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In-Born Radio Frequency Identification Devices for Safeguards Use at Gas-Centrifuge Enrichment Plants

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Abstract:

Global expansion of nuclear power has made the need for improved safeguards measures at Gas Centrifuge Enrichment Plants (GCEPs) imperative. One technology under consideration for safeguards applications is Radio Frequency Identification Devices (RFIDs). RFIDs have the potential to increase IAEA inspector's efficiency and effectiveness either by reducing the number of inspection visits necessary or by reducing inspection effort at those visits. This study assesses the use of RFIDs as an integral component of the "Option 4" safeguards approach developed by Bruce Moran, U.S. Nuclear Regulatory Commission (NRC), for a model GCEP [1]. A previous analysis of RFIDs was conducted by Jae Jo, Brookhaven National Laboratory (BNL), which evaluated the effectiveness of an RFID tag applied by the facility operator [2]. This paper presents a similar evaluation carried out in the framework of Jo's paper, but it is predicated on the assumption that the RFID tag is applied by the manufacturer at the birth of the cylinder, rather than by the operator. Relevant diversion scenarios are examined to determine if RFIDs increase the effectiveness and/ or efficiency of safeguards in these scenarios. Conclusions on the benefits offered to inspectors by using in-born RFID tagging are presented.

1. Introduction:

Recent advances in Radio Frequency Identification Devices have made them an attractive option to study for safeguards applications. RFID tags can be applied to an object to identify and associate that object with certain information. This information can be transmitted wirelessly via radio waves to a data-managing system, allowing items to be tracked with great ease, efficiency, and accuracy. As the technology continues to develop, RFID tags have become more affordable, robust, and readily available. These tags are currently used for a variety of industrial and commercial applications, particularly those which require managing large inventories. Their efficacy is highlighted by the decision of the U.S. Department of Defense to require the use of high data capacity active RFID to serve as unique identifiers (UID) for all items with a cost of $5000 or more as part of its inventory control system. The ability of RFID technology to facilitate item tracking with a high degree of accuracy in an efficient way has piqued the interest of international safeguards experts as having potential for tracking uranium hexafluoride cylinders, particularly at GCEPs and, thereby, improving either the effectiveness or the efficiency of the safeguards approach used by the International Atomic Energy Agency (IAEA) .

IAEA safeguards measures at GCEPs are still based largely on the outcome of the Hexapartite Safeguards Project, completed in 1983. These measures include regular inspections outside the cascade hall to verify the flow and inventory of declared material and Limited Frequency Unannounced Access (LFUA) visits inside the cascade hall to verify the absence of high-enriched uranium (HEU) production. Increases in the size of GCEPs, the introduction of flexible cascades, and the need to detect undeclared feed have made additional safeguards tools necessary. In a study conducted for the U.S. NRC, Bruce Moran presented four options for the safeguarding of a model GCEP, the last of which included the use of RFID tags to track cylinders. Moran's "Option 4" included the use of Mailbox declarations; Short-Notice Random Inspections; load-cell monitoring of Feed, Product, and Tails (F, P, and T); Continuous enrichment monitors (CEMO) at feed, product, and tails stations; and RFIDs placed on all F,P, and T cylinders with readers in all F/P/T Stations and accountability scales [1].

An analysis of the effectiveness and efficiency of RFIDs for use by the IAEA at GCEPs was conducted by Jae Jo (BNL), wherein he assumed Moran's "Option 4" safeguards approach was implemented at a model GCEP. His paper, "Radio Frequency Identification Devices: Effectiveness in Improving Safeguards at Gas-Centrifuge Uranium-Enrichment Plants," presented several diversion scenarios and analyzed the benefit to inspectors of RFIDs with respect to each scenario [2]. He concluded that RFID tagging significantly increases the efficiency of inspectors in determining the declared flow and inventory of feed, product, and tails cylinders, and it can improve the effectiveness of inspections in detecting undeclared materials.

Despite the overall benefit offered by RFIDs, the paper revealed several vulnerabilities of the RFID and subsequent diversion paths. In his analysis, Jo used the assumption of Moran that a passive RFID tag would be applied by the operator as cylinders are brought into the GCEP. This paper presents a similar analysis of the effectiveness of RFID tagging; however, it assumes that the RFID is attached at the birth of the cylinder, rather than by the operator. In addition, in order to isolate the benefits achievable by RFIDs, it is also assumed that the operator cannot defeat the seal, for example, by replacing it with a substitute seal or by falsifying the data, recognizing that such a seal may not exist at this time. Changes in value added and diversion paths as a result of these assumptions are presented.

