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Process Monitoring for the Next Generation Safeguards Initiative (NGSI)

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ABSTRACT

For large throughput nuclear facilities, such as commercial reprocessing plants, it is difficult to satisfy the IAEA safeguards accountancy goal for detection of diversion. Process monitoring is used in safeguards as an additional measure to nuclear material accountancy. Process monitoring consists of utilizing process control measurements to detect abnormal plant operation. Process control measurements are those used by the operator to control the chemical and/or physical processes. Examples of process control measurements include (1) feed and product flow rates by measuring the change in tank volume versus time and/or inline flow meters, (2) concentration measurement of nonnuclear material reagents, and (3) process temperatures. Significant challenges for the future use of process monitoring include (1) greater access to the plant operator's process control data, (2) leveraging the development of new process control instrumentation to also be used for process monitoring, and (3) reducing inspector time required to evaluate process monitoring data, in particular since enhanced process monitoring for the future will likely include additional operator data. Enhanced process monitoring above and beyond what is currently used in a facility such as Rokkasho, can be implemented near-term in existing facilities and advanced process monitoring can be implemented in the long-term in new facilities.

The United States National Nuclear Security Administration (NNSA) has initiated a Process Monitoring project through its Next Generation Safeguards Initiative (NGSI) to contribute to both near-term and long-term implementation objectives. In the near-term, the analysis tools being developed by this project can be used to identify existing process control data in operating facilities not currently shared with the IAEA that could significantly enhance current process monitoring efforts. Results of this task could be used by the IAEA to request additional process control data from the operator to be used for process monitoring, that has the potential for significant safeguards gains. In the long-term, the analysis tools being developed by this task could be used to identify new independent IAEA process monitoring instrumentation that could be used for advanced process monitoring in new facilities.

INTRODUCTION

The purpose of this project is to demonstrate the added value for safeguarding a spent fuel reprocessing facility by process monitoring, in addition to nuclear material accountancy alone. Additionally, the development of potential diversion paths, detection algorithms, and advanced process monitoring instrumentation has been pursued in support of demonstrating this added value.

The authors of this paper have not been able to identify an IAEA sanctioned definition for process monitoring. The "IAEA Safeguards Glossary" does not discuss process monitoring as a distinct safeguards measure. However, members of the international safeguards community have defined process monitoring as the IAEA's use of the operator's process control data to detect abnormal plant operation that could be indicative of nuclear material diversion (Burr, et al., 2007). In this context, IAEA process monitoring is not nuclear material accountancy but rather an additional safeguards measure above and beyond material accountancy to enhance overall safeguards. On the other hand, the U.S. Nuclear Regulatory Commission (NRC) definition for process monitoring does include nuclear material accountancy (10 CFR 74.53). This conflict in definition for process monitoring, related to international safeguards and domestic (i.e. NRC) material control and accountancy (MC&A), is mentioned here only to help highlight past confusion when discussing the subject in a mixed audience of domestic and international safeguards experts. The subject of this paper will be only IAEA process monitoring.

Improvements for nuclear material accountancy (NMA) have become increasingly difficult, uncertainties for destructive assay (DA) can be ~0.3% of measured value, while nondestructive assay (NDA) measurement uncertainty is typically significantly greater than DA. Current IAEA safeguards objectives for NMA, such as that for timeliness and quantity, cannot be satisfied for large throughput facilities based on DA measurement uncertainties of 0.3%. Furthermore, NDA will be increasingly favored over DA by both the operator and IAEA due to its potential to reduce measurement cost though less labor. Because process monitoring tends to be NDA rather than DA dependent, it will likely become an increasingly favored safeguards measure.

Process monitoring has been, and continues to be developed for, many types of nuclear facilities such as uranium enrichment, nuclear reactors, spent fuel reprocessing and mixed oxide (MOX) fuel fabrication. Examples of process monitoring for these facilities is given in the following text. Process monitoring for uranium enrichment by Gas Centrifuge Enrichment Plants (GCEPs) includes (1) the use of load cells for continuous monitoring of feed, product and tails cylinder weight [Carchon, et al., 2011 and Howell, et al., 2010] and (2) enrichment monitors for the cascade header pipes [Ianakiev, et al., 2010]. IAEA verification of NMA is based on DA of a withdrawn sample or NDA of a cylinder for enrichment, and cylinder weighing before and after the feed and withdrawal stations. Verification is not comprehensive for every cylinder but rather based on a predetermined statistical plan. Because of their continuous operation, load cells enrichment monitors have been used to measure trends and abrupt changes that may indicate abnormal or undeclared operations. As their development progresses and use expands, load cells and enrichment monitors could potentially be combined for NMA, but that would not exclude their use for process monitoring.

