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A Method for Assessing the Performance of a Material Control and Accounting System at an Operating Nuclear Fuel Processing Facility

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Prepared by
L. Harris, L. B. Ellwein

Science Applications, Inc.
1200 Prospect Street
LaJolla, Ca. 92037

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Division of Safeguards
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
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ABSTRACT

A method for assessing the performance of a material control and accounting (MC&A) system in an operating nuclear fuel processing facility has been developed. The performance criteria inherent in the assessment are 16 key goals established by NRC's 1978 Material Control and Material Accounting Task Force. The top level of the assessment structure consists of four adversary goals (abrupt theft, protracted theft, theft from shipment and hoax) against which MC&A system performance is assessed. The bottom level of the structure consists of operational functions of a MC&A system: alarm generation, alarm assessment and loss assessment. Measures of effectiveness (MOEs) have been defined for each function. A complete MC&A assessment involves the evaluation of 30 MOEs by an assessment team. Methods for synthesizing these MOEs to produce assessments of MC&A performance at intermediate levels of the structure and to produce an overall performance assessment are described and have been computerized. Example MC&A synthesis exercises are presented.

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ACKNOWLEDGEMENTS

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1. INTRODUCTION AND SUMMARY

The purpose of this work was to develop a method for assessing the performance of a material control and accounting (MC&A) system at an operating nuclear fuel processing facility. It is assumed that the facility is licensed by the U.S. Nuclear Regulatory Commission (NRC), and that the assessment is to be performed by 5 NRC technical experts during a 5-day visit to the facility. The assessment team would include one expert in nuclear material accounting statistics, one expert in U or Pu chemistry and non-destructive assay, an accountant or auditor, a process engineer familiar with the processes at the facility and a NRC inspector familiar with the facility and its MC&A system. The team leader or one member would be familiar with the analysis associated with synthesizing the data. It is also assumed that the visit would be preceded by several person-weeks of data collection and analysis, and that it would be followed by several person-weeks of data analysis and synthesis. The total NRC effort is estimated to be 11 or 12 person-weeks required to assess a single MC&A system. Much of what follows does not depend explicitly on these assumptions, but they did provide the context within which this work was done.

The work proceeded in four stages. First, criteria against which MC&A system performance is to be judged were needed. These criteria were found in the MC&A assessments performed under NRC's 1977 Comprehensive Evaluation Program[1] and, more explicitly, in the goals established by NRC's 1978 Material Control and Material Accounting (MC & MA) Task Force.[2] These two NRC MC&A projects, which greatly influenced the assessment procedure reported here, are discussed in Section 2.

The second stage was to formulate a hierarchical structure for assessing MC&A system performance against the criteria. A four-level structure, which is shown in Figure 1.1, was developed. As shown in the figure, MC&A system performance against four adversary goals (Level 1) is assessed. For each adversary goal, two or three MC&A timeliness ranges (Level 2) are possible. For each combination of adversary goal and timeliness range, one, two or three of the five types of MC&A activity (Level 3) are applicable. Finally, for each triad of

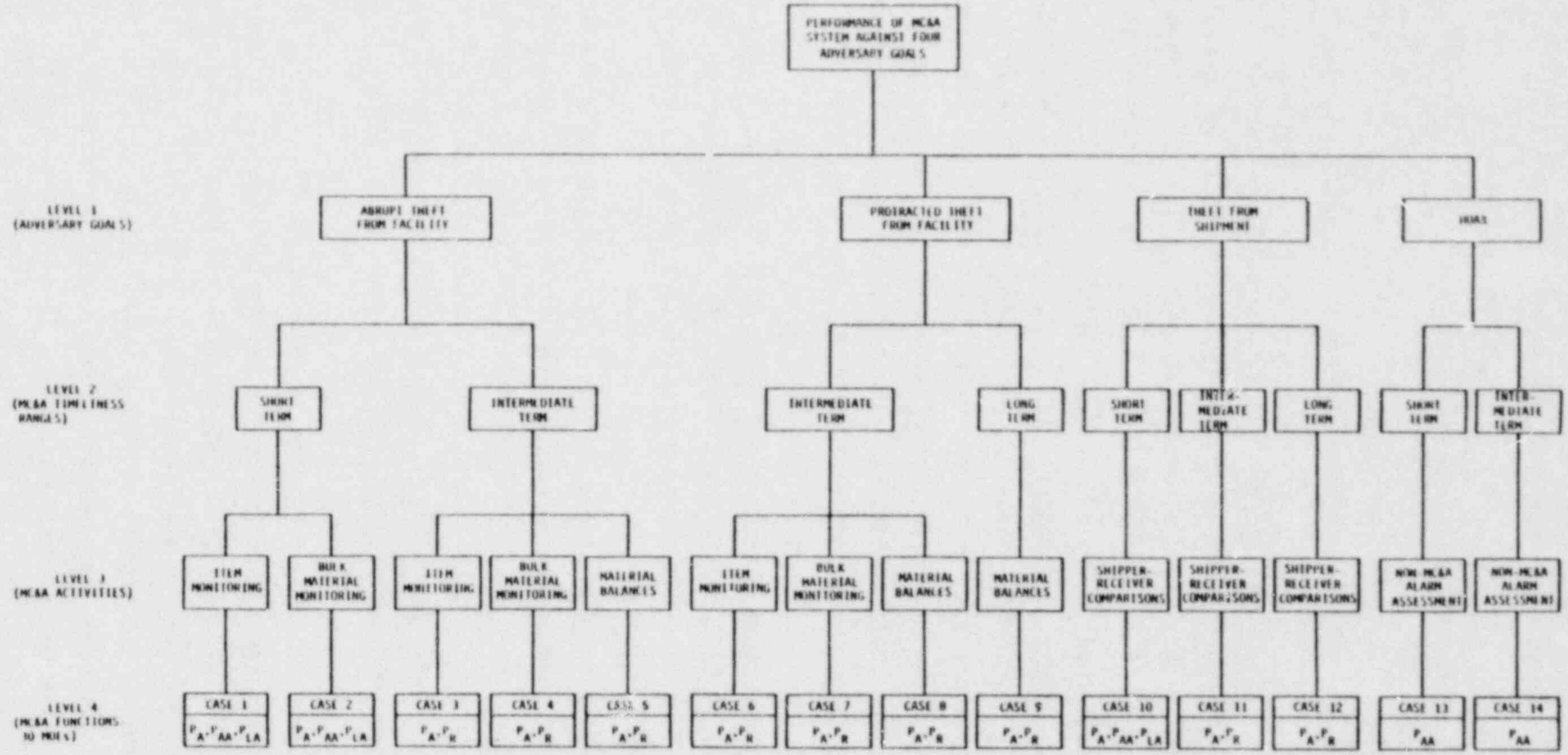


Figure 1.1. General Hierarchical Structure for Assessment of MC&A System Performance.

adversary goal, MC&A timeliness range and MC&A activity, one, two or three MC&A functions (Level 4) are relevant. These functions, which are lower-level operational functions, are alarm generation, alarm assessment and loss assessment. Measures of effectiveness (MOEs) for these functions are represented by the symbols P_A, P_{AA} and P_{LA}, respectively. A composite MOE for the combination of alarm assessment and loss assessment has been designated alarm resolution and is represented symbolically by P_R. The MOEs are generally defined as conditional probabilities: the probability that a particular MC&A function will be performed satisfactorily given a specified adversary goal and quantity of lost nuclear material, the MC&A activity being considered, and a time frame within which the performance must be completed. The formulation of the general MC&A assessment structure and its adaptation to incorporate 16 key goals of the MC and MA Task Force are described in Section 3.

The third and fourth stages involve the synthesis of data to evaluate MOEs and the synthesis of MOEs to assess MC&A system performance at each level of the structure. These two synthesis processes are designated Phases I and II synthesis, respectively. These two phases are identified in an overview of the assessment hierarchy shown in Figure 1.2. Phase I synthesis begins with the collection and analysis of data at the facility by the NRC assessment team. The data are synthesized into MOEs through deliberations by the team. This unstructured synthesis procedure provides opportunity for introduction of judgement into the evaluation process. Phase I synthesis is discussed in Section 4, and evaluation aids to assist the assessment team in evaluating each of the 30 MOEs are given in Appendix A. These evaluation aids can be expanded and refined as appropriate by the team members.

Phase II synthesis is the aggregation of the MOEs to assess elements in each level of the structure. A general multiplicative function is used as the basis for aggregation. The rationale upon which function coefficients (called weights) are chosen is described by way of identifying nominal weight values for all elements within the assessment structure. A computer code, which performs the Phase II synthesis, was prepared. Two example sets of MOE values were selected and synthesized using the nominal weights. Phase II synthesis methods,

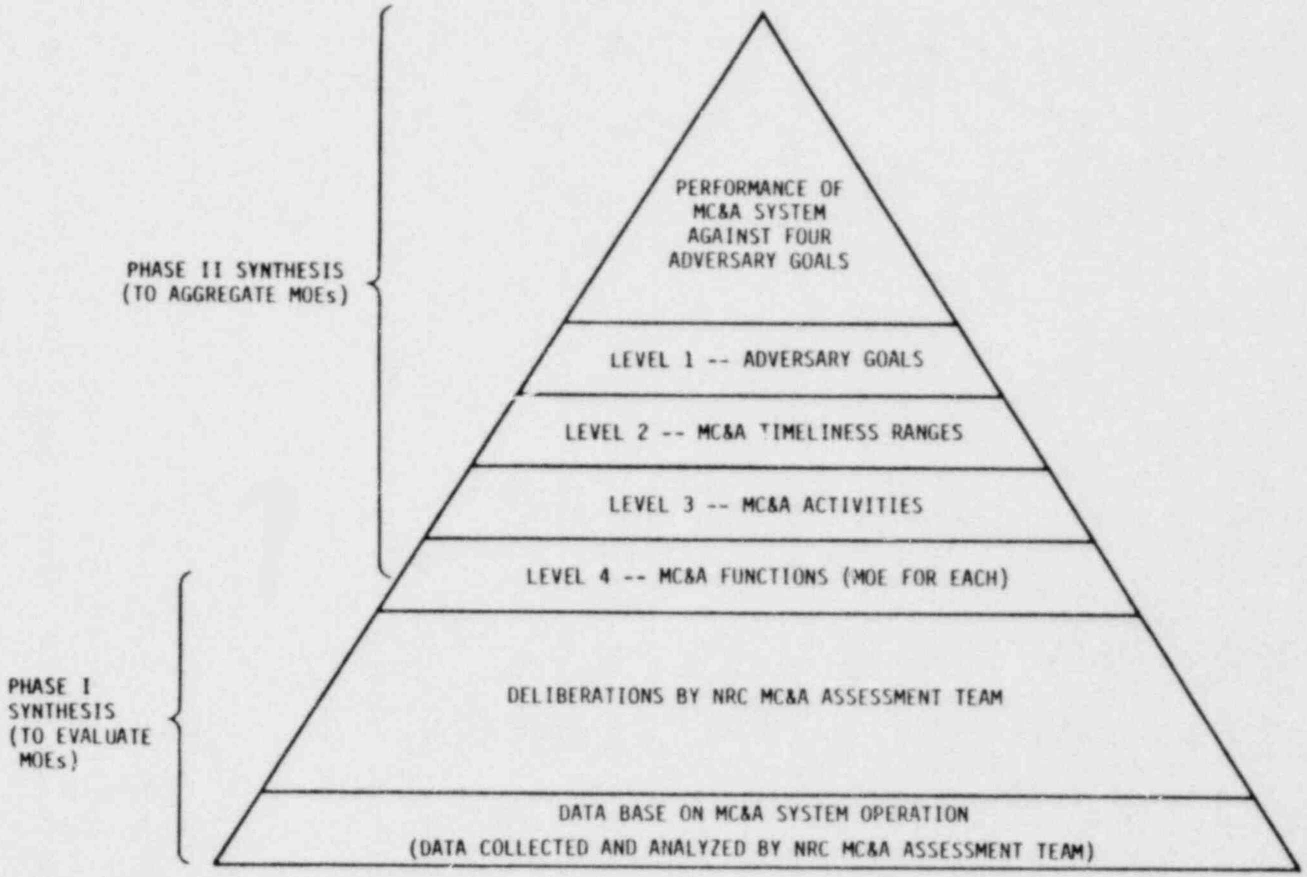


Figure 1.2. Overview of MC&A Assessment.

together with the two example exercises, are presented in Section 5. The computer code which performs the Phase II synthesis is described and listed in Appendices B and C, respectively.

Two other considerations which are important to MC&A assessments, false alarms and insider adversary, are discussed in Section 6.

2. PREVIOUS NRC MC&A ASSESSMENTS

Inspection of MC&A systems at licensed facilities for compliance with NRC regulations and license conditions is a continuing activity of the NRC Office of Inspection and Enforcement. Other MC&A assessments, which are more performance or capability oriented rather than compliance oriented, have been performed. In 1977, NRC's Comprehensive Evaluation Program (CEP) for fuel cycle facilities with strategic special nuclear material (SSNM) was developed and evaluations were begun at licensee facilities.(1) The CEP, which evolved during 1977 and 1978 as evaluation experience was gained and personnel changed, consisted of the following four evaluations which were performed by four different NRC teams.

