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EXECUTIVE SUMMARY

A TEST APPLICATION OF THE NRC REFORM AMENDMENTS TO A LICENSED FACILITY

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ABSTRACT

Science Applications, Inc. (SAI), has evaluated the feasibility, costs and impacts of implementation, at a specific licensed facility, a material control and accounting (MC&A) system that meets the requirements of the Nuclear Regulatory Commission's 1981 proposed draft amendments. This evaluation consisted of defining and modeling the current MC&A system for a no-cost base, then designing a series of four successive and cumulative modifications to attempt to meet the published requirements for (1) abrupt diversion protection, (2) abrupt diversion detection with substitution, (3) localization of losses to potential diverter personnel, and (4) protracted diversion detection. These designs involved establishing material control areas called control units (CU's), goal quantities for diversion detection called control quantities (CQ's), and personnel teams, called control teams (CT's), who are responsible for the material in given control units. Process and process measurement modifications were made, control unit total sigmas were estimated, and alarm thresholds were defined. The CU's, CQ's, CT's and alarm thresholds were optimized for the minimum false alarm rate and minimum impact on plant throughput. Specific response and overcheck activities and responsibilities are defined for the completed design. Costs and benefits resulting from implementation are estimated. Several alternative strategies are presented and their performance and costs are presented. These alternatives focus on areas where it would be difficult or very expensive for the licensee to meet the draft rules.

ABBREVIATIONS

ADU	Ammonium diuranate
AT	Alarm Threshold
CFR	Code of Federal Regulations
CPU	Computer Central Processing Units
CQ	[illegible] Quantity
CT	Co[illegible] Team
CU	Control Unit
CUSUM	Cumulative sum - an MC&A procedure for detecting trickle losses
CV	Conversion CU designation
FAR	False Alarm Rate
FARG	False Alarm Rate in grams
FF	Finishing CU designation
F kg	Formula kilograms
FNMCP	Fundamental Nuclear Material Control Plan
g	Grams
l	Liters
MAIT	Matrix Analysis of the Insider Threat (Computer Code)
MC&A	Material Control & Accounting
Mod	Modification (4 Modifications are identified Mod 0 - Mod 3)
NDA	Nondestructive assay
NRC	Nuclear Regulatory Commission
SAI	Science Applications, Incorporated
SF	Semifinishing CU designation
SNM	Special Nuclear Material
SR	Scrap recovery CU designation
SSNM	Strategic Special Nuclear Material
UFS	Uranium feed stock

EXECUTIVE SUMMARY

Introduction

On September 10, 1981, the Nuclear Regulatory Commission (NRC) issued draft Material Control and Accounting Reform Amendments for public comment. These amendments proposed major modifications in Material Control and Accounting (MC&A) procedures to improve both the effectiveness and timeliness of MC&A.

Science Applications, Incorporated (SAI), was awarded a contract to examine the feasibility, costs and impacts of the implementation of a revised material control and accounting system that would meet the requirements of the published rule at a specific licensed facility. This report presents the results of an effort on the part of SAI to provide an appraisal of the application of the reform amendments to the plant designated by the NRC.

During the course of the program, it was determined that successfully meeting some parts of the draft rule would be technically difficult or would have a high cost. In these situations, discussions ensued with the NRC and possible alternatives were developed and evaluated.

The NRC is very sensitive to the workability, costs and impacts of the resulting MC&A system, and is continuing to give serious consideration to variations in the rule. Therefore, the effort to develop and evaluate alternatives is continuing. A report detailing the results of the continued analyses will be forthcoming in late FY 83.

The following discussion presents a summary of the proposed rule, a brief description of the facility, the methodology used by SAI to apply the rule to the specified facility, the results of this application, the costs and impacts of the application, possible alternatives to the requirements as published and the conclusions of the study.

The Reform Amendments

The draft reform amendments are based on the premise that the current bi-monthly physical inventory system employed by Strategic Special Nuclear Material (SSNM) licensees has several important flaws, the most important of which is the difficulty of localizing losses in time and space. An additional problem is the fact that the generally observed inventory difference (ID) distribution is not what is predicted by the limit of error on the inventory difference (LEID).

The purpose of the reform amendments is to refocus material accounting and control away from reliance on the infrequent, cleanout inventory accounting toward frequent, timely tests over small portions of the plant. The performance objective is the rapid detection of a loss of 5 formula kilograms of SSNM from a facility and the development of an appropriate loss resolution method. The advantages of the new approach include the more rapid observance of problems before they can become large, the localization capabilities for losses both in time and space when they are detected, and possible reduced facility downtime due to material accounting requirements. This last item can be realized if physical inventories are reduced to one or two per year and fewer and/or shorter forced outages are required in the modified system.