Process monitoring for nuclear reactors includes the use of (1) NDA for spent fuel [Tobin, et al., 2011] and (2) the Advanced Thermal-Hydraulic Power Monitor (ATPM) for coolant flow and temperature drop [Aparo and Whichello, 2003]. Tobin and others have begun to evaluate a suite of technologies with potential application for NDA of the spent fuel. NDA measurement has the potential to enable the detection of missing pins. Aparo describes the ATPM as a continuous measurement for coolant flow and temperature drop that can be used to monitor trends and abrupt changes that may indicate abnormal or undeclared operations.

Process monitoring for spent fuel reprocessing facilities includes the use of (1) solution monitoring [Burr and Wangen., 1996] and (2) the neutron balance technique [Tobin, et al., 2011]. Burr and Wangen define solution monitoring as "essentially continuous monitoring of solution level, density, and temperature in all tanks in the process that contain, or could contain, safeguards-significant quantities of nuclear material." He adds that for safeguards purposes these measurements should be authenticated and independently verified. With solution monitoring it is possible to observe relevant liquid transfers, where the transfers should correspond to expected operations. The neutron balance technique is described by Tobin et al. as the complete tracking of all neutrons from the spent fuel to the waste and product. The neutrons originate from ^{235}U, ^{239}Pu and ^{241}Pu. Estimates of the neutron disposition between the waste and product can be made based on known chemical separation factors, so that actual neutron measurements have the potential to identify undeclared facility operation.

Process monitoring for MOX fuel fabrication facilities could include neutron monitoring of nuclear material movement within and/or between glove boxes [Shimizu, et al., 2006]. Shimizu describes the development of a NDA system to measure the plutonium inventory in glove boxes. This same system could potentially be use to monitor the movement of plutonium within and/or between glove boxes where material movement should correspond to expected operations.

The Next Generation Safeguards Initiative (NGSI) process monitoring task is currently focused on demonstrating its ability to provide enhanced safeguards for a reprocessing facility. More specifically, the NGSI effort is concentrated on quantifying safeguards gains beyond NMA alone. In order to achieve this goal, a number of tasks were initiated and integrated. The details of these tasks are described in the Discussion section.

DISCUSSION

As stated in the Introduction section, the Next Generation Safeguards Initiative (NGSI) process monitoring (PM) project is currently focused on demonstrating the ability to provide enhanced safeguards for a reprocessing facility. More specifically, the NGSI effort is concentrated on quantifying safeguards gains beyond NMA alone. Figure 1 shows the individual tasks of which the PM project is composed.

