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Use of Process Monitoring Data for the Enhancement of Nuclear Material Control and Accounting

Prepared by J. C. Miles, J. E. Glancy, S. E. Donelson

**Mound Facility
Monsanto Research Corporation**

**Prepared for
U. S. Nuclear Regulatory
Commission**

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Contents

<u>Section</u>		<u>Page</u>
	ABSTRACT.	2
1	INTRODUCTION.	5
2	DESCRIPTION OF PROCESS MONITORING DATA.	7
	2.1. Production Control Data	7
	2.2. Process Control Data.	9
	2.3. Quality Control Data.	10
3	DESCRIPTION OF ALTERNATE SYSTEMS.	12
4	EVALUATION OF ALTERNATE SYSTEMS	16
	4.1. Evaluation Methodology.	16
	4.2. Diversion Possibilities	16
	4.3. Performance Analysis.	20
	4.4. Localization of Loss.	21
	4.5. Loss Detection Timeliness and Sensitivity	22
	4.6. Semiquantitative Evaluation of Alternate Systems	23
	4.7. Trends in Effectiveness Among Generations and Concealment Strategies.	24
5	COST ANALYSIS	27
	5.1. Cost Estimation	27
	5.2. Operating Costs	31
	5.3. Implementation Costs.	32
	5.4. Measurement Control Procedures.	32
	5.5. Management Control Procedures	32
6	CRITICAL DISCUSSION OF THE USE OF PROCESS MONITORING DATA FOR SAFEGUARDS PURPOSES	33
7	RECOMMENDATIONS	34
8	REFERENCES.	35

Abstract

This study was conducted for the United States Nuclear Regulatory Commission (NRC) to determine if the use of process monitoring data currently being taken by licensees can increase the effectiveness of special nuclear material (SNM) safeguards. Specifically addressed was whether the use of process monitoring data, instead of certain current measures, can provide improved loss detection effectiveness and loss localization.

Two licensed fuel fabrication facilities, one processing low-enriched and the other high-enriched uranium, were examined in this study. Safeguards effectiveness of the current material accounting system at each licensee was quantitatively assessed using an evaluation methodology. Additionally, two generations of alternate material control systems using portions of the facilities' process monitoring data were developed and similarly evaluated for each facility. The two generations differ in the quantity and type of process monitoring data that would be recorded and analyzed for safeguards. The first generation system uses data presently taken and recorded. The second generation system requires both recording of some process monitoring data presently taken, but not retained for analysis, and more frequent recording of other data.

Process monitoring data refers to three types of data: production control, process control, and quality control data. Data of each type are used for specific functions and elements of each type were identified as useful for safeguards. Production control data consist primarily of bulk measurements such as process yield and product inventories. An abnormally low yield may indicate that a bulk material diversion or loss has occurred. Process control measurements such as flow rate, pH, and specific gravity can be used to detect diversions in certain process operations. Quality control data generated by chemical or NDA measurements can be used to detect diversions concealed by material substitution.

The methodology used to evaluate the nuclear material control systems consisted of identifying a set of nuclear material diversion or loss possibilities and calculating the effectiveness of each system in detecting these possibilities.

The set of diversion possibilities was derived by enumerating each nuclear material in a facility that could be a target for diversion. In doing this, materials in different forms or locations were considered different target materials. For each target material, three diversion concealment strategies were considered: bulk substitution, isotopic substitution, and no substitution. Additionally, each target material was assigned a relative diversion likelihood factor to represent a relative target material attractiveness.

The effectiveness of each system for detection of each diversion possibility was measured by the detection timeliness, detectable mass sensitivity, and degree of localization obtainable from the various process monitoring and accountability measurements at each process step. An overall, semiquantitative effectiveness factor for each system was computed as the weighted average of the products of detection timeliness and mass sensitivity for each target material using the assigned target material attractiveness values as the weighting factors.

For the low-enriched facility, the overall effectiveness factors show that the first generation alternate system offers improvements in diversion detection by factors of 3, 7, and 38 over the present system for the no substitution, bulk substitution, and isotopic substitution strategies, respectively. Loss localization is improved from 19 to 11 target materials as a worst case for the no substitution strategy. Additional improvement is obtainable from the second generation alternate system for the first two concealment strategies.

For the high enriched facility, the first generation system improves diversion detection effectiveness by factors of 12, 16, and 11 for the no substitution, bulk substitution and isotopic substitution strategies, respectively. The worst-case loss localization shows improvements from 66 to 20 target materials. Again, further improvement is obtainable from the second generation system for the first two strategies.

The results of this study demonstrate that the use of production control, process control, and quality control data can significantly improve loss detection sensitivity, timeliness of loss detection, and localization of loss. These improvements can be obtained at a modest increase in cost. However, the improvement resulting from the alternate systems is facility specific, because it depends primarily on the specific process monitoring data that can be collected from the unique processing operations in a particular facility. Thus, general improvement can be realized through the use of process monitoring data; but the degree of improvement cannot be generalized.

