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# Integration of Materials Accountancy and Process Monitoring Data with Physical Protection

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**Abstract.** Materials accountancy and process monitoring data in bulk handling facilities can provide timely information about plant processes that can augment physical security. This work evaluated the integration of safeguards data with physical protection systems to determine the potential improvement to physical security response. This represents one aspect of Safeguards, Security, and Safety by Design (3SBD) where future facilities can be designed to use plant data more effectively and efficiently. The work specifically looked at insider diversion scenarios for an electrochemical reprocessing plant. Insiders have intimate knowledge of plant systems and so may be able to bypass certain physical protection system (PPS) elements. Materials accountancy and process monitoring data are more difficult for an insider to beat, so their use could help to protect against the insider threat. Two codes were used to perform the evaluation. The STAGE software was used to model the 3D plant layout and develop a generic PPS. The Separation and Safeguards Performance Model (SSPM) was used to set up the diversion scenarios and determine the probability of detection as a function of time. The data from the SSPM was fed to STAGE to alter the physical security response. Combined, both codes can be used to evaluate a complete diversion scenario including both detecting the material loss in the process and modeling the path of the material out of the facility. For all diversion scenarios, three cases were examined. The baseline case relied on the physical security elements only to respond to the material loss—since an insider is able to circumvent some of these protections, the effectiveness of the PPS was limited. The improved cases used the simulated data from the safeguards system to alter the behavior of the PPS. For example, a detection of material loss in the materials accountancy system would lead to a heightened state of alert which would increase the probability of detecting the removal of material from the facility. Both materials accountancy and plant process monitoring data were used for the integration. In all cases, a significant improvement in the PPS response was seen with the integration of the safeguards data. These results are intended to represent a generic example, but of course results will vary depending on facility design. One key conclusion of this work is that full integration of safeguards and security systems is not necessary—3SBD can be achieved by maintaining separate systems that only share pertinent data between systems in a timely manner. The example scenarios and results will be described.

**Key Words**: 3SBD, Integration of Safeguards and Security, SSPM, STAGE

## 1. Introduction

While physical protection systems for nuclear facilities have steadily become more robust with time, the insider threat continues to be an area of concern since an insider is more likely to be able to circumvent PPS elements [1]. Materials accountancy and process monitoring data provide an additional way to detect material theft or other illicit activities. The integration between safeguards data and the PPS does not need to be a tight coupling with all data shared—rather, the passing of select data provides an efficient way to link the two systems. This approach, which is one aspect of 3SBD, can allow future facilities to be built with optimized safeguards and security systems.

To demonstrate this approach, a safeguards model was used along with a physical security model to evaluate a series of insider diversion scenarios for a hypothetical electrochemical reprocessing facility. The purpose of the work was to quantify the potential improvement to PPS response by integrating safeguards data. This paper presents the modelling approach and general results of the analysis.

## 2. Modeling Approach

Two modeling capabilities were utilized for this work: the Separation and Safeguards Performance Model (SSPM) and Scenario Toolkit and Generation Environment (STAGE) commercial software. Each have strengths for the particular areas they were designed for, but together provide an ability to evaluate complete diversion scenario analysis.

### 2.1 Separation and Safeguards Performance Model (SSPM)

The SSPM was developed at Sandia National Laboratories for a variety of safeguards analyses [2,3]. The model is built using Matlab Simulink, and multiple versions of the SSPM exist, including PUREX, UREX+, and electrochemical versions. Recent work has also expanded to include modeling of gas centrifuge enrichment plants. These models track elemental and bulk material flows and inventories through various unit operations. Measurement blocks are used to simulate materials accountancy and process monitoring data, and these data are fed into a material unaccounted for (MUF) calculation. Capabilities include:

- Spent fuel source term library for user-defined runs
- Mass tracking of elements 1-99, bulk solids/liquids/salt, heat load, and radioactivity
- Customizable measurement points with user-defined error
- Automated calculation of Material Unaccounted For (MUF) and error in real time
- Statistical tests to set alarm conditions
- Diversion scenario analyses
- Integration with process monitoring data and physical protection systems

The electrochemical SSPM version is shown in Figure 1. The grey blocks represent the key unit operations in pyroprocessing, and contain many functions to simulate vessels filling and emptying, separation of materials, and the appropriate timing sequence. The signals connecting the blocks contain the mass flow information of all the tracked species. The blue and green blocks represent various materials accountancy and process monitoring measurements that may be taken.