The draft reform amendments are embodied as possible changes to 10CFR 70 Sections 4, 81, 83, 85, 87, 89, and 91. Sections 70.4, 70.81, and 70.91 deal with definitions of terms, general performance objectives and record retention requirements, respectively. Sections 70.4, 70.81 and 70.91 will not be considered further here. Sections 70.83 and 70.85 deal with detection and response and will be discussed in some detail below. These sections deal with system overcheck and falsification protection, respectively. They will be discussed below only briefly.

Diversion Detection

Draft section 70.83 specifies that control units (CU's) be established within the facility so that all material is within a CU. Tests must be established for each CU so that abrupt material diversion of a control quantity (CQ) from a control unit will be detected within 24 hours with a 90% probability. Control quantities and access limitations are to be established so that individual workers cannot obtain 5 formula kilograms (Fkg) by removing less than a CQ from multiple control units.

Protracted diversion is to be detected by the use of CUSUM or other appropriate tests with action thresholds established so that a 90% detection probability exists for a 5 Fkg cumulative loss for periods up to one year. Trend analysis of time series data is required to observe trends that project to a 5 Fkg loss prior to the next scheduled physical inventory.

Response Limits

Draft section 70.85 identifies two specific types of predefined response procedures; first, a response to alarms generated by the detection system established in Section 70.83 and, second, response to externally generated alarms such as telephone calls indicating a possible theft of nuclear material.

For an internal alarm indicating loss of more than 5 Fkg, the Nuclear Regulatory Commission must be notified within one hour and material processing must be halted. For smaller indicated losses, 72 hours are allocated for licensee resolution prior to NRC notification, and the CU may continue processing.

For external alarms, two plans must be established, one to rapidly (within one hour) establish whether there is evidence of diversion and one that provides a more detailed test of material status with a longer reporting period.

The Facility

The facility considered in this study is a complex chem, processing plant that has two separate processing lines. The first of these is a fabrication facility that receives high enriched uranium as UF_6 and processes this through many chemical steps that involve changes among all three states of matter (solid, liquid, gas). The final product is a uranium nuclear fuel material. For our purposes, we have separated this processing into three steps called conversion, semifinishing and finishing. Semifinishing is split into two parallel process areas.

The second plant is a scrap reprocessing plant that treats scrap from the first plant through a two stage solvent extraction system. The product of this plant is a material that can be fed back into the fabrication facility at the beginning of the semifinishing operation.

The Approach

SAI studied previous reports that had been generated concerning this facility, talked with the NRC licensing personnel familiar with the plant, and visited the facility to collect as much pertinent, timely data as possible. In addition, SAI initiated a subcontract with the licensee for assistance in defining the plant processes, equipment and procedures.

The first step was to model and evaluate the current MC&A and process monitoring systems relative to the draft reform amendments. This system was called the Mod 0 system and was used as a zero-cost baseline to determine the impact of modifications required to meet the reform amendments. In the Mod 0 system, a control unit structure was defined to take advantage of current licensee measurement points. Compliance and workability were assessed for this modification.

The first modification to this system, Mod 1, is concerned with meeting the abrupt loss detection criteria in the reform amendments. This excluded the consideration of removal with substitution. The types of changes that were made in this mod included adding CU's or changing boundaries between CU's, adding new measurement points for measuring side loss streams, adding new measurements to obtain the required timeliness, and improving the accuracy of some measurements currently being made. Minor processing changes were considered where it was believed that they were necessary.

Two constraints that were given priority in all postulated modifications were the minimization of impact on total plant processing throughput and making certain that recommended changes were feasible and practical in a manufacturing environment. It was also decided that, for a near-real-time system to be effective, the false alarm rate must be kept low. This decision was based on several factors including design philosophy and the results of current process monitoring requirements. In order to meet this requirement, it was found that the total CU measurement uncertainties (sigmas) must be kept in the range below about 500g/lot processed. Six of the seventeen CU's met this criterion in the Mod 0 system. In the Mod 1 system three CU's out of twenty-four had measurement uncertainties between 500 and 600 grams/lot. All of the rest were below 500 grams. This led to a statistical false alarm rate of about sixteen per year for the entire facility.

For our purposes, a statistical false alarm is one that can only be explained on the basis of the statistical probability of a set of measurements yielding a result that is above an alarm threshold. No other explanation can be given for the observed alarm, given that no diversion has taken place.