2. Current Safeguards Practices:

Gas-centrifuge enrichment facilities declared for the production of low-enriched uranium (LEU) have three primary safeguards concerns:

1. The production and diversion of a significant quantity of uranium with enrichment greater than declared (in particular, HEU with $\geq$20% U-235),

2. The diversion of a significant quantity of declared uranium (particularly in the form of LEU product), and
3. The production of LEU in excess of declared amounts (e.g. using undeclared feed).

At present, IAEA inspectors fulfill these objectives by verifying the declared material balance through regular visits. This requires verifying the declared feed, product and tails assays, as well as the declared weights for the F, P, and T cylinders. It is assumed that the CEMO system can provide a gross-defects test for the feed and tails assay and a partial-defects test for the product assay. The IAEA's target value is a 50% detection probability, which is achieved through Non-Destructive Assay (NDA) partial-defects tests, the results of CEMO tests, and sampling/Destructive Analysis (DA).

3. Evaluation of Effectiveness of RFID tagging:

An evaluation of the benefit that RFIDs offer to the IAEA with respect to these objectives is presented below. The diversion scenarios used in this analysis focus on the vulnerabilities in the latter two objectives– the diversion of declared product or tails and the production of undeclared LEU from undeclared feed. The undeclared production of HEU is not addressed in this paper because this situation represents a major departure from normal plant operating conditions; namely, this is achieved primarily through the rearranging of cascade piping to send the material along a different path through the cascades. RFID tags are being studied as a way to facilitate and bolster material balance verification. This may not be the most effective way to safeguard against the undeclared production of HEU, which uses generally a combination of design information verification, environmental sampling, and in situ measurement of enrichment levels. However, further investigation of the value of RFIDs in this regard is needed. Much of the analysis is taken from Jo's paper and modified appropriately to account for the new assumption that the operator does not apply the tag. A summary of his analysis will be presented in brief; see the full paper for more details.

3.1 Assumptions

Questions exist about the viability of RFIDs from a technical standpoint; however, this paper treats only the systematic elements associated with the implementation of RFIDs. As such this paper assumes that the tag in use is an active tag that will not fail and can withstand the operating conditions of a GCEP. An active tag is assumed because of the advantages it offers over a passive RFID, specifically the increased difficulty associated with mimicking an active RFID. One possibility is to use an RFID that randomly generates an encrypted key, which would allow the inspector, operator and RFID reader to be certain the RFID signal is authentic. While the production of an unauthorized RFID is still viable, using an active tag would certainly complicate this scenario, thus adding depth to the safeguards approach.

It is assumed that the tag uniquely identifies each cylinder and is applied at the birth of the cylinder by the manufacturer, and it cannot be removed or tampered with without raising alarm. The manufacturer is responsible for reporting the type of cylinder that is associated with each tag to the IAEA. Upon receipt of the full feed cylinder, the operator places the cylinder on the accountability scale where the reader reads the RFID and the scale weighs the cylinder. The cylinder is then identified and associated with a weight, which is automatically recorded in the Mailbox system without any intervention from the operator. A similar procedure is followed for the arrival of empty 30B customer product cylinders.

3.2 Declared Material Balance

Inspectors visit GCEPs with enough regularity to achieve a 50% detection probability. At the time of inspection, the Interim Inventory List (IIL) is generated from the Mailbox declarations that the operator has made. The inspector then identifies the relevant cylinders in the field and performs the necessary inspection and measurements.

- Verification of Feed Assay
  The utility of RFID tagging is most apparent when used in conjunction with CEMO results, as it allows a certain CEMO result to be associated with a certain container. In the verification of the feed assay, there are no CEMO results available, so RFID tagging has no bearing on the effectiveness of the inspection. The tag will, however, facilitate the location of the cylinder in the field for both the inspector and the operator and permit the associated cylinder data to be read from the RFID, thus marginally increasing the efficiency of the inspection.

- Verification of Product Assay
  CEMO produces a partial-bias test for the product assay, and the use of an RFID tag in combination with this technology will allow a certain cylinder to be associated with a certain CEMO result. This reduces the number of NDA measurements the inspector must conduct, thus increasing the efficiency of the inspection. Again the RFID does not improve the effectiveness of the inspection [2].

- Verification of Tails Assay
  This situation is similar to that of the product assay, except that there exists less urgency to verify the tails assay, as tails reside at the facility for an extended period. As is the case above, RFIDs will increase the efficiency, but not the effectiveness, of this activity [2].

- Verification of Declared F/P/T Weights
  The weight of a cylinder is taken at the F/P/T station on the Load-Cell Based Weighing System (LCBWS) and at the accountability scale, and these values are compared to the values declared in the Mailbox system. Jo’s paper concludes that RFIDs will increase the effectiveness of safeguards in this respect, as they provide depth to the safeguards

approach by allowing a specific weight to be associated with a uniquely identified cylinder. This tool would be more effective still if the tag were applied at the birth of the cylinder and the tare weight automatically entered into the Mailbox system. This would allow for the true and exact tare weight of the cylinder to be known throughout the entire fuel cycle, thus preventing the intentional or inadvertent falsification of a cylinder weight by any facility operator.

