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The Use of Process Monitoring Data for Nuclear Material Accounting

Summary Report

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ABSTRACT

A study was conducted for the Nuclear Regulatory Commission (NRC) as part of a continuing program to estimate the effectiveness of using process monitoring data to enhance strategic special nuclear material (SSNM) accounting in nuclear facilities. Two licensed fuel fabrication facilities with internal scrap recovery processes were examined. The loss detection sensitivity, timeliness, and localization capabilities of the process monitoring technique were evaluated for single and multiple (trickle) losses. The impact of records manipulation, mass and isotopic substitution, and collusion between insiders as methods for concealing diversion were also studied.

SUMMARY

This report describes a study of the possible application of the process monitoring technique to two licensed fuel fabrication facilities. For each facility the safeguards effectiveness of an alternative material accounting system using portions of the facility's process monitoring data was evaluated and compared with the capability of the current material accounting system. The results of the study were similar to those of previous investigations by Miles, Glancy and Donelson[1,2] which showed that substantial improvement of SNM control can be achieved in a nuclear manufacturing facility by using process monitoring data. However, the extent of applicability and effectiveness would be dependent on the specific characteristics of the facility.

The estimated annual incremental cost of the alternative system is a modest staff effort equivalent to the addition of one to 1.5 professional personnel plus a computerized, near real time data handling system. The principal results for the loss detection capability are presented in charts and tables that show the timeliness, sensitivity, and localization to specific process steps and target materials. With the current material control and accounting system, the estimated average time from a diversion to the detection of the loss would be 30 to 35 days for most of the target materials in the process.[a] Some target materials are checked more frequently because they are subject to item control and identification procedures for either accounting or production control purposes. For the proposed system utilizing process monitoring information, the estimated timeliness for diversion detection ranged from a few hours to a few days rather than 30 to 35 days and the loss detection sensitivities for most target materials are estimated to be a small fraction of that of the current material accounting system. These improvements occur mainly because there are few process steps between successive measurements or other material checks. In addition to enhanced timeliness and sensitivity, loss alarms would generally localize the trouble point to a small part of the process area and to very few target materials.

(a) The maximum time is 70 days, based on a requirement for a physical inventory each 60 days and assuming ten days for data evaluation.

When substitution of other material for diverted SSNM is considered, the timeliness of the process monitoring technique was increased by a few days for many target materials because SSNM assay or isotopic analysis data are required to detect the substitution. However, the detection sensitivities were usually not reduced appreciably.

A multiple diversion strategy could result in an appreciable cumulative SSNM loss over a period of time at a small risk of detection of each single diversion. However, the process monitoring technique facilitates monitoring for a cumulative loss by sequential analyses of mass or material balances because many such balances are obtained in each control unit in the time interval of one conventional material balance period. Therefore, detection of the cumulative loss would be more timely than achieved by the current system. The estimated probability of detecting multiple losses before the cumulative sum equals the detection capability limits (time and sensitivity) of the current accounting system was found to be of the order of 90 percent for one-half the target materials in the first plant (HEU) and for three-quarters of the target materials in the second plant (Pu-U mixed oxide).

Data manipulation (falsification) would further delay detection in many cases but with small effects on sensitivity. Some falsification scenarios could prevent detection of diversion in certain process steps if record audits and internal controls were not thorough. In many target material locations the collusion of two or more plant personnel would be required to successfully falsify data without prompt detection.

CONTENTS

FIGURES

TABLES

1.0 INTRODUCTION

The Nuclear Regulatory Commission is considering a revision of current regulations that would incorporate existing process monitoring practices into a formal regulatory requirement for control of strategic special nuclear material (SSNM) in nuclear processing plants.[3] Previous evaluations of the potential effectiveness of using process monitoring data were conducted jointly by Mound Laboratories and Science Applications, Inc.[1,2] In this study the application of the process monitoring technique at two additional licensed facilities was evaluated to help reduce uncertainties about the general application of the technique to all types of facilities and to estimate the effectiveness for detection of multiple (or trickle) losses. Because this study uses process monitoring data that are currently recorded, the effectiveness of process monitoring determined by this study in aiding the safeguarding of SNM is also an approximation of the current benefits. To achieve the full benefits, performance should be quantified and formal procedures that would insure consistent usage must be established. However, consideration should be given in the formalization to the impact of increased alarms because of data errors and the resulting demands for clerical accuracy, both of which are due to a significant increase in the quantity of data in the SNM accountability system.

2.0 METHODOLOGY

Process monitoring data refer to production control, process control, and quality control data. Examples of process control data are flow rate, pH, and specific gravity, and examples of quality control data are chemical and NDA measurements used to insure product quality. Production control data, which consist primarily of results derived from bulk measurements, such as process yields and in-process inventories, were most useful for monitoring fuel fabrication, while process control data were most useful in scrap recovery operations. Quality control data were most useful for detecting diversion concealed by a mass or isotopic substitution.