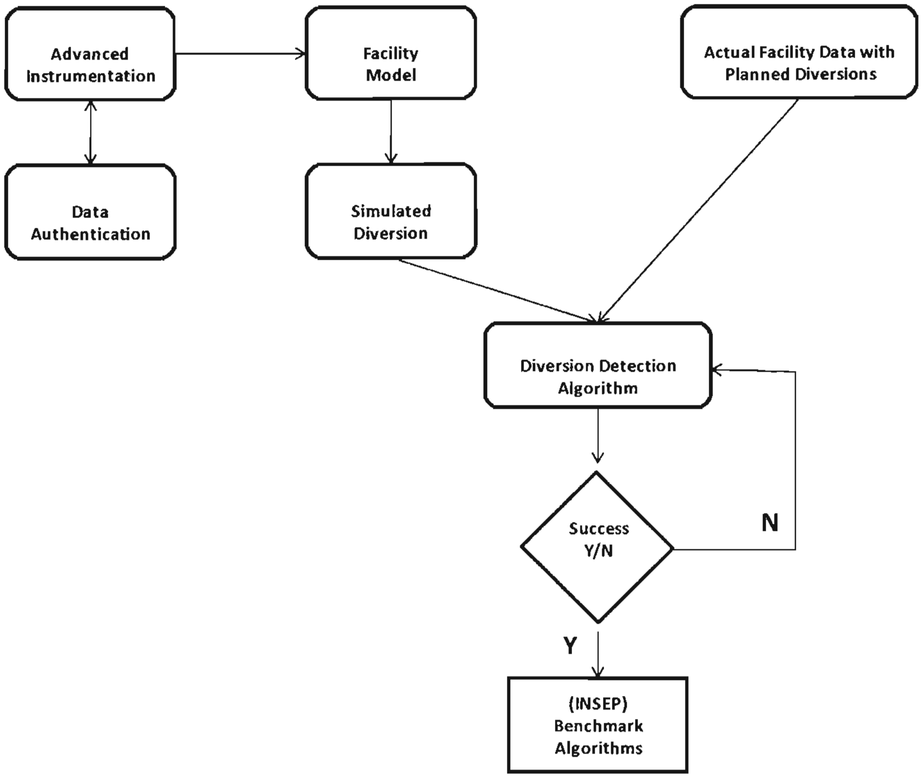

Figure 1. Components of NGSI Process Monitoring project

The Diversion Detection Algorithm (DDA) task consists of developing mathematical tools that can be used to analyze process monitoring instrumentation to detect undeclared operations. In order to exercise and test the DDA either actual plant operating data or simulated plant operating data with diversions, must be available. The DDA test will consist of determining the probability of detecting diversion with PM plus NMA and comparing it with NMA alone. Validation of the test results will be accomplished by benchmarking against a similar model being developed by the Japanese through as collaboration sponsored by the U.S. NNSA NA-24 International Nuclear Safeguards Engagement Program (INSEP). Benchmarking is often used in the nuclear industry where actual testing cannot be conducted, such as a nuclear reactor loss-of-coolant event. Benchmarking involves comparing the results of two or more independently developed models for selected operating scenarios. Following validation by benchmarking, the simulated plant operating data will be modified to include advanced instrumentation to determine if the probability of detecting diversion can be improved.

Facility Model and Simulated Diversion

The diversion scenario identified by the NGSI PM team, and developed for the first test was concerned with a PUREX-type reprocessing plant. This diversion scenario involved incomplete dissolution of the fuel that leads to greater than usual plutonium remaining in the waste spent fuel cladding. Incomplete dissolution was accomplished by reducing the acid concentration and/or reducing the solution temperature. A partial reprocessing plant model, developed by

Argonne National Laboratory (ANL) for the PM team [*Bakel, et al., 20xx*], was used to determine the impact of the diversion scenario upon the plutonium content of the waste cladding, or more generally the distribution of nuclear material within the plant.

Diversion Detection Algorithm
The results from the Facility Model and Simulated Diversion were used with the Diversion Detection Algorithm to estimate the probability of detection. With knowledge of the process monitoring instrumentation within the reprocessing plant and the expected distribution of nuclear material within the plant following the diversion, the detection algorithm provides an estimate of the likelihood that the diversion will be detected. Detection Algorithms have been developed by Idaho National Laboratory (INL) [Garcia, et al., 2010] and Los Alamos National Laboratory (LANL) [Burr, et al., 2010] as part of the NGSI PM project. The Detection Algorithms developed by INL and LANL were also used for identifying new instrumentation that could provide for significant detection of the selected diversion path, and can be used in the future for other diversion paths to be studied.

Advanced Instrumentation and Data Authentication
Results of the Diversion Detection Algorithm can be used to identify measurement locations and associated advanced instrumentation that can provide significant detection gains over existing systems. Additionally, advanced instrumentation currently being developed for in-line mass measurement of plutonium, such as real-time Raman/UV-vis-NIR spectroscopic monitoring Spectroscopy and the Multi-Isotope Process (MIP) monitor, both being developed by Pacific Northwest national Laboratory (PNNL) [Orton, et al., 2010], can be evaluated for their contribution to the detection of specific diversions using the Diversion Detection Algorithm. Associated with development of real-time spectroscopic use for process monitoring is the development of data authentication techniques. For independent use of operator's data by the IAEA, authentication will likely be required in most cases.

Actual facility data with Planned Diversions
Actual facility data based on deliberate diversions for safeguards testing was collected during cold testing at the Barnwell facility in the United States during the early 1980s. The plan was to apply the Diversion Detection Algorithms instrument readings recorded during the testing and determine if the diversion could be detected. Complete interpretation of the original Barnwell data from the 1980s has not yet been successful. Other facilities with real-data considered by the NGSI PM team include the Chemical Plant Facility at INL, the Integrated Equipment Test Facility at ORNL, Hanford operations at PNNL, and the canyon operations at SRL. Historical data from foreign reprocessing plants at Tokai-mura and Rokkasho-mura in Japan, as well as La Hague in France, and the Thorp plant in the United Kingdom have also been considered; however, data from all but Tokai-mura are of a proprietary nature.