- Diversion Path Survey
- External Assault Survey
- Physical Security Assessment
- Material Control and Accounting Assessment

For the CEP, the purpose of the MC&A Assessment was to determine the following: (a) whether the licensee's material accounting system was capable of detecting after the fact, a loss of five formula kilograms of SSNM if such a loss occurred during a prior two-month inventory period or during a period of up to 12 months in duration, (b) whether the licensee's material control system was capable of detecting, a loss of five formula kilograms of SSNM during the inventory period in which the loss mig t occur, and (c) whether the material control and accounting system could determine quickly, in response to an external stimulus (such as an alleged theft), if a five formula kilogram loss of SSNM had occurred. The above purpose is represented in the first-level of the two-level assessment structure shown in Figure 2.1. The second level contains the key factors considered in the evaluation of each capability.

For the CEP Physical Security Assessment, a four-level assessment structure was developed.(3) Two techniques were formulated for synthesizing the 67 questions associated with the fourth level. One method, developed at NRC, is based on an adaptation of Bayes' theorem(3,4), and the other, developed by Woodward-Clyde Consultants and Sandia Laboratories, is based on the use of utility functions.(4-6) Each of the four or five members of the Physical Security Assessment Team answered the 67 questions, and their answers were synthesized to produce intermediate scores at each level as well as an overall score for physical security capability.

A four-level MC&A assessment structure was also developed for the CEP.(7) The fourth level consists of several hundred questions. These questions, which were formulated before June 1977, assisted the MC&A Assessment Team, but they were not answered systematically and then synthesized. In September 1977, NRC's Material Control and Material Accounting Task Force was formed.(2) This Task Force carried out a comprehensive, top-down review and analysis of material control and material accounting, beginning with NRC's overall safeguards objective and a set of high-level safeguards functions (deterrence, prevention, response, assurance) and proceeding on to produce 16 material control (MC) goals and 22 material accounting (MA) goals. The hierarchy corresponding to the Task Force approach is shown in Figure 2.2. The 16 MC goals and 22 MA goals are listed in Figure 2.3 as they were summarized in the Task Force Report. From this list, 7 MC goals and 9 MA goals were identified by NRC as being key to the performance of a licensee's MC&A system. The remaining goals were either supportive of one or more of the key goals or were applicable to NRC activities rather than to those of licensees. The 16 key goals underlined in Figure 2.3 provided the quantitative basis for the MC&A assessment structure described in the next section. In addition, the discussions contained in the 5-volume Task Force Report(2) provided numerous ideas which were incorporated into the assessment procedure.

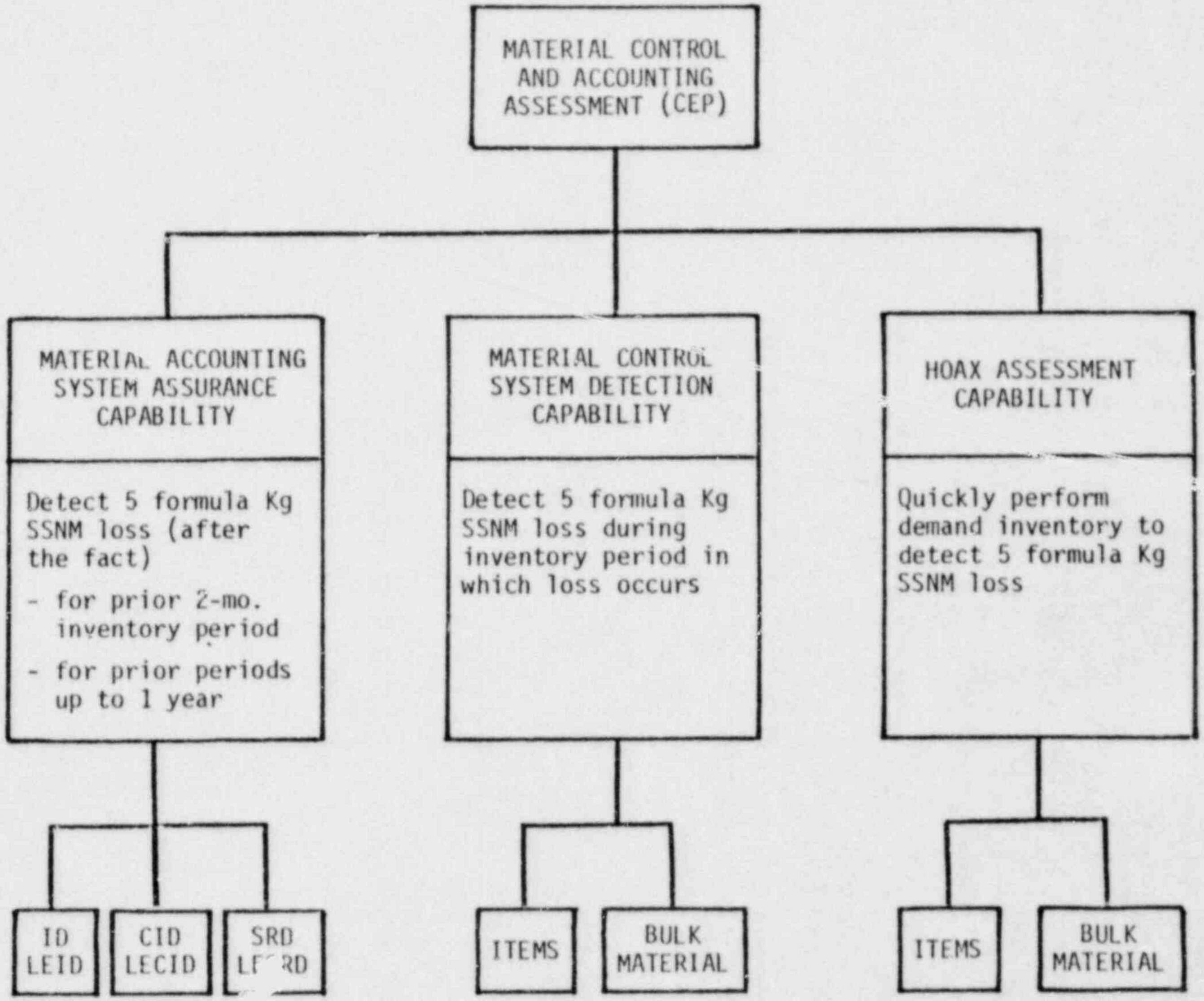


Figure 2.1. Hierarchical Structure for MC&A Assessment for Comprehensive Evaluation Program.

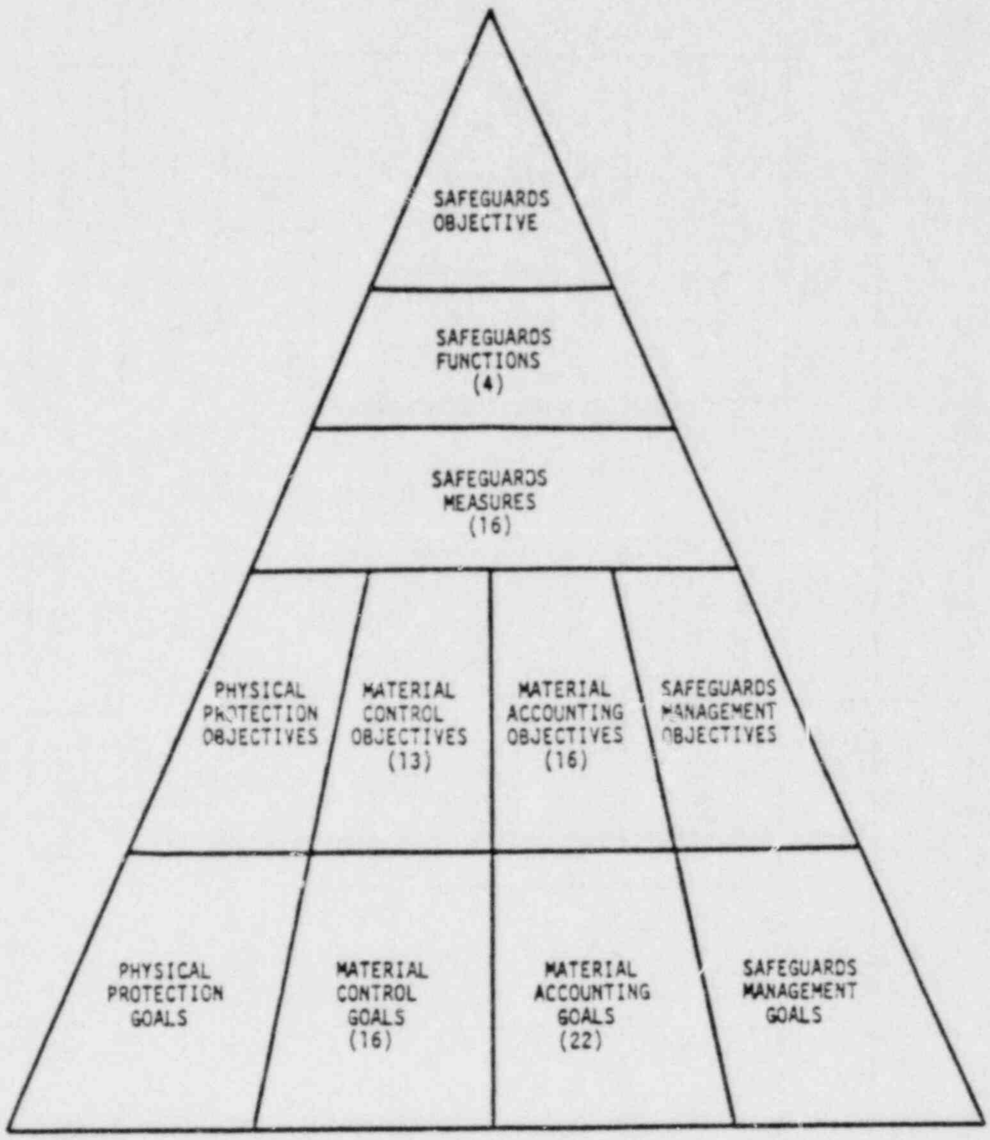


Figure 2.2. Hierarchical Approach Used by MC and MA Task Force to Establish Goals.

FUNCTION		MATERIAL CONTROL GOALS
DETERRENCE		No separate goals primarily supporting deterrence were identified
PREVENTION	MC 1	Secure records from falsification
	MC 2	Separation of functions
	MC 3	Shift monitoring
	MC 4	Assign custodial responsibility
	MC 5	Vigilance by well-trained individuals
	MC 6	Protect against unauthorized transfers
	MC 7	Separation of responsibilities for movements of material
	MC 8	Detect 5 kg loss of accessible material
	MC 9	Assess alarms in 1 hour
RESPONSE	MC 10	Detect 5 kg loss in period between inventories
	MC 11	Rapid loss assessment
ASSURANCE	MC 12	As much material as practicable in in items or measurable form
	MC 13	Confirm item status each shift
	MC 14	Confirm bulk status each day
	MC 15	Confirm safeguards effectiveness between inventories
	MC 16	NRC periodically confirm effectiveness of material control system

FUNCTION		MATERIAL ACCOUNTING GOALS
DETERRENCE		No goals specific to deterrence were identified
PREVENTION	MA 1	Limit record access
	MA 2	Redundant accounting records
	MA 3	Separation of duties
RESPONSE	MA 4	Verify presence of items within 24 hours of receipt
	MA 5	Through S/R analysis, detect loss of 5 kg within 10 days
	MA 6	Detect 5 kg loss by physical inventory
	MA 7	Reports of demand inventories within 20 days
	MA 8	Localize loss
	MA 9	Traceability of transactions
ASSURANCE	MA 10	Reconcile S/R differences within 30 days
	MA 11	Cumulative S/R difference <5 kg for 1 year
	MA 12	NRC S/R analysis capability
	MA 13	Discard measurement verification
	MA 14	Bimonthly inventories
	MA 15	CID<LECID over 12 months, and trend of CID toward zero
	MA 16	Recover scrap within an inventory period
	MA 17	NRC monitoring of IDs and other accounting data
	MA 18	Three random audits per year
	MA 19	Quality measurements
	MA 20	Strong measurement control program
	MA 21	NRC assurance to public through public reports
	MA 22	IAEA support

Seven MC goals and nine MA goals, which were identified by NRC to be key goals, are underlined.

Figure 2.3. MC and MA Task Force Goals.

3. MC&A ASSESSMENT STRUCTURE

This section describes two related hierarchical structures for assessing the performance of MC&A systems at licensee facilities: a general structure which reflects the MC&A assessment objectives of NRC's Comprehensive Evaluation Program and a specific version of this structure which incorporates 16 key goals of NRC's MC & MA Task Force. The general structure is described first.

3.1 GENERAL MC&A ASSESSMENT STRUCTURE

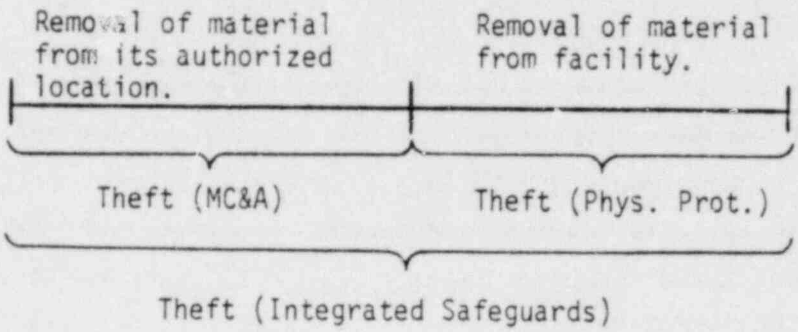
The general assessment structure consists of four levels and can be described either from the top down or from the bottom up. The structure was actually formulated by identifying the top and bottom levels, and then devising the two intermediate levels. It is described below in the same order.