A material accounting system using portions of the facility's process monitoring data presently taken and recorded was developed and then evaluated for each facility. To develop the system design, the fabrication and scrap recovery processes were described as a series of unit operations with an overlay of production, process, quality control, and nuclear material accounting measurement points. All possible target materials for diversion were identified in each unit operation. Finally, the information obtained at each measurement point was applied as a loss monitor over the applicable unit operations and target materials. Most loss monitoring techniques were process yields and mass balances based on net weight data or combined net weight and assay data. Efforts were made to monitor losses over small segments of the process. A summary of the characteristics of the two facilities as they were broken down into unit operations is presented in Table 1.

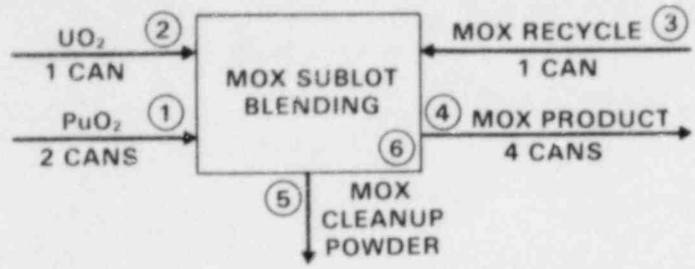
The material accounting system was evaluated by calculating the effectiveness of using process monitoring to detect a loss under various diversion modes. The effectiveness in detecting each diversion was measured by the detection timeliness, mass sensitivity, and degree of localization obtained from the process monitoring and accountability measurements at each process step. This was generally achieved by: 1) calculating the average time lapse from the postulated loss to the time when all measurements required to close the balance had been performed and recorded, 2) calculating the variance of the balance, and 3) determining the number of target materials that would have to

TABLE 1. Characteristics of the Two Nuclear Fuel Fabrication Plants

	First Plant High-Enriched Uranium	Second Plant Plutonium-Uranium Mixed Oxide
Type of Process:		
Conversion	No	Yes
Fabrication	Yes	Yes
Scrap Recovery	Yes	Yes
Number of Unit Operations in Bulk Material Processing:		
Fuel Fabrication	14	33
Scrap Recovery (includes conversion in the MOX plant)	24	16
Number of Target Materials:		
Fuel Fabrication	20	49
Scrap Recovery (includes conversion in the MOX plant)	39	24
Number of Target Materials Monitored by the Process Monitoring Technique:		
Fuel Fabrication	20	45
Scrap Recovery	38	16

be investigated if the balance closed outside the control limits. The statistical distribution of the variance was assumed to be normal and the alarm limits for the balance were set at a level to minimize false alarms. Calculation of each variance included consideration of measurement errors, estimated process variance, estimated holdup variability, and variability of the scrap and waste generation rates. The sensitivity was then defined as an amount of SSNM loss that would have a 95% probability of causing an alarm.

An example of a loss detection unit ("control unit") is given in Figure 1. This control unit comprises one typical unit operation, blending sublots of plutonium-uranium oxides. The feed materials, UO_2 and PuO_2, have known chemical compositions based on previous analyses and only net weighings are



MEASUREMENT POINT	DATA COLLECTED
1	NW OF PuO_2 IN EACH CAN (NW_1)
2	NW OF UO_2 (NW_2)
3	NW OF MOX RECYCLED FROM PREVIOUS LOTS (NW_3)
4	NW OF MOX IN EACH CAN (NW_4)
5	NW OF MOX CLEANUP POWDER COLLECTED AFTER TWO SUBLOTS (NW_5)
6	ESTIMATED AMOUNT OF HOLDUP OF MOX AND PuO_2 IN THE BLENDING SYSTEM AND GLOVED BOX

FIGURE 1. Example Control Unit A. PuO_2-UO_2 Mixed Oxide (MOX) Blending

needed to prepare the MOX mixture. Five measurement points for weighings and an estimate of the holdup in the gloved box and equipment after cleanup are utilized. Cleanup consists of removing visible holdup and spilled powder in the equipment (without disassembly) and on the floor of the gloved box. It is done after every MOX lot.

The control unit is monitored for each complete lot of MOX powder, which consists of two sublots. The loss monitoring equation is:

$$\sum_{i=1}^{4} NW_{1i} + \sum^{2} NW_{2i} + \sum^{2} NW_{3i} - \sum^{8} NW_{4i} - NW_5 - E(dNW_6) = \Delta$$

where $E(dNW_6)$ is the estimated charge in the holdup and Δ is the mass balance difference.

