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Evaluation of MC&A Detection Time

**B. W. Smith
N. M. Thomas**

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ABSTRACT

The U.S. Nuclear Regulatory Commission has proposed reform of the material control and accounting (MC&A) requirements for facilities authorized to possess and use formula quantities of strategic special nuclear material (SSNM). The purpose of the reform is to strengthen MC&A capabilities by requiring more timely detection of possible SSNM losses and by providing for more rapid and conclusive resolution of discrepancies.

This study was conducted to identify the advantages and disadvantages of detection time intervals ranging from one day to two weeks. Material loss tests based on existing process monitoring data are used to compare the detection sensitivity, alarm frequency, resolution capability and effort to collect and process data for the stipulated range of detection times.

SUMMARY

This study was conducted for the U.S. Nuclear Regulatory Commission as part of a continuing program to estimate the effects of using process monitoring data to enhance strategic special nuclear material (SSNM) accounting. The purpose of the study was to identify and assess the advantages and disadvantages associated with detection times ranging from one day to two weeks. To achieve this purpose, existing process monitoring data from two facilities were evaluated to quantify the effects of different detection times on the detection capability, effort to process data and alarm resolution.

The first consideration, detection capability, was observed to decline as the detection time increased. Longer detection times resulted in poorer test timeliness and increased loss indicator variability, with the nominal increase in variability predicted by summing variances for a biweekly detection time. The increased variability of the loss indicator leads to increased alarm frequencies, with some control areas incurring alarm rates exceeding 50%. The non-normality of the data distributions is more noticeable for short detection times and analyses suggest that the data is better described by a mixture of two or more normal distributions.

Longer detection time intervals would, however, allow process runout and cleanup which are not currently performed on a daily basis for process control. It would also be more practical to incorporate improved measurements methods for longer detection time intervals, such as chemical analyses currently performed for shipments and receipts that are not available on a daily basis. An additional consideration is that several process control areas could be combined to avoid a transfer measurement that dominates the variances of adjacent process control areas; for the two facilities investigated, this resulted in an increase in the frequency of alarms per test at both facilities although one facility was observed to have a decrease in the absolute number of alarms because of the decrease in the number of tests performed. For one process unit where runout is routinely performed on a weekly basis, it was observed that the variability of the material loss indicator decreased as compared to the variability of the daily indicator without runout.

Varying the detection time changes the level of effort required to collect and process data for material loss detection by affecting the requirements for additional measurements, the data collection, the calculation of loss estimators and alarm thresholds, and the testing of estimators. These effects were found to be dependent on the type of facility. In one case, changing the detection time had no effect on the number of required measurements nor the effort to collect transfer and inventory data. For the same facility, however, longer detection times required an increase in the number and complexity of calculations to determine the loss indicator. On the other hand, the second facility required an increase in the number of measurements (in addition to those already performed for process control) in order to adequately quantify transfers and inventory; shorter detection times would require more of an increase in the number of additional measurements than longer detection

times. The task of inventory data collection at the second facility is expected to require increased effort for longer detection times because of the increased turnover. Finally, the number of calculations necessary to determine the loss indicator at the second facility decreased as the detection time interval increased.

The effects of changing the detection time on the effort to determine alarm thresholds or control limits depends on throughput variability, estimator complexity, and historical data availability. A tradeoff exists; longer detection times reduce effort requirements by decreasing the visibility of the daily process variabilities, yet at the same time increase effort requirements by reducing the availability of historical data for studying process characteristics. The relative lack of historical data also makes it more difficult to evaluate loss indicator behavior and identify the specific causes of alarms. However, the smaller number of weekly or biweekly tests allows more time for detailed loss indicator evaluation and validation of source data.

Alarm resolution is generally more difficult for longer detection times, a conclusion based on observations that as alarm frequencies increase, localization capabilities decrease, and material is less likely to be available for remeasurement. Longer detection times also allow short-term, systematic changes in material processing to accumulate into significant fractions of the alarm threshold, without a data base for trend analysis to identify the change. Localization becomes more difficult for longer detection times because the larger volume of accumulated data allows for more frequent multiple-cause alarms. The time elapsed between material measurement and alarm resolution activities increases for longer detection times, thus decreasing the likelihood that the same material is available for remeasurements.

The recommendation of this study is that the detection time should be chosen to be one week or less, where the licensee is given the option to use a shorter detection time as needed to meet the sensitivity requirements for abrupt loss detection. The daily test in general, provides good sensitivity and low alarm rates. The one week detection time would, however, allow for runout and cleanup when the process is shut down for a weekend.

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1.0 INTRODUCTION

The Nuclear Regulatory Commission (NRC) has proposed reform of the material control and accounting (MC&A) regulations for fuel conversion and fabrication facilities authorized to possess and use formula quantities of strategic special nuclear material (SSNM). The principal objective of the proposed MC&A reform amendments is to establish the capability for timely detection of an abrupt five-formula-kilogram (Fkg) loss of SSNM and to provide for more conclusive resolution of discrepancies. The purpose of this study is to identify and assess the advantages and disadvantages of detection times ranging from one day to two weeks. Experience obtained in applying various aspects of the proposed reform amendments at two existing facilities is the basis for the evaluation.

In this study, material loss indicators based on existing process control data at two facilities are evaluated to determine their existing detection capabilities, alarm frequencies and alarm resolution capabilities as a function of the detection time chosen. These characteristics are compared for daily, weekly and biweekly detection times. The basic unit of the detection time interval was chosen to be one day for this study. Advantages and disadvantages, as a function of the detection time, are discussed to assist NRC decision makers in choosing a detection time; the discussion addresses the changes in detection sensitivity, the effort to collect and process data, the alarm frequency, and the effort to resolve alarms.

The proposed reforms ⁽¹⁾ have specified a three working day detection time interval for accessible material which is directly usable in the manufacture of a nuclear explosive device. To avoid allowing the detection time interval to include weekends and holidays, this three working day detection time interval could be performed using combinations of two-working day and three-working-day detection times. This would result in an increased process variability due to the bimodal nature of process throughput. An alternative would be to use three consecutive working days, which results in an administrative complexity in that the start and end times are not consistent from week to week. In this alternative, it is expected that detection intervals which include weekend shutdowns or runout may have different variances than would detection time intervals which do not include an intermediate shutdown or runout. In either of these cases, approximations and inequalities would be used to simplify the multivariate characteristics of establishing alarm thresholds and estimating alarm frequencies. As such the three-working-day detection time is not discussed, and it is assumed that estimates of the capabilities at this detection can be determined by interpolating between the one day and one week detection times.

1.1 PREVIOUS STUDIES

Previous studies(2-8) addressing the effectiveness of using process monitoring data for material loss detection have described the detection capability, expected alarm frequency and resolution capabilities at several nuclear material processing facilities. In each of those studies, a detection time

interval was selected based on either the timing of existing process control measurements or the detection times proposed in the NRC Advanced Notice of Proposed Rule Making.⁽⁹⁾ Other studies⁽¹⁰⁻¹¹⁾ addressing the use of process monitoring data for material loss detection have estimated how costs vary as a function of the detection time interval. These studies generally show that the costs decrease as the detection time interval is lengthened. Byers and Heaberlin^(a) examined the qualitative effects of detection time alternatives for a range of cases. Specific cases addressed were four-hour to one-week detection time intervals for abrupt loss, and 24-hour to one-week detection time intervals for plant-wide tests. The examination included values of detection capability, recovery potential, deterrence and benefits outside of MC&A enhancement, as well as the disvalues of feasibility and operational practicality. Cost estimates were developed based on implementation, operations and equipment. The study indicated a three-day detection time for abrupt losses as the tradeoff point between increased value and increasing costs.

