining "time in the autoclave." This timing information may be useful for detecting events that violate process rules associated with particular equipment or operations of a facility. The rules-based feature is inherent in the ORNL CATS software and can be used to trigger other safeguard technologies (i.e., cameras) to collect additional data to provide additional verification.

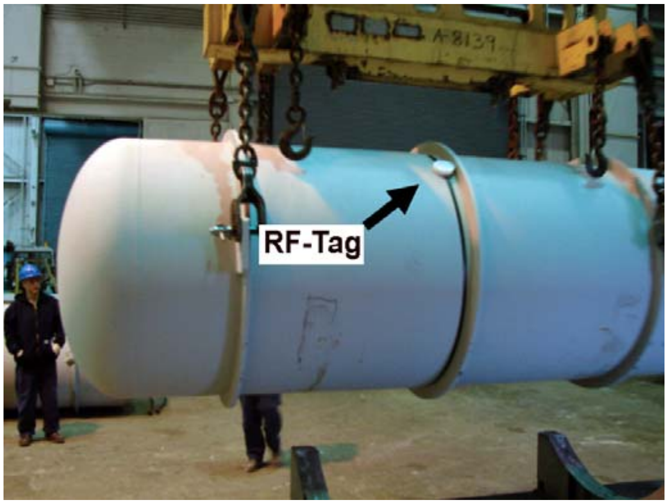
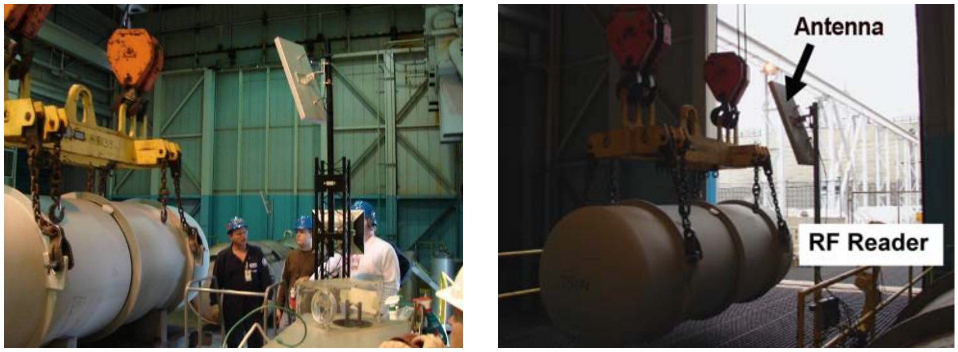


Fig. 5. RF-tagged UF_6 cylinder passing the staging-area antenna as it is raised on its way to the autoclave.

After the cylinder is removed from the autoclave, it is moved to the accounting scale [see Figs. 5 and 6(a)], where the tag is read by the scale reader/antenna to log its presence. The weight of the cylinder is manually entered into the CATS computer system by the operator. (Future testing will include this weight being automatically read by the CATS computer system.) As the cylinder exits the facility, its tag is read for the last time by the exit reader/antenna located near the exit [shown in Figs. 5 and 6(b)].



(a) **(b)**

Fig. 6. RF detection (a) as the cylinder is moved to the scale for post-process weighing and (b) gas cylinder exits facility into the cylinder yard.

The CATS system installed at the USEC facility at Portsmouth demonstrated the capability to track cylinder movements within an autoclave facility. However, before the results and lessons learned from the project are discussed, the system software of the CATS will be detailed.

6. CATS OPERATION

The Cylinder Accounting and Tracking System (CATS) was designed for the purpose of providing a useful mechanism for data collection, user interaction, situation-based rule implementation, technology integration, and report generation. The CATS software is modularized in way that supports future integration of other technologies to support safeguards monitoring and the implementation of specific software routines and protocols that may be mandated by sites of the IAEA. This section provides an overview of the implementation of this software for the Portsmouth cylinder tracking effort.

6.1 SOFTWARE REQUIREMENTS

The initial functional software requirements for a system to track UF_6 cylinders using passive RF tags in a pilot/testing environment include the following functions:

- associate the readers with the assigned locations,
- associate and record an RF tag with a specific cylinder,
- disassociate an RF tag from a specific cylinder,
- record pertinent pre- and post-process data regarding that cylinder (data supplied by operators),
- record cylinder accountability scale weight from manual operator entry,
- communicate with the RF tag readers to determine when an RF-tagged cylinder is seen by a reader and when it is not seen by a reader and record these events,
- interpret reader events and associate them with the known process (reader) locations,
- provide a method for reviewing and analyzing historical tracking data,
- provide a simple Mailbox declaration mechanism, and
- provide predefined reports.

6.2 USER INTERFACE RATIONALE

The CATS user interface for the UF_6 Portsmouth field test was designed to provide multiple methods for viewing the data from a single user interface. This facilitated on-site troubleshooting and provided quick field assessments of all system operations. The user interface also was designed to facilitate the system setup process, which involves the placement, orientation, and optimization of the readers/antennae.

6.3 SOFTWARE COMPONENTS

The CATS functional requirements are each partitioned into the individual program elements that together constitute the entire system. The heart of the system is an enterprise-class relational database consisting of a schema that includes multiple data tables. Some of the tables include data for system configuration, acquired event data, and manually entered data (i.e., tag assignment to cylinder). There is a Windows service that receives RF tag visibility notifications from readers. This service parses the notification messages, interprets the notifications, and stores the notifications in a data table—the where, when, and what of the system operation.

6.4 IDENTIFYING THE READERS

The Motorola XR400 UHF RF readers are networked devices that communicate via TCP/IP. The database schema includes the data table called “rfidmanager,” which collects information from each networked reader’s IP address and antenna number in the notification message that is translated into the assigned location of the antenna. Table 1 shows the information collected by the “rfidmanager” data table.

Table 1. RFID manager

ID	System ID	Location	RegDT	IP	Antenna
4	PORTS	Exit	1/17/2008 3:22:00 PM	192.168.0.254	1
5	PORTS	Staging area	1/17/2008 3:22:00 PM	192.168.0.251	1
6	PORTS	Weighing	1/17/2008 3:22:00 PM	192.168.0.252	1
8	PORTS	Autoclave	1/17/2008 3:22:00 PM	192.168.0.250	1

6.5 TAG ASSOCIATION AND DISASSOCIATION

One of the first things that must be accomplished in tracking UF_6 cylinders is associating an RF tag with a specific cylinder. This process is necessary for the system to be able to associate the actual cylinder (via its unique cylinder identification number stamped on the nameplate by the manufacturer) with the unique electronic ID of the RF tag. For the purposes of this field test, it was also important to be able to disassociate a tag from a cylinder, so that it may be used again on another cylinder. Tags were reused on other cylinders for two reasons: (1) there were a limited number of RF tags available and (2) it was important to determine the number of cycles in the autoclave that each tag could survive. The tag/cylinder association registration process is shown in the dialog boxes in Fig. 7, where the actual cylinder identifier is associated to the identifier of the RF tag. This dialog box also is where the operator-declared data are entered prior to the cylinder moving into the staging area.