Section 1

Introduction

This study was conducted for the United States Nuclear Regulatory Commission (NRC) to determine if process monitoring data currently taken by licensees can be used to obtain increased effectiveness of Special Nuclear Material (SNM) safeguards. Two licensed fuel fabrication facilities were studied to determine the extent of existing process monitoring data and its potential for improving safeguards loss detection sensitivity, timeliness, and localization. This report describes general summary results obtained from the study.

Table 1.1 lists some characteristics of the two facilities examined in this study. The current SNM accounting systems at both facilities are based on the designation of material balance areas (MBA) and item control areas (ICA) in the facilities and recording of SNM transfers into and out of those areas. Physical inventories of SNM holdings are periodically performed to provide the basis for maintaining accurate inventory records.

Each site was visited and data were collected. The information that was gathered included: process descriptions, process inventories, storage inventories, MBA and ICA transfers and inventories, and process monitoring data descriptions and characteristics. Performance of the present SNM accounting system was either derived or obtained directly from the facility or inventory reports to the NRC.

In the report, Section 2 provides a description of the process monitoring information that was collected and its usefulness for safeguards. In Section 3, the development of alternate systems using process monitoring data to provide improved safeguards loss detection sensitivity, timeliness, and localization is discussed. A methodology was developed to evaluate the current and alternate systems, and the safeguards effectiveness of the current and

Table 1.1 - COMPARISON OF THE TWO PLANTS
EVALUATED IN THE PRESENT STUDY

	<u>First Plant</u>	<u>Second Plant</u>
Uranium-235 enrichment	Low (3-5%)	High (>90%)
UF ₆ to intermediate product conversion	Yes	Yes
Intermediate to final product fabrication	Yes	Yes
Final product form	Assemblies containing fuel pellets	Fuel material
Scrap recovery processing	Yes	Yes
Number of MBAs	4	2
Number of ICAs	4	2
Scrap recovery in separate MBA	No	Yes
Processing modes:		
UF ₆ conversion	Semi-Continuous	Batch
Final product fabrication	Batch	Batch→continuous→batch
Scrap recovery	Batch	Batch

alternate systems were evaluated and compared. Results of this work are reported in Section 4. Section 5 presents an analysis of the costs to be incurred in implementing the two alternate systems. The use of process monitoring data is critically discussed in Section 6. Recommendations for further study of material control systems utilizing process monitoring data are given in Section 7.

Section 2

Description of process monitoring data

Production control, process control, and quality control data, which would supplement accountability measurements and offer more effective safeguards controls, are collectively referred to as process monitoring data in this report. This section describes each data type and identifies those data available at the visited facilities.

2.1. PRODUCTION CONTROL DATA

Data representing bulk measurement of process throughputs and inventories are defined as production control data. Primary functions of these data are to indicate the status and completion of production orders and the efficiency of material processing operations so that production schedules can be established and maintained. Extensive production control data were recorded by the licensees and were extremely useful for safeguards. Examples of such data are masses of uranium-bearing materials and liquid quantities of uranium solutions. These bulk measurements are usually related to SNM quantities by the use of average process factors for the SNM concentrations. When such data are considered in terms of process yields spanning single or sequentially related process steps, safeguards information is provided. Yields significantly lower than normal values may indicate bulk material diversions have occurred.

Various yields may be calculated -- for example, production control systems commonly provide net yields given by the ratio of acceptable product and supplied input quantities. However, the preferred yield for safeguards use would represent a gross yield computed using the gross output, which includes not only acceptable product but also any reject product, scrap, waste or recycle streams leaving the particular process. By including measurements on these sidestreams and in-process holdup, nuclear material not

appearing in the product output can be accounted for with greater accuracy and precision thereby improving the detection sensitivity of yield data. Some yield data of both types were collected and utilized.

Yield calculations are performed differently for batch and continuous processes, and safeguards timeliness and detection sensitivity would depend partially upon different factors. In a batch process, the yield is usually computed when a batch of material has been processed through a sequence of operations. The timeliness of yield data would be the time between input and output measurements and includes the characteristic processing time for a batch. Detection sensitivity depends partially upon uncertainties in both sidestreams and residual holdup after batch runout. In contrast, yields in continuous processes are usually calculated at convenient periodic intervals. In this case, timeliness, which can be arbitrarily changed, is the interval selected for the yield calculation. Detection sensitivity now depends partially on both uncertainty in sidestreams and uncertainty in the in-process inventory.

Continuous processes may have poorer detection sensitivities than batch processes because in-process inventories are larger than residual holdups and often vary more widely making it difficult to determine yield accurately. Yields also may fluctuate widely during nonequilibrium conditions, such as startup or cleanout, but historical data or holdup predictors enable continued use of yield data under these conditions.

The degree of localization using yield data is the span of operation over which the yield is determined. Since yield determinations are conveniently made at process points where easily measured intermediate products exist, the localization would be the process step(s) lying between product measurement points. In contrast, MBAs and their resultant localization may be based on such other factors as personnel operation responsibilities or

physical area separations and would not be specific to single process steps.