Hawkins, Lynch and Lumb⁽¹⁰⁾ examined the potential use of process monitoring data to improve material control in a high-enriched uranium scrap recovery facility. Four levels were addressed ranging from expansion of currently used process monitoring to development of new techniques and major modifications to the existing process. The study indicated that costs decrease as the detection time interval is increased. The detection time intervals that were considered ranged from one day to two weeks. The study recommended development of an option which had a 3-day detection time interval. Glancy et al.⁽¹¹⁾ used a different approach based on diversion path analysis to evaluate several options. While showing costs decreasing as the time to detection increased, the study did not recommend a detection time interval.

1.2 METHODOLOGY

The methodology used in this study to evaluate the alternative detection times consisted of identifying control areas where a material loss test could be performed on a daily basis using existing data and determining the currently available detection capabilities. Process control data were initially summed into a material loss indicator for each day. Then, the daily material loss test data in each calendar week were summed, and finally the daily material loss test data were summed in two-week increments. In some cases, there were data available for material loss tests performed for each input item processed in a day. For each set of data, the mean and standard deviation were calculated. The alarm threshold was then determined for 99% probability of detecting a 5 Fkg loss. For each alarm threshold, the data were reviewed to identify alarms and calculate the alarm frequency. If the frequency was significantly greater than expected, the probable causes are discussed in terms of resolution of alarms, combinations of normal distributions, and non-normal distributions. The final activity in analyzing plant detection data was to

(a) Heaberlin, S. W., and K. R. Byers. 1980. Value Impact Analysis of Alternatives for Prompt Accountability of SSNM, (Draft), Pacific Northwest Laboratory, Richland, Washington.

estimate the change in effort to collect and process the loss detection data. Following the analysis of the actual plant loss detection data, a set of generic advantages and disadvantages is discussed as they appear to be descriptive of the data.

For the purposes of this study, the detection time is defined as the time interval in which a loss could be localized by the detection test. The detection start time is:

- when the last loss detection test time interval was completed,
- for material in an inaccessible process step, the time when the material should have been produced and accessible to diversion,
- for a process with intermittent operations, the time when material is entered into a process step and is accessible to diversion, or
- for material in storage, the time when an identifiable item is received at a storage location.

The detection end time is when the collection of the loss detection data has been completed. The detection times as used in this study are average times; that is, if the test is performed once each day, then the detection time interval is one day. The detection time, as defined here, does not include the time required to process the data and calculate a material loss estimator.

Two facilities were studied to determine their capabilities if process monitoring data were used for material loss detection. Both facilities process high enriched uranium (HEU). Facility 1 is a conversion/fabrication facility which receives uranium oxide, converts it, and forms it into particles for reactor element fabrication. The material loss test at Facility 1 is a process yield which compares the predicted product weight to the measured product weight, where the predicted product weights are based on input measurements, historical process characteristics determined from quality control measurements and stoichiometric factors. Small amounts of holdup are accumulated proportional with the processing throughput. The process is cleaned out when the cumulative difference between input and output quantities exceeds predetermined limits. Facility 2 is a scrap recovery facility. The material loss test at Facility 2 is a material balance where in-process inventories are measured in storage vessels and estimated in process equipment. Unmeasured holdup is primarily contained in connecting piping and pumps and is assumed to remain constant with a variance determined by process variability. Both facilities' processes involve changes of chemical and physical forms of the uranium. At each facility, the throughput of a specific control area is dependent on the recycle from other control areas within the facility. The range of throughput varies from 100-kg U to 500-kg U per two-month period per control area at the two facilities; where control areas having the highest recycle fractions showed the greatest variability of throughput between control areas. Because of

recycle, it was not possible to clearly identify one facility as having the largest throughput in all control areas, as this study only addressed part of each facility's process.

While these facilities are similar in that the processes involve both changes in the chemical and physical form of the uranium processed and changes in the throughput of the processes, they are different in the complexity and predictability of the process used to change the material form. As such, the differences in the variability of the material loss indicator between facilities, for a given detection time interval, is primarily determined by the complexity of the process rather than the throughput.

Both of the facilities referred to in this study utilize a manual data collection system. Control areas are allowed to continue processing material after the detection end time and before the material loss indicator is calculated. Therefore, the detection end time is not clearly defined, but represents a nominal value of what may be achievable if an electronic data processing system were implemented to collect and process loss detection data.

This study is based on initial efforts to use process monitoring data for material control and accounting. As experience is gained with this type of data, it can be expected that key measurement points will be identified that will result in improved material control capability, and that in-process holdup will be better characterized. Consequently, loss estimator variances and goal quantity loss detection sensitivity will likely improve and false alarm rates will decrease.

The results of this study are based on data collected for several control areas at each facility. The data do not cover all aspects of either facility or item controls. Effort estimates should only be used to indicate trends when changing detection times.

2.0 DETECTION CAPABILITY

This section contains a description of the existing material loss detection capabilities as a function of loss detection time. Loss detection capabilities are based upon the variances of material loss indicators calculated from existing process control data. Tables 1 and 2 show the control areas, the type of loss test performed (material balance or process yield), the type of processing (whether batch or continuous), the basic unit of the detection time interval (item or day) and the nominal number of data entries required to calculate the material loss indicator.

Two types of material loss indicators are used: material balances and process yields. Where process yields are used, a relative value is converted to an absolute quantity by multiplying the material input value by the expected process yield factor and subtracting it from the material output value. Material balances should be more accurate because they are less susceptible to process variabilities. However, in the facility examples shown here, unmeasured or poorly measured holdups were major contributors to process variability in

TABLE 1. Characteristics of Facility 1 Process Monitoring Loss Detection System

<u>Control Area</u>	<u>Loss Detection Test</u>	<u>Process Type</u>	<u>Loss Detection Time Unit</u>	<u>Number of Data Entries Per Test</u>
1. Mix	Material Balance	BATCH	Item ^(a)	2
Grind	Process Yield	BATCH	Day	50
Mix/Grind Combined	Process Yield	BATCH	Day	50
2. Conversion	Process Yield	BATCH	Item	6
Screen	Material Balance	BATCH	Item	2
Conv/Screen Combined	Process Yield	BATCH	Item	6
3. Furnace	Process Yield	BATCH	Item	2
Screen-1	Material Balance	BATCH	Item	2
Screen-2	Material Balance	BATCH	Item	2
4. Furnace	Process Yield	BATCH	Item	6
5. Furnace	Process Yield	BATCH	Item	6
6. Furnace	Process Yield	BATCH	Item	6

(a) Each item processed is tested.

TABLE 2. Characteristics of Facility 2 Process Monitoring Loss Detection System

<u>Control Area</u>	<u>Loss Detection Test</u>	<u>Process Type</u>	<u>Loss Detection Time Unit</u>	<u>Number of Data Entries Per Test</u>
1. Dissolution	Material Balance	Continuous	Day	52
2. Extraction	Material Balance	Continuous	Day	108
3. Extraction	Material Balance	Continuous	Day	72
4. Extraction	Material Balance	Continuous	Day	76
5. Conversion	Material Balance	Continuous	Day	40
6. Dissolution	Material Balance	Continuous	Day	34
7. Sum of Six Control Units	Material Balance	Continuous	Day	300

both material balances and process yields. Additionally, the throughputs and measurements differed in each control area at each facility. Consequently, specific recommendations addressing key causes of process variability cannot easily be ascribed.