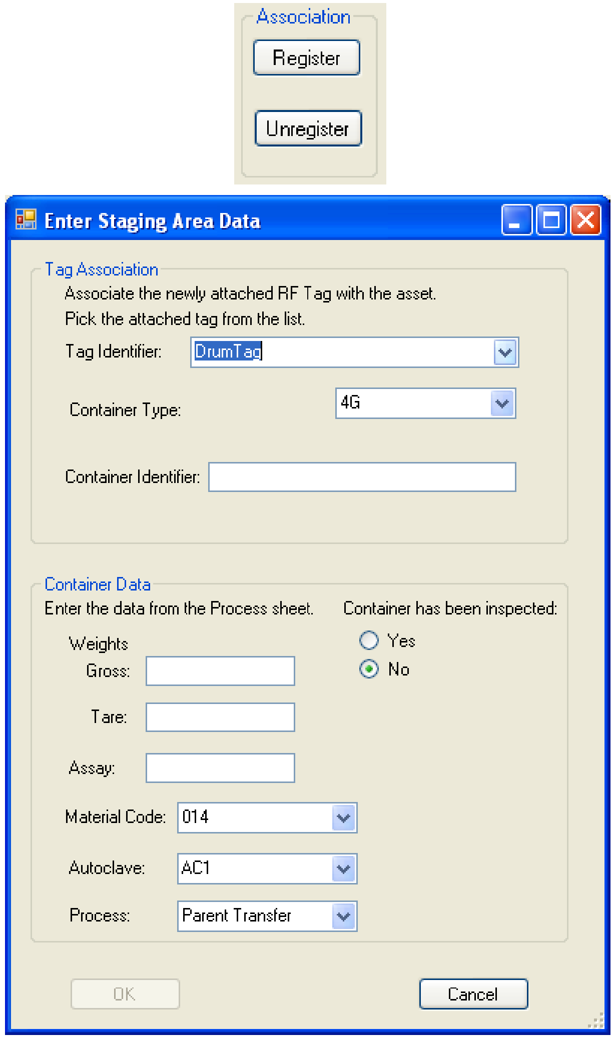


Fig. 7. CATS dialog box for tag/cylinder association and operator-declared information.

Once registered, the cylinder will be identified by and referenced by the RF tag identifier that was attached. The tag/cylinder registration process also incorporates operator-entered data that accompany the cylinder.

When an RF tag is removed from the cylinder, it must be disassociated from the current cylinder. This process ensures that future visibility events (that occur when the RF tag is reused on another cylinder) will not be attributed to the earlier cylinder. This is accomplished by unregistering the association using the dialog box shown in Fig. 8.

6.6 CYLINDER/TAG TRACKING NOTIFICATION AND EVENT CAPTURING

The RF tag readers implement a notification for reporting the visibility of tags that they "see." The notification mechanism for multiple readers and a notification listener connected via a network is shown in Fig. 9. This mechanism is TCP/IP based and relies on a computer that is listening on a specified port for visibility event notifications. Each reader continuously scans for tags and maintains a buffered cache of tags that have been detected. When a tag is detected that a reader does not already have cached or a tag that is cached is not detected, a visibility notification of the appropriate type is signaled to the listening application. The listening application parses the notification as a

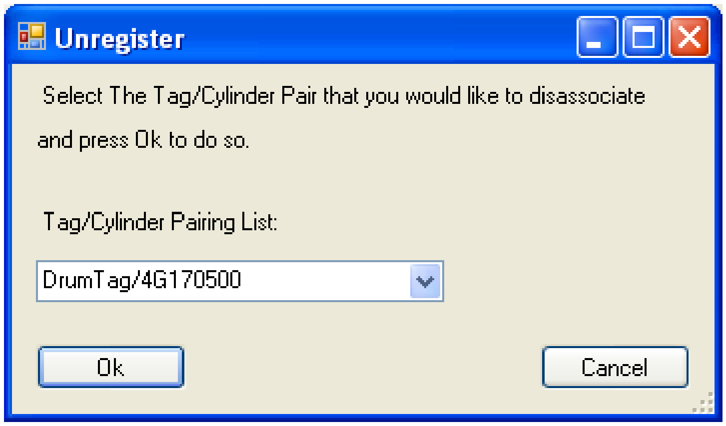
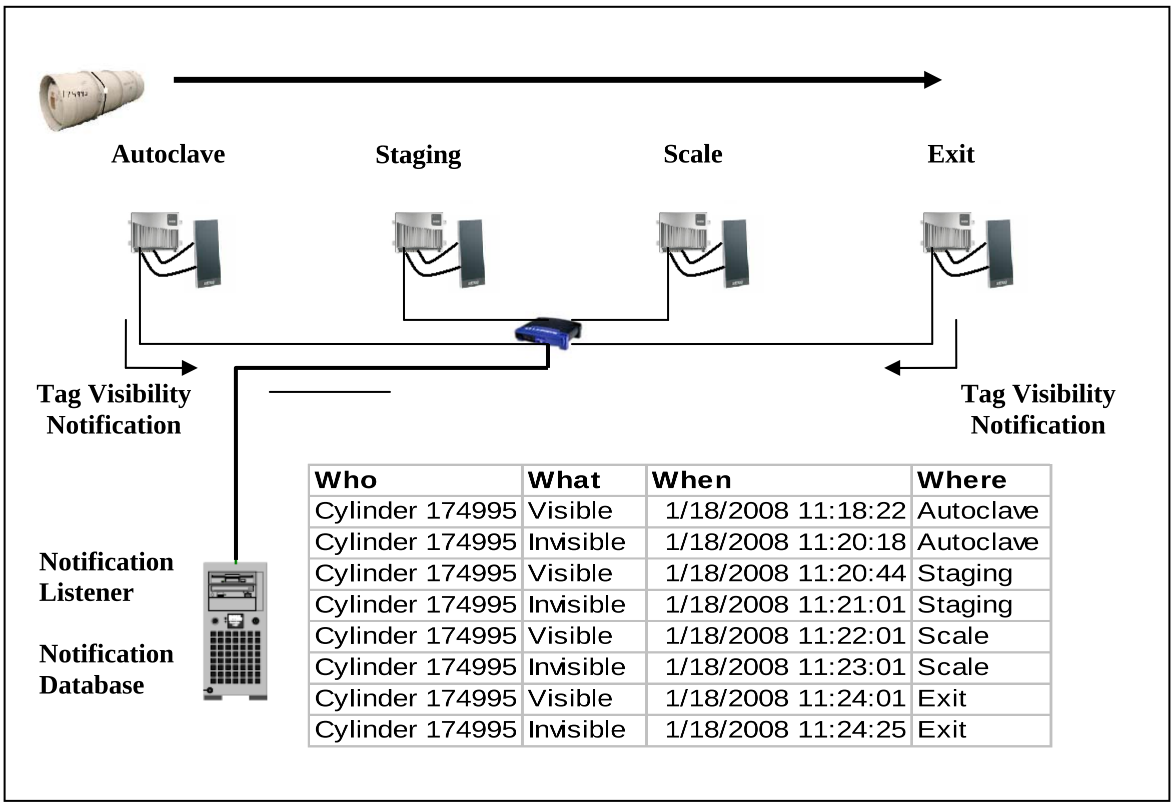


Fig. 8. CATS dialog box for disassociating tag/cylinder registrations.