In order to estimate these false alarm rates we have assumed that all measurements are distributed according to Gaussian or normal distributions. This is characteristic of random errors. Current process monitoring data for the facility in question do not follow normal distributions in every case. This is characteristic of the presence of systematic errors. Many of the suggested changes presented in Mod 1 are designed to reduce the systematic or bimodal components of the total observed errors so that normal distributions will accurately represent the situation in the facility.

The sixteen alarms per year mentioned above include only those false alarms that are the result of the statistics of the measured processes. These alarms will remain unresolved after all resolution activities are carried out. Other false alarms due to operator error, digit transposition, etc., are not included in the numbers quoted. The response activities, however, are designed to detect and correct these problems before their impact becomes large.

The next modification, the Mod 2 design, builds on the Mod 1 design and adds measurements necessary to detect abrupt diversion with material substitution. The impacts of this mod over and above Mod 1 are relatively small. The necessary changes are the addition of isotopic and chemical measurements at a few points in the facility so that quantitative backup tests for prior visual tests are made within the timeliness constraints of the rule.

Up to this point, CQ's and alarm thresholds have been developed based on summing the CQ's to 5 Fkg in the separate processing areas of the plant (i.e., conversion, semifinishing line 1, semifinishing line 2, finishing, and scrap recovery.) In the Mod 3 design the control team (CT) requirements are overlaid on the Mod 2 detection design. This is to provide localization of losses to a small group of plant personnel and to limit the amount of material available to any individual or pair of personnel for diversion without a high likelihood for detection. No changes were made in the measurements or frequencies from the Mod 2 design, but control teams were defined and assigned responsibility for CU's so that no control team was responsible for more than 3 CU's, no person had hands-on access to material under the control of more than one CT, and the sum of CQ's under the control of any two CT's was less than 5 Fkg.

One negative feature of the control team requirement is a significant reduction on the flexibility that the licensee has in assigning operations and relief personnel. On the other hand, the CQ's can now be renormalized based on the CT's rather than the processing areas. This yields revised CQ's and alarm thresholds that reduce statistical false alarms to about nine per year.

After completion of the Mod 3 design and evaluation, a detection system for protracted diversion was added. This design was considered Mod 4. A CUSUM test was chosen because of its power and simplicity. An evaluation of the facility using the CUSUM according to the requirements of the rule led to the realization that with CU sigmas near 500g/lot the expected time to first false alarm of the CUSUM test is on the order of 16 days. Equilibrium false alarms are considerably more frequent than this.

Although this design provided the required detection probability, it was determined that the high expected CUSUM false alarm rate would make Mod 4 unworkable and impractical to implement. As a result of this, several alternatives are under consideration for the detection of protracted diversion. The problem of protracted diversion is also exascerbated by the fact that once an alarm is sounded, meaningful response activities are difficult to devise since much of the material may already be gone from the plant by the time an alarm occurs.

After completing the evaluation of the protracted diversion detection system, complete definitions of alarm response activities for each CU were produced. These generally took the form of flow schemes for necessary activities with the required time constraints identified. Descriptions and notes for each activity were included as necessary.

System overcheck requirements identified in the draft reform amendments were considered after the response activities were defined.

These requirements have the objective of creating an overcheck system and are similar to those identified in previous versions of 70.87. The impact for meeting this part of the rule is expected to be small.

Costs and Impacts of the Mod 2 System

SAI has accumulated estimates of costs in terms of capital requirements and the expense items of additional manpower and consumable supplies required to meet the draft reform amendments. Capital requirements include plant modifications to reduce holdup or facilitate better volume determinations, addition of chemical analytical apparatus to handle the increased sample load on a more rigid time schedule, and added nondestructive assay (NDA) equipment for in-plant measurements. The capital costs were amortized over the expected lifetime of the equipment, generally over ten years, and the costs of installation, setup, procedure development and training were included. The result was an annualized cost for the capital items. An annual maintenance figure for the capital items was included as appropriate.

To this annualized capital cost were added the additional expense items, largely staff hours, required to complete the necessary added tests. The additional costs of maintaining the separate control teams with the necessary number of personnel were also identified and quantified. MAIT (Matrix Analysis of the Insider Threat) analyses were used to determine the manpower requirements to maintain the required protection. The estimated annualized cost of implementing the Mod 3 system is $1.54 million.