2.1 MATERIAL LOSS INDICATOR VARIABILITY

Tables 3 and 4 show by facility the standard deviations of the material loss indicator calculated for each control area. The standard deviations are shown when performing the loss detection tests for daily, weekly and biweekly loss detection time periods. Additionally, Tables 3 and 4 show the effects of combining two adjacent control areas into a single, larger control area. The purpose of combining two adjacent controls was to avoid a transfer measurement, and thereby reduce the variance of the loss test. Of the 18 tests for single control areas shown in Tables 3 and 4, where biweekly test standard deviations are calculated, 17 show the standard deviation increasing as the detection time is increased to two weeks from one day. This is expected from summing the variances; however, there are three reasons why it is not possible to estimate a specific value for predicting the increase:

- the processing per week is variable
- there are serial correlations in the data (loss/gain pairs) (a)
- there are short-term systematic errors.

(a) A loss/gain pair is defined as two (or more) consecutive, unusually large material loss indicators calculated from item processing data. Most often, the first such indicator is a large loss that is subsequently followed by an equally large gain. This behavior can be attributed to an initial in-process holdup of material that is recovered in the succeeding material processing.

TABLE 3. Variability of Facility 1 Material Loss Indicator as a Function of Detection Time

Control Area	Standard Deviation (grams)			
	Item	Daily	Weekly	Biweekly
1. Mix	22.7	87.7	162.1	253.4
Grind	--	251.9	444.1	811.7
Mix/Grind combined	--	290.3	550.4	1013.2
2. Conversion	62.6	94.6	168.0	212.2
Screen	28.8	41.8	68.7	147.5
Conv./Screen combined	82.8	151.5	196.2	241.1
3. Furnace	70.5	139.9	(2)	(2)
Screen-1	55.8	71.5	140.5	147.4
Screen-2	312.4(7.3)(1)	487.6(16.3)(1)	39.7	44.4
4. Furnace	300	933.7	3042.1	4366.3
5. Furnace	331	1326.3	2591.6	2835.1
6. Furnace	270	1711.4	4350.7	6443.4

(1) Values in parentheses are standard deviations when large (greater than four standard deviations) loss/gain pairs are deleted.

(2) Standard deviations are not shown for less than five data points.

The observed ratios of the standard deviation of the two-week test to the standard deviation of the daily test ranged from 0.09 to 5.76 with a median value of 3.15. If the throughput were constant in each of 10 daily tests per two-week period and the daily data were independent normally distributed, the expected ratio would be approximately 3.16. The tests are not independent because the ending inventory of one test is the beginning inventory of the next test. Additionally there are short-term systematic changes in measurements and process characteristic which are more significant in the biweekly detection time.

At a one-week detection time, there are three control areas where the loss indicator standard deviation decreased as compared to a one-day time. Two were caused by loss/gain pairs canceling as data were summarized over several individual inputs, while one resulted from routine process runout that occurred on

TABLE 4. Variability of Facility 2 Material Loss Indicator
as a Function of Detection Time

Control Area	Standard Deviation (grams)					
	Daily		Weekly		Biweekly	
	Initial	With Holdup and Bias Correction	Initial	With Holdup and Bias Correction	Initial	With Holdup and Bias Correction
1. Dissolution	641.0	625.0	423.3	449.7	844.2	810.7
1-2 Combined	949.3	761.0	1240.0	1340.5	2214.6	2589.6
2. Extraction	752.6	469.9	1505.9	1440.9	2678.2	2706.9
2-3 Combined	1287.1	501.7	2039.0	1133.0	2175.2	1830.5
3. Extraction	1123.3	354.1	1931.4	904.3	3462.7	1651.4
3-4 Combined	1865.7	692.9 (434.5)	4936.3	1859.7 (899.5) ⁽¹⁾	9029.0	3158.5 (1420.9) ⁽¹⁾
4. Extraction	1782.2	735.7 (416.3) ⁽¹⁾	3808.6	1706.1 (421.9) ⁽¹⁾	6334.9	2130.9 (500.6) ⁽¹⁾
4-5 Combined	2074.2	773.7 (475.0) ⁽¹⁾	4685.2	983.0 (753.7) ⁽¹⁾	6630.9	1007.1 (1033.1) ⁽¹⁾
5. Conversion	1273.9	535.9 (289.8) ⁽¹⁾	1862.1	1046.3 (510.0) ⁽¹⁾	1786.6	1940.1 (598.8) ⁽¹⁾
6. Dissolution	44.0	28.9	69.6	67.2	90.1	66.8
Total of six control areas	2499.4	1100.1	5250.5	955.9	7925.9	1233.6

(1) Loss/gain pairs in daily tests between CA-4 and CA-5 deleted.

a weekly basis. For the cases in which variability decreases due to the canceling of loss/gain pairs, it is shown that the standard deviation of the material loss indicator always increases with increased detection time if the loss/gain pairs are deleted beforehand. On the other hand, for the case in which variability decreases due to process runout, the decrease in standard deviation occurs because the process is shut down for the weekend and material in-process is runout before shutdown. Loss indicators summed over a period of a week or more are not susceptible to such daily variabilities. Cleanout and waste measurements are not included in daily measurements because the measurement results are not received for one to two weeks.

Combining two adjacent process control areas may be used to avoid a transfer measurement point which may be the primary cause of alarms. Table 3 shows the results of two combinations of adjacent process units at Facility 1 and Table 4 shows four combinations involving five adjacent control areas at Facility 2. For Facility 1, six of the seven combinations show that the variance of the combined indicator is larger than the sum of variances shown for the two indicators combined. This indicates a positive covariance between the adjacent process operations. The positive covariance is unexplained and a negative covariance is expected due to the common transfer measurement. A possible explanation is that the material characteristics vary from batch to batch in a manner which affects the process yield. For Facility 2, 23 of the thirty combinations show that the variance of combined indicator is smaller than the sum of variances for the two sets of data combined, which can provide an estimate of the variance of the transfer measurement. The seven cases, where the variance of the combined indicator is larger than the sum of variances for the control units combined, involve the presence of a loss/gain pair. At both facilities, combining adjacent control areas results in higher probability of an alarm per test.