Production scheduling information is another example of production control data that were useful for safeguards. For example, when item containers having tamper-indicating seals are selected from storage for processing, observations of tampered seals would necessitate remeasurements. Loss detection sensitivity depends on measurement accuracies of the previous and current contents in the tampered container. Assuming randomness in the selection of containers for processing, detection timeliness is the average storage time of the containers.

2.2. PROCESS CONTROL DATA

Data specifying process operation parameters and conditions are called process control data. Their primary function is to permit process operations at desired conditions or levels. The desired values were predetermined to provide safe, efficient, and controllable operations.

Although a considerable amount of process control data may exist in licensee facilities, much of it will not be useful for safeguards. The nature of a facility's processing operations may cause wide variation in the quantity of useful process control data. Chemical processing operations generally have much process control data, whereas mechanical processing steps may have little useful data. Process control readings may be taken but not recorded nor retained unless required for production records or customer audits.

Examples of data of limited usefulness were those that indicated such equipment conditions as: temperature, time, and pressure. Process control data more useful for safeguards were, either singly or in combination, related to nuclear material flow or

properties; examples of such data were: flowrate, mass, pH, specific gravity, and liquid or powder level in process equipment. These data are frequently observed at regular intervals, for example when process operators make observation rounds, and may be recorded on process operation records. Maximum safeguards usefulness of this data would require continuous or frequent recordings so that fluctuations could be detected and evaluated.

Again, as with yields, it is data agreement at successive measurement points that provides useful safeguards information from process control data. Data in agreement at successive measurement points can lead to conclusions that there were no bulk diversions between those points. Localization is again related to the span of process steps between the utilized process control measurement points. Loss detection timeliness and sensitivity depend on data evaluation time and sensitivity to mass or SNM, respectively.

2.3. QUALITY CONTROL DATA

Quality control data represent measurements of a material's chemical and physical attributes. These data indicate acceptability of intermediate or final product materials for their intended uses or compliance with predetermined specifications that will ensure such acceptability.

Because of their effectiveness for detecting diversion concealed by substitution, quality control data are essential safeguards data. Quality control data should detect both bulk and isotopic substitution. Quality control data collected in the facilities were: uranium-235 enrichment by mass spectrometry, uranium concentrations, chemical and physical properties of SNM-bearing materials, visual inspections, and NDA measurements that show concentrations or enrichments. Generally, quality control data are recorded, reviewed, and are readily available. Additional uranium enrichment and concentration measurements are recorded for accountability purposes and are equally useful.

Using quality control data, the probability of detecting losses concealed by substitution can vary considerably, depending on the quality control sampling plan. If a blending operation lies between the substitution and sampling points, quality control data on withdrawn samples will always reveal the substitution (unless the substituted material concentration is too low for detection by analytical measurements). Therefore, the detection probability is very high. In contrast, substitution occurring in the absence of blending steps would be revealed only if the sample included substituted portions of the inhomogeneous bulk material. In this case, the detection probability depends on sampling parameters such as sample fraction and may be quite low.

Section 3

Description of alternate systems

Alternatives to present material accountability systems can be considered for implementation by licensees provided safeguards effectiveness is maintained. Alternate systems using process monitoring data would be capable of providing better detection timeliness and localization of SNM losses than present multiple MBA/ICA systems. These systems can be described in terms of: the quality and amount of data that are acquired, the frequency and amount of data that are recorded, and the analysis that is made for safeguards utilization of the data. Although considerable process data were acquired at the two facilities, with some of the data recorded frequently and some of it never formally recorded, none of the data were analyzed for safeguards purposes.

Four generations of alternate systems are envisioned for the development of safeguards measurement systems using process monitoring data. Using the present accountability system as a basis, the first generation adds safeguards analysis of process monitoring data that are now being acquired and recorded. The second generation involves the above data plus more frequent recording of data that are now being infrequently acquired or never recorded; this additional data would also be analyzed for safeguards use. The scope of this study included only the first and second generation systems because they are limited to current measurement capabilities. Certain elements of existing accountability systems may become unnecessary in the alternate systems, for example, multiple MBAs and ICAs.

The third generation system results from optimization of the second generation system to provide a consistent level of loss detection sensitivity and timeliness for all materials in a facility or process. The fourth generation system would be a

safeguards measurement system designed to satisfy an absolute NRC performance criterion.

The advanced generations can be effectively designed using the Controllable Unit Approach (CUA) developed at Mound Facility (Seabough, 1979). Using this technique, any locations requiring improved or additional instrumentation, more data collection, or more extensive analysis to meet a specified performance goal or criterion are identifiable. Concentrating design modifications on those areas provides optimized resource expenditure.

Descriptions of the generations of alternate systems are summarized in Table 3.1. This table includes a column labeled "implementation" that is meant to convey an impression of the cost of implementing each generation system. The actual cost would depend on the facility. For example, at one of the facilities that was studied, a computer-based, production-control information system was being designed; and, if used, would enable implementation of parts of the first and second generation systems with little additional cost. Costs would be higher at facilities without centralized and automated information systems.