3.1.1 Top Level--Adversary Goals

The assessment objective identified for the top of the structure is to measure the overall performance of an MC&A system against a set of designated adversary goals. Hence, the first level of the structure is the set of adversary goals against which an MC&A system provides countermeasures:

- Abrupt theft from the facility
- Protracted theft from the facility
- Theft from shipments
- Hoax

"Theft" has a special meaning for an MC&A assessment. From a general integrated safeguards viewpoint, theft is the removal of material from its authorized location to somewhere outside the facility. However, for an MC&A system, theft is limited to removal of material from its authorized location, while for a physical protection system, theft is removal of material from inside the facility to outside the facility. These differences in definitions can be illustrated by considering theft to occur in two segments as shown below.



"Abrupt" and "protracted" also have special meanings depending on whether MC&A or physical protection is being considered. For MC&A systems, theft is usually regarded as being abrupt if it occurs during the period between two MC&A tests (e.g., between two item checks or between two physical inventories). Hence, the meaning of "abrupt theft" varies for different MC&A measures, depending on the test period. The length of these periods can range from hours to months. For an MC&A assessment which covers many MC&A measures, it is helpful in the characterization and interpretation of the assessment results if "abrupt theft" is defined for all MC&A measures in terms of the same time period, usually the shortest period associated with any MC&A measure. "Protracted theft" is, then, any theft which occurs during multiple time periods. For physical protection systems, theft may be considered abrupt if all the material is removed from the facility during a single move through an exit such that there is only one opportunity to detect its removal. Otherwise, multiple material removals associated with protracted theft provide multiple detection opportunities. This explanation of "abrupt and protracted theft" is given to clarify their meanings as used for the MC&A assessment and to put the MC&A assessment into perspective relative to physical protection and integrated safeguards assessments.

The third adversary goal, "theft from shipments," refers to removal of material from some part of the transportation cycle, before the material comes under the control of the MC&A system of the facility being assessed. The fourth adversary goal, "hoax", is a claim that material is missing from the facility when it is not.

The overall performance of the MC&A system is to be assessed according to how well it provides countermeasures against these four adversary goals.

3.1.2 Bottom Level--MC&A Functions

Two distinct MC&A functions*, which provide countermeasures against theft of material, were identified: loss detection and loss assessment. Loss detection can be regarded as a composite function, consisting of 1) alarm generation and 2) alarm assessment. The result of a loss detection is a validated alarm which confirms that a loss has occurred. Loss assessment may also be treated as a composite function consisting of 1) characterization of the loss, 2) identification of the loss mechanism and 3) determination of the appropriate follow-up actions.

The two parts of loss detection naturally occur as sequential events, and hence alarm generation and alarm assessment are designated "primary" MC&A functions for the purpose of this assessment. In contrast, the investigative nature of loss assessment suggests that its three parts may proceed in parallel and may not be separable events. Hence, loss assessment is designated a primary MC&A function.

The three designated primary functions are shown in Figure 3.1 as a series of three distinct events. Loss detection is shown as a composite of the first two events. For situations where an alarm is generated long after the loss occurs, it is expected that the alarm assessment and loss assessment will not be readily separable events. Rather, the investigative process to assess the alarm and to assess the possible loss would proceed in parallel. Hence, for delayed alarms, a composite MC&A function, called alarm resolution, and consisting of alarm assessment and loss assessment, has been designated as shown in Figure 3.1. The three primary MC&A functions are defined as follows.

- Alarm generation is the production of a signal by any part of the MC&A system which senses an anomaly or deficiency which could indicate that material has been or is being removed from its authorized location in the facility.

- Alarm assessment is the determination by the MC&A system whether the alarm is true or false.

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*Functions, as used here, refer to operational functions, in contrast to the basic functions (prevention, response and assurance) which are included in or inferred from NRC's 1976 "Statement of Safeguards Objective." (See Reference 2, Volume 2, Chapter 2).

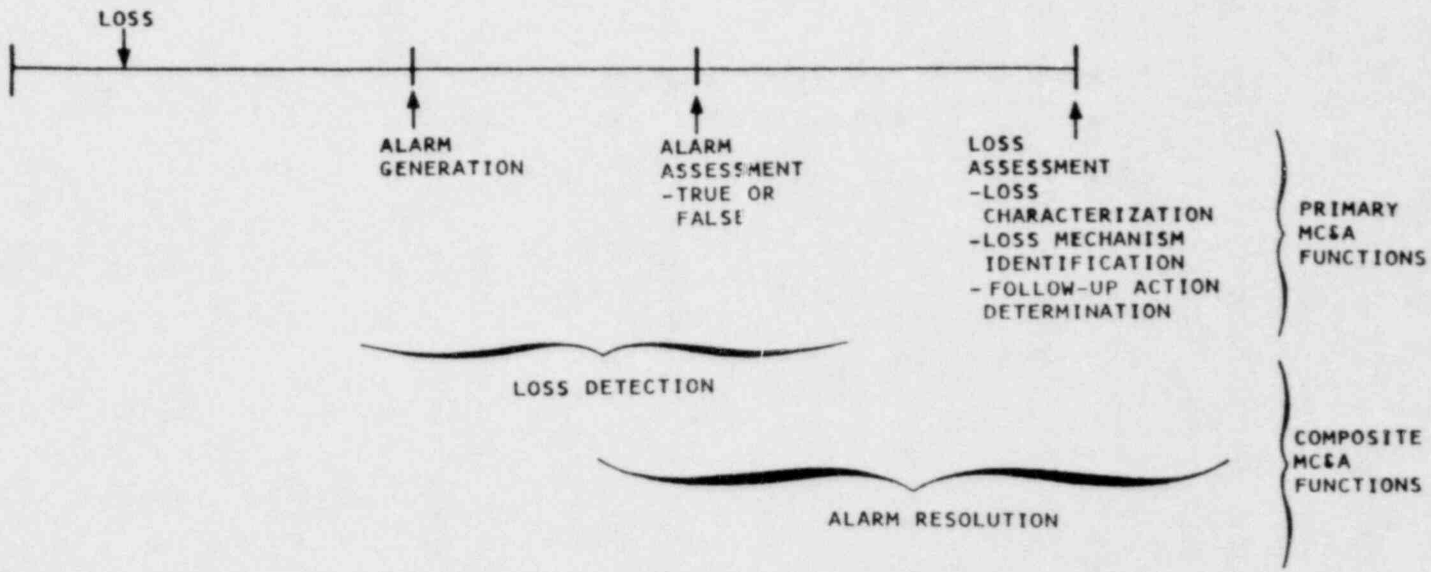

Figure 3.1. Event Line for MC&A Functions.

- Loss assessment is the activity of the MC&A system to 1) characterize lost material in terms of its important attributes including form and quantity, 2) identify the loss mechanism and determine if the loss was an accident or theft, and 3) determine the appropriate follow-up actions, such as response actions to recover the lost material and corrective actions to prevent or reduce the likelihood of further losses.

Having identified and described a set of primary MC&A functions, a scheme for measuring how well the functions are performed is needed. Three parameters can be associated with the performance of these functions.

- quantity of lost material
- timeliness in performing function
- probability of performing function properly

Both the MC&A assessment portion of NRC's Comprehensive Evaluation Program and, to a greater extent, NRC's MC & MA Task Force Report express MC&A goals in terms of specified quantities of lost material and specified performance times. Hence, the third performance parameter, the probability of performing the function properly, was chosen to be the measure of effectiveness (MOE) for the MC&A functions. This means that each function is to be evaluated in terms of the probability, given the loss of a specified quantity of material, that the MC&A system properly performs the function within a specified time. The MOEs for the three primary and two composite MC&A functions are summarized in Figure 3.2, in terms of their abbreviated descriptions, their identification symbol as used throughout this report, and the meanings of the bottom and top of the MOE scale for each.

3.1.3 Intermediate Levels--MC&A Activities and Timeliness Ranges

The final step is to formulate the structure which connects the top and bottom levels. This was begun by examination of the MC&A activities which generate alarms when material is lost. The following MC&A activities which can generate alarms were identified:

PRIMARY MC&A FUNCTION	MEASURE OF EFFECTIVENESS (MOE)	BOTTOM OF MOE SCALE (0)	TOP OF MOE SCALE (1)
ALARM GENERATION	PROBABILITY OF ALARM GENERATION (P_A)	ALARMS NEVER GENERATED	ALARMS ALWAYS GENERATED
ALARM ASSESSMENT	PROBABILITY OF VALID ALARM ASSESSMENT (P_{AA})	ALARM ASSESSMENTS ALWAYS WRONG	ALARM ASSESSMENTS ALWAYS RIGHT
LOSS ASSESSMENT	PROBABILITY OF VALID LOSS ASSESSMENT (P_{LA})	LOSS ASSESSMENTS ALWAYS COMPLETELY WRONG	LOSS ASSESSMENTS ALWAYS COMPLETELY RIGHT
COMPOSITE MC&A FUNCTION			
LOSS DETECTION	PROBABILITY OF LOSS DETECTION ($P_D = P_A \times P_{AA}$)	LOSSES NEVER DETECTED	LOSSES ALWAYS DETECTED
ALARM RESOLUTION	PROBABILITY OF VALID ALARM RESOLUTION ($P_R = P_{AA} \times P_{LA}$)	ALARM RESOLUTIONS ALWAYS COMPLETELY WRONG	ALARM RESOLUTIONS ALWAYS COMPLETELY RIGHT

Figure 3.2. Measures of Effectiveness for MC&A Functions.

- Item Monitoring

- Bulk Material Monitoring

- Material Balances

- Shipper-Receiver Comparisons

These alarm-generation activities, together with their corresponding alarm- and loss-assessment activities, have been designated "primary" MC&A activities for the purpose of this assessment. Hence, each primary MC&A activity can perform the three primary MC&A functions. This relationship is summarized in Figure 3.3, together with the areas of the facility to which each activity applies.* Also, the alarm assessment activity for hoaxes, where no loss has occurred, is designated as a fifth primary MC&A activity: non-MC&A alarm assessment.

Next, the timeliness ranges which would be appropriate for these MC&A activities were considered. Three general ranges of timeliness were identified.

- Short-term (hours or weeks) for MC&A activities which can contribute to prevention of abrupt theft, early response to recover lost material and take corrective actions, or assurance of no losses over the short term.

- Intermediate-term (weeks or months) for MC&A activities which can contribute to prevention of protracted theft occurring at a moderate rate, delayed response to recover lost material and take corrective actions, or assurance of no losses over the intermediate term.

- Long-term (years) for MC&A activities which can contribute to prevention of protracted theft occurring at a low rate, late response to recover lost material and take corrective actions, or assurance of no losses over the long term.

Each MC&A activity was examined in terms of the applicability of each timeliness range. Of the possible 5 (activities) x 3 (timeliness ranges) or 15 possible combinations, 11 combinations, which are shown in Figure 3.4, were found to be relevant. Each relevant combination was examined to determine which adversary goals might be applicable. From this examination, 8 combinations were found to have a single adversary goal to be applicable, and 3 combinations were found to have two adversary goals to be applicable. The resulting 14 triads, each of which consists of a MC&A activity, a MC&A timeliness range, and an

*The terms "controllable units" and "accounting units" are used in this report as defined in the glossary of Reference 2.