2.2 ALARM FREQUENCY

Based on the calculated standard deviations (s), Tables 5 and 6 show the estimated alarm threshold to detect a 5-Fkg abrupt loss with 99% probability. It is assumed that the material loss indicator is an independent normally distributed variable. The alarm threshold (AT) was calculated as

$$AT = 5000 - 2.33s.$$

Several control areas show negative alarm thresholds for detecting a 5-Fkg loss. This occurs when the standard deviation of the material loss indicator is greater than $5000 \div 2.33 = 2145$ grams. When the alarm threshold is negative, the alarm rate will be greater than 50%. For those control areas where the alarm threshold is negative, it is anticipated that the routine effort to resolve false alarms will be significantly greater than the effort to generate loss estimators because resolution would routinely involve holdup cleanout and regeneration of detection data with improved measurement methods. As such, resolution of alarms would be providing the actual detection mechanisms and the

TABLE 5. Facility 1 Alarm Thresholds for 99% Probability of Detecting 5-Fkg Loss (AT = 5000 - 2.33s)

Control Area	Alarm Threshold, (grams)			
	Item	Daily	Weekly	Biweekly
1. Mix	4947	4795	4622	4410
Grind	--	4413	3965	3109
Mix/Grind Combined	--	4323	3717	2639
2. Conversion	4854	4780	4690	4506
Screen	4932	4903	4840	4656
Conv./Screen Combined	4807	4647	4543	4438
3. Furnace	4836	4674	(1)	(1)
Screen-1	4870	4833	4673	4657
Screen-2	4273	3864	4908	4896
4. Furnace	4301	2824	-2088	-5173
5. Furnace	4229	1910	-1038	-1606
6. Furnace	4371	1012	-5137	-10013

(1) Variance not estimate with less than 5 points.

purpose of the detection system would degenerate to providing a sorting mechanism for performing the actual loss test. This would result in decreased deterrence value for the detection system.

If it is assumed that the data can be described by a single normal distribution, then an expected alarm frequency can be determined. Based on the 5-Fkg abrupt-alarm thresholds shown in Tables 5 and 6, the expected and observed alarm frequencies by control area were determined and the results presented in Tables 7 and 8. The data for the biweekly tests shows larger variability between the expected and observed alarm frequencies because of the smaller number of data points. In general, the observed alarm frequencies are greater than the expected values because of recording errors and unusual process occurrences such as spills and holdup.

Daily 5 Fkg abrupt alarm threshold values shown in Table 5 and 6 were used to test loss indicators in order to determine overall facility alarm rates for

TABLE 6. Facility 2 Alarm Thresholds for 99% Probability of Detecting 5-Fkg Loss (AT = 5000 - 2.33s)

Control Area	Alarm Threshold, (grams)(1)		
	Daily	Weekly	Biweekly
1. Dissolution	3506	4014	3033
1-2 Combined	2792 (3230)	2116 (1882)	-151 (-1023)
2. Extraction	3246 (3905)	1491 (1643)	-1240 (-1307)
2-3 Combined	2006 (3833)	257 (2360)	-59 (742)
3. Extraction	2383 (4175)	500 (2893)	-3068 (1152)
3-4 Combined	660 (3989)	-6482 (2908)	-16002 (1695)
4. Extraction	847 (4030)	-3874 (4017)	-9760 (3833)
4-5 Combined	175 (3895)	-5898 (3247)	-10423 (2597)
5. Conversion	2032 (4324)	661 (3787)	837 (3605)
6. Dissolution	4897	4838	4790
Sum of 6 Control	-824 (2436)	-7234 (2773)	-13467 (2126)

(1) Alarm thresholds in parentheses are based on bias corrections, holdup estimation, and deletion of loss/gain pairs.

a detection time of one day. The results of these calculations are shown in Tables 7 and 8. As can be seen from these tables, Facility 1 would have had an observed 0.4% alarm rate and Facility 2 would have had an observed 11% alarm rate. At Facility 1, one alarm was observed and was resolved to be an unusual process occurrence of material holdup. At Facility 2, the observed alarm rate was caused primarily by biases in transfer measurements and variability of holdup in the piping. If the estimated holdup in the piping is included in the material balance and the biases corrected, the observed alarm rate reduces to approximately 2% with the primary cause of the remaining alarms being recording errors.

An alternative to using a 5 Fkg goal quantity would be to establish criteria for alarm thresholds at a value as low as reasonably achievable. If it is assumed that each facility will choose alarm thresholds to have a low false-alarm rate, for example approximately 1%, then the control quantity will be greater than 4.66 standard deviations for 99% probability of detection if it is also assumed that the data are normally distributed. The maximum desired

TABLE 7. Facility 1 Alarm Frequencies for Alarm Threshold to Detect 5-Fkg Loss with 99% Probability (expected alarm frequency based on normal distribution)

Detection Time Control Area	Item	Alarm Frequency (%)						Expected	Observed
		Daily		Weekly		Biweekly			
		Expected	Observed	Expected	Observed	Expected	Observed		
1. Mix		<.01	0.0	<.01	0.0	<.01	0.0	<.01	0.0
Grind		---	---	<.01	0.0	<.01	0.0	<.01	0.0
Mix/Grind Combined		---	---	<.01	0.0	<.01	3.3	0.46	6.7
2. Conversion		<.01	0.0	<.01	0.0	<.01	0.0	<.01	0.0
Screen		<.01	0.0	<.01	0.0	<.01	0.0	<.01	0.0
Conv./Screen Combined		<.01	0.0	<.01	0.0	<.01	0.0	<.01	7.7
3. Furnace		<.01	0.0	<.01	0.0	(1)		(1)	
Screen-1		<.01	0.3	<.01	5.0	<.01	7.7	<.01	10.0
Screen-2		<.01	0.0	<.01	0.0	<.01	0.0	<.01	0.0
4. Furnace		<.01	0.0	0.23	0.0	75.42	90.0	88.2	85.7
5. Furnace		<.01	0.0	7.49	20.0	65.72	72.7	71.52	62.5
6. Furnace		<.01	0.0	27.76	36.0	88.10	100.0	94.01	100.0

(1) Variance not estimated for data set.

TABLE 8. Facility 2 Alarm Frequencies for Alarm Threshold to Detect 5-Fkg Loss with 99% Probability (expected alarm frequency based on normal distribution)

Detection Time Control Area	Daily		Weekly		Biweekly	
	Expected	Observed	Expected	Observed	Expected	Observed
1. Dissolution	<.1	0.0	<.1	0.0	<.1	0.0
1-2 Combined	.2 (<.1)	0.0 (0.0)	4.4 (8.0)	0.0 (12.5)	52.6 (65.4)	50.0 (50.0)
2. Extraction	<.1 (<.1)	0.0 (0.0)	16.1 (12.7)	12.5 (25.0)	64.1 (68.4)	50.0 (75.0)
2-3 Combined	6.1 (<.1)	10.3 (0.0)	45.0 (1.9)	87.5 (0.0)	51.1 (34.3)	100.0 (50.0)
3. Extraction	1.7 (<.1)	25.0 (0.0)	39.7 (0.1)	75.0 (0.0)	81.3 (24.2)	100.0 (25.0)
3-4 Combined	36.2 (<.1)	10.0 (0.0)	90.5 (<.1)	87.5 (0.0)	96.2 (11.7)	100.0 (0.0)
4. Extraction	31.9 (<.1)	18.9 (0.0)	84.1 (<.1)	87.5 (0.0)	93.8 (<.1)	75.0 (0.0)
4-5 Combined	46.6 (<.1)	27.8 (0.0)	89.5 (<.1)	87.5 (0.0)	94.2 (0.5)	75.0 (0.0)
5. Conversion	5.5 (<.1)	8.0 (0.0)	36.2 (<.1)	50.0 (0.0)	31.9 (<.1)	25.0 (25.0)
6. Dissolution	<.1	0.0	<.1	0.0	<.1	0.0
Total of Six Control Areas	62.9 (1.3)	72.0 (0.0)	91.6 (0.2)	87.5 (0.0)	95.5 (4.3)	75.0 (0.0)

(1) Alarm Frequencies in parenthesis are based on bias correction and estimation of in-process holdup.

standard deviation would be 1.08 kilograms to detect a 5-Fkg loss. Four of 34 tests shown on a daily basis would have a false alarm rate greater than 1% to achieve 5 Fkg loss detection, whereas 11 of 18 would have greater than 1% false-alarm rate for a two-week detection time. By comparison, nearly all of the control areas would have false-alarm rates greater than the predicted 1% rate if the alarm thresholds were based on criteria as low as reasonably achievable, established on the assumption of normality. At Facility 2, there

was not enough data to empirically estimate a 99% control limit. At Facility 1, there was sufficient data for item monitoring to estimate empirical alarm thresholds; for those cases where sufficient data was available to test consecutive data sets, the alarm frequency agreed reasonably well with predictions.