Benchmark Algorithms
Recent joint discussions between the U.S. and Japan related to the International Nuclear Safeguards Engagement Program (INSEP) have identified a safeguards topic for joint collaboration, "Benchmarking Process Monitoring Models for Reprocessing in support of Joint Safeguards Modeling & Simulation". Process monitoring models will be independently developed by the U.S. and Japan to avoid conflicts due to Export Control. Identical diversion

scenarios will be evaluated for detectability by process monitoring, based on modeling and simulation. The use of actual data will be minimal, if any, due to Proprietary Information concerns. Benchmarking will be used in a fashion similar to that done by the U.S. Nuclear Regulatory Commission (NRC) for thermal-hydraulic codes, where actual reactor loss-of-coolant data is limited, and therefore the results of independent codes based on synthetic scenarios are compared (i.e. benchmarked) for validation. An additional value added for this task is the development of a methodology that can provide a measure of increased safeguardability for the use of process monitoring beyond that for nuclear material accountancy alone

CONCLUSIONS

Conclusions to date are limited to demonstration of process monitoring for the selected diversion path, and the usefulness of the overall methodology shown in Figure 1 for development process monitoring components. As discussed by Bakel [2010], for the selected diversion path of deliberate incomplete dissolution of the spent fuel, in order to divert a significant quantity of the plutonium in the cladding waste in a timely period, a substantial decrease in nitric acid and/or temperature would be required. Given the estimated decrease in nitric acid and/or temperature required, Garcia [2010] determined that there was a high probability of detecting abnormal operation with existing process control instrumentation in a PUREX reprocessing plant. However, what remains is to assess the safeguards gain with the use of process monitoring in addition to NMA for the selected diversion path. As for the usefulness of the overall methodology shown in Figure 1, this assessment will require completion of the benchmarking activity.

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REFERENCES

J. Aparo and J. Whichello, Installed Safeguards Monitoring Instruments (-and how they are implemented), IAEA, 6 November 2003.

A. Bakel, J. Krebs, et al., A Dissolver Diversion Scenario Illustrating the Value of Process Monitoring, Argonne National Laboratory, ...

T. Burr and L. Wangen, Enhanced Safeguards via Solution Monitoring, Los Alamos National Laboratory, LA-13186-MS, 1996.

T. Burr, J. Howell and M. Ehinger, Process Monitoring for Safeguards, Los Alamos National Laboratory, Los Alamos, NM, LA-UR-07-7305, 2007.

T. Burr, J. Howell and M. Suzuki, Loss Detection results on Simulated Tank Data Modified by Realistic Effects, Los Alamos National Laboratory, LA-UR-10-06354, 2010.

R. Carchon, L. Dechamp, L.G. Eklund, Willem Janssens, G. Mercurio, P. Peerani and P. Richir, Load Cell Monitoring in Gas centrifuge Enrichment Plants: Potentialities for Improved Safeguards Verifications, Nuclear Engineering and Design, Elsevier, Pgs 349-356, 2011.

H. Garcia, System-centric Approach for Process Monitoring: Progress Report for Phase 1, Idaho National Laboratory, INL-10-17893, 2010.

J. Howell, T. Burr and B. Boyer, Mailbox-Centered Utilization of GCEP Station Load Cell Data, Los Alamos National Laboratory, LA-UR-10-05451, 2010.

IAEA Safeguards Glossary, 2001 edition, International Nuclear verification Series No. 3, International Atomic Energy Agency, Vienna, 2002.

K. Ianakiev, B. Boyer, A. Favalli, J. Hill, C. Keller, M. Lombardi, M. Paffett, D. MacArthur, C. McCluskey, C. Moss, R. Parker, M. Smith and M. Swinhoe, Advanced Technology for Enrichment Monitoring in UF6 Gas Centrifuge Enrichment Plants, Los Alamos national Laboratory, LA-UR-10-06263, 2010.

C. Orton, et al., FY-2010 Process Monitoring Technology Final Report, Pacific Northwest National Laboratory, PNNL-20022, 2010.

J. Shimizu, et al., Development of Non-destructive Assay System to Measure Pu inventory in Glove Boxes, Proceedings of the 47'" Annual Meeting of the Institute of Nuclear Materials Management, 2006.

S. Tobin, H. Menlove, et al., Overview of Research Program focused on Determining Plutonium Mass in Spent Fuel Assemblies with Nondestructive Assay Techniques, Los Alamos National Laboratory, LA-UR-11-00514, 2011.