The first generation system at one of the facilities used the following data: production control yield data for the conversion line, the fuel fabrication line, and for a number of process steps in the assembly fabrication area; production control scheduling data for feed and two intermediate products; quality control enrichment data from mass spectrometry on the feed and two intermediate products; quality control enrichment data from nondestructive analysis of one intermediate product and fuel assembly products; quality control chemical and physical property data on two intermediate products; and quality control data from dimensional measurements and visual checks for surface appearance of intermediate products. Since process control data are recorded infrequently they would have limited usefulness in the first generation system.

Table 3.1 - GENERATIONS OF MATERIAL CONTROL
SYSTEMS THAT USE PROCESS MONITORING DATA

<u>Material Control System Generation</u>	<u>Acquisition of Data</u>	<u>Recording of Data</u>	<u>Safeguards Utilization</u>	<u>Implementation</u>
First generation	No change	No change	Add data review and analysis	Manpower and management control
Second generation	No change	Record new data or record more frequently	More data review and analysis	Manpower, management controls and recording devices
Third generation	Sufficient meas- urements to pro- vide uniform level of control for all materials	Record data as required to obtain uniform level of control. Automa- tion may be necessary	Improved complete- ness and quality of data analysis	Manpower, management controls, recording devices and possibly additional or better instruments
Fourth generation	Measurement system designed to meet NCR performance criterion	Record data as re- quired by CUA or other analysis to meet performance criterion. Auto- mation probably necessary	As required by de- sign which may in- clude advanced data analysis on a com- puter	Same as above plus possibly computer analyses and ad- vanced statistical tech- niques

The second generation system at the same facility used the same production control data with upgrades gained by: including scrap and recycle quantities in some of the conversion yield calculations, recording process step yield data more frequently, and recording the inventory of one intermediate product in buffer storage. No new quality control data were recorded. Process control data would be recorded and used in the conversion area only.

Section 4

Evaluation of alternate systems

4.1. EVALUATION METHODOLOGY

The method used to evaluate the alternate systems that use process monitoring data starts with an identification of a set of hypothetical diversion or loss possibilities that are described in terms of the target material involved, the mode of diversion or loss, and the diversion concealment strategy. Then, for each possibility, the detectable mass, the detection time, and the localization of the diversion or loss are determined to indicate the performance of a given system. An overall safeguards effectiveness factor may be calculated that takes into account both the relative attractiveness of the diversion possibility and the performance of the safeguards system for each loss possibility. This method of evaluation is based in part on the reported work on diversion path analysis (DPA) (Maltese, 1976), the U. S. Atomic Energy Commission Regulatory Guide 5.24 on the use of process data for safeguards (USAEC, 1974), and a vulnerability analysis of a proposed mixed oxide processing facility (Foster, 1979).

4.2. DIVERSION POSSIBILITIES

The important aspects of diversion that are usually specified are shown in Figure 4.1. Only the target material, diversion mode, and concealment strategy were considered in this study. The adversary aspect was not considered for this evaluation, even though it is very important and can greatly impact the conclusion regarding material control effectiveness, because the identity of the adversary(s) determines the opportunities for tampering with the material control system to conceal diversion. An evaluation that explicitly considers the number and identities of the adversaries requires a clear model of the working duties and authorizations of all facility personnel as they relate to the material control system. Because the alternate systems do not exist, such

Figure 4.1. - The important aspects of a diversion possibility.

details are not available. The adversary could be treated explicitly in structuring the work rules for the alternate systems if they are implemented. The removal aspect was not considered because material control ceases to function for a material once it is diverted from the authorized location. Other components of the integrated safeguards system would, of course, play a role in detecting the removal.

The target materials are described by: the chemical and physical form of the material; the containerization of the material, and the location of the material. For example, UF_6 , UO_2 , and ammonium diuranate (ADU) are different diversion targets because they have different forms. UO_2 inside process equipment and UO_2 in transportable vessels are different targets because the containers are different. UO_2 in vessels in the process area and UO_2 in vessels in a storage vault are different targets because the locations are different. The form defines the utility of the material for making a clandestine fission explosive or creating some other hazard or threat. Although it is impossible to fabricate a fission explosive from LEU, no distinction was made between LEU and HEU material forms in this study. The location defines the ease of access to the material and the amount of surveillance of the material by facility personnel or monitoring equipment; and the container defines the ease of transporting material. Diversion of each target was evaluated as a separate problem.

The diversion mode designates the amount of material per diversion and the number of diversions. Only one mode involving a single-event diversion was evaluated. A single-event diversion takes place within the period of time between analyses of the process monitoring data.

The concealment strategies considered were: diversion or loss without substitution, diversion with a mass or bulk substitution, and diversion with an isotopic substitution. Concealment involving falsification of data was not included because it requires an

accurate description of the duties of all personnel involved in operating the material control and accounting system. This type of analysis has only been cursorily studied for the present accounting system and could not be performed for the alternate systems until the personnel work duties are clearly defined. The type of method needed for this evaluation would be similar to the collusion analysis method proposed for physical protection systems.