2.3 OTHER CONSIDERATIONS

Options to improve alarm rate prediction would include the use of empirical distributions and the use of mixes of normal distributions to describe heterogeneous populations. Based on the observed distributions, the empirical distribution could be used to set the alarm thresholds and estimate alarm rates. The problem in using empirical methods will be in obtaining enough data to estimate the alarm thresholds. Achievement of 75% confidence in identifying the 99th percentile limit of the distribution would require 138 data points. While these confidence levels could be attained for daily detection times based on one year of operating experience, weekly and biweekly detection times would require three and five years of operating experience, respectively. As licensees operate under a system to use process monitoring data to improve material accounting, it can be expected that analysis of data will identify potential improvements and the system will accordingly be modified. Based on these requirements, it is estimated that five and ten years would be required to accumulate enough data under constant operating conditions to determine alarm thresholds for a system based on an empirical distribution for weekly and biweekly detection time, respectively. If the frequency of changes in the process operations are considered, it may not be practical to consider empirical distributions for use with weekly and biweekly tests. One potential advantage of using longer time periods would be that when variables are not normally distributed, the distribution of a sum of the variables over several days may approximate a normal distribution. The degree to which adding data from several distributions may produce a normal distribution is variable.

Table 9 shows the confidence level above which the hypothesis of the data being normally distributed would be rejected for Facility 1. If the test of the hypothesis were made at the 0.95 level (which is commonly accepted criteria), all of the cases shown in Table 9 would be rejected. Figures 1 through 3 show an example set of histograms of mass balance differences for three detection times in one of the control areas at Facility 2 where it was observed that data came from a heterogeneous population. The histograms also show an expected distribution based on the means and variances of the data, if it is assumed that the data is normally distributed. These histograms show the observed distributions separate from the expected normal distribution in the tails.

For several control areas, the observed distributions were fit to a mix of two normal distributions.⁽¹²⁾ Table 10 compares the confidence level that the data is described by a single normal distribution and the confidence level for

TABLE 9. Confidence Level at Which the Hypothesis That Loss Indicators Are Normally Distributed at Facility 2 Would be Accepted

<u>Test Frequency</u> <u>Control Area</u>	<u>Probability of Normal Distribution</u>		
	<u>Item</u>	<u>Daily</u>	<u>Weekly</u>
1. Mix	<.005		
Grinder	---	<.005	
Combined	---	<.005	
2. Conversion	<.005	.15	.02
Screen-1	.4	.6	.2
Screen-2	<.005	.08	.4
Combined	<.005	.02	.6
3. Screen	<.005	<.005	
Furnace	<.005		
4. Furnace	.01	.025	.01
5. Furnace	.5	.6	.6
6. Furnace	.01	<.005	<.005

a mix of two normals as compared to a single normal. The results of Table 10 indicate heterogeneous populations of at least two phenomena. In some cases, the mix of two normal distributions can be described by correlations that result from loss/gain pairs. The method of using a mix of normal distributions did not converge to a solution for other control area tests which is a characteristic of the method which has been observed in other studies. (13-14)

2.4 SUMMARY

The detection capability incorporates three aspects: timeliness, sensitivity and localization. For shorter detection times, all three aspects are generally improved and, therefore, so is detection capability. This occurs because fewer personnel are involved, throughput is smaller, and data bases are smaller. Localization, although not directly improved for shorter detection times, is improved because as variances are reduced, ambiguity in decision about the location of an alarm is also reduced. Review of Section 2 shows that all of the control areas reviewed could detect a 5-Fkg abrupt loss with 99%

FIGURE 1. An Example Histogram of Material Balances of Item Processing

probability and could have an expected false alarm rate from routine variability of less than 5% for a one day detection time, and generally, less than 1% false alarm rate. Specifically, analysis of existing process control data as it could be used for material loss detection at these two HEU fuel fabrication facilities indicates the following characteristics of system performance:

- the data is non-normally distributed, but the normality of the data increases somewhat for longer detection times. The data is better described by a mix of two normal distributions.

- the material loss indicator standard deviations increases for longer detection times, with the standard deviation of a two-week test nominally 3.15 times that of a daily test.
- 5-Fkg alarm frequencies are greater for longer detection times. In several control areas, the alarm rate for the biweekly detection time exceeds 50%.

FIGURE 2. An Example Histogram of Control Area Material Balances for a Daily Detection Time Interval

FIGURE 3. An Example Histogram of Control Area Material Balances for a Biweekly Detection Time Interval

TABLE 10. Comparison of Modeling Data by Single Normal and Mix of Two Normal Distributions

Control Area	Confidence Level	
	Single Normal ⁽¹⁾	Mix of Two Normals ⁽²⁾
2. Conversion	0.75	(3)
Screen-1 item	.4	.994
Screen-1 daily	.6	.91
3. Screen	<.005	.995
4. Furnace	.01	.995

(1) Confidence level below which the hypothesis that the data is normally distributed would be accepted.

(2) Confidence level that the data is more adequately modeled by a mix of two normal distributions.

(3) Solution for mix of two normal distributions yielded a single normal.

3.0 EFFORT TO PROCESS DATA

The task of collecting and compiling the process monitoring data to be used for material loss detection may be divided into five general subtasks:

- making the required measurements and performing an inventory
- collecting measurement data, transfer records and inventory records
- calculating a material loss estimator
- determining the control limit or alarm threshold for testing each estimator
- testing the estimator.

3.1 ADDITIONAL MEASUREMENTS

Measurements are routinely performed for process control, quality assurance and material accountability. Inventory records are routinely updated for production control and accountability. Using process monitoring data for material loss detection may, however, require that additional measurements be performed to ensure that adequate information is included in a material loss estimator to meet the detection sensitivity requirements. Sidestreams and in-process inventory are the primary categories where additional measurements may be needed. Performing an inventory of the material in-process is an activity that is not currently performed on a uniform time scale, but is performed in conjunction with the frequency of process operations. In some cases, the sidestreams and in-process inventories, which are not currently measured, can be modeled to provide the required detection sensitivity. It may, however, be necessary to measure the material periodically to verify the model.

At Facility 1, no measurements in addition to those performed for process control were required to perform the material loss tests; as a result, varying the detection time will not change the number of measurements performed. However, performing the material loss test will affect the method of processing data and will require performing item checks at the end of each detection time interval. The inventory in the process area is in-process holdup and items of material between process steps. In-process holdup is difficult to measure and would be modeled. Items are intermediate products for further processing and may not be sealed. It is postulated that the effort to list and reconcile the inventory is inversely proportional to the detection time, since fewer inventory listings and reconciliations will be necessary in a given time interval if the detection time is longer. For example, assuming 20 operating days or four operating weeks to a month, a weekly detection time will require performing only four physical inventories of items in the process area per month, instead of 20 for a daily detection time. In any event, it appears that the entire

inventory process could be simplified by the development of an automated data collection system to generate near-real-time inventory listings.