The SSPM was designed to evaluate key safeguards metrics including: MUF, the overall measurement error or $\sigma_{MUF}$, and probability of detection of material loss. Multiple iterations of the model are run to develop the probabilities since every run will lead to slightly different results. The SSPM was designed for evaluating detection probabilities of material loss, but cannot model the 3D aspects of removing material from a facility. For this reason, this work was integrated with the STAGE model to provide a more robust capability.

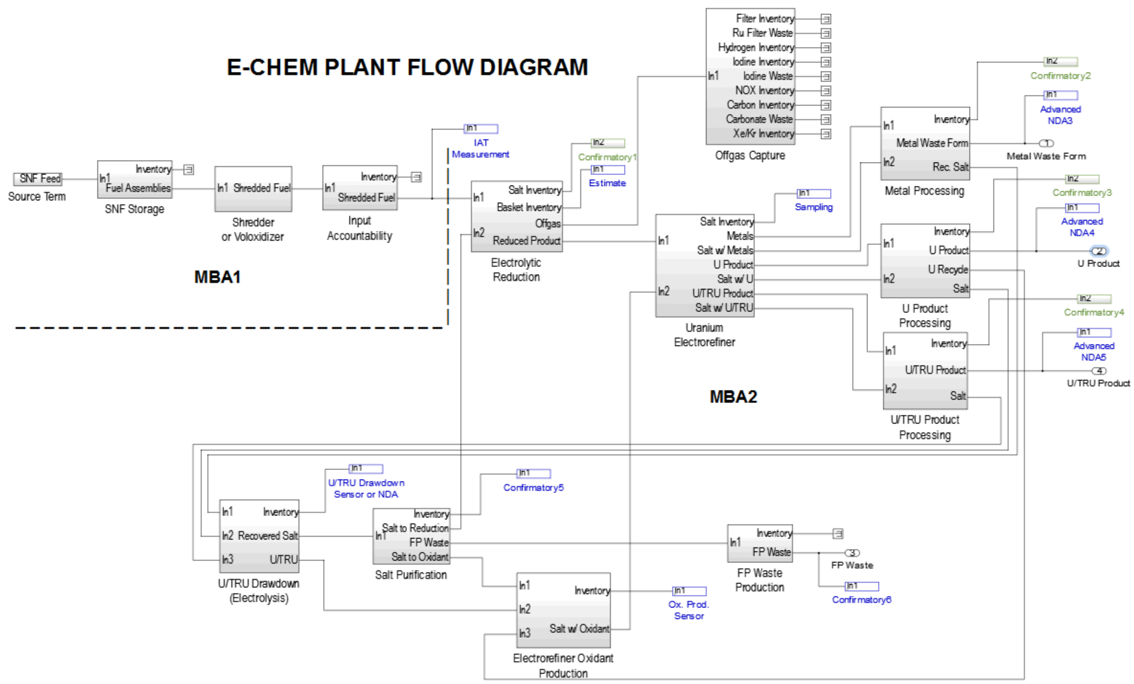


*FIG. 1. Pyroprocessing SSPM.*

## 2.2 Scenario Toolkit and Generation Environment (STAGE)

STAGE is a commercial software from Presagis that is used for force-on-force modeling of adversary attack [4]. Traditionally STAGE has been used to model outsider attack, but for this work it was set up to model insider diversion scenarios. STAGE provides a 3D platform for modeling all aspects of the physical security design including sensors, operators, and guard forces. It provides the following capabilities:

- Logic based behavior: Human entities model the ability to "make a decision" based on the current situations, partially controlled by probability analysis.
- Ground navigation: Humans and mobile equipment can dynamically find paths both inside and outside the facility. Sensing abilities possessed by the human entities enable visual detection of other humans and objects.
- Event-based entity missions: Help define the main thread and strategies of the scenarios.
- Scripting support: Provides the ability to integrate MC&A data from other codes such as the SSPM.
- 2D/3D environment: Provides visual representation of the scenarios.