In order to illustrate how the concealment strategies were evaluated, consider the diversion target to be a uranium-235 bearing material temporarily stored in process operation area vessels. If there is no substitution, the evaluation consists of determining the time until the next bulk measurement (usually weighing) and the detection sensitivity of the measurement. If there is a mass substitution, the evaluation consists of determining the time until the next measurement of the uranium concentration or the next process measurement sensitive to the change in material properties caused by the substitution. The substituted mass is not specified and is not assumed to have the same chemical or physical properties as the diverted material. In the case of an isotopic substitution, the evaluation consists of determining the time until the next enrichment measurement and the detection sensitivity of the mass spectrometer or gamma-ray instrument that is used. In the substitution cases, the evaluation also considered whether the process monitoring data were acquired before or after a blending operation and whether the data were acquired from a sample.

The relative attractiveness of target materials was quantified by assigning a value from zero to one for each of the three target parameters and then multiplying the three values. The numerical scheme that follows, a modification of the one used in DPA and Regulatory Guide 5.24, provides a better representation of the material forms found in the facilities studied.

<u>Target Form</u>	<u>Target Location</u>	<u>Target Containerization</u>
Feed, intermediate product, product = 1.0	Storage = 1.0	Transportable item = 1.0
Scrap and recycle = 0.5	In-process = 0.5	Bulk = 0.5
Waste = 0.1		Nontransportable item = 0.1

The numerical relative attractiveness values were used in combining performances discussed in Section 4.3. for the individual targets to give a semiquantitative analysis of system performance. Numerical factors for the concealment strategies were not assigned; consequently, the performance against the three different strategies was determined separately; that is, the relative performances against each strategy were not combined.

4.3. PERFORMANCE ANALYSIS

The three concealment strategies multiplied by the number of targets in each facility gave the total number of diversion problems that were evaluated. The performance of each of the three systems -- the present system and the first and second generation alternatives -- was calculated for each diversion problem.

Performance was measured by the detectable mass, the detection time, and the degree of loss localization. The magnitudes for detectable mass and detection time were chosen to provide a 50% probability of loss detection. For quantity measurement errors, twice the standard deviation (2σ) is the detectable mass at this probability of detection. For such process quantities as yields, twice the standard deviation of process variability defines the detectable mass. Thus, detectable masses can be determined if process monitor measurement errors and variability are determined. The detection time is defined as the time to detection after a diversion or loss. For example, the detection time for yield data is equal to the time it would have taken the diverted

material to pass through the process and for the yield data to be obtained and analyzed.

For production scheduling data, detection time is the period between the diversion and the scheduled time for its processing. For consistency with the detection probability, one half the storage time was used which represents a detection probability of 50%, assuming random selection from storage for processing.

The use of tamper-indicating seals was considered in the evaluation of the material control systems. It was assumed that any diversion from a sealed item could not be concealed by falsifying the seal. Thus, when a check for that item occurs, the broken seal would be discovered and a measurement would be made. The detectable mass would be the limit of error in the collection of measurements that were used.

4.4. LOCALIZATION OF LOSS

In one MBA in one of the facilities, 19 target materials are processed (45 target materials were identified for the facility). Detection of an apparent loss of SNM in the MBA cannot be identified to any particular target materials from these 19 using the present accountability system. Thus, any apparent diversions (actual or false alarm) would require investigation of as many as 19 target materials.

The first generation system would reduce the number of candidate targets to be investigated to 11 for the no substitution concealment strategy. The second generation system would further simplify the investigation to a worst-case number of 8 target materials. Similar loss localization improvements are obtained for the other two concealment strategies. An even greater improvement in loss localization was obtained for the other facility studied, partly because the single production MBA contains a greater number of target materials. Thus, a significant

improvement in loss localization is obtained simply by utilizing process monitoring data presently being acquired.

4.5. LOSS DETECTION TIMELINESS AND SENSITIVITY

The detection timeliness of the present accountability system is the inventory period for all target materials except those few that are tamper-sealed items in storage. Present regulations require inventories at least every two months for HEU and six months for LEU facilities. The detectable mass sensitivity of the present accountability system is the limit of error of inventory difference (LEID) of the individual MBAs or the facility for the target materials that are not sealed items. Detection timeliness and sensitivity for sealed items depend on the storage time and contents measurement errors, respectively.

The first and second generation systems have improved performance for many target materials. The following improvements for the no substitution concealment strategy for the 45 target materials in one facility are summarized.

First Generation System

- Improvement by factors of 6 to 20 in detection time for 25 target materials.
- Improvement by factors of >10 in detectable mass for 23 target materials

Second Generation System

- Improvement by factors of 6 to 20 in detection time for 30 materials.
- Improvement by factors of >10 in detectable mass for 23 target materials and by factors of 2 to 10 for 5 others.

Similar improvements in increased timeliness and sensitivity were obtained for the other two concealment strategies.

The analysis of the first and second generation systems clearly identified those target materials for which additional data are required to develop a uniformly effective safeguards system (namely, third and fourth generation systems). Some intermediate, scrap and waste materials, accumulating in buffer storage and process areas while awaiting further processing, exhibited no improvement because no process data exists for them.