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

Fig. 9. Reader visibility notification mechanism architecture.

visibility event to the appropriate fields in the database table. The visibility event includes the tag identification, the visibility of the tag, the time of the notification, and the reader that detected it.

6.7 VISIBILITY EVENT FILTERING AND PROCESSING

One feature built into the reader's visibility event notification system is the capacity to filter 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. For a number of reasons, it is also expected 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 the location within the facility's operations.

Knowing the process operation, such as the path that the cylinder travels, the time spent at each location, and the time between locations, allows scenario-specific software rules to be developed that can be used to detect process or safeguards anomalies. If it were determined that a cylinder's path went from the autoclave to the facility's exit, bypassing the accountability scale, an alert condition could be generated, reporting a path deviation. Likewise, a rule could be established to detect when a cylinder removed from the autoclave took too long to reach the accountability scale.

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 antennae 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.

6.8 TAG TRACKING SOFTWARE COMPONENT

The CATS software utilizes a stand-alone Windows service that was written to run continuously on the computer; this service is named RFIDBobcat. It is responsible for receiving the visibility notifications from the readers, interacting with the database tables, recording events into the RFIDEvents table (see Table 2), interpreting the events, and writing the associated interpretation into the cylinder's data table. RFIDBobcat is the piece of software where situation-specific safeguards rules can be implemented to support the appropriate detection of material movements and activities.

Table 2. RFID events

ID	System ID	Event type	Direction	Event DT	Tag ID
8663	Data	Area	Data	2008-01-30 22:50:34	4a2001988
8664	Staging Area	Area	Visible	2008-01-30 22:51:05	4a2001988
8665	Weighing	Area	Visible	2008-01-30 22:51:05	4a2001988
8666	Staging Area	Area	Invisible	2008-01-30 22:51:08	4a2001988
8667	Weighing	Area	Invisible	2008-01-30 22:51:09	4a2001988
8668	Autoclave	Area	Visible	2008-01-30 22:54:10	4a2001988
8669	Autoclave	Area	Invisible	2008-01-30 23:09:50	4a2001988
8736	Autoclave	Area	Visible	2008-02-02 01:15:45	4a2001988
8737	Staging Area	Area	Visible	2008-02-02 01:39:26	4a2001988
8738	Staging Area	Area	Invisible	2008-02-02 01:39:27	4a2001988
8739	Autoclave	Area	Invisible	2008-02-02 01:47:31	4a2001988
8740	Staging Area	Area	Visible	2008-02-02 01:49:44	4a2001988
8741	Staging Area	Area	Invisible	2008-02-02 01:49:51	4a2001988
8742	Weighing	Area	Visible	2008-02-02 01:50:46	4a2001988
8743	Weighing	Area	Invisible	2008-02-02 01:50:56	4a2001988

6.9 DATA REVIEW

A cylinder tracking database at an active facility could easily become very large, thus requiring a manageable database structure for handling the information. The CATS computer system provides advanced database management based on selection filters that allow information to be sorted by user-defined criteria.

Asset categories can be chosen from a predefined list. To find information on UF_6 cylinders, one would select the asset category "Cylinder" as shown in the dialog box in Fig. 10. One would next select the location(s) in which to look for cylinders. If cylinders in a certain location are desired, the "Items in Location" filter can be set to a specific location. The "Items in Location" filter is set to "All" if searching in all areas is desired. Filters can be set up to show a cylinder's history over a selected time period, the cylinders that have been run through a specific process, and many other types of desired information. Two filters that proved useful during system testing are "registered" (to show what cylinders are currently registered) and "Last 5 minutes" (to show what cylinders were seen in the last 5 min).

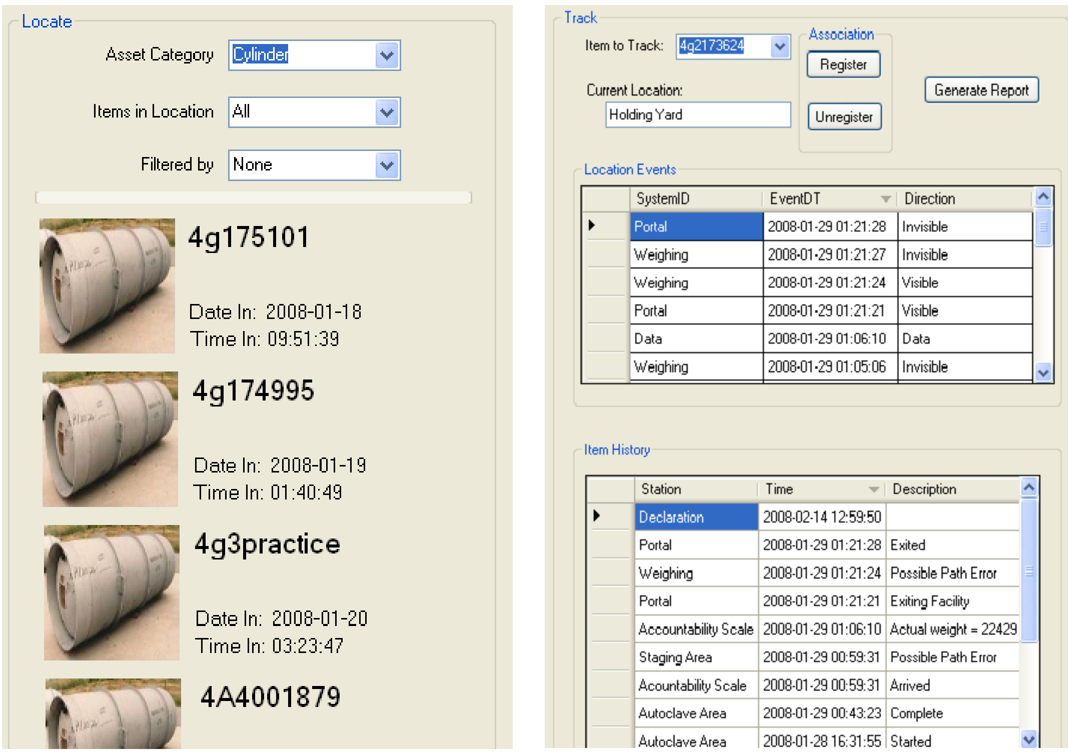
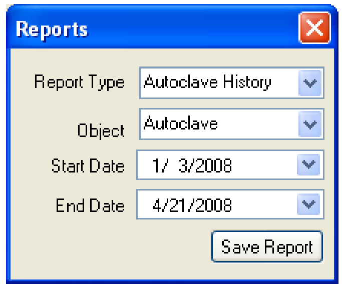


Fig. 10. Data-reviewing dialog boxes.

6.10 REPORT GENERATION

Custom reporting for both the operator and the inspector is a very important aspect of the CATS software. Several report formats are available via the Generate Reports menu. The reports menu will generate reports from the CATS database that are saved as pdf documents. Five report types are currently included in CATS: Facility History, Facility Status, Autoclave History, Cylinder History, and Cylinder List. This software can be easily configured to generate other types of reports. Figure 11 shows the report generation dialog box and a sample report of all tagged cylinders that were processed through a selected autoclave.