3.3 Diversion Scenarios

Jo introduces several diversion scenarios and analyzes the impact RFID tagging would have on each scenario. Below the scenarios are reviewed. For each scenario, the standard operating procedure is presented, followed by the possible diversion scenarios based on the assumption of an RFID applied by the operator and an in-born RFID.

3.3.a Diversion of Product in a 30B cylinder filled directly from the cascade

Product is generally withdrawn from the Product Withdrawal (PW) station into a declared 30B customer product cylinder. The cylinder is stored for the agreed upon residence time and is then shipped to the customer. If RFID tagging were used, an RFID would be applied to the declared product cylinder.

Jo presents a diversion scenario wherein the RFID from a declared cylinder is moved to an undeclared cylinder. The product is then withdrawn into the undeclared cylinder. The RFID reader at the PW station reads the RFID, so there is no indication of diversion activity. The RFID would then be removed from the undeclared cylinder and placed back on the declared cylinder. The product, in the undeclared cylinder, is shipped to a concealed location and the declared cylinder (with RFID) is filled with the appropriate weight of steel shot, in order that its weight accounts for the amount of product withdrawn. A small amount of product could also be added to the declared cylinder so that neither traditional DA nor NDA sampling techniques can detect the true contents of the cylinder. Jo concluded that RFIDs were not effective in detecting this method of diversion.

Clearly this diversion scenario is contingent upon the operator's ability to remove and reattach the RFID to different cylinders; thus this diversion path is impossible if the RFID is attached permanently to the cylinder upon arrival at the plant. This would force all activities to be carried out with the declared cylinders that are received at the site. The crux of the problem in this scenario is that the tag is attached by the operator– it is conceivable that the operator could fashion a way to attach that tag such that it could be removed, even if the tag is intended to be attached permanently. In this regard, the in-born RFID offers a significant advantage, as the operator does not have access to the RFIDs and therefore cannot attach them to undeclared cylinders. Here the application of an RFID before the cylinder arrives at the GCEP proves a more effective safeguards tool than an RFID applied by the operator. While it is not critical to the prevention of this diversion scenario that the tag be applied at the birth of the cylinder, applying the tag at that time would make this advantage available throughout the entire fuel cycle.

3.3.b Diversion of Product in 48Y product cylinder filled from the cascade

Upon receipt of a new 48Y product cylinder, operators must declare the cylinder, attach an RFID, and place the cylinder (with RFID attached) on the LCBWS to obtain the weight of the cylinder, which will then be associated with that specific RFID. Product can then be withdrawn into the cylinder at a PW station, at which point the RFID reader will read the RFID of the cylinder and ensure that the weight of the cylinder plus product matches the weight of product withdrawn plus the weight of the empty cylinder.

In this scenario, the operator has a newly declared 48Y cylinder, to which he has not yet applied an RFID, and an undeclared 48Y cylinder. The operator attaches an RFID to the undeclared cylinder and then loads it into the PW station where the RFID is read, the LCBWS records the weight, and the operator makes a Mailbox declaration. Product is then withdrawn into the undeclared cylinder with the RFID. The operator then removes the RFID from the undeclared cylinder and ships the undeclared cylinder, full of product, to a concealed location. He takes the RFID that was read at the PW station and associated with a certain weight and attaches it to the newly declared cylinder. The declared cylinder is filled with the correct weight of steel shot so that its weight matches that of the undeclared cylinder (the weight associated with that particular RFID in the Mailbox). Thus, the RFID reader sees the correct RFID associated with the correct weight, and does not know that the tag is physically attached to a different cylinder. Just as in the last scenario, a small amount of UF_6 can be added to the declared cylinder so that traditional NDA and DA analysis cannot detect its contents.

As in the previous scenario, the vulnerability of the RFID in this scenario is the ability of the operator to affix it to a cylinder and then later remove it. The advantage offered by the in-born RFID tag in this scenario is identical to the advantage offered in the previous scenario.

The possibility still exists for the operator to attach an RFID that mimics the behavior of the ones applied by the manufacturer. The above scenario could be executed, but would essentially require that the operator "declare" a falsified cylinder, one that was not manufactured with an RFID but that was attached by the operator to resemble a standard, declared cylinder. As discussed previously, the use of an active tag with some authenticity feature would greatly reduce this risk.

3.4 Detection of Undeclared Product Produced from Undeclared Feed

Recently the undeclared production of LEU product has become of greater safeguards concern. Production of excess product can potentially be concealed by using undeclared feed or by lowering the tails assay and not reporting it. Undeclared feed must be introduced to the cascade and undeclared product must be withdrawn, both of which can occur at declared F/P/T stations or away from the declared F/P/T stations, such as at the Process Handling Area.