At Facility 2, 20-30 measurements per control test period in addition to those performed for process control were required to adequately quantify transfers and inventory for the daily material loss tests. That is, 10-15% of the measurements used in the material loss tests for a daily detection time interval are not routinely collected for process control, and 5% of the measurements for a two-week detection time are not routinely collected for process control. As shown in Section 2, significant improvements in the detection capability could be achieved from bias correction and estimation of holdup. Even with the bias correction case shown, Table 8 indicates that several of the control areas would have high alarm frequencies (25-75%) for the weekly and biweekly detection time intervals. This indicates that an increase in the number of measurements performed would result from resolving alarms. It also may not be possible to consistently achieve the bias correction with existing equipment, and improved measurement capability may be required. The initial effort for measurement improvement would be independent of the detection time, except that measurement improvements are more likely to be required for longer detection time intervals. The material is generally processed on a daily basis; however, three of the six control units have process equipment which only operates on a frequency of once to twice per week. Changing from a daily detection time interval to a one-week detection time interval would result in a 70% decrease in the number of measurements to be performed for inventory. The number of measurements performed at the end of the detection interval is larger for the weekly and biweekly detection times because a larger number of vessels will have been used. Intermediate product storage is material in-process, and no changes in effort to perform an inventory are anticipated when the detection time is changed.

3.2 DATA COLLECTION

Once the measurements and physical inventory are performed, the data would be collected and processed. For the longer time periods, a larger fraction of the data collection time would be spent to ensure that all the data were collected. For short detection times, it is less likely that a measurement value would not be included because there is a closer proximity between recording inputs and outputs.

At all facilities, the effort to collect transfer data does not change as a function of the detection time. For the short detection time intervals (less than one week), additional verification may be required to ensure that the data set is completed in a time commensurate with the detection time. For longer detection times, mechanisms may have to be developed for sorting and summarizing the data by type. At Facility 1, the in-process inventory is small amounts of unmeasured holdup and intermediate products stored as identifiable items. Therefore, the effort to collect the measurement data does not change as a function of detection time. At Facility 2, while the effort to collect transfer data remains constant, the in-process inventory data comprise 60% of

TABLE 11. Estimation of the Effort to Collect Material Loss Indicator Data

Facility	Number of Data Elements Collected Per Day				Calculations Per Day			
	Item	Daily	Weekly	Biweekly	Item	Daily	Weekly	Biweekly
1	62	62	62	62	124	144	130	131
2	--	300	180	160	---	450	270	240

the data required to calculate the material loss indicators. In addition, all inventory vessels may not be used on a daily basis, but would be used on a weekly basis. The inventory data collection, while becoming a smaller fraction of the loss detection data at Facility 2, would require an increased effort for longer detection times at the point in time when the inventory is taken. This would result in an uneven usage of personnel for loss detection.

3.3 CALCULATION OF MATERIAL LOSS ESTIMATORS

Table 11 shows the number of data elements collected and the number of calculations performed each day at Facilities 1 and 2 for three detection times. The data is shown as averages per day, although for weekly and biweekly detection times the data processing will not be uniformly distributed. These two facilities demonstrate two aspects of the data collection: 1) at Facility 1, as the detection time increases, the amount of data collected remains constant and the number of calculations performed increases; 2) at Facility 2, both the amount of data collected and the number of calculations performed decrease as the detection time is lengthened. At Facility 1, inventory measurement values are the same as transfer measurement values such that the number of data elements collected per day is independent of the detection time chosen. The number of calculations increases as the detection time increases for two reasons: 1) an alarm threshold would have to be calculated since there is significant variability in processing throughput from day to day or week to week in each control area, and 2) summary calculations would have to be performed as the loss test is a process yield. By contrast, at Facility 2 there are approximately 75 inventory points to be measured for the six control areas. The average number of transfer measurements per day is independent of the detection time. Therefore, the processing is more constant, and longer detection times smooth out variability in throughput, while the material balance calculational method does not change except to increase the number of transfers.

A general conclusion is that the method to calculate the material balance is generally independent of the detection time, and that effort for a single test increases for longer detection times due to the increase in transfer measurements while the total effort decreases. The method may, however, be more complicated for longer detection times when the material balance includes cleanouts. For a process yield, the method is altered to provide summation in a manner that relates the test to the power of loss detection.

3.4 DETERMINING CONTROL LIMITS OR ALARM THRESHOLDS

The effort to determine the control limit or alarm threshold for testing the loss estimator will be dependent on 1) the variability of processing throughput, 2) the complexity of the estimator, and 3) the amount of historical data available for studying the estimator behavior. When tests are performed for an item added to process, the control limit will remain relatively constant when the quantity of input material remains relatively constant compared to the inherent process variability. As the detection time is increased from testing each item processed to summarizing the processing of a day, the day-to-day variability of processing throughput will affect the alarm threshold calculation. As the detection time is further increased, the average throughput will likely stabilize. Short detection times will be better for modeling startup and shutdown of process systems that most likely will have different alarm thresholds. For a one-day detection time, it would not be practical to calculate an alarm threshold because of the timeliness of the required calculations to be performed.

If the throughput variability in a detection time interval is large or the estimator is based on a complex combination of variables, it may be necessary to develop a propagation of error methodology, similar to the methodology used to determine the standard error of the estimated inventory difference, $[SD(ID)]$, for establishing alarm thresholds. This methodology will be additionally complex due to the inclusion of the process variabilities of holdup and the increased number of material types. These may be estimable from historical data. As shown in Table 9, the loss estimators generally have a non-normal distribution and estimators for longer detection times appear to be more normally distributed than for shorter detection times. The number of historical data points required to estimate the 99% probability point with 75% confidence is 138. As such, because of changes in process characteristics, it may not be practical to consider using historical data in establishing alarm thresholds for longer detection times. However, they will be more representative for a simple test performed on the basic unit of throughput.

3.5 TESTING THE ESTIMATOR

Once the loss indicator and its alarm threshold have been calculated, the results would be evaluated to 1) authorize continued processing, 2) request investigation to resolve anomalies, or 3) request shutdown for response to a potential loss. Monitoring items or daily tests, MC&A would review a large number of indicators compared to a detection time of one or two weeks. The item or daily test would provide a large historical data base for evaluating loss indicator behavior. The one- or two-week test would allow MC&A to expend more effort in evaluating the loss indicators because there would be fewer of them. Obviously, there is a tradeoff in terms of having enough indicators to be evaluated and having few enough that MC&A responds with sufficient interest.

3.6 SUMMARY

Measurements are routinely performed for process control, quality assurance, and accountability. Similarly, inventory records are routinely updated for production control and accountability. The effects of detection time on the effort to produce the material loss indicator are listed below for the two facilities studied.