Cylinder Accountability and Tracking System
Autoclave History Report

Facility: Oak Ridge National Laboratory
Generated: 8/21/2008 11:35:20 AM
By: jy4

Report For: Autoclave
Report Begin Date: 2008-01-03
Report End Date: 2008-04-21
Cylinders Processed: 25

Item Identifier	Entry Date/Time	Exit Date/Time
4g175101	2008-01-17 14:34:29	2008-01-18 01:00:13
4g174995	2008-01-18 11:10:18	2008-01-19 01:32:41
4A4001879	2008-01-19 01:39:07	2008-01-19 13:13:44
4a1002476	2008-01-19 13:30:02	2008-01-19 13:40:30
4g3practice	2008-01-20 03:16:45	2008-01-20 03:23:47
4g4174017	2008-01-24 10:34:57	2008-01-25 03:20:20
4a2001551	2008-01-25 15:59:48	2008-01-26 15:03:06
4a4002463	2008-01-26 15:18:14	2008-01-27 17:13:00
4a2pp5031	2008-01-27 17:34:12	2008-01-28 15:49:32
4g2173624	2008-01-28 16:20:48	2008-01-29 00:58:23
4a4002161	2008-01-29 01:12:52	2008-01-30 22:45:26
4a2001988	2008-01-30 22:54:10	2008-02-02 01:47:31
4g4174661	2008-02-02 09:54:39	2008-02-02 12:30:02
4g5175170	2008-02-16 21:23:46	2008-02-16 21:51:31
4g6174299	2008-02-17 08:42:22	2008-02-17 08:50:11
4G7174884	2008-02-18 20:28:00	2008-02-20 00:59:11
4g174638	2008-02-21 22:06:34	2008-02-23 13:01:06
4g4174637	2008-02-23 13:16:18	2008-02-25 00:42:36
4g4174150	2008-02-27 00:03:15	2008-02-28 12:46:36

Fig. 11. Example of the report generation features of CATS.

6.11 MAILBOX DECLARATION MECHANISM

The Mailbox declaration is based on providing agreed-upon information from the CATS database from items that are considered declarable. When the declare button is pressed, the declarable items from the database that have not previously been declared are read from the database, encrypted via Pretty Good Privacy (PGP) and either written as a file or packaged as an attachment to an e-mail message. The viewer or recipient of the file can then enter the privacy key to access the information. This mechanism allows select information to be securely shared without requiring any direct access to the database. Table 3 shows an example of a Mailbox declaration.

Table 3. Example of Mailbox Declaration

ID	Station	Time	Description	Declareable	Declared
1	Attaching Area	2008-08-19 15:00:14	RF Tag Association = DrumTag	No	No
2	Attaching Area	2008-08-19 15:00:14	Declared weight = 100.0	Yes	Yes
3	Attaching Area	2008-08-19 15:00:14	Tare weight = 58	Yes	Yes
4	Attaching Area	2008-08-19 15:00:14	Assay = .7	No	No
5	Attaching Area	2008-08-19 15:00:14	Container Type = Drum	No	No
6	Attaching Area	2008-08-19 15:00:14	Material Code = 014	No	No
7	Attaching Area	2008-08-19 15:00:14	Autoclave = AC1	No	No
8	Attaching Area	2008-08-19 15:00:14	Process = Parent Transfer	No	No
9	Attaching Area	2008-08-19 15:00:14	Inspected = Yes	No	No
10	Staging Area	2008-08-19 15:00:43	Arrived	Yes	Yes
11	Entry Video	2008-08-19 15:00:43	http://192.168.0.2/cameraServerImages/Cam6/img_378464.jpg	No	No
12	Autoclave Area	2008-08-19 15:01:29	Arrived	Yes	Yes
13	Autoclave Video	2008-08-19 15:01:29	http://192.168.0.2/cameraServerImages/Cam4/img_378615.jpg	No	No
14	Autoclave Area	2008-08-19 15:09:15	Started	Yes	No
15	Autoclave Area	2008-08-19 15:09:26	Complete	Yes	No
16	Acountability Scale	2008-08-19 15:09:37	Arrived	Yes	No
17	Weighing Video	2008-08-19 15:09:37	http://192.168.0.2/cameraServerImages/Cam5/img_380175.jpg	No	No
18	Accountability Scale	2008-08-19 15:09:50	Actual weight = 58.5	Yes	No
19	Staging Area	2008-08-19 15:09:59	Exiting Facility	Yes	No
20	Exit Video	2008-08-19 15:09:59	http://192.168.0.2/cameraServerImages/Cam6/img_380241.jpg	No	No
21	Portal	2008-08-19 15:10:02	Exited	No	No

6.12 VIDEO CAPTURE MECHANISM

Although not used at the USEC facility, the CATS system can trigger cameras to record short video snippets initiated by reader visibility events. The CATS camera server has been designed to operate as a Windows service. It captures images periodically to the hard drive, currently set at 300 ms between images (3.33 frames per second). The images are acquired from the cameras using an http web interface. The maximum rate of image capture has not been determined: however, 5–10 frames per second will likely be the limit with the current camera server. A method of triggering camera events is available using an http request. The request returns the network location of the event frame, which can be used to load the entire stored video. When an event is triggered, the pre-buffer is saved along with a post-buffer. They are currently set to 50 frames each. All images are stored to a local web server, where they can be accessed over the local network for playback. A simple method for playback was created in the CATS software for video playback. A trigger is initiated by the notification of events from the RF tag readers. Figure 12 shows a video clip triggered by an RF tag passing a reader, which was demonstrated at the Safeguards Workshop held at ORNL in

(a) (b)

Fig. 12. CATS event-triggered video capture: (a) network camera with antenna and (b) video clip triggered by an RF-tag visibility event.

July 2008. This could be used to verify that actual cylinders were really moved through the appropriate monitored checkpoints.

6.13 VISIBILITY EVENT DATA ANALYSIS AND PERFORMANCE

For each tagged cylinder that is processed and tracked, a manual data log was kept by operators. This was done for this test to be able to compare the manual data log with the visibility (tracking) 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 Fig. 13.

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	

Fig. 13. 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, a data event that is generated during tag registration, assigns a specific tag to a cylinder (see Fig. 8). This tag registration event can occur at a time different from when the tag was actually attached to the cylinder, since the same people may conduct the tag attachment and data entering. 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 h and 11 min 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 was loaded onto 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 facility exit where it passes by the exit antenna on its way to the cylinder storage yard. A summary of the manual log data and the system's data is provided in Fig. 14. Correlation between the actual data captured and the manual logs has been very good.

Cylinder Number	Notes	Time the Tag was attached	Tag	Placed At Staging	Placed Into Autoclave	Shell Closed	Shell Opened	Removed From Autoclave	Acountability Scale	Cylinder Exits Facility
175101	Empty Test Cylinder to optimize tag and Autoclave antenna alignment.	1/17/2008 13:48	3							
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	Tag only		3							
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	No reads after entering 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	Intermittent	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
174661 RF	Was registered after already being at autoclave	2/2/2008 2:05	4	*	*	2:21	9:54	12:30	12:32	12:53
174661 Log		2/2/2008 1:40		2:03	2:05	2:20	9:40	12:30	12:35	12:55
174638 RF	Registered after autoclave	2/21/2008 22:05	2	*	22:06	22:22	12:38	13:01	13:03	13:13
174638 Log		2/21/2008 21:55		21:55	22:00	22:30	12:38	13:03	13:10	13:23
174637 RF		2/23/2008 12:57	4	17:12	13:16	13:37	0:31	0:42	0:44	0:55
174637 Log		2/23/2008 13:10		13:20	13:22	13:44	0:15	0:40	0:50	0:50
174150 RF		2/26/2008 23:43	4	23:59	0:03	0:22	12:24	12:46	13:06	13:07
174150 Log		2/26/2008 23:40		0:00	0:05	0:25	12:25	12:30	no data	13:07

Fig. 14. Cylinder processing and tracking summary.