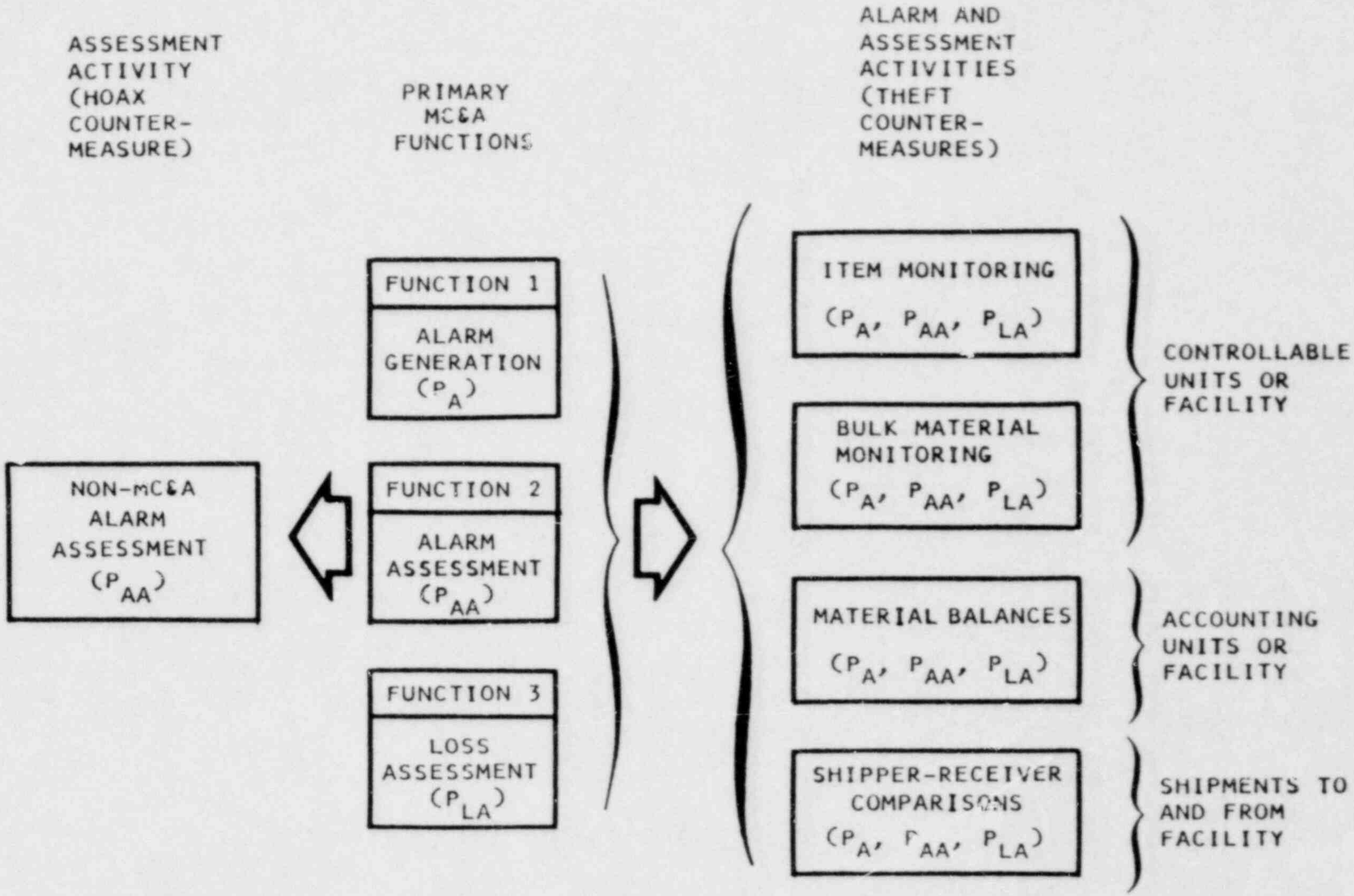

Figure 3.3. MC&A Activities Corresponding to Primary MC&A Functions.

PRIMARY MC&A ACTIVITY	MC&A TIMELINESS RANGE FOR ALARM AND ASSESSMENT			
	SHORT-TERM (Hours-Days)	INTERMEDIATE-TERM (Weeks-Months)	LONG-TERM (Years)	
ITEM MONITORING	CASE 1 ABRUPT THEFT FROM FACILITY	CASES 3 AND 6 ABRUPT AND PROTRACTED THEFT FROM FACILITY		CONTROLLABLE UNITS OR FACILITY
BULK MATERIAL MONITORING	CASE 2 ABRUPT THEFT FROM FACILITY	CASES 4 AND 7 ABRUPT AND PROTRACTED THEFT FROM FACILITY		
MATERIAL BALANCES		CASES 5 AND 8 ABRUPT AND PROTRACTED THEFT FROM FACILITY	CASE 9 PROTRACTED THEFT FROM FACILITY	ACCOUNTING UNITS OR FACILITY
SHIPPER-RECEIVER COMPARISONS	CASE 10 THEFT FROM SHIPMENT	CASE 11 THEFT FROM SHIPMENT	CASE 12 THEFT FROM SHIPMENT	SHIPMENTS TO & FROM FACILITY
NON-MC&A ALARM ASSESSMENT	CASE 13 HOAX	CASE 14 HOAX		FACILITY

CASE = MC&A ACTIVITY + MC&A TIMELINESS RANGE + ADVERSARY GOAL

Figure 3.4. Definition of Fourteen Cases for Timeliness Ranges and Adversary Goals Relevant to Primary MC&A Activities.

adversary goal, were designated "cases" for the purpose of this assessment. These 14 cases are defined in Figure 3.4. Implicit in this figure are the two intermediate levels of the assessment structure. For each adversary goal, the relevant MC&A timeliness ranges are identified. For each combination of adversary goal and timeliness range, the relevant MC&A activities are identified. In addition, for each activity, the relevant MC&A functions and their associated MOEs are identified in Figure 3.3. The information contained in Figures 3.3 and 3.4 was used to produce the MC&A assessment structure shown in Figure 3.5. This structure was shown earlier in Figure 1.1. The choice of MC&A timeliness ranges for the second level and MC&A activities for the third level was made to facilitate aggregation at these levels. If experience should show that the opposite choice would be preferable, the modification is straightforward to implement. The adaptation of the general structure to incorporate 16 key goals of the MC & MA Task Force is described next.

3.2 MC&A ASSESSMENT STRUCTURE BASED ON MC & MA TASK FORCE GOALS

The general MC&A assessment structure described above already reflects many of the qualitative features of the MC & MA Task Force goals. In this section, the structure is adapted to reflect the quantitative aspects of the 16 key goals which were identified earlier in Section 2. The main quantitative aspects are the quantity of lost material which is to be detected and the times after the loss occurs by which it is to be detected and the loss accessed.

The procedure used to incorporate the key goals into the general structure was to match each goal with one or more of the MC&A functions associated with the 14 cases. The result of this process is shown in Figure 3.6. One or two key goals are shown with the MOE for each MC&A function. The timeliness requirement associated with each key goal is shown in parenthesis. On the right edge of the figure are shown the areas of the facility to which the indicated MC&A activities, and hence MOEs for the corresponding MC&A functions, are applicable.

Most of the matches between key goals and MC&A functions were straightforward to make. For some situations, however, there was not a key goal which was clearly applicable to an MC&A function. This occurred for the alarm generation and alarm resolution functions under cases 3 and 6, and for the alarm assessment and loss assessment functions under case 10. For these situations,

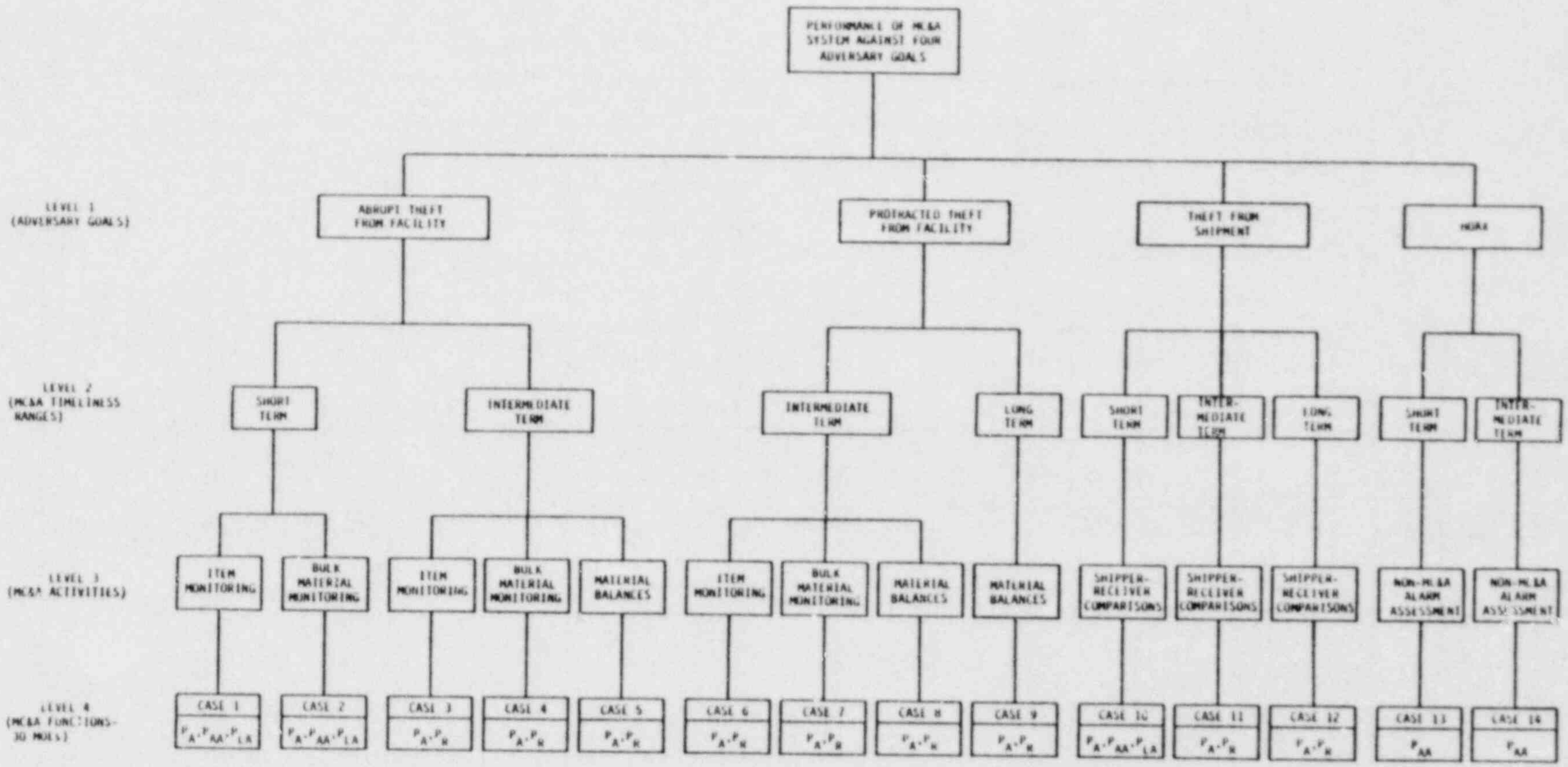

Figure 3.5. General Hierarchical Structure for Assessment of MC&A System Performance.

PRIMARY MC&A ACTIVITY	MC&A TIMELINESS RANGE FOR ALARM AND ASSESSMENT			
	SHORT-TERM (Hours-Days)	INTERMEDIATE-TERM (Weeks-Months)	LONG-TERM (Years)	
ITEM MONITORING	CASE 1 (ABRUPT THEFT) P_A: MC 8(a), MC 13 (8 hours) P_{AA}: MC 9 (1 hour) P_{LA}: MC 11 (24 hours*)	CASES 3 & 6 (ABRUPT & PROTRACTED THEFT) P_A: MC 10, MC 15 (60 days) P_R: MC 11 (1 day)		FACILITY
BULK MATERIAL MONITORING	CASE 2 (ABRUPT THEFT) P_A: MC 8(b), MC 14 (24 hours) P_{AA}: MC 9 (1 hour) P_{LA}: MC 11 (24 hours*)	CASES 4 & 7 (ABRUPT & PROTRACTED THEFT) P_A: MC 10, MC 15 (60 days) P_R: MC 11 (1 day)		CONTROLLABLE UNITS
MATERIAL BALANCES		CASES 5 & 8 (ABRUPT & PROTRACTED THEFT) P_A: MA 6, MA 14 (90 days) P_R: MA 7, MA 8 (20 days)	CASE 9 (PROTRACTED THEFT) P_A: MA 15 (14 months*) P_R: MA 15 (3 months*)	ACCOUNTING UNITS
SHIPPER-RECEIVER COMPARISONS	CASE 10 (THEFT FROM SHIPMENT) P_A: MA 4 (24 hours) P_{AA}: MC 9 (1 hour) P_{LA}: MC 11 (24 hours*)	CASE 11 (THEFT FROM SHIPMENT) P_A: MA 5 (10 days) P_R: MA 10 (30 days)	CASE 12 (THEFT FROM SHIPMENT) P_A: MA 11 (14 months*) P_R: MA 11 (3 months*)	SHIPMENTS TO & FROM FACILITY
NON-MC&A ALARM ASSESSMENT	CASES 13A & 13B (HOAX) P_A: Not Applicable P_{AA}: MC 9 (1 hr), MC 11 (24 hr*) P_{LA}: Not Applicable	CASE 14 (HOAX) P_A: Not Applicable P_{AA}: MA 7 (20 days) P_{LA}: Not Applicable		FACILITY

*TIME ASSUMED WHEN TIME IS NOT SPECIFIED BY MC OR MA GOAL.

Figure 3.6. MC and MA Task Force Goals Associated with Each MC&A Function for Each Case.

the most closely related goal is shown with these MC&A functions. In one other situation the match was uncertain; the goal MC 11 which is associated with the alarm resolution function under cases 4 and 7 could be supplemented or possibly replaced by goal MA 7. Case 13 was partitioned into two parts to retain the different timeliness criteria of goals MC 9 and MC 11.

The quantity of lost material to be detected is specified in by the key goals as 5 formula kilograms of SSNM. This quantity is applicable to abrupt and protracted theft from the facility and to theft from shipment. Abrupt theft is defined to be removal of 5 formula kilograms of SSNM from its authorized location during the shortest MC&A period specified by the key goals: one shift, or eight hours. Protracted thefts are defined to be removal of 5 formula kilograms of SSNM from its authorized location during the applicable MC&A period: two months for intermediate-term cases 6, 7 and 8 and one year for long-term case 9.

Using the above definitions of theft and the information contained in Figure 3.6, the general MC&A assessment structure was adapted to incorporate the 16 key goals of the MC & MA Task Force. The resulting structure is shown in Figure 3.7. The thirty MOEs which are shown at the bottom of the structure are described, and a process for determining them at a licensee facility is discussed in Section 4. A procedure for aggregating the MOEs at each level of the structure is presented in Section 5.