- At Facility 1, varying the detection time will have no effect on the number of measurements needed to perform material loss tests, whereas Facility 2 would require an increase of 5-15% in the number of measurements to insure that transfers and inventory are adequately quantified if daily tests were used instead of a weekly or biweekly detection time interval.
- No change in transfer data collecting effort is anticipated for either facility. However, the collection of inventory data at Facility 2 will require increased effort for longer detection times, while Facility 1 effort will remain unchanged.
- The number of calculations necessary to determine the material loss indicator increases at Facility 1 and decreases at Facility 2 as the detection time is lengthened.

The general conclusions from the results of these two facilities are:

- The effort associated with determining control limits or alarm thresholds is dependent on throughput variability, estimator complexity, and historical data availability. As the detection time increases, day-to-day processing variability will decrease, as will the availability of historical data. Process yields will require additional effort to summarize for longer detection times than would material balances.
- Item and daily tests provide a large historical data base for evaluations of indicator behavior, while the fewer number of weekly or biweekly tests allow MC&A more time to evaluate the loss indicators.
- Varying the detection time will have no effect on the number of measurements needed to perform material loss tests for facilities that operate in a batch mode, whereas, facilities that operate in a continuous mode may need an increase in the number of measurements for short detection times as compare to longer detection to ensure that sidestreams and inventory are adequately quantified to provide the detection sensitivity.

4.0 CAPABILITY TO RESOLVE ALARMS

For the purposes of this study, "alarm resolution" is defined as the identification of a cause(s) for the alarm. The general causes of alarms are procedural errors, process variability, measurement variability and failure, mistakes, and losses. The first four general causes are considered innocent causes and the fifth cause, losses, may be either an innocent or malevolent cause. Alarm resolution procedures will primarily be directed toward predictable innocent causes unless the loss indicator is excessively large both in relative terms of its standard deviation and in comparison to a strategic quantity. Resolving an alarm as being caused by a loss may require a more extensive safeguards investigation involving physical security. The key elements of a set of alarm resolution procedures for routine use are as follows: audit of records and comparison to historical data to identify recording mistakes; interviews of operators to identify unusual occurrences that may not have been recorded or were recorded incorrectly; remeasurement of material still available, or use of backup measurement data to reduce measurement variability and to identify measurement mistakes; and process equipment cleanout or continued processing to reduce the uncertainty of holdup or to put the material in a form that can be better measured.

In practice, alarm resolution is limited by the inherent variabilities of the loss detection system. The proposed systems would be more susceptible to process variabilities, as compared to the existing MC&A practices which use bimonthly physical inventories with more extensive shutdown and cleanout. Additionally, measurement control practices may not be as rigid as existing measurement control practices. Alarm resolution is simplified if the primary causes are recording errors and unusual occurrences which are not a function of the inherent variabilities of the loss detection system. Recording errors are identified by record audits and measurement verifications. Unusual conditions are identified by interviews with operators, reviews of cleanup records, observations of the process area, and comparisons of process control data to historical characteristics.

4.1 CAUSES OF ALARMS

Resolution of alarms caused by process variabilities and measurement errors could potentially impact the process operation by requiring shutdown for cleanout of holdup or by requiring that material be retained for additional measurements. For processes with high alarm rates, the licensee should consider improving the detection system to avoid confrontations with production over what may be considered routine process variability.

Procedural errors and process variabilities are more difficult to resolve because they, in general, are inherent to the system. A procedural error is a wrong step or series of steps in the procedures for collecting and processing the process control data into the material loss indicator. Procedural errors occur when procedures are incorrectly or inconsistently followed. Procedural

errors can occur with personnel, computer software and control hardware. Procedural errors are identified by systems audits and by trend analysis for comparison to predicted behavior. Procedural error will most likely involve a mistake, such as an incorrect factor entered in an automated system or a confusion of two similar characteristics. Procedural errors may systematically affect the material loss detection system and will then only cause alarms when a change occurs in the system, or they may only affect a component of the material loss detection system. The effects of procedural errors will be determined by process variability that causes the role of the affected data to vary. When the affected data is relatively constant in the loss indicator calculation, the procedural error may only cause an alarm in startup and shutdown which will be difficult to distinguish from unmeasured or poorly measured holdup. When the procedural error only affects a component of the loss detection system, the resulting variability will be easier to identify in the simple loss estimator where only a small number of components are included. For more complex loss indicators, it is anticipated that procedural errors will be difficult to resolve because they are unlikely to be the primary cause of an alarm.

Process variabilities are identified by systems studies that involve holdup cleanout, additional measurements of material characteristics, observation of actual process operation, and data analysis. If the cause of a process variability affects only a portion of the data, i.e., a random material holdup or process leakage, then the licensee may choose either to develop a model by a system study for inclusion in the loss detection estimator or to treat its occurrence as an unusual event to be resolved by cleanout. As the detection time interval is increased, the effect of process variability increases the variability of the material loss indicator, because short-term systematic changes are more likely to accumulate to a significant fraction of the alarm threshold for larger quantities of throughput. Additionally, it can be expected that the holdup will gradually increase as the process operates such that a bias exists in the material loss indicator. For a longer time period, this will result in more frequent alarms which would require cleanout for the resolution. By contrast, for short detection time intervals, the average holdup would be a small fraction and could be identified by data analysis. The frequency of cleanout would then be determined by limits on cumulative sum tests for trickle losses. Figure 4 shows an example of daily loss detection data for a control area with process startup and shutdown on a daily basis and runout on a weekly basis. For this example, the variance of the loss indicator is reduced when the data is combined on a weekly basis. However, the resolution is complicated as the process characteristics are not distinguishable on a weekly basis. In this example, the effects of "filling" the system on Monday and the recovery of "fill" on Friday can be observed. It can also be observed that large values on Monday are followed by a recovery and stabilization on Tuesdays. By using a daily detection time, it is possible to describe one of the characteristics of process variability, filling the system.

Measurement performance includes random measurement errors, biases and measurement instrument failures. For short detection times (less than one week), random measurement error is not expected to be a primary cause of an alarm as compared to process variabilities. At longer detection times, random

FIGURE 4. Example of Daily Loss Detection Differences for a Control Area with Systematic Differences Between Days

measurement error may accumulate to become a significant source of variability, particularly if cleanout is performed to reduce process variability. Biases may be caused by an estimatable calibration error or by an inability to calibrate the measurement in a manner similar to actual operating conditions. The first cause of a bias is similar to that in existing MC&A systems. The second cause of bias occurs because of the dynamic nature of the process operation. Data may be collected while a process is operating whereas calibrations are performed under static conditions. Also, the material characteristics may rapidly change when removed from process such that it may not be practical to develop and retain standards representative of the material in-process. Primary concerns in developing standards would be oxidation and precipitation. Continuous processes will have some of the measurements performed during or near-in-time to the operation of the process. The likelihood that measurements are performed while the process is operating is greater for shorter detection times. For measurements performed on process vessels or equipment under operating or near operating condition, sources of uncertainty include material in piping and pumps, drainage of vessel walls and buildup of holdup or sludges with different characteristics. For detection times of one week or longer, the detection end time can be coordinated to routine shut down for the weekend to reduce the effects of piping, pumps and drainage. The buildup of holdup or sludges is less likely for shorter detection times to be the primary cause of an alarm as the buildup is gradual. The buildup of sludges in liquid systems can periodically be tested by the addition of an independently measured quantity to check the calibration. Measurement instrument failure will be detected by measurement control procedures, by the loss detection test, and by the operator's experience. Measurement control procedures are more important for longer detection times as material is less likely to be available for remeasurement if an alarm occurs.