Cylinder Number	Notes	Time the Tag was attached	Tag	Placed At Staging	Placed Into Autoclave	Shell Closed	Shell Opened	Removed From Autoclave	Acountability Scale	Cylinder Exits Facility
175161	Empty Test	2/26/2008 10:25	4							
175171	Empty Test	4/10/2008 10:22	4							
174084 RF	Intermittent	4/14/2008 21:16	4	21:39	*	*	2:21	3:00	8:30	9:03
174084 Log		4/14/2008 21:00		21:40	21:42	21:55	2:00	3:00	8:30	9:05
288 RF		4/16/2008 13:27	4	13:38	13:41	13:52	23:40	1:08	1:11	1:23
288 Log		4/16/2008 1:00		13:25	13:45	14:00	23:50	1:10	1:20	1:45
3254 RF	No reads after entering autoclave	4/16/2008 22:29	2	1:14	1:16	1:35	*	*	*	*
3254 Log		4/16/2008 22:30		1:14	1:16	2:25	8:15	8:35	8:40	8:50
3287 RF		4/18/2008 8:48	4	8:50	8:53	9:12	14:19	14:37	14:38	14:39
3287 Log		4/18/2008 8:30		8:47	8:55	9:15	14:25	14:40	14:45	15:05
3336 RF		4/19/2008 15:07	4	15:15	15:16	15:27	8:55	9:40	10:03	10:12
3336 Log		4/19/2008 15:12		15:17	15:19	15:40	9:15	9:40	10:05	10:12
2050 RF		4/22/2008 0:39	4	0:39	0:42	1:00	16:13	16:33	16:38	16:47
2050 Log		4/22/2008 0:30		0:39	0:42	1:05	16:10	16:40	16:41	16:48
1099 RF	No reads after entering autoclave	4/26/2008 10:22	4	10:23	10:25	10:53	*	*	*	*
1099 Log		4/26/2008 10:21		10:23	10:24	10:55	15:50	14:35	14:45	14:55

Fig. 14 (continued).

7. RESULTS AND OBSERVATIONS FROM PROOF-OF-CONCEPT DEMONSTRATION

The CATS was installed at the Portsmouth, Ohio, autoclave facility in January of 2008. The tags were attached to cylinders as they entered the autoclave facility. All tags were removed from cylinders after exiting the facility (in the cylinder yard) and then used again on cylinders entering the facility.

7.1 SUMMARY OF DATA AND OBSERVATIONS

The data collected and observations to date from the proof-of-concept evaluation can be summarized as follows:

For the tags:

- Four specially prepared RF tags were used during testing.
- Two tags did not survive their initial autoclave process exposure (which involved being heated for up to 30 h with low-pressure steam to approximately 230°F). This failure occurred primarily due to a tag design that did not seal well enough to protect the paper RFID tag from curling and delamination of the antenna.
- One tag began to fail after multiple runs in the autoclave. This was due to warping of the tag housing.
- Tag performance did not seem to be affected by thermal shock (of leaving the autoclave and moving into the cylinder yard during January temperatures of less than 10°F).
- No tags showed any significant damage due to operational handling and cylinder moves.
- The two tags that survived the initial autoclave process continued to operate properly for many successive autoclave process cycles. They eventually failed due to warping of tag housing, which eventually led to seal failure or the same type of failure that occurred with two of the tags during their initial run through the autoclave.

Detection summary:

- There were 26 total tagged cylinders run through the system over a 5-month period (including downtime for autoclave maintenance and calibration).
- Fifteen cylinder runs were in agreement with log sheets.
- Two runs occurred where the operators initially forgot to register the tags until they had moved to the autoclave. (After the late registration, these detections were in agreement with the log sheet.)
- Four runs were test runs with empty cylinders that went through the entire tracking process.
- Three runs showed tag failure at autoclave. (Detections were in agreement with the log sheet prior to the failure.)
- Two runs were started but not detected afterwards, because the antennae had been turned off to avoid RF interference with NDA equipment and operations personnel forgot to turn them back on.

The four paper-based tags tested during this project were high-temperature tags, all of which eventually failed due to repeated exposure to moisture in the autoclave. The pressurized steam in the autoclave seeped through the tag housing (which slowly warped due to repeated exposure to high temperatures) and delaminated the antenna structure of the tag, causing the failure. One tag that was sealed with a cork gasket absorbed water, which attenuates RF transmissions, and could not be read when it exited the autoclave. Several tags did survive multiple runs through the autoclave and failed only after the housing wore out and let in the hot steam. Future efforts will require more focus on ensuring hermetic sealing and improved housing for tags and their associated components. It should be noted that metal housing is typically not an option for RF tags since it blocks RF transmissions. Thermal shock did not seem to be an issue during this phase of testing, but could have been a factor in some of the sealed tags that began to leak over time.

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. Tags also will require tamper-resistant packaging and an approved form of data authentication. Current work involves following commercial efforts to provide these types of features along with technology development efforts. The rapid progression of technology should make cylinder tracking an attractive option for near-term IAEA consideration.

7.2 RF INTERFERENCES AT PORTSMOUTH

Before the RF-based CATS could be put into operation at the autoclave facility, several tests for RF interference with operating equipment had to be conducted. The first set of tests involved turning on all of the CATS equipment and then turning on all RF-based systems in the autoclave facility—one device at time. The first device tested was the radio-controlled bridge crane used to move the 14-ton cylinders. This crane operated at a different frequency than the 900-MHz CATS equipment and exhibited no effects from the CATS.

The next device tested was an RF-based portable radiation dosimeter, which was a crucial component of the radiation safety system. There were two versions of this device at the site: an older analog-based model and a newer one composed primarily of digital electronics [see Fig. 15(a)]. Although the analog model had problems while CATS was operating, the newer digital one did not. The requirement during operation of CATS was to use only digital dosimetry devices.

The other device found to be prone to RF interference was the equipment on an NDA measurement cart [see Fig. 15(b)]. This equipment was also analog based but was required for use in the facility. The decision was made to turn off the RF readers when NDA measurements were made. Digital-based NDA equipment in the area seemed to be immune to RF interference.

(a) (b)

Fig. 15. Measurement of RF interference in the autoclave facility: (a) RF-based dosimetry and (b) NDA measurement cart.