The detection sensitivity is based on an estimate of the standard deviation of the the mass balance, s_{Δ}, and the loss alarm would be set at a multiple of s_{Δ}, such as $2s_{\Delta}$. The s_{Δ}^2 is estimated as follows:

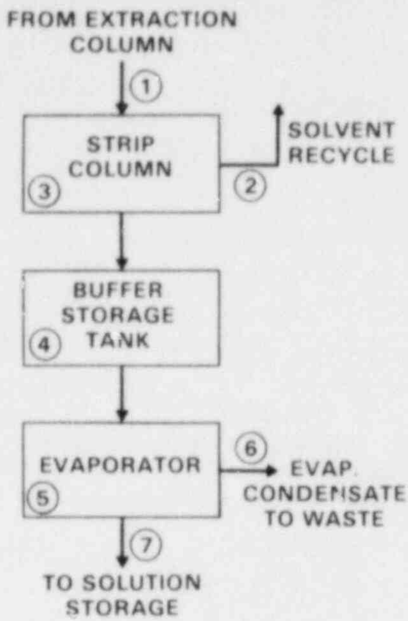
$$4s_1^2 + 2s_2^2 + 2s_3^2 + 8s_4^2 + s_5^2 + s_E^2 + \left(\sum^{2} NW_{3i}\right)^2 \frac{s_f^2}{f^2} + 4^2 s_{1c}^2 + 2^2 s_{2c}^2$$

$$+ 2^2 s_{3c}^2 + 9^2 s_{4c}^2 = s_{\Delta}^2$$

where s_1, s_2 .... s_5 are the standard deviations of net weighings at measurement points 1 through 5, s_E is the standard deviation of the estimated change in the in-process holdup, s_f is the between-lots standard deviation of the plutonium factor, f, in MOX, and s_{1c}, s_{2c}, ... s_{4c} are the calibration standard deviations of the weighing systems used (note that NW_4 and NW_5 are on the same scale). All values of s are expressed in absolute units, such as grams of MOX.

The term for the plutonium factor for the MOX recycle is included because that material is recovered from previous MOX lots and the factor may differ from that of the other material added to and removed from the blending operation. The effect of this difference on the factors for the product, cleanup powder, and holdup is assumed to be small enough to be ignored. It is also assumed that the measurements involved in the control unit are independent and possible correlations between them are ignored.

Other loss monitoring units were evaluated in a similar manner. Figure 2 shows a typical control unit in an enriched uranium scrap recovery process. The unit operation consists of a typical solvent extraction and interstage concentration cycle. The process is semicontinuous with evaporation by batches and continuous, uniform flow through the extraction columns. The boundaries of the control unit were chosen at measurement points that permit completion of uranium balances over short time intervals. Because the process is shut down for one shift each day, the time interval chosen for a control unit balance is one day of two shifts. A uranium balance is based on recorded flow and uranium concentration measurements made hourly at each measurement point. The



MEASUREMENT POINT	DATA COLLECTED
1, 2 AND 6	HOURLY FLOW RATES AND URANIUM CONCENTRATIONS
3	U IN HOLDUP OF STRIP COLUMN AFTER SHUTDOWN, ESTIMATED FROM DESIGN AND OPERATING INFORMATION
4	LIQUID LEVEL READINGS AFTER SHUTDOWN EACH DAY, VOLUME CALCULATED FROM CALIBRATION EQUATION, AND U ASSAY OF SOLUTION SAMPLE
5	U IN HOLDUP IN THE EVAPORATOR (USUALLY EMPTY) AFTER SHUTDOWN, ESTIMATED FROM DESIGN AND OPERATING INFORMATION
7	VOLUME AND U CONCENTRATION MEASUREMENTS OF EACH BATCH DISCHARGED FROM THE EVAPORATOR

FIGURE 2. Example B, Uranium Extraction in a Scrap Recovery Process

standard deviation of Δ and the loss alarm level are estimated in a manner similar to that of Example A. The material balance equation for this control unit is:

$$\sum U_{1i}F_{1i}t_{1i} - \sum U_{2i}F_{2i}t_{2i} - \sum U_{6i}F_{6i}t_{6i} - \sum V_{7i}U_{7i} - E(dU_3) - E(dU_5)$$
$$+ (V_4U_4)_b - (V_4U_4)_e = \Delta$$

where U_1, U_2, ... = the hourly uranium concentration measurements at points 1, 2, ... respectively. (They were ^{235}U concentration measurements by NDA)

F_1, F_2, ... = the hourly flow rate measurements at points 1,2, ... respectively.

t_1, t_2, ... = the time intervals of flow corresponding to F_1, F_2, ...respectively.

V_7 = the volume of a batch discharged from the evaporator.

$E(dU_3)$ and $E(dU_5)$ = the estimated differences in the quantities of uranium holdup in the strip column and evaporator at the beginning and end of the day's run.

$(U_4V_4)_b$ and $(U_4V_4)_e$ = the inventories of Tank 4 at the beginning and end of the day's run.