There are potential cost savings that offset some, if not all, of the cost expenditures as a result of the draft reform amendments. In many cases these cost savings cannot be identified as crisply as the costs of implementation because they are indirect or contingent on the assumptions rather than specific direct costs. The most obvious example of this is the elimination of physical inventories. The elimination of four physical inventories would save approximately $668,000 per year in facility downtime. If there is no market for the additional material that can be produced in this time, this is not a real cost savings. Other benefits which are more difficult to quantify include better process understanding, more rapid detection of process upsets, reduced scrap generation rates and better characterization of material transferred into scrap recovery (hence a more optimum operation of the head-end of the scrap recovery plant). SAI has used its best judgement to reach an expected value of the cost savings for these items.

Alternatives

Several alternatives to the draft reform amendments have been considered in this project at the request of the NRC. These include (1) An alternative approach for protracted diversion that combines protracted and abrupt diversion detection methods and considers credits for physical security, (2) considering a 72-hour time limit for Type A material and a personnel control team rotation on a shift basis rather than a weekly basis, (3) a minimum cost system that relaxes the timeliness limit to 72 hours, that eliminates controls on a plant-wide basis, and that allows each control quantity to be 5 Fkg, (4) the examination of the use of a 5 Fkg limit for each Mod 2 CU and the elimination of the control quantity concept, (5) the use of control teams that do not include process operators, and (6) alternatives to SSNM control teams.

The first alternative attempted to solve the protracted diversion false alarm difficulties by use of a fixed CUSUM alarm threshold at a given multiple of the CUSUM standard deviation (e.g., 3 sigma). This controlled the false alarm rate but reduced the detection probability from that required by the rule. The CUSUM test was combined with the abrupt detection system from Mod 2, and total detection probabilities were calculated for a range of diversion scenarios. In this design, the detection probability for protracted diversion is initially very low, but rises as the amount of material accumulated increases. In many cases, the detection probability rose to 90% before a 5 Fkg amount had been diverted; however, nine CU's had scenarios that did not reach 90% and the worst case reached only 20%. SAI identified physical security requirements that could be coupled with this MC&A scheme to provide an integrated probability of detection of 90% or greater for every CU. This system is sensitive to the CU sigma but has a reasonable statistical false alarm rate. The total false alarm rate for this system is the sum of the CUSUM false alarm rate and the abrupt false alarm rate. With the CUSUM alarm threshold set at three sigma, the expected CUSUM statistical false alarm rate is one per 741 tests. The expected statistical false alarm rate for this system applied to the Mod 2 CU's is 24 per year, including 8 per year from the CUSUM tests and 16 per year from the abrupt loss tests.

The second alternative system, with a 72-hour time limit for Type A material and with personnel rotation on a shift-wise (rather than a weekly) basis, has substantially reduced costs and impacts. This system permits the combination of several Mod 2 CU's into single CU's, thereby permitting balances to be made across CU's with better measurement points. This system, with the combined abrupt and CUSUM test method, was found to have an expected statistical false alarm rate of 9 per year, including 0.7 per year from the abrupt loss tests and 8 per year from the CUSUM tests. The estimated annualized costs for this system is $384K, which, with an annual credit of $688K for reduced inventories, results in an estimated annual net savings of $284K. This alternative sacrifices some timeliness, material type and personnel localization capability but eliminates the need to perform many (thousands per year) material balances on subbatch quantities.

The third alternative system, also with a 72-hour time limit for Type A material but with no plantwide detection capabilities (all CQ's were set to 5 Fkg), reduced the costs and impacts only slightly relative to those of Alternative 2 described above. Although the required CU measurement uncertainties (sigmas) for the relaxed CQ's are much more easily accomplished, most of the measurement activities and process modifications of Alternative 2 are still necessary. With CQ's relaxed to 5 Fkg, the abrupt loss tests no longer provide protection against protracted diversion, and the combined abrupt and CUSUM test method used in Alternatives 1 and 2 is no longer useful. Although a very low statistical false alarm rate (about 0.04 per year) is expected, the capability to detect both plantwide diversion and protracted diversion is lost. As mentioned above, the reduction of costs and impacts relative to Alternative 2 is marginal. The annual costs are reduced by only an additional $18K, and the statistical false alarm rate is reduced by less than one per year. The most attractive feature of this alternative appears to be the relative ease with which the required CU sigmas (about 825 grams) may be achieved. Because of this ease, this alternative might be used as an intermediate step or goal in the implementation of a more satisfactory system.