8. OPERATIONAL EXPERIENCE AND LESSONS LEARNED FROM THE PORTSMOUTH CATS INSTALLATION

8.1 OPERATOR EXPERIENCE

One key objective of this field trial test was to obtain feedback from the operations personnel involved in the testing of the CATS, as well as the Material Control and Accounting (MC&A) personnel familiar with the testing performed at the USEC site. The list of survey questions contained in Appendix B was developed for use in the interviews conducted with individuals at the site. This section summarizes the feedback received from those interviews, as well as feedback received during the Safeguards Workshop held July 2008 in Oak Ridge.[8]

8.2 USE OF THE RF TAGS

Some early difficulty was noted in mounting the tags on the cylinders. However, these problems were addressed and resolved, and attaching the RF tags was not a significant issue during the performance of the tests. Some operators experienced more difficulty than others did, which may be attributed to the varying levels of mechanical skills. The operators recognized that this was a proof-of-concept test and that future design activities would include identifying a more effective approach for attaching the tags. As such, the tag attachment scheme was chosen for expediency due to its simplicity and to address safety concerns. Future attachment schemes will be more application specific.

Several individuals noted that the best approach would be one in which the RF tags, or similar devices, were provided as an integral part of the cylinder. This approach would require the tags to have a reliable life expectancy of 5 years, which is the time lapse between the required “hydrotesting and recertification” of the cylinders.

The operators provided input on the locations on the cylinders where tags could be read while providing the most physical protection to the tag during cylinder handling. One of the important considerations in the attachment of the tags to the cylinders was to ensure that there were no impacts to the safety systems of the autoclaves. During the performance of all of the test runs in the autoclaves, no problems were encountered with the tags detaching from the cylinders and potentially affecting the autoclave safety systems.

There were some reliability problems with the early tags. Occasional problems with the cylinder tag being improperly read by the antenna system were usually corrected by unplugging and reconnecting the antenna and then rescanning the tag. These problems were corrected early in the testing by fixing the tag enclosure and adjusting the antennae gain for each location.

8.3 SYSTEM USER INTERFACE

The majority of the operators surveyed felt that the software used to operate the system was "user-friendly." Because of the rotating shifts and rotating job assignments used in the X-344 Transfer Facility, many of the operators had to reacquaint themselves with the system when they were assigned to Autoclave (A/C) #1. However, this was not a significant issue and generally required only minimal guidance from the facility's first-line managers.

8.4 PLANT SYSTEM INTERFERENCE

The only system interference noted was during the NDA monitoring of inbound cylinders. (It should be noted that previous interferences with electronic dosimetry were solved by using the digital dosimetry mentioned in Sect. 7.) The NDA instrumentation used was an older technology, which caused interference with the CATS system. This problem was addressed and corrected by unplugging the tower at the scale during the NDA measurement activities. The tower was reconnected after the NDA measurements were obtained. During the planning for these field tests, consideration was given to potential interference with remote controlled cranes and facility monitoring equipment; however, there were no instances of interference with these systems during any of the testing.

8.5 ENHANCING FACILITY SAFETY

One of the Design Basis Accidents for an enrichment facility is the rupture of a cylinder containing liquid UF_6. The USEC facility utilizes a Lockout/Tagout (LOTO) system to prevent the movement of cylinders containing liquid UF_6 until the cylinder contents have sufficient time to solidify. This is accomplished by placing the cylinder in a "cooldown" area to allow the contents to solidify before further movement. The manager of the MC&A organization and the operators felt that the CATS system could potentially be integrated with the LOTO system to provide an increased margin of safety in preventing the movement of "liquid cylinders." The CATS could be utilized to capture the time that cylinders were removed from the autoclave, and an antenna placed at the entry/exit path of the cooldown area could be used to send an alarm that the cylinder was being moved from the area before to the established cooldown period. This alarm would need to provide local notification so that further movement could be stopped immediately.

The cylinders are required to be inspected for any defects or deficiencies that would result in an unsafe operating condition. CATS could be utilized to "flag" cylinders with deficiencies, such as a rejected cylinder valve, in order to prevent the inadvertent heating or use of such a cylinder. These cylinders are presently identified through the plant's tagging system; however, CATS could provide "defense in depth" for preventing the inadvertent use of "flagged" cylinders.

8.6 IMPLICATION FOR MATERIAL CONTROL AND ACCOUNTING AT THE SITE

The ultimate goal of any nuclear material accounting system is to provide real-time knowledge of the quantity and location of all nuclear material at the facility. Since UF_6 must be kept in cylinders when it is not physically part of the enrichment process, the more accurately a site can track the cylinders and their movements, the more effective the accounting will be.

Most enrichment plants utilize some form of computerized accounting system to track UF_6 materials. Thus, the integration of the RF-based system with the computerized nuclear materials accounting system could provide increased effectiveness of tracking and accounting for the nuclear materials. By providing automatic and real-time cylinder position input into the computerized accounting system, manual entry is virtually eliminated, making personnel more efficient and reducing inaccuracies due to human error.

Another potential use of CATS is monitoring what cylinders are authorized for movement. Depending on the authorization basis for which cylinders are moved, the use of CATS on a real-time basis could indicate the unauthorized movement of a cylinder. In facilities (such as Portsmouth), which have cylinder movements preauthorized by a group independent of production, the RF signal could be used to flag a move that was not part of the authorization. Of course, the criteria for such a flag, and how it alerts the proper personnel, would be site specific. However, at a minimum, it could be used to initiate an investigation.

8.7 REDUCTION OF ACCOUNTING INPUT ERRORS

As has already been mentioned, one area in which RF technology integration would enhance the accountancy of the nuclear material is in reducing accounting/input errors. The transposition of numbers when entering data into the accounting system is one of the more common errors. Depending upon the way information is entered into the accounting system, an RF tag on the cylinders can reduce such errors. This is especially true when the RF tag number is captured along with a weight measurement, as replicated in the demonstration at Portsmouth. If the data captured during the test were integrated with the site MC&A system, the process would provide error-free input of which cylinder was being weighed. Although the Portsmouth operation required the operators to input the weight manually into the data program, it is easy to see how capturing this weight electronically could greatly enhance the accuracy of the operation. Such a system would provide transposition-error-free input to the accounting system regarding what cylinder was weighed, when, and what that weight was.

Although not demonstrated during the Portsmouth test, the interviews also revealed another area in which RF tags can significantly reduce transposition errors: the physical inventory-taking process. Typically, a site will require periodic inventory of cylinders in storage lots. The most effective way to ensure the inventory is complete is to perform the inventory without the use of a preprinted declaration. This requires the operators to physically record each cylinder present and not just check each off a preprinted list. One of the most common errors when taking such a physical inventory is transposing cylinder numbers. The use of RF tags would eliminate the transposition errors associated with these inventories. With proper programming and setup, RF antennae could be placed in cylinder lots and an inventory taken almost instantaneously and without error.

8.8 IMPROVEMENTS TO REAL-TIME ACCOUNTING

As stated earlier, one of the goals of the accounting system is to provide real-time information on the nuclear material and cylinders. As demonstrated at the Portsmouth site, simple programming can be used to capture the exact time at which cylinders are moved, weighed, etc. If the site could capture the data directly and update the accounting system in real time, it would enhance its effectiveness. This may require some programming on the part of the facilities, but the benefit of having the error-free data in real time would be attractive. Even if the data captured were not directly integrated with the accounting system, the facility could use these data to ensure that all transactions have been properly entered into the database and in the correct sequence. Similarly, the installation of additional antennae in and around cylinder paths and storage lots could provide real-time data on cylinder movements.