One of the diversion scenarios considered was substitution of other material for plutonium or high enriched uranium. In that case, simple mass balance monitoring, as shown in example A, would not detect the diversion. However, where assays are performed, as in example B, substitution would not mask the diversion and the detection capability would not be affected. Since the uranium assays in this case are ^{235}U determinations (by NDA), isotopic substitution would also be detected. In cases analogous to example A, other, overlapping control units based on monitoring plutonium assay data were used to detect diversion with mass substitution. The detection sensitivities in those cases were estimated by evaluating the variance of the ratio of the input and output assays. The input assay values could be either previous feed assays, nominal values or historical lot average values.

Multiple losses that occur over more than one loss detection interval, often called trickle losses, would usually be detectable using the process monitoring data before the cumulative loss reaches the level of detectability of the current material accounting system. To detect a trickle loss when the rate of loss is too small to be detected in a single interval, a study should be made of sequential data utilizing loss rate indicators, such as cumulative sums or Kalman filters.(4) Although sufficient information on the statistical characteristics of the loss indicators based on process monitoring data was not available in this study to perform statistical evaluations of sequential data, a cursory analysis of the trickle loss detection capability was performed for each target material. To perform this analysis, the variances of the cumulative loss indicators were assumed to be affected predominantly by the random measurement and process errors. Two cases were chosen as examples to demonstrate the effectiveness of detecting a trickle loss: one in which the cumulative loss would equal the high probability detection capability of the current material balance accounting system, i.e., approximately twice the facility Limit of Error of Inventory Difference (LEID), and the other in which the cumulative diversion would equal five formula kilograms (FKg) in two months. To determine if there is a high probability of an alarm from a trickle loss within a two-month period, two tests were performed. The first test calculated the time period until there was a high probability of an alarm for at least one SSNM loss in the series. The second test was based on estimates of the control limits for the cumulative sum of the losses, assuming that all process variance is random. If either of the tests indicated that the trickle loss would be detected within two months, the result was classified as possible, and if both tests indicated that the trickle loss would be detected, the result was classified as capable of detecting the trickle loss.

3.0 EVALUATION RESULTS

Examples of the evaluation results for the process monitoring technique are shown in the following figures. Figure 3 shows the sensitivity of loss detection for a simple loss as a function of the target material attractiveness[a] for the HEU facility. The number beside each point indicates the

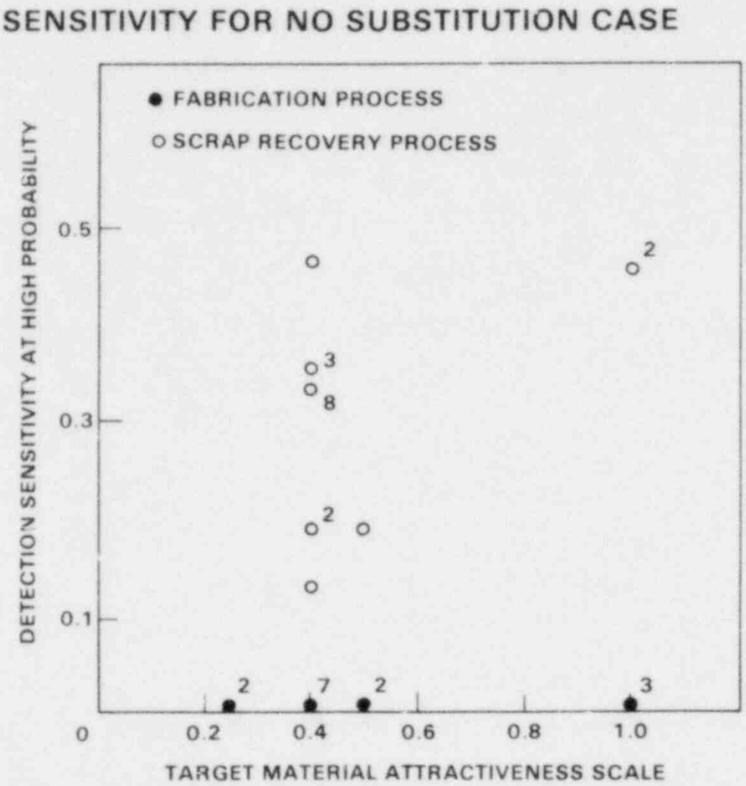


FIGURE 3. Detection Sensitivity versus Target Material Attractiveness; HEU Plant. (Attractiveness values <0.25 omitted; sensitivity expressed as a fraction of the facility LEID)

(a) The attractiveness of the target material to a potential adversary is used to interpret the evaluation results. The numeric attractiveness values were based on three characteristics: 1) location, including accessibility to the target material, 2) form, which includes type, purity, and fissile fraction of the material, and 3) mobility, which factors in size, weight, containment, transportability, and ease of concealment. The overall numeric attractiveness value is the simple product of the three values.

number of target materials that have those characteristics. The sensitivity for each target material is shown as a fraction of the sensitivity for the current SNM accounting system based on LEID.