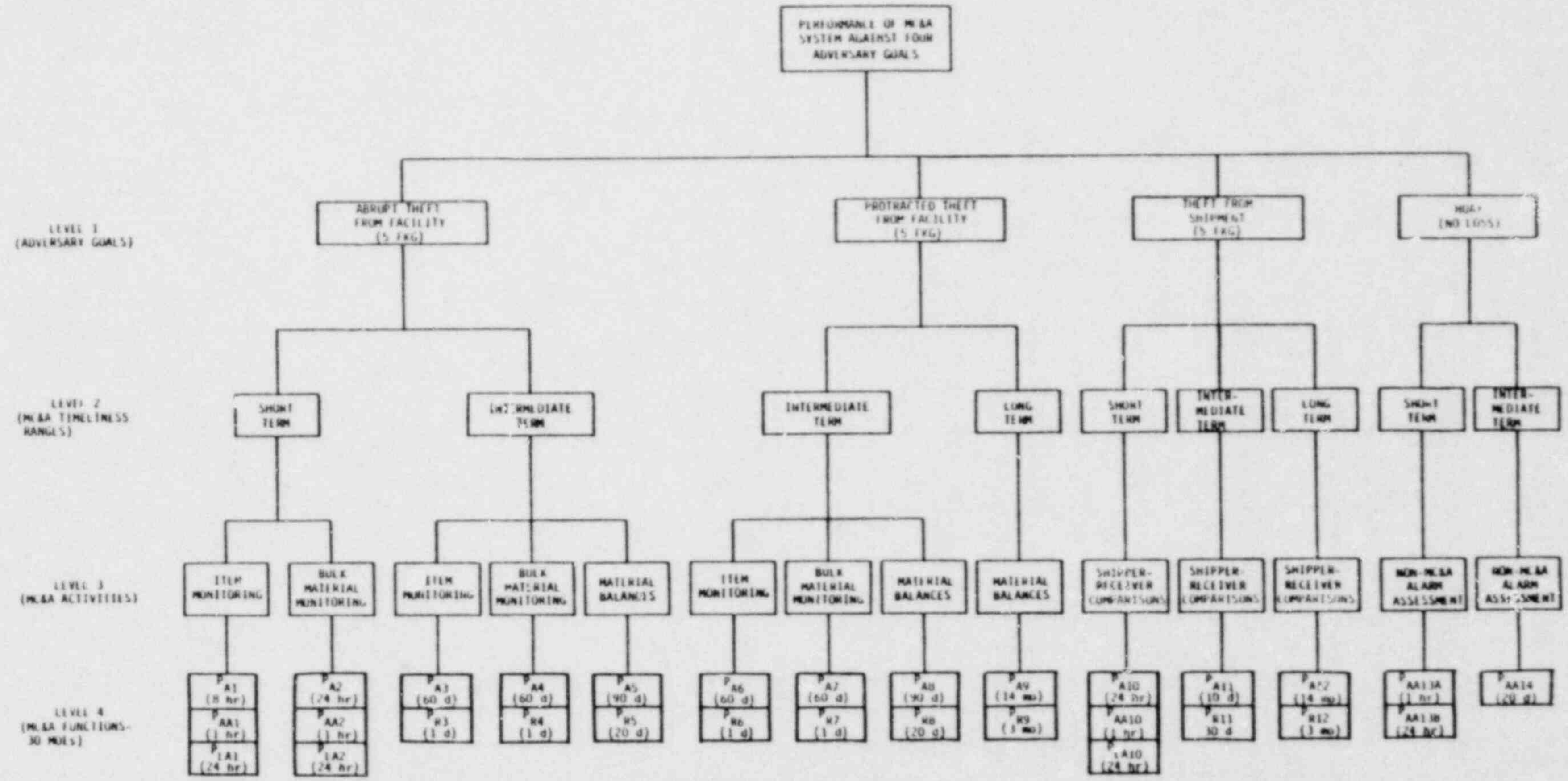

Figure 3.7. Hierarchical Structure for Assessment of MC&A System Performance to Achieve Goals of MC and MA Task Force.

4. PHASE I SYNTHESIS FOR EVALUATION OF MOEs

Examination of the bottom of the MC&A assessment structure raises the question: Should one or more lower levels be developed? Certainly there is much data which can be collected and analyzed to evaluate each of the MOEs. This question was discussed with NRC staff members who had been associated with earlier assessments. The conclusion was that, at least for the initial assessments to be performed using this method, it would be preferable to have the individual MOE determination be an unstructured process. Hence, the evaluation of each MOE would be the result of the NRC assessment team's collection and analysis of the relevant data together with their synthesis. The synthesis of these data, designated "Phase I synthesis," would be performed during deliberations by the NRC assessment team members and would provide full opportunity for the introduction of judgement into the assessment process. Phase II synthesis, which deals with aggregation of the MOEs up the four levels of the assessment structure, is described in the next section.

The role of Phase I synthesis is illustrated in Figure 4.1. A data base on the MC&A system being assessed should be available. The data base would consist of design data associated with the licensing process, performance data associated with prior operation of the MC&A system, and field data collected at the facility by the NRC assessment team. Parts of the data base would be applicable to evaluation of each individual MOE. Review by the NRC assessment team of the design and performance data may reveal questions to be investigated at the facility. These questions could be in the areas of data contradictions, gaps in available data, demonstrated problems and potential problems. The history of licensee follow-up to correct prior deficiencies and licensee adherence to procedures are relevant to evaluation of the MOEs. The quality of licensee support activities, such as management delegation of responsibilities and authority, personnel selection and training, equipment repair and maintenance, quality control/quality assurance programs and internal/external audit programs, are also important to evaluation of the MOEs. Finally,

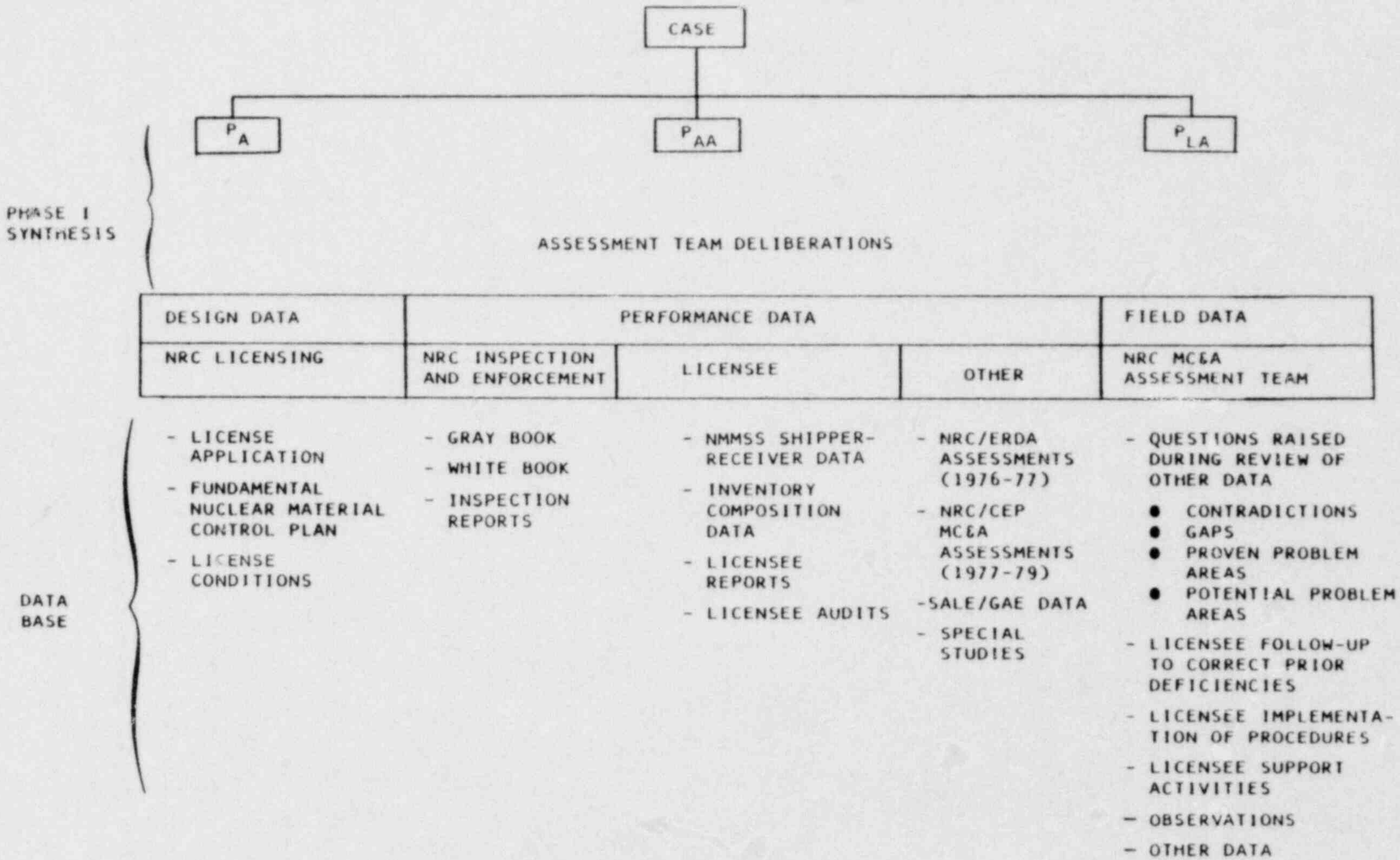

Figure 4.1. Framework for Phase I Synthesis.

observations of routine and random occurrences at the facility may give additional insights into facility operations.

The above discussion of data synthesis for MOE determination has been general. More specific information is needed for evaluation of each of the thirty MOEs summarized in Figure 4.2. An evaluation aid has been prepared on each MOE to provide assistance for the assessment team members. Each evaluation aid consists of three parts: 1) the definition of the MOE, 2) the key goal or goals of the MC & MA Task Force which are applicable to the MOE, and 3)a discussion on the evaluation of the MOE. In addition, evaluation aids for some MOEs include: 1) discussion of specific technical issues relevant to the evaluation, 2) references, and 3) data sheets. These evaluation aids can be extended and refined by the assessment team members as appropriate. The thirty evaluation aids are presented in Appendix A. Four data sheets, which are for use with 16 of the evaluation aids, are given at the end of this appendix.

MOE NUMBER	MOE ID*	MC&A ACTIVITY	TIME	ADVERSARY GOAL	AREA OF FACILITY	PORTION OF SSNM	MATERIAL FORM	SIMILAR OR SAME MOE
1	P_{A1}	Item Monitoring	8 hr	Abrupt Theft	Facility	Accessible SSNM	Items Only	
2	P_{AA1}		1 hr					
3	P_{LA1}		24 hr					
4	P_{A2}	Bulk Material Monitoring	24 hr		Controllable Unit		Bulk Only	
5	P_{AA2}		1 hr					
6	P_{LA2}		24 hr					
7	P_{A3}	Item Monitoring	60 d		Facility	All SSNM	Items Only	
8	P_{R3}		1 d					
9	P_{A4}	Bulk Material Monitoring	60 d		Controllable Unit		Bulk Only	
10	P_{R4}		1 d					
11	P_{A5}	Material Balances	90 d		Accounting Unit		Items & Bulk	
12	P_{R5}		20 d					
13	P_{A6}	Item Monitoring	60 d	Protracted Theft	Facility		Items Only	
14	P_{R6}		1 d					No. 8--P_{R3}
15	P_{A7}	Bulk Material Monitoring	60 d		Controllable Unit		Bulk Only	
16	P_{R7}		1 d					No. 10--P_{R4}
17	P_{A8}	Material Balances	90 d		Accounting Unit		Items & Bulk	No. 11--P_{A5}
18	P_{R8}		20 d					No. 12--P_{R5}
19	P_{A9}		14 mo					
20	P_{R9}		3 mo					
21	P_{A10}	Shipper-Receiver Comparisons	24 hr	Theft from Shipment	Not Applicable		Items Only	
22	P_{AA10}		1 hr					
23	P_{LA10}		24 hr					
24	P_{A11}		10 d				Items & Bulk	
25	P_{R11}		30 d					
26	P_{A12}		14 mo					
27	P_{R12}		3 mo					
28	P_{AA13A}	Non-MC&A Alarm Assessment	1 hr	Hoax	Facility	Accessible SSNM	Items Only	No. 2--P_{AA1}
29	P_{AA13B}		24 hr				Bulk Only	No. 6--P_{LA2}
30	P_{R14}		20 d			All SSNM	Items & Bulk	No. 12--P_{R5}

*MOE Identification, P_{XN} where X = A (Alarm Generation), X = AA (Alarm Assessment), X = LA (Loss Assessment), X = R (Alarm Resolution) and N = Case Number.

Figure 4.2. Summary of MOEs for MC&A Assessment.