8.9 COMMENTS BY MATERIAL CONTROL AND ACCOUNTABILITY MANAGER

In discussing the use of such a system at Portsmouth, the MC&A manager felt that in its current format and with the present operating conditions, the data collection would have no negative and minimal positive impact on the MC&A effectiveness. Because Portsmouth utilizes a preauthorization basis for its transfers, which includes a check of the item being moved by both the shipper and the receiver, the movement of the wrong cylinder should be caught without the need for the CATS. Portsmouth personnel did note occasions where cylinders with very similar numbers have been mistakenly moved. However, these occurrences were rare and were typically identified with minimal impact to operations/accounting. The manager did feel that the system could be used to validate the accounting data being generated from the operations personnel and to ensure timely entry of the data into the database. By comparing the data captured from the RFID system with the pending transactions, the MC&A Department can ensure that the cylinder moves are updated in the accounting system as required.

One of the key concerns of the MC&A manager was the cost of implementing such a system. Although, the potential benefits (as discussed above) are present, the cost to a site to implement them—including the cost of the RF tags, the antennae, and all of the necessary programming and interface—may be cost prohibitive. This would be especially true for a low-enriched processing facility, such as the enrichment sites declared under IAEA safeguards. He felt CATS would prove more useful in high-enriched operations, where safeguarding is more stringent and demanding.

In summary, the manager felt that the implementation of such a system by the IAEA would have no negative impact to the site MC&A system and could possibly provide some enhancement to the reconciliation process of real-time data entry and transaction reconciliation.

8.10 INTERFACE WITH OTHER EQUIPMENT AND SYSTEMS

During the Safeguards Workshop held July 2008 in Oak Ridge,[8] a number of groups observed the CATS field-trial demonstration. There were numerous comments regarding the value of having the CATS tracking system integrated with a camera surveillance system to record activities during the time a cylinder is being processed through the operations of a facility. The capability to integrate the CATS system with other equipment, such as load cells and NDA monitoring instrumentation, was also discussed as a positive design approach for improving the safeguarding of a facility’s operation. Properly designed, CATS provides the capability for notification that an “undeclared” cylinder is being processed in a facility.

The enrichment operations at the Portsmouth facility were discontinued in 2001; however, discussions were held with members of the former Production Planning and Scheduling Organization. These individuals saw future potential advantages of having a CATS-type system to interface with a system that tracked the movement of all cylinders on the site. RF tags, or similar devices, could be utilized to track customer feed cylinders, product cylinders and sample containers that are utilized to provide enrichment services for the company’s customers. By integrating CATS with a Production Planning and Scheduling System, the opportunity exists to minimize the need for manual data entry and to eliminate the possibility of transposition errors. Many of the reports and shipper/receiver documentation required for the management of customers’ orders could be computer generated in the future.

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/RF interferences and ac/dc magnetic fields;
- survivability from operational disturbances (vibration, dropping, and rough handling) at the plant and during transport;
- resistance to software viruses;
- resistance to tampering; and
- multiyear durability, including long battery life, if applicable.

9. FUTURE EFFORTS AND SYSTEM DESIGN ISSUES TO ADDRESS

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.[5] However, in moving forward with a proposed CATS concept, it is important that issues and vulnerabilities be clearly identified. The effectiveness and added benefits of RF technology as a security measure need to be evaluated at the safeguards-systems level. Diversion path analysis and evaluation of effectiveness and efficiencies of RF technology in safeguards applications will help delineate requirements necessary to design a robust system. Vulnerability 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.

9.1 ISSUES IDENTIFIED

A team of RF technologists and safeguards professionals met in Oak Ridge in May 2008 to discuss vulnerability issues and technical and functional requirements that would need to be addressed for a next-generation RF-based cylinder tracking system to be acceptable for IAEA safeguards.

The following is a list of near-term steps that were identified:

- engaging stakeholders (operators, IAEA, etc.) in developing full system requirements;
- integrating the system with continuous load cell (weighing) measurements;
- working with Los Alamos National Laboratory on supporting Global Positioning System tracking of cylinders from a shipping site to the receiving site;
- evaluating other RF technologies; and
- developing and testing tamper-indicating attachment options.

9.1.1 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 work. Below is list of some known system vulnerabilities that need to be addressed, along with some potential solutions.

Tag attachment	Solutions: Embedded technologies
Tamper detection	Solutions: Tamper-indicating packaging, smart tags
Battery lifetime	Solutions: Passive tags, low-power circuitry, batteries with extended life
Environmental concerns	Solutions: Improved tag packaging technologies
RF interference	Solutions: Site and route survey, ultra-wide-band and spread spectrum
Shielding	Solutions: Low frequencies, heartbeat (for an active tag), multiple antennae
Spoofing/authentication	Solutions: Advanced cyber security techniques

Data security/integrity	Solutions: Advanced cyber security techniques
Orientation and range	Solutions: Distributed readers, ultra-wide-band antenna design
Location of readers	Solutions: Tamper-indicating packaging and location sealing

It also will be important to better define the system requirements for cylinder tracking within facilities throughout the globe. Such requirements include identifying which radio frequencies are acceptable for use, best locations for secure attachment of antennae and readers, and appropriate implementation of site-specific rules-based data processing. All solutions will require repetitive testing and system evaluations. The implementation of red/blue team evaluations for all proposed system designs is recommended.

Some issues that need to be addressed for system use include

- operator and state or IAEA acceptance,
- international standards,
- export control, and
- system costs.

9.1.2 Security and Cultural Issues

Wireless systems need to be evaluated to determine whether they constitute an inventory or 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 perform as specified and provide adequate protection of sensitive information.

9.1.3 Reliability

Future efforts will need to address and demonstrate the reliability of an RF tracking system. The RF technologies must be compared with current approaches and existing systems to demonstrate clear advantages in both cost and performance. Data exist from some similar types of facility installations that detail cost savings of wireless systems versus wired systems during system installation and operation. Past efforts with bar-code technology for nuclear material inventories have typically suffered from human error issues (i.e., items being missed or not scanned) that forced spending additional time to obtain reconciliation. One existing study[2] evaluates RF-based monitoring for safeguards within a nuclear material storage area, but more data would be needed to determine the reliability of this technology for cylinder tracking applications.

Tags must be sufficiently durable to survive the environmental and operational environments at a facility that processes, stores, and transports UF_6 cylinders.

9.2 CATS FUNCTIONAL REQUIREMENTS

Proof-of-concept testing at Portsmouth provided insights into some of the basic functional requirements needed to achieve the operational and safeguards readiness desired for CATS. These requirements were also brainstormed at the May 2008 meeting of experts in Oak Ridge. Below is a list of basic functional requirements that were considered essential to fielding a credible system for IAEA safeguards.

Tag including mounting/attachment

- Ability to withstand a variety of environmental exposures
- No degradation of tag performance over a 2–5-year period
- Resistant to normal handling and transportation practices
- No compromise to the integrity of the cylinder

Tamper detection

- Detect tag modification, removal, and replacement
- Advantages of passive versus active RF devices (How important is timely detection of tamper attempts?)
- Indication of tampering for readers and critical system components

Battery lifetime (for battery-powered tags)

- Communication of status of battery life
- Shelf life
- Operational life
- Replaceability

Environmental concerns

- Temperature ranges at –50°C to +150°C for anticipated cycles per year
- Steam bath at 10 psi
- Other cylinder heating ranges (hot box)
- Radiation (X-rays, gamma, neutron exposure)
- Weather exposure (rain, wind, dust, extreme sunlight)

Cost

- Commercially available
- Requires no or only minor modifications to facilities or cylinders
- Ability to be exportable or available internationally

9.3 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.

