Exploring the Possibility of Quantitative Roles for Process Monitoring in Nuclear Safeguards

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Process monitoring (PM) is increasingly important in nuclear safeguards as a supplement to material-balance (MB)-based nuclear materials accounting (NMA). The main goal for using PM is to improve the ability to detect off-normal plant operation, which could indicate intent to divert special nuclear material [1-13]. However, while PM is used to support NMA in various ways, PM does not currently provide direct input to quantitative measures of safeguards effectiveness. With this main goal in mind, programs within the DOE and the NNSA aim to advance the quantitative use of PM. In addition, analysis of the extent to which PM can provide quantitative assessment in effectiveness evaluation is one of 10 recognized technical challenges in the anticipated increased used of PM data.

Toward the goal of understanding how to quantify the effectiveness of PM, recent work has provided a possible new role for it, placing PM on "equal statistical footing" with NMA. The focus of our work has been on safeguards at aqueous reprocessing plants where, in the particular case of solution monitoring, PM tracks frequent measurements of bulk solution mass and volume. More recently, PM consisting of, for example, measured current and/or voltage in the electrorefiner unit in a pyro-reprocessing facility has begun to be investigated.

In this work, safeguards performance is defined as system detection probabilities (DP) under various diversion scenarios. Our proposed system includes residuals from both NMA and PM. Using somewhat limited real data to guide us, we have simulated non-anomalous and anomalous data from an aqueous reprocessing facility that includes process variation and measurement error effects. This allows the broader community full access to our perturbation methods and to generate statistically equivalent challenge data sets. Specific tasks are: (1) to provide example "benchmark" data with process variation and measurement error effects to allow the safeguards community access to the same simulated data we use to assess system DPs, (2) to provide an aqueous reprocessing facility model description in sufficient detail to enable effective expert elicitation regarding diversion scenarios, and (3) as an initial step toward model validation, to perform a "sensitivity study," in which we estimate system DPs and assess the effect of measurement error and process variation on the estimated DPs.

As an example, Fig. 1 shows plots of simulated data from seven tanks in a generic aqueous reprocessing facility. Figure 2 shows plots of both PM and NMA residuals. The NMA residual is the usual MB. The PM residuals arise from marking events and treating each tank as a sub-material-balance area, plus from having a model-based prediction of pulsed-column inventory and waste-stream material flows. For combined PM and NMA residuals such as shown in Figure 2, we are developing pattern recognition methods with the ability to detect special nuclear material loss (through diversion, theft, or innocent loss mechanisms such as pipe leaks) over time and/or space.

In a nutshell, we seek a more quantitative role for PM in anticipation of increased reliance on very rapid and relatively low-quality, on-line measurements. Key technical obstacles include: (1) modeling of uncertainty as related to understanding the normal background facility data with process variation and quantifying the impact of various facility misuse scenarios (to better understand the impact of different facility model fidelities on estimated safeguards performance), (2) distinguishing sensor anomalies from material loss, (3) the possibility of data falsification, and (4) developing custom pattern recognition options for combining disparate data types (from PM and NMA) on differing time scales as seen in Fig. 2.

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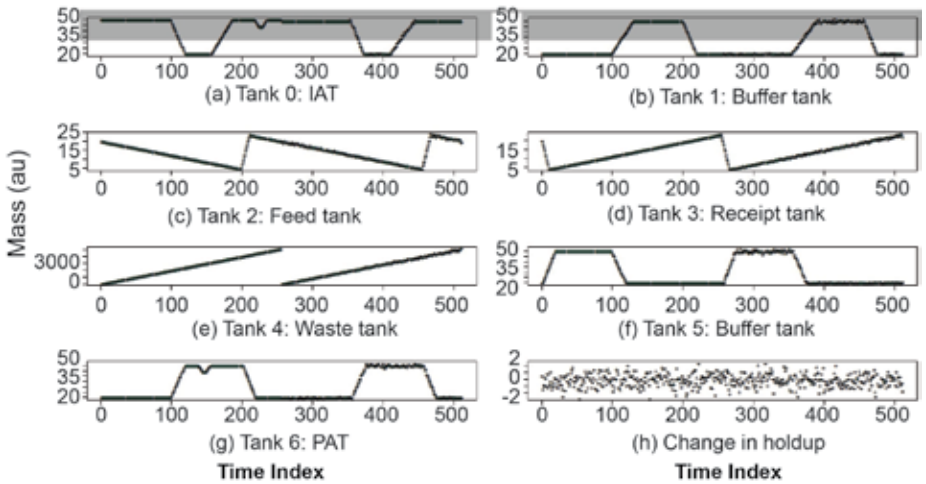

Fig. 1. Simulated data from tanks 0 to 6. The holdup in subplot (h) is in the holdup in the pulsed column between the feed and receipt tank.

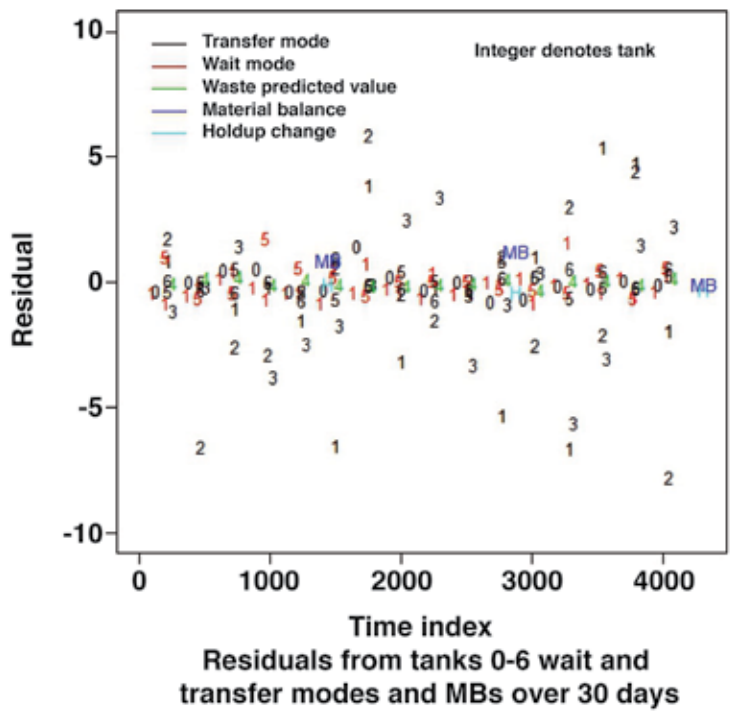

Fig. 2. Residuals from NMA and PM for the seven tanks (tanks 0 to 6) in Fig. 1.

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