4.6. SEMIQUANTITATIVE EVALUATION OF ALTERNATE SYSTEMS

A quantitative analysis of diversion sensitivity and timeliness of the current and two alternate systems can be obtained using developed methodologies such as CUA. Such an analysis is beyond the scope of this study; however, a useful semiquantitative analysis was developed to provide a method for evaluating these alternate systems.

A total safeguards factor, F , was calculated for each material control system using the formula:

$$F = \frac{\sum_{i=1}^n \alpha_i M_i t_i}{\sum_{i=1}^n \alpha_i} \text{ [kilogram-days]},$$

where: α_i = attractiveness factor for target material i
 M_i = detectable mass for target material i
 t_i = detection time for target material i
 n = number of target materials.

A smaller value of F indicates improved safeguards effectiveness. This weighted average considers detectable mass and detection time to be equally important factors in safeguards systems. This effectiveness factor depends indirectly upon the detection probability level selected in determining the detectable masses and detection

times. However, since the effectiveness factors for each system will scale similarly when different probability levels are chosen, the relative ranking of the systems will remain the same.

Normalized results of these calculations for both facilities are shown in Table 4.1. The values shown are normalized such that the effectiveness factor equals 1.0 for the most effective system against a particular concealment strategy for each facility.

Table 4.1. - RELATIVE EFFECTIVENESS FACTORS FOR PRESENT AND ALTERNATE ACCOUNTABILITY SYSTEMS

<u>Concealment Strategy</u>	<u>Present System</u>	<u>First Generation</u>	<u>Second Generation</u>
No Substitution ^a	25	7.8	3.8
Bulk Substitution ^a	38	5.6	2.4
Isotopic Substitution ^a	38	1.0	1.0
No Substitution ^b	38	3.1	1.8
Bulk Substitution ^b	38	2.3	1.4
Isotopic Substitution ^b	11	1.0	1.0
^a Low-enrichment uranium facility.			
^b High-enrichment uranium facility.			

4.7. TRENDS IN EFFECTIVENESS AMONG GENERATIONS AND CONCEALMENT STRATEGIES

Two trends in effectiveness can be seen in Table 4.1. The first trend is increasing effectiveness in progression from the present accountability system, to the first, and to the second, generation alternate systems. The magnitude of the improvement is roughly related to the number of process monitoring measurements used in each generation. Consequently, the first generation exhibits large improvement over the present system; whereas the second generation shows relatively smaller additional improvement, since only a few additional process monitoring measurements are used. In

fact, since no new enrichment measurements are included, no additional improvement is obtainable for detection of isotopic substitution concealment in the second generation.

The second trend is increasing effectiveness for loss detection within each generation alternate system progressing from no substitution, to bulk substitution, to isotopic substitution concealment. The principal reason for this trend is related to the sensitivities of the process monitoring measurements for detection of each type of substitution. The sensitivity of a measurement to detect an earlier substitution is, in turn, partly dependent upon the effect of intervening process operations on the substituent.

As an example, consider a diversion from the precipitator in a UF_6 conversion line. Without substitution, detection of the diversion is principally by an abnormally low mass yield of the conversion product. The detection sensitivity is related to the constancy of normal conversion yields.

If a substitution is made to conceal the diversion, two situations may exist. First, if the substituent does not produce a precipitate in the precipitator, the conversion yield will be low from the diversion. If filtrate-stream analytical measurements are taken, the substitution may be detected but the diversion itself may not be revealed. Thus, the detection sensitivity is similar to that for no substitution since the yield provides the loss detection. In the second situation, the substituent is assumed to produce a precipitate whose mass may even be sufficient to result in an apparently normal conversion yield. Now quality control analytical data on the conversion product is relied upon to detect the substitution and, in combination with the yield, the magnitude of the diversion. Substitution detection is normally more sensitive than simple diversion detection since product quality is usually more stable and predictable than yields.

Although either situation may occur in chemical processing operations, the first situation, which has the worse detection sensitivity, was assumed for each such operation in the effectiveness evaluation. Generally, mechanical processing operations are similar to the second situation with improved detection sensitivity since mechanical processing steps normally would not remove the substituent. So in a facility with both chemical and mechanical processing steps, like the facilities evaluated in this study, there will be an average improvement in safeguards effectiveness for bulk substitution concealment compared to simple diversion. Furthermore, since neither chemical nor mechanical processing performed in fuel fabrication facilities will remove isotopically substituted material, current isotopic measurements result in the isotopic substitution case having the best effectiveness for detection of the three concealment strategies considered.

One other factor can adversely affect the detection sensitivities for the substitution cases and alter the effectiveness trends. Sampling parameters, especially bulk homogeneity or sample representativeness, can reduce the effectiveness of quality control measurements on samples for revealing substitution concealment.