- Must support radio frequencies approved for use internationally
- Must not interfere with other equipment frequencies or be vulnerable to other frequencies
- Resistant to jamming detection/denial of service
- Resistant to shielding
- Watchdog heartbeat for active tag
- Resistant to spoofing/amenable to authentication
- Data security and integrity
- Insensitive to orientation
- Location accuracy and read range
- RFID standard versus proprietary

9.4 POTENTIAL DIVERSION SCENARIOS

As with any new safeguards approach or system design, a site-specific diversion path analyses will need to be completed. However, the team that met in Oak Ridge in May 2008 identified several potential diversion scenarios where an appropriately designed RF-based CATS-type system may provide improved detection of material diversion.

- Feed/Withdrawal operations
- Extra (unidentified, undeclared, unauthorized) cylinders at the facility
- Abnormal processing paths
- The need for weigh stations (and roughing scales) to have a way to identify cylinder and an assay measurement to go to Mailbox declaration with weight
- Approaches for different areas
  - In processing facility
  - Storage yards
  - In transit or during shipment in commerce
  - Cylinder failure from weather or wear (e.g., valve failure)
  - Unusual operating conditions

9.5 OTHER LAYERED TECHNOLOGIES TO IMPROVE OVERALL SYSTEM EFFECTIVENESS

By appropriately layering other technologies into the safeguard system design, a system can be provided that enhances effectiveness of the safeguards approach and facilitates the reconciliation of anomaly events. Some of the layered components one might consider for integration with CATS are listed below.

- Load cells
- Reusable tamper-indicating devices
- Image recognition/video technology
- Radiation detection sensors
- Tamper-indicating technologies for packaging and/or attachment (such as the reflective particle tag)

10. CONCLUSION

The results of this project demonstrate the feasibility of constructing RF devices that can survive the operational rigors associated with the transportation, storage, and processing of UF_6 cylinders. It is also clear that many operators who have observed the technology recognize facility benefits that can improve their domestic MC&A systems. Custom report generation was one of several features operators regarded as beneficial.

The elements of the CATS rules-based architecture highlight a flexible approach for supporting the effective integration of layered safeguards methods for site- and scenario-specific monitoring and asset tracking applications.

Many of the proposed options and needs for improving the safeguards aspects of the technology center on the need to address vulnerability concerns associated with the technology and the need to conduct further evaluations of the technology under other types of operating conditions. The system must demonstrate reliability for providing enhanced data security and remote monitoring capabilities to the IAEA. If successful, RF-based monitoring systems have the potential to significantly enhance the tools available to the IAEA for conducting international safeguards inspections at facilities that use UF_6 cylinders.

If future efforts focus on addressing the issues and system needs identified in this report, the safeguards readiness of the technology will be significantly improved—to the extent that a more efficient and effective system for detecting material diversion and undeclared production can be made available for IAEA consideration.

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APPENDIX A
TYPICAL LOG SHEET AND DATA LOG

X344 PARENT CYLINDER TO BE SAMPLED

AC# 1 CYL. 173624

CYLINDER HAS BEEN INSPECTED
YES ✓ *NO*___

PARENT CYLINDER INFORMATION

ASSAY .7110

MAT. CODE 014

WEIGHTS GROSS 22499 lbs

TARE 2545 lbs

NET 19.954 lbs

Sample 2S Container #__________

Sample 2S Container Tare Wt.__________

File: Cylinder Info

Revision 2

TAG #2

ATTACHMENT - A

UF6 Cylinder Tracking System Field Test Data Log

Data Point	Log Entry	Initials	
1. Cylinder identification number	173624	SJH	
2. Time the tag was attached to the identified cylinder	Date: 1/28/08 Time: 1615	SJH	
NMC&A notifies that tag has been attached	Date: 1/28/08 Time: 1640	[illegible]	1
3. Time when the cylinder is placed at the staging area (Antenna A) (North Hi Bay)	Date: 1/28/08 Time: 1620	SJH	
4. Time the cylinder was placed into the autoclave;	Date: 1/28/08 Time: 1623	SJH	1
5. Time the autoclave shell was closed	Date: 1/28/08 Time: 1635	[illegible]	
6. Times the autoclave shell is opened during heating and processing of the cylinder (1st opening)	Date: 1/28/08 Time: 2315	[illegible]	1
2nd opening	Date: 1/29/08 Time: 0030	[illegible]	
3rd opening	Date: 1/29/08 Time: 0040	[illegible]	
4th opening	Date: 1/29/08 Time: 0050	[illegible]	
7. Time the cylinder is removed from the autoclave	Date: 1/29/08 Time: 0100	[illegible]	
8. Time the cylinder is placed on the accountability scale (Antenna A)	Date: 1/29/08 Time: 0100	[illegible]	
9. Time when the cylinder exits the facility (Antenna C)	Date: 1/29/08 Time: 0125	PM	
10. Time the tag was removed from the identified cylinder	Date: 1/29/08 Time: 0130	[illegible]	
NMC&A notifies that tag has been removed	Date: 01/29/08 Time: 0235	[illegible]	1
11. Time and Description any abnormal events, such as the presence of HF in the autoclave during the heating cycle, should be recorded. Description/Comments; NONE	Date: 1/29/08 Time: ____	[illegible]	

APPENDIX B
SURVEY QUESTIONS FOR PROOF-OF-CONCEPT FIELD TEST

Benefits to the operator:

1. What is the basic benefit of the Cylinder Accounting & Tracking System (CATS) from an operator's standpoint?
2. Can this system assist the operator with more efficient performance of his tasks?
3. How is this technology different from what the operator is presently using?
4. As a facility operator, would you be interested in deploying this technology?
5. From an operational perspective, would implementation of an automated cylinder tracking system enhance or degrade your ability to maintain regulatory compliance?

Interface with the operator:

1. How "friendly" was the software user interface with the operator?
2. Did the utilization of this system present any significant obstacles to the routine operation of the facility?
3. What changes would you make to improve the interface with the operator?
4. Can the system be operated in a safe manner?

System Reliability:

1. Were there problems encountered with the reliability of the system?
2. What are the most significant weaknesses of this technology?
3. What were the most significant problems encountered with this system during the performance of the test?

System Improvements:

1. What are some recommended improvements for this system?
2. What are some thoughts for reducing the costs for installing and/or operating this system?

Other comments:

1. Please provide any additional comments regarding the installation, operation, and future implementation of this system.

Interface with Management Systems:

1. From a management perspective, can this system be effectively implemented at a large, commercial facility?
2. Would integration/implementation of such a system enhance or degrade the site's ability to track commercial assets?
3. From a management perspective, list the top three benefits you see regarding utilization of an automated CATS.

    a. ____

    b. ____

    c. ____

4. List the top three challenges you see regarding utilization of an automated CATS.
   a. ____
   b. ____
   c. ____

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