5. PHASE II SYNTHESIS FOR AGGREGATION OF MOEs

The Phase II synthesis deals with the combination or aggregation of the 30 individual MOEs described in the Phase I synthesis. The hierarchical structure introduced in Figure 3.7, and repeated as Figure 5.1, provides the basis upon which this aggregation takes place. The structure can be viewed as an identification of objectives and subobjectives for which there is interest in measuring quantitatively the extent to which each is attained. The hierarchy provides a vehicle whereby MC&A system objectives, too comprehensive for direct evaluation, can be assessed indirectly by decomposing them into successively more detailed and narrowly defined subobjectives. The success of the Phase II synthesis is based on the premise that it is possible to identify lower level hierarchical elements for which direct assessment is practical and that the functional* relationships between higher and lower level elements can be explicitly characterized.

This section focuses on the definition of these quantitative functional relationships. An example, which demonstrates the methodology, is given at the end of this Section. The essential ingredients are:

- A structure representing the overall objective and the different hierarchical sublevels at which performance is to be quantified.

- An evaluation of performance for each element at the lowest level of the hierarchy.

- An identification of appropriate quantitative relationships or functions to be used in expressing the performance of elements on one level as a function of the performance of subsidiary elements on the next lower level.

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*In this section, except when referring to MC&A functions, use of the words 'functional' and 'functions' is in reference to an analytical interpretation.

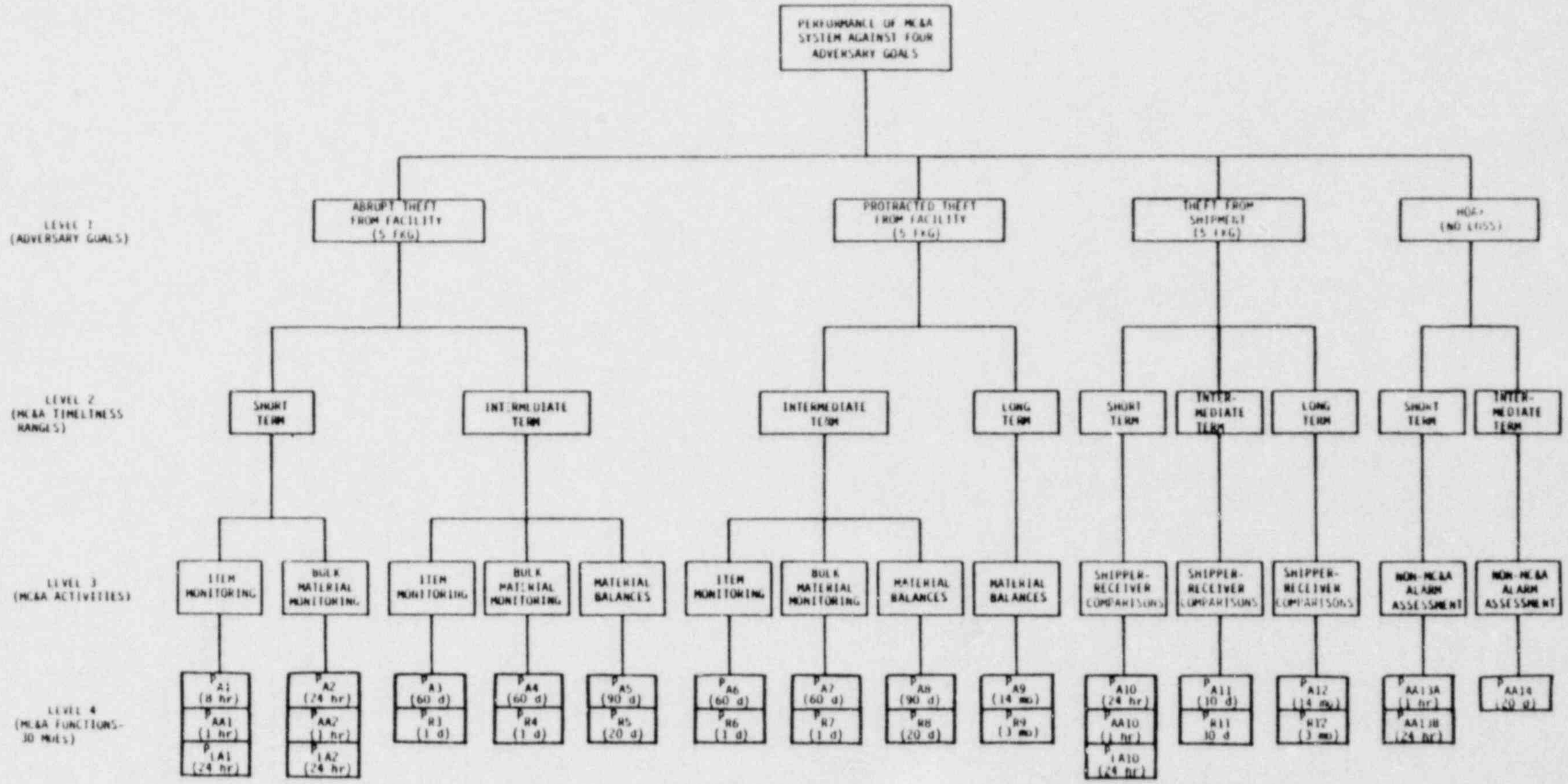


Figure 5.1. Hierarchical Structure for Assessment of MC&A System Performance to Achieve Goals of MC and MA Task Force.

5.1 HIERARCHICAL STRUCTURE

The hierarchical structure of Figure 5.1 contains four levels for evaluation of system performance. The first level makes explicit that there are four general adversary goals against which system performance is to be assessed: abrupt theft, protracted theft, theft from shipment, and hoax. It is possible for system performance to be effective against one adversary goal and ineffective against another. It is for this reason the performance is assessed separately for each.

The possibility of further heterogeneity in system performance is allowed in the second level which introduces the issue of timeliness. A system may be effective when a long time frame is allotted for its performance, but it may be ineffective if results are required over the short term. Variation in the time frame within which system performance must be attained is shown for each adversary goal.

The third level of the hierarchial structure gives explicit recognition to the fact that a comprehensive MC&A system will encompass more than one activity. As shown, the four major activity categories are item monitoring, bulk material monitoring, material balances and shipper-receiver comparisons. Again, it is possible for the performance of the system to vary from one activity to another. Of course the performance of any specific activity is to be considered in the context of the hierarchical levels above it. For example, item monitoring may be effective in the intermediate term against an abrupt theft of nuclear material in item form but not in the short term against the same theft.

The fourth level identifies the three key MC&A functions: alarm generation, alarm assessment, and loss assessment. When taken together the alarm assessment and loss assessment functions are referred to as an alarm resolution function. Utilizing the methodology described in Section 4, these fourth level functions are assessed directly by a NRC assessment team. Each of these 30 MOEs pertain to the alarm generation, alarm assessment or loss assessment performance of a specific MC&A activity within some particular time frame and against some specific adversary goal.

5.2 MOEs FOR FOURTH-LEVEL ELEMENTS

The measurement of performance, or effectiveness, at each of the fourth level elements has been described in Section 4. Section 4 describes the background necessary for these direct evaluations which are obtained through deliberations of the NRC assessment team. Included is the identification of a measurement (the conditional probability of alarm generation, valid alarm assessment, or valid loss assessment being achieved) for each element and evaluation aids upon which quantification can take place.

For the purposes of Phase II synthesis, it is necessary to define a value function over each MOE. Although the assessment of performance at the bottom level can be characterized as a probability, the design of the structure precludes continuation of the synthesis within a probability framework; the interrelationships between many of the elements at the various levels do not permit a probability interpretation. The value function provides for a numerical expression of relative preference for each possible MOE outcome. This function is scaled so that a value of zero represents the worst possible performance and a value of one the best. The resulting values for MOEs are then used as the basis upon which performance can be expressed at any level of the hierarchy. Because the MOEs are assessed in terms of probabilities, the definition of a (linear) value function is straightforward: the value is set equal to the probability corresponding to each MOE. Were the performance associated with each MOE to be expressed in qualitative terms (e.g., low, medium, high), the definition of a value function could require more effort. In either case, the purpose of the value function is to represent, in quantitative terms, relative preferences between possible MOE outcomes.

5.3 THE MULTIPLICATIVE WEIGHTING FUNCTION

Each higher level element has one or more subsidiary elements under it, indicating that quantification of the value attained at any point in the hierarchy depends on performance values for the subsidiary elements. This section describes a formalization of these hierarchical relationships.

The structure itself imposes no limit on the possible functional forms that may be used in expressing the performance of an element in terms of the performance of its subsidiary elements. In practice, the functional form should be sufficiently general and robust so that it is applicable and remains representative over all possible values of performance at the subsidiary levels; different outcomes at the subsidiary levels should not require different functions for their aggregation. On the other hand, it is necessary that a synthesis function not be so complex that it precludes understanding.

Expressed notationally, the general problem is one of describing a function f such that

$$v = f(v_1, v_2, . . ., v_n),$$

where v is the value of the higher level element being addressed and $v_1, v_2, . . ., v_n$ are the values of the n subsidiary elements. For the hierarchy of Figure 5.1 a multiplicative function is proposed such that, in general,

$$v = \prod_{i=1}^{n} (a_i + b_i v_i),$$

where a_i and b_i are constants. A multiplicative function was chosen on the basis of pragmatic considerations. This function adequately characterized the various synthesis forms that were intuitively appealing.*

For the case where n = 3, this model results in

$$v = a_1a_2a_3 + b_1a_2a_3v_1 + a_1b_2a_3v_3 + a_1a_2b_3v_3 + b_1b_2a_3v_1v_2$$
$$+ b_1a_2b_3v_1v_3 + a_1b_2b_3v_2v_3 + b_1b_2b_3v_1v_2v_3$$

---

*We recognize that based on value function theory, it can be shown that a multiplicative function is appropriate only if certain conditions on preferences for outcomes hold[8,9]. As stated, however, value theory considerations did not provide the basis upon which the multiplicative function was selected and, thus, are not addressed.

To ensure that $v = 0$ when each of the element $v_i = 0$, we drop the constant $a_1a_2a_3$ from the multiplicative formulation. It is also now possible to reduce the number of coefficients by using the expression

$$v = w_1v_1 + w_2v_2 + w_3v_3 + ww_1w_2v_1v_2 + ww_1w_3v_1v_3 + ww_2w_3v_2v_3 + w^2w_1w_2w_3v_1v_2v_3$$

where $w_1 = b_1a_2a_3$, $w_2 = a_1b_2a_3$, $w_3 = a_1a_2b_3$ and $w = 1/a_1a_2a_3$. A compact form for this multiplicative function when it involves n terms is

$$wv + 1 = \prod_{i=1}^{n} (ww_iv_i + 1)$$

The coefficients $w_1, w_2, \ldots, w_n$ can be viewed as weights corresponding to the element values $v_1, v_2, \ldots, v_n$, and the coefficient w is a normalizing constant. The weights $w_1, w_2, \ldots, w_n$ are assessed such that $w_i = v$ when $v_i = 1$ and $v_j = 0$ for all $j \neq i$. The constant w is found by solving

$$1 + w = \prod_{i=1}^{n} (ww_i + 1)$$

for given w_i, i.e., $v = 1$ when all $v_i = 1$. In solving for w we see that when $\sum w_i > 1$, $-1 \leq w < 0$, and when $\sum w_i < 1$, $w > 0$. When $\sum w_i = 1$, the multiplicative function reduces to an additive function (a weighted average) and $w = 0$.

The additive form is appropriate when a constant rate of substitution exists among the subsidiary elements: a specified increase in v_i is equivalent to some specific increase in v_j regardless of the other values v_k where $k \neq i,j$. The multiplicative function allows for nonlinearities in these trade-offs.

It should be noted that the multiplicative function represents two qualitatively different circumstances: one when $\sum w_i > 1$, and the other when $\sum w_i < 1$. When $\sum w_i > 1$, a complementary situation exists among the subsidiary elements. "Overlap" of one element by another occurs such that they reinforce each other. The result is that their combined value is greater than the value of either one alone, whatever the individual values. A different circumstance exists when $\sum w_i < 1$. In this case, there is enforcement of both strength and weakness. If two individual values are both low, their combined value will be even lower; correspondingly, if they are both high, the combined value is higher.

Figure 5.2 illustrates qualitatively the nature of a two variable multiplicative function as the relative weights change. In addition to the situations discussed above, two other cases are shown. One is a case where the element value is taken to be that of the minimum of the subsidiary elements and the other where it is taken to be a simple product. Strictly speaking, the minimum function is not a special case of the multiplicative function. The simple product is simply an extreme case of the supplementary category; however, for computational purposes, it should be recognized that, as w_1 and w_2 both approach 0, the product of all three weights (ww_1w_2) approaches 1.

5.4 ASSESSMENT OF WEIGHTS

As we move upward in the hierarchical structure, each element must have a weight associated with it. This weight represents, in a sense, the relative importance of one element with respect to the other subsidiary elements which contribute to the same higher-level element. The determination of these weights will be considered taking each level in order, starting with the bottom. The focus will be on describing nominal weights, primarily for the purpose of illustrating the considerations involved in the weight-setting process.