Figure 4 shows the detection sensitivities for the HEU facility as a function of the timeliness of detection. Average delays of 20 days occur for several target materials in fabrication because a holding period is required to await release by quality control before further processing.

For diversion concealed by substitution of other material, the sensitivities changed only slightly but the detection times increased appreciably, generally by about two weeks. For the HEU facility, Figure 5 shows the detection sensitivity as a function of timeliness for detection of diversion when concealed by mass substitution. Data manipulation would

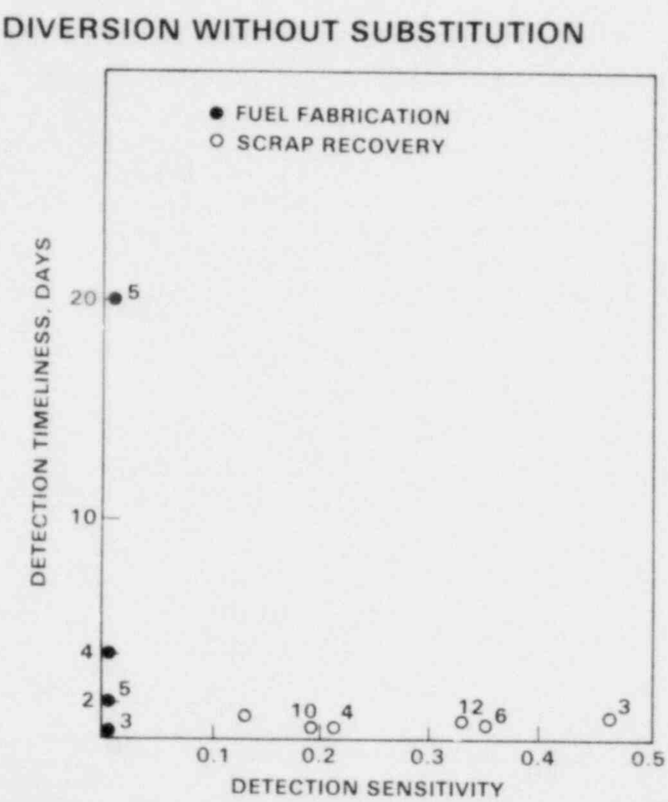


FIGURE 4. Detection Sensitivity versus Timeliness; HEU Plant. (Sensitivity expressed as a fraction of the facility LEID)

SENSITIVITY FOR MASS SUBSTITUTION CASE

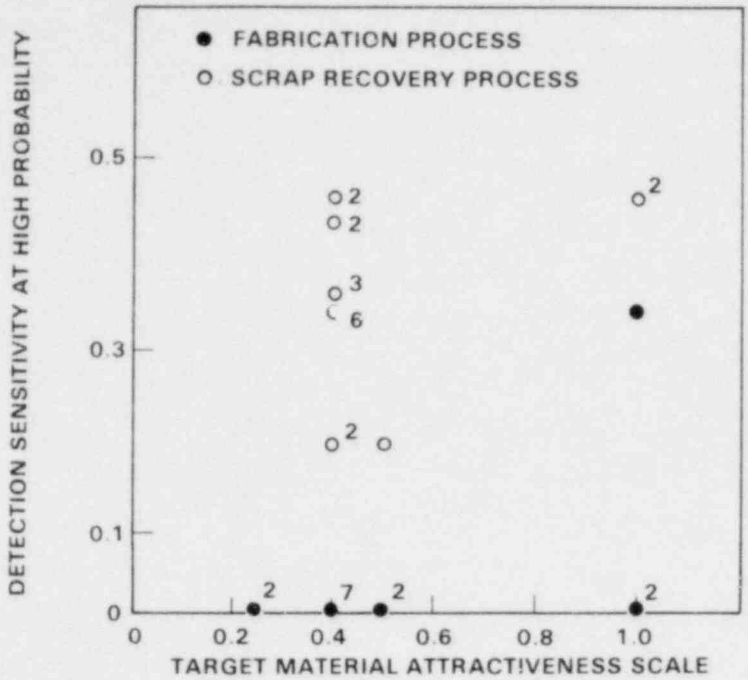


FIGURE 5. Detection Sensitivity for Diversion With Mass Substitution versus Target Material Attractiveness; HEU Plant. (Attractiveness values <0.25 omitted; sensitivity expressed as a fraction of the facility LEID)

further delay detection in many cases but with only small effects on sensitivity. Some falsification scenarios could prevent detection by this technique in certain process steps if record audits and internal controls were not thorough. In many target material locations the collusion of two or more plant personnel would be required to successfully falsify data without prompt detection.