Section 5

Cost analysis

The evaluation results presented in Section 4 show the safeguards system improvements obtainable in the two generations of systems that use existing process monitoring capabilities. Significant improvements in loss detection sensitivity, timeliness, and localization were noted. Although the level of control to be provided by a safeguards system will be specified by the NRC, the benefit considered here is the attainment of the level of control resulting from this study and discussed in Section 4. This benefit will have an associated incremental cost which is discussed and estimated in Section 5.1.

These costs represent those for the stated alternate systems. A cost/benefit analysis, which would be required to develop cost-effective safeguards systems, was not performed on each individual measurement. Instead, all existing measurements were used in the alternate systems -- regardless of the magnitudes of the safeguards gains. Therefore, the costs presented represent those required to consider all existing data for their inherent safeguards usefulness.

5.1. COST ESTIMATION

The incremental costs to implement the generations of alternate systems were estimated by considering each additional data element and its use in the alternate systems compared to the usage of present data. For each of these elements, four items (data recording frequency, data evaluation frequency, measurement and management control program requirements, and implementation requirements) were specified which, in turn, led to the manpower and cost projections. Incremental manpower requirements were estimated from this data and are summarized and converted to equivalent costs for each facility in Tables 5.1. and 5.2.

Table 5.1 - INCREMENTAL COSTS OVER PRESENT ACCOUNTABILITY SYSTEM FOR IMPLEMENTATION AND OPERATION OF FIRST AND SECOND GENERATION ALTERNATE SYSTEMS FOR THE LOW-ENRICHED FACILITY

Item	First Generation ^a		Second Generation ^a	
	(man-months)	(thousands of dollars)	(man-months)	(thousands of dollars)
Implementation Requirements ^b				
Computer Software and Forms Development	11	33	17	51
Data and Control Program Development	6	18	9	27
Incremental Operation Requirements (per year)	25	75	50	150
Incremental Management Control Operation (per year)	2	6	3	9
Total First Year Cost	44	132	79	237
Total Annual Cost after First Year	27	81	53	159
Annual Credit from MBA Elimination	12	36	12	36
^a One manyear is assumed to cost \$36K.				
^b A one-time expenditure for development and implementation.				

Table 5.2 - INCREMENTAL COSTS OVER PRESENT ACCOUNTABILITY SYSTEM FOR IMPLEMENTATION AND OPERATION OF FIRST AND SECOND GENERATION ALTERNATE SYSTEMS FOR THE HIGH-ENRICHED FACILITY

Item	First Generation ^a		Second Generation ^a	
	(man months)	(thousands of dollars)	(man months)	(thousands of dollars)
Implementation Requirements ^b				
Computer Software and Forms Development	18	54	21	63
Data and Control Program Development	7	21	9	27
Incremental Operation Requirements (per year)	27	81	32	96
Incremental Management Control Operation (per year)	2	6	3	9
Total First Year Cost	54	162	65	195
Total Annual Cost after First Year	29	87	35	105
Annual Credit from MBA Elimination	2	6	2	6
^a One manyear is assumed to cost \$36K.				
^b A one-time expenditure for development and implementation.				

Sections 5.2. through 5.5. discuss the assumptions made and the items considered in various aspects of this cost analysis.

A portion of this incremental cost may be offset by a credit for elimination of elements in the present accountability system that become unnecessary in the alternate systems. The existing accountability measurements, as well as periodic physical inventories, are retained and used in the alternate systems. Process monitoring measurements provide information to maintain material control and accountability for SNM movement; but a formalized, double-entry record system for these measurements may not be required. This requirement in the current regulations provides both protection against diversion concealment by a single insider through records falsification and retains an audit trail for inventory reconciliation. The frequent, sequentially related, process monitoring measurements from a number of process operators provide a degree of overlap, independence, and redundancy in control data, thereby affording protection against this diversion strategy. If the process monitoring data are entered into a computer for safeguards evaluation, computer generated transaction logs and backup files should suffice for auditing purposes.

Along with the elimination of the double-entry material transfer, the multiple MBA structure itself may also be considered unnecessary since more effective localization of losses is available in the alternate systems. Loss detection of those target materials not sensed by process monitoring data is through periodic physical inventory comparison. Some degree of localization will be sacrificed if the multiple MBA structure is eliminated since all of those materials are not within a single MBA. However, even with this sacrifice, overall localization is improved with the alternate systems.

Estimated cost credits for these eliminated portions of the present accountability system are shown in Tables 5.1. and 5.2. for

each facility. The larger credit for one facility results from the larger number of material transfers currently performed because of the multiple MBA structure. Although the MBA structure may be eliminated, some of the present duties of MBA custodians and related personnel remain. For example, transporting material, item sealing, item logging, conducting inventories, and evaluating material control status are still required. Logically, some of the new duties in the alternate systems, such as ensuring completeness of process monitoring data entry and regularly evaluating and reporting material safeguards status, would be performed by existing (MBA-related) personnel.