At the bottom of the Figure 5.1 structure, we are faced with representing the value of each third-level element as a function of the one, two or three elements below it. As described in an earlier section, P_A represents the probability of an alarm given a loss, P_{AA} is the probability of a valid alarm assessment given both a loss and an alarm, and P_{LA} is the probability of a valid loss assessment given a loss and a valid alarm assessment. The probability of a valid loss assessment, conditional on only a loss, is the product of P_A, P_{AA} and P_{LA}. For those instances where P_{AA} is not readily separable from P_{LA}, a composite alarm resolution probability P_R is defined which takes the place of the P_{AA}, P_{LA} portion of the product. If we wish to measure the performance of

	w_1	w_2	w	v_1	v_2	v
Weighted Average	$0\le w_1\le 1$	$1-w_1$	0	low medium high high	low medium high low	low medium high medium
Complementary (reinforcement or overlap of one by the other)	$.5<w_1\le 1$	$.5<w_2\le 1$	$0>w\ge -1$	low medium high high	low medium high low	med. low med. high very high high
Supplementary (enforcement of strength and weakness)	$0\le w_1\le .5$	$0\le w_2\le .5$	$w\ge 0$	low medium high high	low medium high low	very low medium very high medium
Variable Weighted Average; e.g., $v = \min(v_1,v_2)$	0* * when $v_2 < v_1$	1	0	low medium high high	low medium high low	low medium high low
Simple Product $v = v_1v_2$	$w_1\to 0$	$w_2\to 0$	$\frac{1}{w_1w_2}$	low medium high very hi high	low medium high very hi low	very low low medium high low

$$v = w_1v_1 + w_2v_2 + ww_1w_2v_1v_2, \text{ where } 0\le w_1\le 1,\ 0\le w_2\le 1 \text{ and } w_1 + w_2 + ww_1w_2 = 1$$

Figure 5.2. The Multiplicative Weighting Function.

the MC&A system as a stand-alone system, we can focus on this product. It provides for a measure of the system's ability to accomplish all three of the necessary functions of alarm generation, alarm assessment, and loss assessment without assistance from other parts of the safeguards system. For the purposes of this study, this stand-alone circumstance was taken to be the base case, i.e., $v(P_A,P_{AA},P_{LA}) = v(P_A)\ v(P_{AA})\ v(P_{LA})$.

When considering a MC&A system as only one part of an integrated safeguards system, it may be desirable to consider an alternative weighting scheme in producing the composite third-level MOE value. It may be appropriate, for example, to realize a non-zero composite value based on short-term alarm generation and alarm assessment performance even if loss assessment in the short term is non-existent. To achieve this flexibility, a product relationship might still be established between P_A and P_{AA}, to produce what is referred to as P_D the probability of detection, as long as a general multiplicative function is then used to combine this detection MOE with the loss assessment MOE. Notationally this is expressed as:

$$\begin{aligned} v(P_A,P_{AA},P_{LA}) &= v(P_D,P_{LA}) \\ &= w_1 v(P_D) + w_2 v(P_{LA}) + ww_1 w_2 v(P_D) v(P_{LA}) \\ &= w_1 v(P_A) v(P_{AA}) + w_2 v(P_{LA}) + ww_1 w_2 v(P_A) v(P_{AA}) v(P_{LA}) \end{aligned}$$

The synthesis of third-level elements to produce second-level element values proceeds as follows. Weighted averages were used to combine the item monitoring value with the bulk monitoring value, and a complementary relationship was used in combining these two elements with the material balance element. The rationale for assigning relative weights to item-monitoring and bulk-material-monitoring elements should include at least two considerations: the relative amount of material in item versus bulk form and the attractiveness and portability of the material in each of the two general forms. (These two criteria are, of course, facility dependent.) For our purposes, nominal relative weights were set at 0.6 for item monitoring and 0.4 for bulk material monitoring. In combining material monitoring with material balances, a complementary relationship was assumed. The sum of the two weights for item and bulk monitoring were left at 1.0, rather than scaled downward, and the weight for material balances was set at 0.9. These values reflect the fact that if there were perfect capability in both item and bulk monitoring, then material balances would not be needed (i.e., as long as both item and bulk monitoring have values of 1, the composite intermediate-term element value should be 1 even if material balances have a value of 0). Material balances were not weighted as heavily as item and bulk monitoring (a 0.9 instead of a 1.0) because material balances are not quite as timely, a 90-day alarm rather than a 60-day one.

The combination of the timeliness elements under each adversary goal proceeded as follows. For abrupt theft, it was thought that if short-term performance were complete, intermediate-term performance would be superfluous. Thus, a relative weight of 1.0 was assigned to short-term performance. On the other hand, if short-term performance were non-existent, perfect intermediate-term performance would have a value only of 0.5, reflected as a weight of 0.5.

For protracted theft, this rationale where the more timely the performance the higher the weight, does not apply in the same way. If 5 FKGs are taken within an intermediate-time frame (recall that time is measured from the start of the protracted theft), the diversion rate would necessarily be higher than if it were taken over a longer time frame. Thus, performance over the intermediate-time frame does not negate the need for performance over the long term. To reflect the view that a MC&A system cannot be considered fully capable until it can deal equally with protracted theft over both the intermediate and long term (corresponding to moderate and low rates of removal, respectively), an equal weighting was given to the two elements.

Theft from shipments was considered in a fashion somewhat similar to protracted theft from within the facility. Here, too, the time frame refers to different approaches to theft, ranging from a single-shipment theft to a multi-shipment theft that takes place over the long term. Nominal weights of 0.35, 0.45 and 0.2 were assigned to the short-, intermediate- and long-term time elements, respectively.

The combination of timeliness elements for performance against a hoax followed the rationale for abrupt theft. Short-term performance was assigned a weight of 1.0 and intermediate-term performance a weight of 0.5.

Finally, the synthesis of the element values associated with each of the adversary goals was considered. Here, a weighted average was used, reflecting to some extent an estimated probability of occurrence as well as the relative seriousness of the adversary goal in terms of the potential consequences associated with it. Nominal weights of 0.4, 0.3, 0.2 and 0.1 were assigned to abrupt theft, protracted theft, shipment theft, and hoax, respectively.

These nominal weights, along with sample sets of MOE values, were used in two examples to illustrate the Phase II syntnesis. This effort is described next.

5.5 EXAMPLE SYNTHESIS

A computer program was written to implement the Phase II synthesis procedure. It was recognized that, in practice, the Phase II synthesis process would be used not only to calculate a single composite score, reflective of the entire MC&A system performance, but also to explore individual areas where improvement would have a particularly noticeable impact on overall performance. The possibility that the synthesis might be accomplished using several weighting alternatives also raised the desirability of computerization.

A FORTRAN code was developed for this purpose. Appendix B contains a description of each module within the computer program. A description of input data requirements is included along with the output format. A listing of the code is presented in Appendix C. The code requires that, for each analysis, values be provided for each of the 30 MOEs. The nominal weights described above are used as default weights. An option exists, however, so that the nominal weights associated with any level of the hierarchy can be altered. As was described earlier, the form of the multiplicative synthesis function is inherent in the specification of the element weights.

The Phase II synthesis is illustrated by considering two different levels of MC&A system performance. These two performance levels were constructed from information provided in the MC & MA Task Force Report. The two performance levels depict a baseline MC&A system whose performance is generally low relative to the key MC & MA goals and an upgraded MC&A system whose performance is improved relative to these goals. These performance levels are shown in Figure 5.3. Although performance measures were presented in ordinal terms (low, medium, high, very high), a value function was defined over these

	PERFORMANCE LEVEL	
MATERIAL CONTROL GOALS	BASELINE MC&A SYSTEM	UPGRADED MC&A SYSTEM
MC 8--Detect 5 kg loss of accessible material	Low (.1)*	Med. to High (.7)
MC 9--Assess alarms in one hour	Low (.1)	Med. to High (.7)
MC 10--Detect 5 kg loss in period between inventories	Low (.1)	Med. to High (.7)
MC 11--Rapid loss assessment	Low (.1)	Very High (.95)
MC 13--Confirm item status each shift	Low (.1)	High (.9)
MC 14--Confirm bulk status each day	Low (.1)	Medium (.5)
MC 15--Confirm safeguards effectiveness between inventories	Low (.1)	Medium (.5)
MATERIAL ACCOUNTING GOALS		
MA 4--Verify presence of items within 24 hours of receipt	Very High (.95)	Very High (.95)
MA 5--Through S/R analysis, detect loss of 5 kg within 10 days	Low to Med. (.3)	Very High (.95)
MA 6--Detect 5 kg loss by physical inventory	Med. to High (.7)	Med. to High (.7)
MA 7--Reports of demand inventories within 20 days	Low to High (.5)	Med. to High (.7)
MA 8--Localize loss	Low to Med. (.3)	High (.9)
MA 10--Reconcile S/R differences within 30 days	Low (.1)	Med. to High (.7)
MA 11--Cumulative S/R difference <5 kg for 1 year	Low to Med. (.3)	High (.9)
MA 14--Bimonthly inventories	High (.9)	High (.9)
MA 15--CID<LECID over 12 months, and trend of CID toward zero	Low (.1)	High (.9)

*Scale: Very Low (.05), Low (.1), Low to Medium (.3), Medium (.5), Medium to High (.7), High (.9) and Very High (.95)

Figure 5.3. Performance Levels of Baseline and Upgraded MC&A Systems for Key MC and MA Goals.

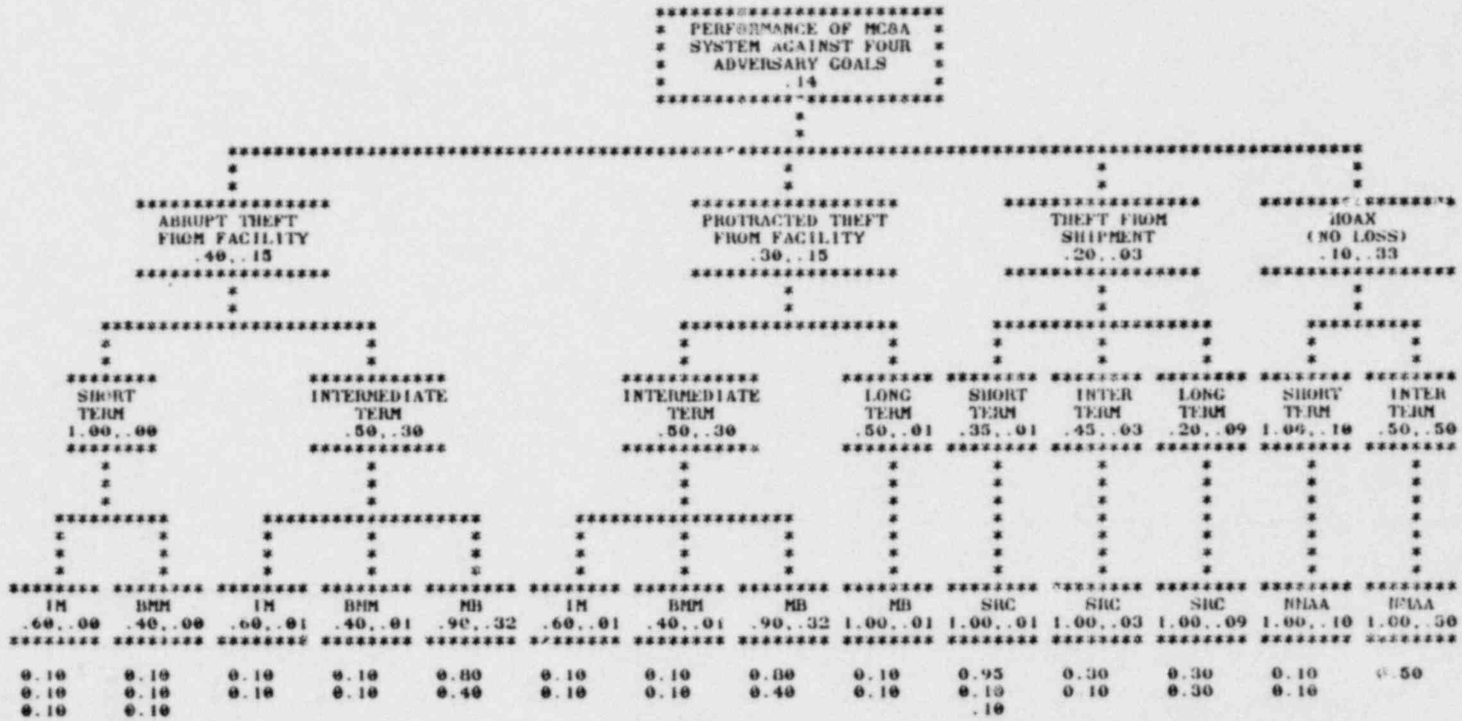
terms which provided the necessary numerical values for each of the 30 MOEs. Figure 5.4 presents the resulting MOE values used for the sample analyses.

Using these two sets of MOE values, along with the nominal weights described above, two illustrative Phase II synthesis exercises were carried out. The results are shown in Figures 5.5 and 5.6. For ease of assimilation, the results are presented using the hierarchical format. When two numerical quantities are associated with a hierarchical element, the first represents the element weight and the second the resulting element value. The numbers listed below the fourth-level elements reflect the input MOE values.

It should be recognized that the analyses shown here are for illustrative purposes only and any inferences regarding MC&A performance in actual facilities are not warranted.