The fourth alternative system analyzed was the Mod 2 or Mod 3 system with the CQ concept eliminated and with alarms based on a 99% detection probability of a 5 Fkg loss in each CU. This modification resulted in a statistical false alarm rate that was exceptionally low (about 10^{-17}/year) for the Mod 2 sigmas. Although this approach is excellent for the detection of loss of 5 Fkg from a single CU, it sacrifices plantwide detection capabilities and must be supplemented with additional tests in order to detect the abrupt diversion of a total of 5 Fkg from more than one CU. After considering several possibilities for abrupt plantwide detection, SAI has concluded that the Control Quantity/Control Team approach in the draft rule is superior to these others because it provides reduced limits for diversion detection in each of the CU's rather than relying on additional tests to detect diversions from several CU's.

The last alternative that was examined, at the request of the NRC, was the redefinition of control teams to exclude process operators and, in fact, to allow operators to have hands-on access to material under the control of more than one control team. In order to provide adequate protection using this scheme, several additional, non-productive personnel must be added to the licensee staff. The costs and impacts of this system and the limited benefits do not seem to warrant further consideration.

During the coming year additional alternatives will be studied to determine their feasability, costs and benefits.

Conclusions and Recommendations

Several conclusions can be drawn from this study. However, these conclusions are dependent on the particular nature of the individual plant examined, and consequently, great care should be exercised by anyone attempting to generalize the results of this study to other facilities.

The first conclusion that can be stated is that the Mod 4 design, with the appropriate response activities and overcheck structure, meets the requirements of the draft reform amendments. However, this design has several significant flaws. Because of the very high CUSUM false alarm rate and an inability to resolve these alarms, it would, in effect, provide no protection against protracted diversion. At a net estimated cost of $860,000 per year, the system would be expensive. The system would also impact plant operations by requiring many thousands of measurements per year, many of which (especially chemical analyses) would need to be completed on challenging time schedules.

Although this design comes closest to meeting the original requirements of the draft reform amendment, SAI believes that the impacts of this system are so great as to preclude its implementation at this facility.

The first alternative, which consists of the Mod 2 system with the combined CUSUM/abrupt detection test scheme supported by physical security would be much more effective for detecting protracted diversion and would meet the requirements of the draft reform amendment if the portions of the rule regarding the detection of protracted diversion are liberally interpreted. However, the system costs (also estimated at about $860,000 per year) would still be high, and the other impacts would remain.

SAI believes that this first alternative, consisting of the Mod 2 CQ's, the Mod 3 SSNM control team layout, and the combined CUSUM/abrupt test scheme, is feasible and could be implemented, but SAI also believes that the costs and impacts are such that the system should not be implemented.

The second alternative, consisting of a redesigned CU structure for a 72-hour timeliness requirement, a modified control team structure permitting more frequent personnel changes, and the combined CUSUM/abrupt test and physical security credits for protracted diversion, has significantly reduced costs (net savings of approximately $248K) and impacts. SAI believes that this alternative is feasible and workable and is the most practical system considered in this study to date.

The third alternative, which differed from the second alternative by setting the CQ's for all CU's to 5 Fkg, has only slightly lower costs and impacts than the second alternative, but loses the ability to detect plantwide diversion. This alternative also reduces the effectiveness of the CUSUM/abrupt tests for detection of protracted diversion because of the reduced sensitivity of abrupt detection. SAI believes that the slightly reduced costs and impacts do not justify the loss of plantwide detection and protracted diversion and suggests that this alternative not be implemented except, perhaps, as an intermediate step in the implementation of Alternative 2.

The fourth alternative, in which the CQ's are all set to 5 Fkg for the Mod 2 system with a 24-hour hour timeliness criterion, has an extremely low statistical false alarm rate but has no capability to detect protracted or plantwide diversion. SAI believes that a capability to detect plantwide or protracted diversion is far more important than 24-hour timeliness, and that this system, therefore, does not make sense. SAI does not believe that this system would justify its cost.

SAI suggests, pending the results of the analysis of further alternatives, the implementation of Alternative 2. This alternative requires the relaxation of several parts of the reform amendment, but retains the basic elements of plantwide and protracted diversion detection and has reasonable localization in terms of time, personnel and material type. The basic modifications in the rule include the following:

- o relaxation of the timeliness requirement for Type A material from 24 hours to 72 hours,
- o relaxation of the falsification time requirement from 5 to 10 days,
- o relaxation of the personnel localization requirement from 12 to 25 persons, and
- o relaxation of the control team turnover rate limit from once per week to once per shift.

SAI also suggests that considerable attention be given to the method of implementation of the reform amendments at any facility. A "shake-down" period should be planned where uncertainties on measurements and CU process variations are established. During this time, measurements and process variations should be determined to be acceptable or strategies altered until adequate results are obtained.