5.2. OPERATING COSTS

The manpower associated with routine data recording, instrument calibration, and safeguards evaluation represent the bulk of the estimated operating costs. No incremental cost is included for acquiring those measurements that are currently performed, which include current accountability measurements and the quality control and process control measurements. However, the cost of acquiring and recording these measurements more frequently, as in the second generation system, is included where appropriate. Recurring costs for any new calibration and measurement control of nonaccountability measurements are also included (such controls already exist for accountability measurements to comply with 10 CFR 70.57 and 70.58).

Both manpower and cost are included for evaluating the process monitoring data for safeguards purposes. In general, data recording and data entry into the evaluation are assumed to be manual operations, except for a few process control measurements that obviously require frequent recording. Data evaluation is assumed to occur onsite (using existing computers), normally using a large centralized computer. Routine manpower and costs are incurred in data entry, output evaluation and report preparation.

Costs for computer time were assumed to be negligible and are not included in the tables. Manpower and cost estimates for designing and implementing data recording forms, data entry forms, evaluation programs, and reporting formats are considered implementation costs that are discussed in Section 5.3.

5.3. IMPLEMENTATION COSTS

As mentioned previously, certain implementation and operations costs are required to institute data-recording/data-evaluation systems. The costs required to design and develop the necessary capabilities are one-time expenditures. These implementation cost estimates are listed in Tables 5.1. and 5.2., which specifically includes such items as: data recording/data entry forms and procedures, personnel training in new procedures/evaluations, collection and review of historical data to establish action limits for data evaluation, development of computer-based evaluation programs, and implementation of adequate measurement and management control programs.

5.4. MEASUREMENT CONTROL PROGRAM

Calibration and measurement control of process control and quality control instrumentation will be required for measurements now being added to the safeguards system. Costs of this requirement are included in the cost summary tables.

5.5. MANAGEMENT CONTROL PROCEDURES

To institute and maintain adequate management review and control of the safeguards results from the alternate systems, some expenditure is included and would include independent audits and reviews of the procedures and systems instituted. Costs of preparation and approval of routine reports, as well as loss detection alarm investigations, were considered in the estimates.

Section 6

Critical discussion of the use of process monitoring data for safeguards purposes

Alternate systems using process monitoring data in lieu of the multiple MBA structure of the present safeguards system were shown to have significantly improved safeguards performance with respect to detection time, detectable mass, and localization of a SNM loss. The alternate systems performed well against concealment strategies involving no substitution, mass substitution, and isotopic substitution for single-event losses or diversions.

The performance of the first and second generation alternate systems does, however, vary drastically for different target materials. At each facility, the detection time may range from hours, for diversion or loss of certain target materials, up to the normal inventory period detection time in the present system for diversions of other target materials. Depending on the target materials, the detectable mass may range from a few grams to the few kilograms of uranium-235 given by the LEID (limit of error of inventory difference) at a facility. Scrap and waste materials and materials in buffer storage comprise most of those target materials that show no improvement from the present system because they currently have no process monitoring measurements. A loss or diversion can be localized to a few target materials and processing steps throughout most of each facility.

Because the process monitoring data tend to be facility specific and unique to each facility processing operation, these results cannot yet be generalized to apply to other facilities. Thus, the conclusion from the two case studies is that there are considerable process monitoring data that can be used for safeguards; and the systems using these data can provide improved detection times, detectable mass, and localization of SNM losses. Furthermore, these improvements are obtainable at nominal cost since extensive process monitoring measurements already exist and can be utilized in safeguards systems.

Section 7

Recommendations

This study clearly demonstrates the safeguards usefulness of process monitoring data in alternate material control and accountability systems. With clear identification of those areas within the facilities that show no improvement, it is recommended that a third generation system be developed with the goal of providing a consistent level of loss detection for the entire facility. A third generation system could be developed for either or both facilities included in this study. The result would be a safeguards system fully utilizing process monitoring and accountability data that would show a significant improvement in loss detection sensitivity, timeliness, and localization over the current accountability system. Performance of the third generation system for detecting multiple-event diversions or losses should also be evaluated.

It is further recommended that, instead of the methodology used in this study, the CUA methodology be employed in the development of the third generation system. The CUA methodology would start with the measurements used in the second generation system and, through its iterative procedure, identify changes or additions to attain a uniform degree of control for the entire facility. The result would be a third generation system. In conclusion, the CUA methodology will provide a quantitative evaluation that is important in developing cost-effective safeguards systems -- which should be a principal goal of any further study.

Section 8

References

Analysis and Use of Process Data for the Protection of Special Nuclear Material, Regulatory Guide 5.24, U. S. Atomic Energy Commission (June 1974).

Foster, K. W., and H. A. Woltermann, Vulnerability Analysis of a Mixed Oxide Plant, Mound Draft Report, NUREG/CR-1017.

Maltese, M. D. K., I. E. Goodwin, and J. D. Schletes, DPA Handbook, Vol. I, Methodology, TID-22793/1, National Bureau of Standards (1976).

Seabaugh, P. W., D. R. Rogers, H. A. Woltermann, F. C. Fushimi and A. F. Ciramella, The Controllable Unit Approach to Material Control: Application to a High Throughput Mixed Oxide Process, MLM-NUREG-2532 (1979).

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