Figure 2 shows an example of a STAGE model during an example outsider attack. The window in the upper left is a text print out of the current event. The 3D view of the facility is shown in the lower left, and an overhead view of the facility is shown on the right. The red triangles represent the adversary forces, and the blue represents the responders. Multiple iterations of STAGE are typically run to develop statistics for a particular scenario since the probabilities lead to slightly different results on every run.

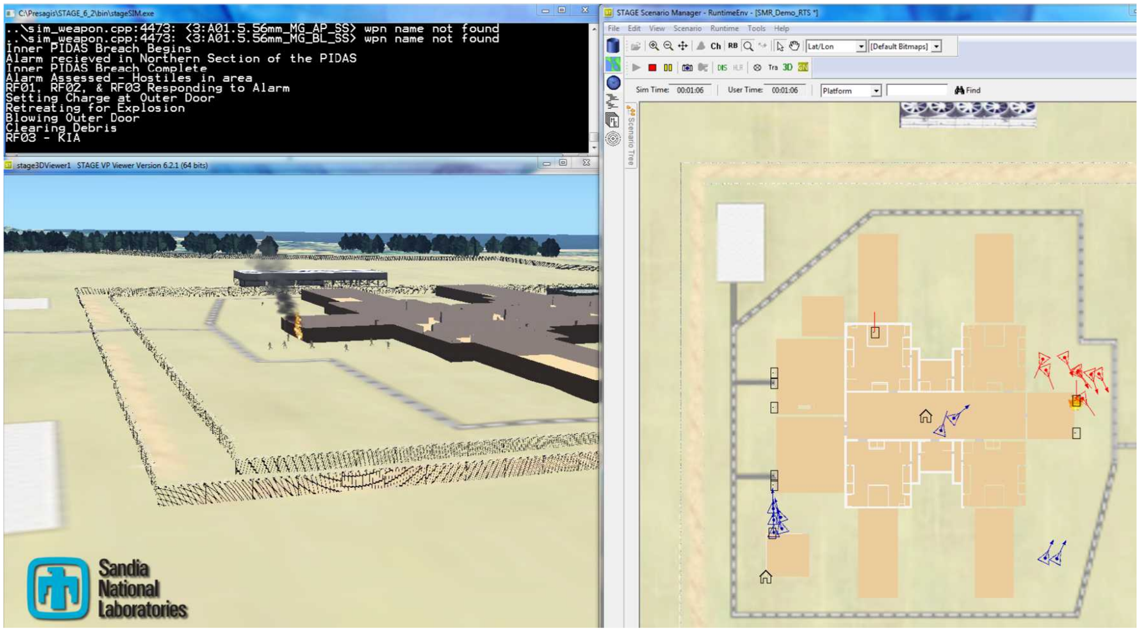


*FIG. 2. STAGE Model.*

## 3. Model Integration

The goal of this work was to demonstrate how the integration of safeguards data can help the PPS in responding to insider diversion scenarios. The electrochemical SSPM was used as the baseline for the analysis. This was modeled as a 100 MT/yr facility processing spent light water reactor fuel. A diversion of one significant quantity of Pu from the U/TRU product was simulated in five scenarios ranging from abrupt to protracted loss.

The SSPM was populated with a baseline materials accountancy system as well as process monitoring measurements. The accountancy system was assumed to perform a Pu balance once every ten days, and the process monitoring system calculated a bulk balance for the plant every day. A Page’s test was used as the statistical test for setting alarm conditions. For the five scenarios, the SSPM was used to determine the detection probability as a function of time from the start of the material diversion.

Additionally, both direct and substitution diversion scenarios were carried out for each of the five scenarios. In the direct case, the material was directly removed and detected quickly by the bulk balance. In the substitution case, the material was removed and replaced with a surrogate metal in order to beat the bulk balance—however, it could still be detected with the overall Pu balance.

The probability of detection as a function of time curves were then passed to the STAGE model of the facility. For this work, a generic site layout was used that included a perimeter intrusion and detection system and typical security features for a nuclear facility. The building was modeled based on expected design of a hot cell and associated support facilities. The STAGE model was populated with typical physical protection elements like portal monitors, access control, cameras, guard patrols, etc.

The material was assumed to be accumulated in the processing cell by an operator and then removed all at once. The most likely means of getting the material out was chosen for all diversion scenarios considered. This diversion also assumed that the insider was able to use their knowledge of the facility to circumvent many of the PPS elements.