For the high-enriched uranium fuels fabrication facility, 58 of 59 target materials are included in the process monitoring data. The target material not included is a low concentration recycle solution in the scrap recovery process. The average timeliness of the proposed system, based on process monitoring data for the case of a single loss without concealment, was less than 24 hours for 43 target materials and less than 1 week for 6 target materials. The detection sensitivity for the proposed system, where process data are available, is a factor of two better than current accounting for all target materials, and for 30% of the target materials the improvement is more than a factor of ten better.

The detection effectiveness of the process monitoring technique for the MOX fuel fabrication plant is shown in Figures 6, 7 and 8. The data are displayed in a manner similar to those for the previous facility. For this facility, 61 of 73 target materials are included in the process monitoring data; the other target materials are cleanout, wastes, and product materials where the measurements are performed for accountability. For all but 5 of the 73 target materials, the average time from a loss to detection by the current materials accounting system would be 30 days (maximum 60 days). The average timeliness of the proposed system, based on process monitoring data for the case of a diversion without concealment, was less than 24 hours for 37 target materials and less than 1 week for 24 target materials. Of the 12 remaining, 5 have low attractiveness (e.g., low concentration wastes), 5 are controlled as sealed items, and the other two are cleanout materials. The detection sensitivity for the proposed system (i.e., the grams of SSNM loss that would be detected with high probability) is a factor of at least two better than the current accounting system for all applicable target materials, and for 60% of the target materials the improvement is more than a factor of ten better.

The ability to identify the process location or target material from which a loss or diversion occurred when an anomaly is observed is referred to as localization capability. An example of typical localization capabilities is shown in Table 2 using data for the MOX plant. The results for the HEU plant are similar. Localization of diversion alarms is shown by target material in Part a and by unit operation in Part b. In the second and third columns the number of diversion monitoring measurement points are given for which an alarm could be localized to only one (1), two (2), three (3), etc., target materials and unit operations, as given in the 1st column. For example, in the no substitution case, there are seven monitoring points for which an alarm would be uniquely associated with a single target material and nine for which an alarm would be associated with just two target materials. Note that the mass substitution scenario results in poorer localization than

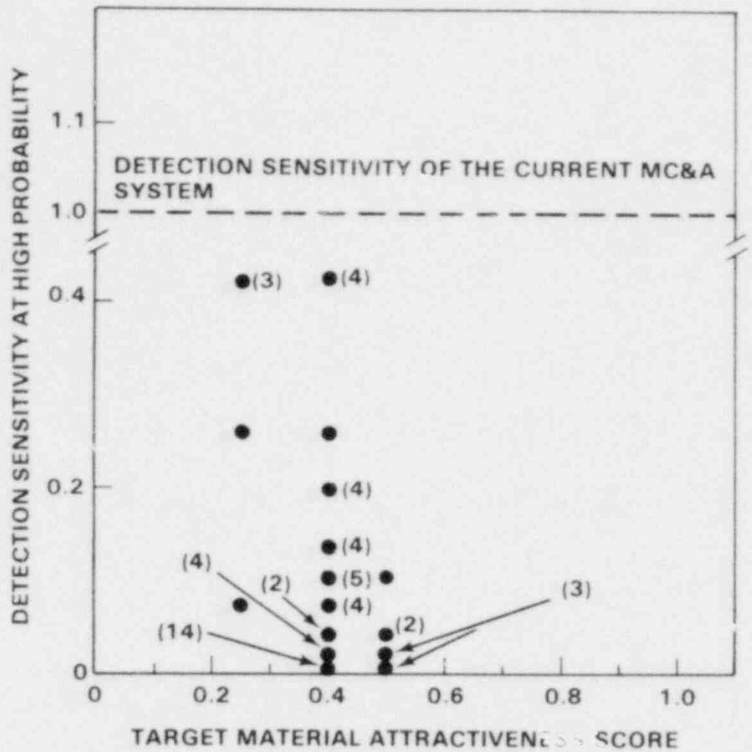


FIGURE 6. Detection Sensitivity versus Target Material Attractiveness; MOX Plant. (Attractiveness values <0.25 omitted; sensitivity expressed as a fraction of the facility LEID)