Discrepancies in the records resulting from human errors are considered mistakes. Studies have reported human error frequencies of 0.5 to 5% in recording and transcribing data. Mistakes are more easily identified as a cause of an alarm if the loss indicator calculation uses a small number of data entries which can be compared to source documents or to remeasurement values. Failure to record or transcribe data and omission of a digit(s) are most likely to cause an alarm. Failure to record data is more likely to be identified if material can be verified or the operator(s) can be interviewed in a timely manner. Substitution of a digit and inverting two digits occur more frequently but are less likely to be the primary cause of an alarm. For longer time periods or complex loss indicators involving many (>100) data entries, there will be some cancellations of the errors. This would, however, enhance falsification as a concealment strategy of an actual loss, when the diverter understands the order in which the performance of resolution procedures checks for mistakes. For example, the diverter inserts two mistakes in the records, one positive and one negative, with one mistake which would explain the alarm being inserted at an early entry in the records. The resolution team would quickly identify the first and accept resolution. While this would not prevent detection because the other mistake would be identified in subsequent tests or audits, it could delay detection and result in the alarm resolution procedures being performed when material for remeasurement and cleanout are not representative of the time period in question. It could also result in a complete

shutdown of the facility for the investigation. Longer time periods would allow for more complete editing of data before calculation of the loss indicator, and shorter time periods would allow for more complete checking of data when an alarm occurs.

Losses occur when material leaves the accountability of the control area. This may include accidental losses and diversions. The loss need not leave the physical premises, but includes placement in a location which normally would not have SSNM or would only have de minimis quantities. Resolving an alarm as caused by a loss would require recovery of the material or a break of the physical perimeter of the facility collaborated in a more general investigation involving physical security or health and safety. Losses within the facility will be easier to identify for short detection times as operators may have witnessed an unusual event. For example, consider a spill of material which is cleaned up with a vacuum and the vacuum is not emptied or normally recorded on inventory. For longer detection times, it is more likely that the cleaned up material is recycled into the process or recorded on inventory.

As discussed in this section, there are several categories for causes of alarms. For short detection times, and small control areas, alarms are in general easier to resolve. This occurs primarily because the alarm will usually have a single cause. For longer times, it is more likely that the alarm will have several causes. The alarm resolution for longer times is more difficult because a larger data set is involved, however, several of the causes of alarms are less likely to occur because of editing the data and routine checks of the process area. As such, the number of potential causes to be routinely included in developing the alarm resolution procedures is reduced. A note of caution should be expressed; the experience and data upon which the preceding discussion is based is for short detection times (item or daily) and existing two month inventory. The weekly and biweekly time intervals may require significant changes in process operating procedures to provide for runout, cleanout, and cleanups on a schedule for MC&A. The short detection times appear to correspond to existing process control practices and development of a system to meet the proposed regulations would focus primarily on the MC&A organizational unit. For the weekly or biweekly test, it appears that production and process control would be required to make more of the modifications.

4.2 LOCALIZATION OF ALARMS

For any of the above causes of alarm, the resolution effectiveness will partially be determined by the ability of the loss detection system to localize the alarm in time and space. By using longer detection time intervals or larger process areas, the data to be reviewed would be increased, which would result in an increase in the time to resolve an alarm.

By increasing the detection time, it may be possible to improve routine cleanouts of holdup or to provide runout of continuous processes to reduce the process variability due to in-process inventory. Even so, the ability to localize recording errors or unusual process conditions is reduced as is the ability of the process operators to identify an unusual occurrence.

4.3 SUMMARY

Alarm resolution requires knowledge of the mechanisms that cause loss estimator variability. Lengthening the detection time will affect alarm resolution capabilities as follows:

- accumulation of short-term fluctuations during the extended detection time period may exceed specified alarm thresholds. However, longer detection times allow for the cleanout of in-process inventory which reduces process variability.
- accumulation of process monitoring data during the detection time period will make data review and, hence, alarm localization more difficult.
- availability of material for remeasurement will likely be reduced.

5.0 OVERVIEW

Advantages and disadvantages as a function of the detection time include changes in detection sensitivity and capability, the effort to collect and process data, and the effort to resolve alarms. The previous three sections addressed each of these topics in detail. This section provides a summary of the characteristics of the different detection times.

Table 12 summarizes the advantages and disadvantages of using detection time intervals ranging from an item or batch to two weeks. The item or batch detection time is probably not practical to specify in regulations and is considered an option under a daily detection time. It could be used if the regulations specified maximum detection times and allowed shorter intervals. In any case, it would only apply to some of the control areas at each facility. It does, however, provide superior simplicity and timeliness to the loss detection test.

Daily detection time still provides a good measure of simplicity and timeliness to the loss detection test and, at the same time, mitigates some of the problems associated with an item detection time. The comparative advantages relative to the item detection time are reduced labor requirements and improved time interval definition. However, cleanouts for holdup and process runouts remain impractical for time periods this short.

As the detection time is lengthened to a weekly or biweekly time period, detection sensitivity begins to suffer, as some control areas may incur high false alarm rates to detect a 5-Fkg loss. Additionally, alarm resolution capabilities worsen due to accumulation of short-term process variabilities and difficulties in localizing the cause(s) of alarms. However, the extended detection times offer advantages over their item and daily counterparts in terms of reduced labor needs, and the ability of these detection times in accommodating cleanouts of in-process inventories to improve detection capabilities. The well-defined nature of the detection time period also allows more time for MC&A to analyze data, report, and make decisions.

TABLE 12. Advantages and Disadvantages by Detection Time

<u>Time</u>	<u>Advantage</u>	<u>Disadvantage</u>
Item	Timeliness	Time interval poorly defined
	Ease of collecting and processing data	Probably requires EDP system to implement
		Difficult to include time for reporting and decision making
	Control limit can be constant	More susceptible to trickle loss
	5 Fkg loss detection sensitivity is achievable	Measurement results may not be available
	5 Fkg alarm rate low	Labor intensive
	Resolution simplified, and will primarily involve a single cause	Cleanout not practical
	Perception of loss detection capability	May not be practical to cleanup for individual test
Daily	Timeliness	Labor intensive
	Data collecting and processing continuous	Cleanout not practical
	Control limit could be a constant	Susceptible to trickle loss
	Good sensitivity	
	Low 5 Fkg alarm rate	
	Resolution simplified, and will primarily involve a single cause	
	Perception of loss detection capability	

TABLE 12. (contd)

Time	Advantage	Disadvantage
Weekly	Timeliness fair	Alarm threshold calculated for each test
	Detection time well defined	Alarm rates exceed 5% to detect 5 Fkg loss for some control areas
	Detection capability improved for some control areas by runout and cleanup for weekend shutdown	Large number of inventory measurements to be made at one time Short-term measurement bias and short-term systematic process variability appear as random error
Biweekly	Detection time well defined	
	Easy to include time for reporting and decision making	5 Fkg alarm rate may be high without measurement improvements and cleanout
	Allow for cleanup, cleanout or process runout to reduce variability of holdup	Data Collection more complex, may require EDP system to calculate alarm thresholds
	Allow time to edit data to reduce frequency of recording mistakes	Resolution more complex and may involve multiple causes Decreased detection sensitivity For some control areas 5 Fkg loss detection sensitivity may not be achievable Bias correction important to control false alarm frequency

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