The STAGE analysis was based on multiple iterations of each of the 15 scenarios starting with the baseline case for each of the five diversions that did not include integration of safeguards data. When the safeguards data was integrated, STAGE used the probability of detection curves to probabilistically determine when accountancy alarms would be indicated. If that happened, the facility was assumed to go into a lock-down mode, and the insider would not be able to remove material. The following section describes the results of the analysis.

## 4. Modeling Results

Using the Pu balance, the probability of detection as a function of time is shown in Figure 3. Due to the ten-day balance period, it takes some time to respond to a material loss. For the more abrupt cases, the detection probability reaches 100%, which might not be useful if the material is removed before detection occurs. For the more protracted cases, the maximum detection probability is lower since the diversion is near the detection threshold.

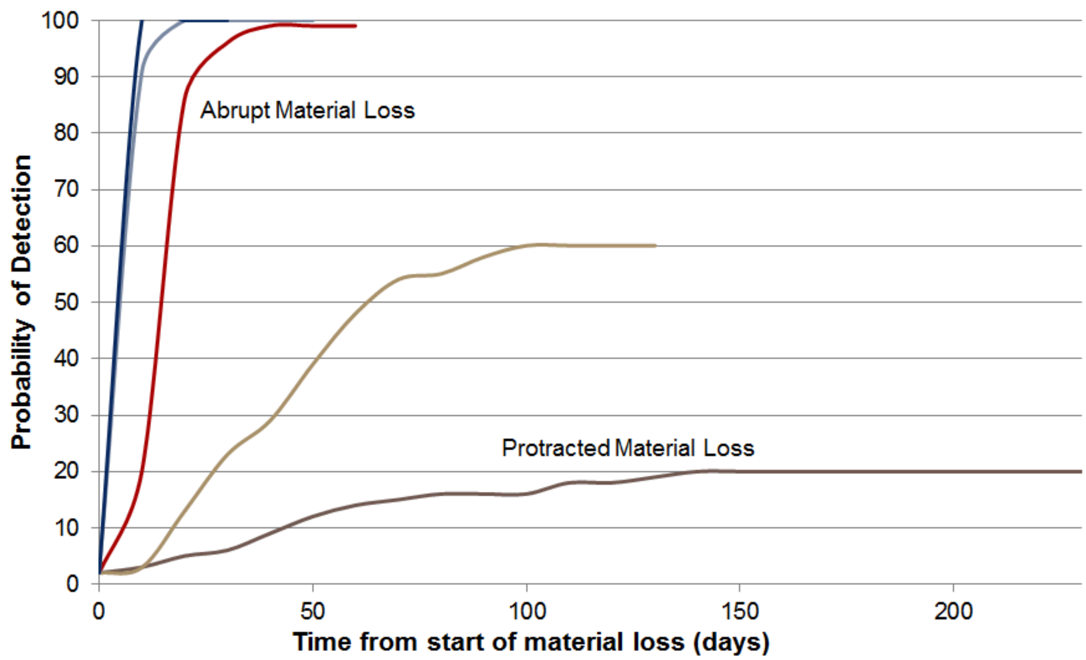


*FIG. 3. Probability of Detection with Time Curves.*

The bulk balance data provides a different set of curves, but only for direct material diversion where the bulk system can detect the loss. In all cases, detection occurred immediately, on the next daily balance for the direct loss cases.

Table 1 shows the key STAGE results for the 15 scenarios. The first column shows the results for the baseline case (without integration of safeguards data). The second column shows the results with the integration of the Pu balance, and the third column shows the results with the integration of the bulk balance (representing only direct material loss cases). The "No Detection" line is the probability that the theft is not detected at all during the removal timeline. The "RF Win %" is the probability that the response force is able to stop the theft. The "100% of Goal Quantity Removed" line refers to the percentage of runs in which the insider was able to remove a full goal quantity of Pu.