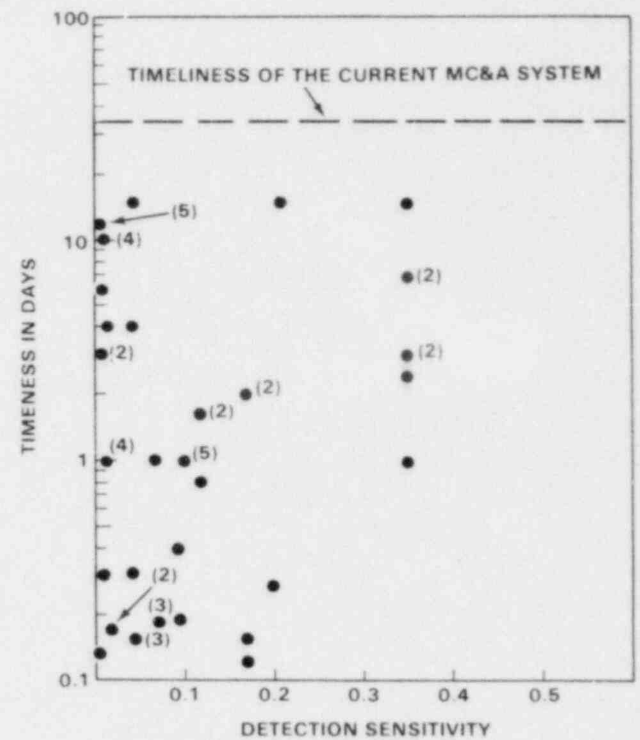


FIGURE 7. Detection Sensitivity versus Timeliness: MOX Plant. (Sensitivity expressed as a fraction of the facility LEID)

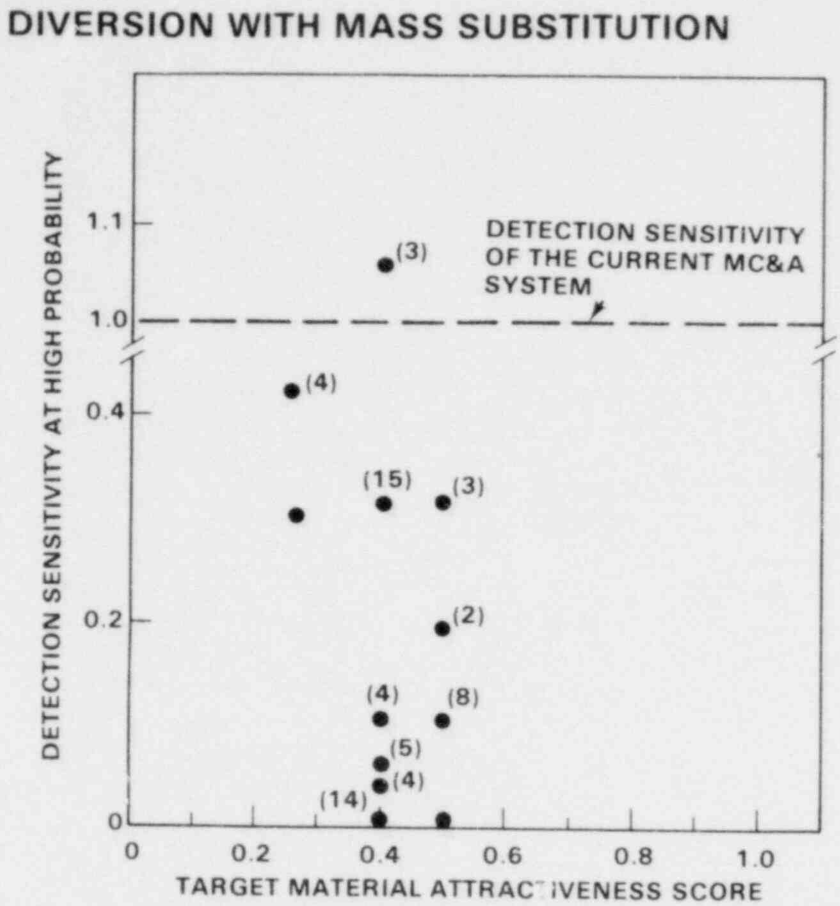


FIGURE 8. Detection Sensitivity for Diversion with Mass Substitution versus Target Material Attractiveness. (Attractiveness values <0.25 omitted; sensitivity expressed as a fraction of the facility LEID)

the no-substitution case. In the worst case, an alarm at one of the monitoring points would require consideration of 22 possible target materials and 17 possible unit operations as potential sources of a diversion.

The results of trickle loss analysis showed that the process monitoring technique would probably detect the cumulative loss of a target material in two months or less in either plant if the trickle loss rate were sufficiently high to accumulate to 5 Fkg in the two-month period. If the trickle loss were at a rate that accumulated in two months to an amount comparable to the detection sensitivity of the current accounting system, the process monitoring system would still detect many of the possible losses. For the MOX facility, 46 target materials would show no difference in detection effectiveness between single and trickle losses, 11 would require analysis of data over several lots, and 9 would not have enough sensitivity to detect the trickle loss in 8 weeks. For the HEU facility, 11 target materials would show no difference in detection effectiveness between a trickle and a single loss, 21 target materials would have to be monitored over several lots to have the capability of trickle loss detection, and 26 would not be detected as a trickle loss in 8 weeks. Even though the process monitoring technique does not detect all losses, it should be noted that in the event of an excessive inventory difference (ID), the investigation could be concentrated on those detection units where sensitivities are insufficient to detect the trickle loss within the material balance period.