Under normal operational circumstances, a feed cylinder is placed at a declared feed station, the LCBWS weighs the full cylinder, the RFID scanner would read the RFID, and a Mailbox declaration would be made. A similar series of events would occur at a declared PW station; an empty product cylinder would be weighed by the LCBWS, the RFID would be read, product would be withdrawn, and a Mailbox declaration would be made.

- Diversion of Undeclared F, P, and T using the declared F/P/T Stations

  In this scenario, material would be introduced into and withdrawn from the cascades in undeclared cylinders at declared F/P/T stations. Because the cylinders are undeclared, they would not have not have a valid RFID, and the LCBWS would indicate feeding or withdrawing in the absence of a valid RFID, which would be an anomalous event. Because the feeding and withdrawing is taking place in undeclared cylinders, these transactions would also not be recorded in the Mailbox system, another anomalous event. Thus this action would raise two alarms: the lack of a valid RFID signal and feed/withdrawal without a Mailbox declaration. In this case, the RFID tag provides redundancy by raising an additional alarm for the same action, but does not increase safeguards effectiveness. This result is independent of the manner in which the RFID is attached to cylinders.

- Diversion of Undeclared F, P, and T using Process Services and/or UF6 Handling Areas away from declared F/P/T stations

  This situation resembles the one presented above; however, in this case the undeclared feed is introduced or the undeclared product is removed in a separate area. It is assumed that RFID readers are located only at F/P/T stations. This scenario reveals the primary vulnerability of this safeguards approach. Because there are no RFID readers in other UF_6 Handling Areas, the absence or presence of RFIDs is inconsequential, thus rendering RFIDs useless. This scenario demonstrates the necessity of using RFID technology in conjunction with other safeguard tools, as proposed by Moran. The use of Design Information Verification (DIV) and Containment and Surveillance (C/S) to monitor extraneous UF_6 Handling Areas could reduce or eliminate the threat posed in this scenario.

Many of the diversion paths detailed above necessitate the use of an undeclared cylinder. The assumption is made that the undeclared cylinder does not contain a valid RFID. The application of RFIDs by manufacturers may increase safeguards effectiveness by making such undeclared cylinders more difficult to obtain. If all major cylinder manufacturers began producing cylinders with RFIDs, states wishing to use undeclared cylinders for non-peaceful purposes would need to seek alternate means to obtain these cylinders. While the production of 30B and 48Y cylinders is not difficult, it does introduce an additional element to any diversion scenario, thus necessitating the expansion of a diversion network beyond the enrichment facility.

3.5 Use of RFIDs in Perimeter Monitoring

All operations that take place at an enrichment plant require the handling of cylinders at some point, and much safeguards knowledge can be gained from being privy to the path that cylinders follow into and out of buildings. To that end, Jo suggests in his paper that the application of RFIDs to perimeter monitoring would greatly enhance safeguards value. The system described is one that would detect cylinders moving into and out of separation buildings using neutron monitoring. The RFID reader will record the location and identify of a tagged cylinder, and an alarm would sound if an untagged cylinder passes through. Video monitoring at emergency exit doors would be triggered by this alarm and would record any activity post alarm.

While this system is an effective safeguards measure, it could be defeated by passing two cylinders through the neutron detector at the same time. If a declared, tagged cylinder full of steel shot were passed through the neutron detector at the same time as an undeclared, untagged cylinder full of product, the neutron detector would not observe any anomaly, as it is obtaining the expected reading from the cylinder containing product, and it would simply record the location and identify of the declared cylinder full of lead shot. This simple diversion path could be eliminated through engineering controls at the neutron monitoring stations.

4. Conclusions

The effectiveness of RFID tagging as a component of Moran's "Option 4" safeguards approach at a model GCEP was evaluated from a systems standpoint, assuming that the tag was applied by the manufacturer at the birth of the cylinder. Conclusions drawn by Jo in his paper on the topic were used as a starting point and modified to account for this new assumption that the tag was not applied by the operator. Relevant diversion pathways were examined and the benefit added by RFID technology was assessed for each diversion pathway. RFID tagging increases the overall efficiency of IAEA inspections by allowing the IAEA to associate a particular cylinder with a CEMO reading, thus reducing the number of NDA measurements necessary to achieve a 50% detection probability. In the verification of weight and complication of diversion strategies, RFIDs also proved to increase safeguards effectiveness. The evaluation of several diversion pathways revealed that the application of the RFID by the manufacturer at the birth of the cylinder will significantly increase the effectiveness and reliability of this tool, as it adds a layer of separation between the operator and the safeguarding technology. Several diversion pathways presented by Jo were eliminated by assuming an unalterable, in-born tag, thus significantly increasing safeguards effectiveness.

References

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