**TABLE 1: Safeguards and Security Integration Results.**

| | Abrupt Theft 1 | | |
|---|---|---|---|
| | Baseline | Integration of Pu Balance | Integration of Pu Balance and Bulk Balance |
| No Detection | 96% | 97% | 0% |
| RF Win % | 25% | 30% | 100% |
| 100% of Goal Quantity Removed | 79% | 79% | 0% |
| | **Abrupt Theft 2** | | |
| No Detection | 62% | 0% | 0% |
| RF Win % | 45% | 92% | 100% |
| 100% of Goal Quantity Removed | 48% | 3% | 0% |
| | **Abrupt Theft 3** | | |
| No Detection | 41% | 0% | 0% |
| RF Win % | 48% | 91% | 100% |
| 100% of Goal Quantity Removed | 40% | 2% | 0% |
| | **Protracted Theft 1** | | |
| No Detection | 15% | 0% | 0% |
| RF Win % | 57% | 80% | 100% |
| 100% of Goal Quantity Removed | 13% | 3% | 0% |
| | **Protracted Theft 2** | | |
| No Detection | 2% | 0% | 0% |
| RF Win % | 68% | 72% | 100% |
| 100% of Goal Quantity Removed | 4% | 3% | 0 |

For the Abrupt Theft 1 scenario, the baseline response force win percentage was fairly low due to the ability of the insider to circumvent PPS elements. The integration of the Pu balance data did not have a significant impact since the theft was completed well before the next balance period. On the other hand, the integration of the bulk balance data provided the ability to stop the theft 100% of the time. In should be noted that this would only apply to a direct material loss, but still shows the value of integrating the bulk balance data.

As the thefts become more protracted, the integration of the Pu balance data provides a more significant impact on improving the RF Win %. Also, the probability of the insider removing a full goal quantity significantly drops off with integration.

It is also useful to point out that the more protracted thefts require many days of material removal, and so they are more likely to eventually be detected by the PPS system. The safeguards data becomes less effective since the probabilities of detection are lower, but there is a very low chance of a goal quantity being removed.

## 5. Discussion

There are a few general trends that can be observed with these results. Very protracted diversion scenarios in which small quantities of material are removed every day for weeks or months are very likely to be detected by the PPS. Even though probabilities may be low for any one day, over several days the chance of the illicit activity being detected goes up significantly. Therefore, the base PPS system provides robustness against protracted material loss.

The integration of safeguards data provided the most value for stopping diversion scenarios that are not too long and not too short. The Pu balance significantly improved the RF Win % and the ability to prevent a full goal quantity from being removed. The Pu balance is also robust to detecting both direct and substitution loss scenarios.

The process monitoring data provided the most value for stopping very abrupt loss which occurs on time frames short compared to the Pu balance period. Although this bulk balance was only set up for detecting direct material loss, it is likely that any abrupt removal of material would be detected soon by a plant operator. Even a substitution diversion would require displacing a large amount of material that would likely be noticed.

The modeling integration only required the passing of the probability of detection curves from the SSPM and STAGE, but the modeling capabilities were maintained as separate models. In reality this integration would be achieved through immediate communication of Pu or bulk balance alarms to the PPS as well as procedures for facility lock-down or alert states when such events occur. It will be important to ensure that false alarm probabilities remain low (< 5% probability per year) so that the response force takes such alarms seriously when they occur.

## 6. Conclusion

This work demonstrated how the integration of material balance data and the PPS can provide a much more robust design for helping to prevent insider theft of material. The combined PPS system augmented by both Pu balances and bulk balances provided robustness in the ability to detection diversion scenarios ranging from very abrupt to very protracted. This integration was carried out through very limited passing of information from the MC&A system to the PPS and would not require a high degree of integration. It is hopeful that this type of integration can be built in to the next generation of nuclear facilities to achieve 3SBD.

## 7. Endnotes

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

## REFERENCES

[1] DURAN, F.A. et al., "Modeling and Simulation of Insider Adversary Scenarios," Proceedings of the 53rd Annual Meeting of the Institute of Nuclear Materials Management (2012).

[2] CIPITI, B.B., "Safeguards Performance Modeling: New Approaches for Safeguards by Design," Proceedings of the 57th Annual Meeting of the Institute of Nuclear Materials Management (2016).

[3] CIPITI, B.B., "Separations and Safeguards Performance Modeling for Advanced Reprocessing Facility Design," Journal of Nuclear Materials Management*,* **40**/3 pp. 6-11 (2012).

[4] DOMINGUEZ, D. et al., "Special Nuclear Material and Critical Infrastructure Modeling and Simulation of Physical Protection Systems," Proceedings of the 46th International Carnahan Conference on Security Technolog*y,* IEEE (2012).