Because these statements are based on low false alarm rates and high probability of detection, there will also be evidence that can be used to test specific hypotheses about the source of the ID, only at some lower probabilty than that used in this system. Also, the system evaluation did not take credit for limitations on frequency of access to the process, presence of other personnel that might deter the diversion, and the benefits of the physical security system.

TABLE 2. Localization Effectiveness of the Process Monitoring Technique

Number of Target Materials or Units Monitored at the Diversion Monitoring Point	Number of Diversion Monitoring Measurement Points	
	Without Substitution	With Mass Substitution
a. Localization by Target Material		
1	7	2
2	9	3
3	4	2
4	3	1
5	2	1
6	2	
10	1	
13		1
17		1
22		1
b. Localization by Unit Operation		
1	10	3
2	8	3
3	5	3
4	1	
5	1	
6	2	
9	1	
13		1
14		1
17		1

4.0 INVESTIGATION OF ALARMS

An important cost element in the inclusion of the process monitoring technique into SNM accountability would be the investigation of alarms. Alarms due to innocent causes only may result from:

- A random deviation of the process sufficient to cause a loss indicator value that exceeds the control limit. The frequency is predictable from the process variance, and raising the control limit will reduce the frequency of false alarms.
- A random deviation of a measurement result sufficient to cause a loss indicator value that exceeds the control limit. The frequency is predictable from the measurement variance and raising the control limit will reduce the frequency.
- A nonrandom process deviation for which a specific cause usually can be found. The alarm may be anticipated by close observation of the process operation.
- A nonrandom measurement deviation caused by an out-of-control situation. A good measurement control program can maintain the frequency of such events to a negligible level.
- Human errors in performing measurements. The opportunities for a false assay result due to a human error are numerous but the frequency of weighing errors should be quite small.
- Human errors in recording and copying measurement data and information.

Human errors in performing measurements and recording data are expected to be the major source of alarms. Some of these alarms will be resolved quickly by review of recorded data and calculations, while others will require checks of labels, criticality safety sheets, or remeasurements of items still in the process line. Because of the timeliness of process monitoring, it is expected that this type of alarm will usually not be difficult to resolve. Alarms due to unusual process variability may be much more difficult to evaluate. Additional measurements of process material, holdup measurements, assay of scrap and recycle material, or improved measurements may resolve these alarms, but because of the localization of process data, these are not expected to affect the whole process. Resolution will also be useful to production and quality control and should coincide with normal operating practices.

5.0 CONCLUSIONS

Loss monitoring effectiveness of the process monitoring technique for the target materials in bulk material processing is usually uniquely affected by the specific processing operation. Generalizations of the sensitivity, timeliness and localization are not feasible, except that for the vast majority of the target materials in these two facilities, loss detection effectiveness is better than the capabilities of the current SSNM accounting systems. Loss detection time periods are usually a few days in contrast to many weeks, and target material sensitivities are usually a small fraction of the typical facility LEID, largely as a consequence of the short time spans involved between measurements. In addition, loss alarms would generally localize the trouble point to a small part of the process area. Because of the inability of the current SSNM accounting system to distinguish between block and trickle losses within the two-month period, the process monitoring technique is generally more sensitive to early detection of trickle losses.

It was observed that the process monitoring data are currently monitored by the staff in these two licensed facilities. If a sufficient loss occurred at any of the monitored points in the process, an anomaly in the process data would be observed and an investigation would undoubtedly follow. However, formalization of the system and involvement of safeguards personnel would probably improve los. detection timeliness and the overall effectiveness for safeguards.

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16. ABSTRACT (200 words or less) A study was conducted for the Nuclear Regulatory Commission as part of a continuing program to estimate the effectiveness of using existing production control, process control, and quality control data to enhance strategic special nuclear material (SSNM) control and accounting of nuclear fuel manufacturing licensees. Two licensed SSNM fuel fabrication facilities with internal scrap recovery processes were examined. The loss detection sensitivity, timeliness, and localization capabilities of these techniques were evaluated for single and multiple (trickle) losses of material undergoing processing. The impact of records manipulation, mass and isotopic substitution, and collusion between insiders on these methods for detecting diversion were also studied. Volume 1 is an unclassified, nonproprietary summary. Volume 2 contains details on the mixed oxide fabrication process studied; its availability is restricted because it contains proprietary information. Volume 3 has details on a HEU fabrication process; it contains classified and proprietary information and so its availability is also limited.

17. KEY WORDS AND DOCUMENT ANALYSIS | 17a. DESCRIPTORS

Safeguards, rapid material accounting, material control, process monitoring, nuclear

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT
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