MOE NO.	MOE ID	KEY MC AND MA GOALS APPLICABLE TO MOE	ESTIMATE OF MOE FOR BASELINE MC&A SYSTEM	ESTIMATE OF MOE FOR UPGRADED MC&A SYSTEM
1	P_{A1}	MC 8, MC 13	.1	.8
2	P_{AA1}	MC 9	.1	.7
3	P_{LA1}	MC 11	.1	.95
4	P_{A2}	MC 8, MC 14	.1	.6
5	P_{AA2}	MC 9	.1	.7
6	P_{LA2}	MC 11	.1	.95
7	P_{A3}	MC 10, MC 15	.1	.6
8	P_{R3}	MC 11	.1	.95
9	P_{A4}	MC 10, MC 15	.1	.6
10	P_{R4}	MC 11	.1	.95
11	P_{A5}	MA 6, MA 14	.8	.8
12	P_{R5}	MA 7, MA 8	.4	.8
13	P_{A6}	MC 10, MC 15	.1	.6
14	P_{R6}	MC 11	.1	.95
15	P_{A7}	MC 10, MC 15	.1	.6
16	P_{R7}	MC 11	.1	.95
17	P_{A8}	MA 6, MA 14	.8	.8
18	P_{R8}	MA 7, MA 8	.4	.8
19	P_{A9}	MA 15	.1	.9
20	P_{R9}	MA 15	.1	.9
21	P_{A10}	MA 4	.95	.95
22	P_{AA10}	MC 9	.1	.7
23	P_{LA10}	MC 11	.1	.95
24	P_{A11}	MA 5	.3	.95
25	P_{R11}	MA 10	.1	.7
26	P_{A12}	MA 11	.3	.9
27	P_{R12}	MA 11	.3	.9
28	P_{AA13A}	MC 9	.1	.7
29	P_{AA13B}	MC 11	.1	.95
30	P_{AA14}	MA 7	.5	.7

Figure 5.4. Estimate of MOEs for Baseline and Upgraded MC&A Systems.



For levels 1, 2 and 3, the pair of numbers given with each element are the weight and composite MOE value, respectively. The numbers listed below level 3 are the thirty MOE values for the level-4 MC&A functions.

Figure 5.5. Results of Phase II Synthesis for Baseline MC&A System.

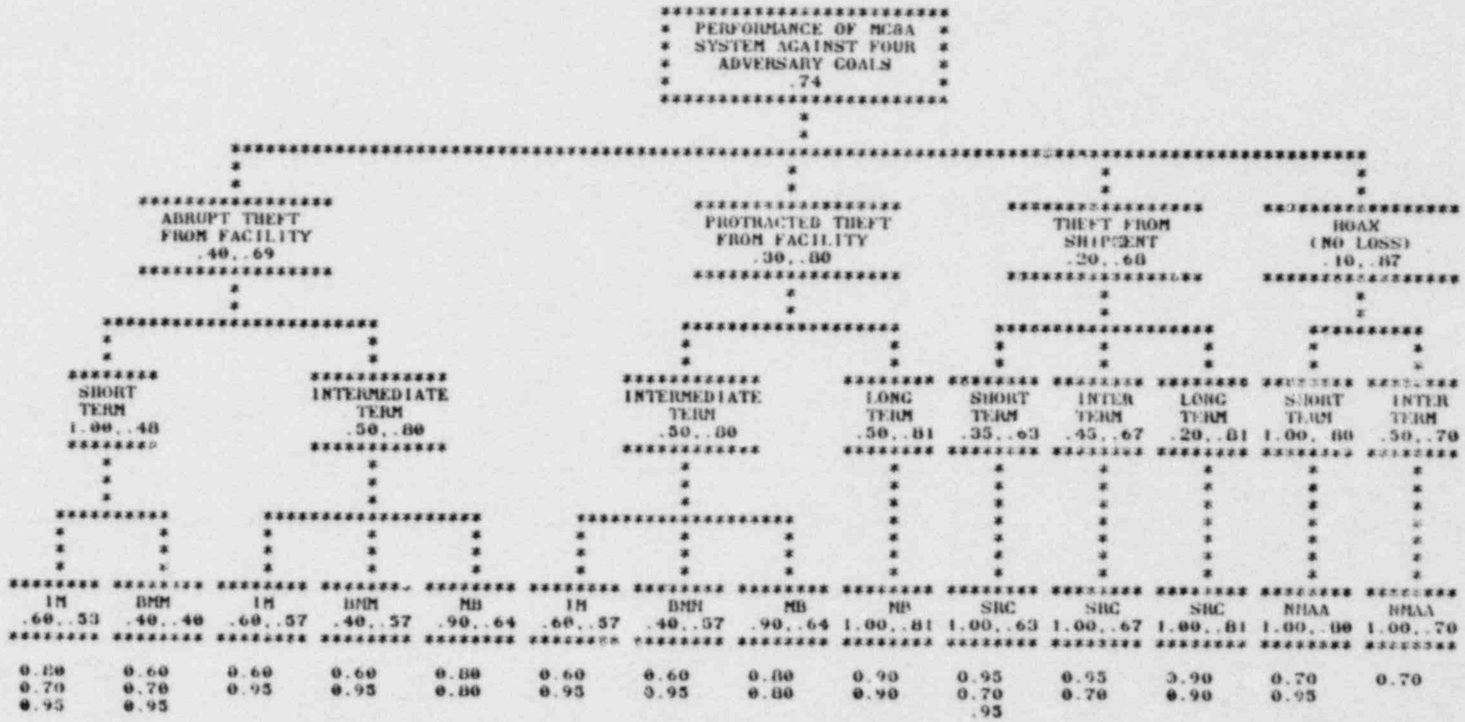


Figure 5.6. Results of Phase II Synthesis for Upgraded MC&A System.

6. OTHER CONSIDERATIONS

Two other considerations which are important for MC&A assessments are discussed briefly in this section: false alarms and insider adversary.

6.1 FALSE ALARMS

False alarms have not been treated explicitly. They are not treated explicitly in the MC&A performance capabilities of the Comprehensive Evaluation Program or in the goals of the MC and MA Task Force. False alarms are recognized to be important. It is envisioned that they could influence, in situations were direct assessment of alarms is not practical or timely, the evaluation of the alarm assessment MOE, P_{AA}. Further, it is noted that the loss assessment function naturally provides a reassessment of alarms and thus would, to the extent that it functions properly, provide protection against false alarms continuing to be regarded as losses.

6.2 INSIDER ADVERSARY

The insider adversary is considered explicitly in the Comprehensive Evaluation Program and by the MC and MA Task Force. There is disadvantage in dealing with an insider adversary in the context of assessing a part (MC&A) of a safeguards system in that the conclusions drawn may be misleading. This can happen for two reasons. First, to be assurred of being covert, one or more insider adversaries needs both access to some requisite quantity of SSNM and control over the safeguards countermeasures. Hence, both access to SSNM and control over safeguards need to be considered. Second, the safeguards countermeasures include MC&A measures and physical protection measures. The latter could include, for example, access controls for MC&A instrument calibration and for MC&A records. Assessment of safeguards performance against a threat which includes one or more insider adversaries is useful when it considers: 1) access to SSNM, 2) control over MC&A countermeasures, and 3) control over physical protection countermeasures. Collection and analysis of a complete data set involves more effort than that normally available for a field assessment of MC&A system performance.

The level of protection provided to the MC&A system against insider adversaries would be indicated by the number of insiders who could compromise the MC&A functions (alarm generation, alarm assessment and loss assessment). If time permits during the field evaluation of the MOEs to identify each insider who could compromise the functional capability represented by each MOE, the resulting list of licensee personnel for each MOE would provide a general indication of the vulnerability of the MC&A system to insider adversaries. In addition, the data could be expanded to include licensee personnel who have access to SSNM and/or control over physical protection measures, and thus permit a comprehensive evaluation of the protection against insider adversaries.

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8. J.S. Dyer and R.K. Sarin, "Measurable Multiattribute Value Functions", Operations Research, 27, 810-822, 1979.

9. R.L. Kenney and H. Raiffa: Decisions with Multiple Objectives, Wiley, New York, 1976.

*Available for purchase from the National Technical Information Service, Springfield, VA 22161.

APPENDIX A

EVALUATION AIDS FOR MOEs

EVALUATION AID FOR MOE NO. 1 - P_{A1}

MOE Definition

P_{A1} is the probability, given an abrupt loss of five formula kilograms of accessible SSNM in item form from the facility, that item-monitoring measures generate an alarm within eight hours.

Key MC & MA Task Force Goals Applicable to This MOE

MC 8(a): Detect within one shift, with high assurance, a loss of five formula kilograms of SSNM in the form of items or sealed containers accessible to theft.

MC 13: Based upon a statistical sampling plan designed for the detection with high assurance of a composite loss of five formula kilograms of SSNM, confirm during each shift the specific location and the integrity of items or sealed containers of SSNM accessible to theft.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system's item-monitoring measures to generate an alarm:

- within eight hours
- after an abrupt loss
- of five formula kilograms
- of accessible SSNM
- in item form
- from the facility.

In general, this MOE could apply to all SSNM items in the facility. However, in order to reflect MC 8(a), it applies only to SSNM items which are accessible to theft. The Task Force Report defines SSNM to be "not accessible to theft if it is a) not readily separable from other radioactive material and the combined materials have a total external radiation dose rate in excess of 100 rems per hour at a distance of 3 feet from any accessible surface without intervening shielding, b) locked in a vault-type room which is tamper-safed and under continuous electronic intrusion detection surveillance, or c) of a size and form which prohibits theft without rapid detection, such as a fuel assembly."

The first step of an evaluation of this MOE is to determine the locations where accessible SSNM items are being stored or used. At each location, the items can be characterized in terms of material form, number, mass, concentration, size, identification type, seal type, residence time at the location, and reason for being at the location. The next evaluation step is to determine what item-monitoring alarms, if any, are in operation to sense losses of these accessible SSNM items. These alarms will consist of some observed item characteristic being compared with an expected one. A list of potentially applicable item characteristics together with the corresponding basis for the comparison are given below.

Item Characteristic	Basis for Comparison
1. Identification (label)	Records
2. Number	Records
3. Location	Records
4. Seal Integrity	Seal Condition
5. Mass	Records
6. Elemental Concentration	Records
7. Isotopic Concentration	Records
8. Use and Movement	Item Control Procedures
9. Transfer	Internal Transfer Procedures

Alarms based on item characteristics No. 1, 2, 3, and 4 are more likely to be used because of their relative simplicity. Also, use of these alarms could satisfy MC 13. Alarms based on the other item characteristics may be more complex, but they are sensitive to different theft scenarios. Alarms based on item characteristics No. 5, 6 and 7 can sense theft of SSNM from items which have been opened and resealed. Alarms based on item characteristics No. 8 and 9 can sense theft of SSNM involving misuse or unauthorized movement or transfer of items.

Another key attribute of the alarms, in addition to the item characteristic tested, is the fraction of the accessible SSNM items which are checked each shift. The tests may be performed for all of the items, for all items above some threshold quantity, for random samples of all items, or for random samples of certain items. The Task Force Report recommends "use of a stratified statistical sampling plan in such a way that the presence and seal integrity of a sufficient subset of items are checked before the end of each shift to ensure that if five formula kilograms or more had been lost during the shift, this loss would be detected with high assurance." If less than 100% of the items are tested for an alarm each shift, then the sampling plan used for that alarm should be evaluated to determine its capability to sense item deficiencies. The resulting data collected in support of evaluating P_{A1} consist of

- locations of accessible SSNM items
- characteristics of accessible SSNM items
- sensitivity of applicable alarms to sense losses associated with different theft scenarios

All of these data need to be considered during the deliberations by the NRC assessment team members who evaluate P_{A1}. Using these data, the assessment team should estimate the probabilities that 5-formula-kilogram-SSNM losses from all of these accessible SSNM item locations and plausible combinations thereof generate alarms. Then, using the probability values obtained, the team should synthesize a composite probability to obtain P_{A1} for the facility. The synthesis could be based on 1) the lowest probability obtained for any location or, combination of locations, 2) an unweighted average of probabilities, 3) a weighted average of probabilities where the weights are assigned by the team based on considerations such as material attractiveness, or 4) a consensus judgement by the team.

Technical Issues

1. Multiple Alarms in Facility

Material at some locations may be protected by more than one alarm. In this situation, the combined performance of the alarms needs to be estimated. For example, if two independent alarms, whose individual performances are represented by p' and p", are in operation, then the combined performance of the alarms would be represented by $p = p' + (1 - p')p''$. If the two alarms are not independent, the above estimate would represent an upper limit on their combined performance. The lower limit would be the larger of p' and p". Hence, the combined performance can be represented by the general expression

$$p = p' + f(1 - p')p''$$

where $p' \geq p''$ and $f = 1$ for independent alarms and $0 \leq f \leq 1$ for nonindependent alarms. The assessment team will have to estimate "f" based on the operation of a specific pair of alarms. The same rationale is applicable to more than two alarms.

2. Sampling Plans for Individual Alarms

If all accessible SSNM items covered by an alarm are not tested within 8 hours, but some fraction of them are, it will be necessary to evaluate the effectiveness of the sampling plan for that alarm. This evaluation should be done by a team member who is familiar with statistical sampling techniques. As an example, for alarms which are based on qualitative tests of item characteristics (such as No. 1, 2, 3 and 4), the effectiveness of an attribute sampling plan to sense gross defects can be estimated using the expression

$$p = 1 - (1 - n/N)^{M_o/M}$$

where p is the probability of sampling a missing or compromised item, n is the number of items sampled, N is the total number of items, M is the average item mass in formula kilograms and M_o is five formula kilograms. The effectiveness of sampling plans for alarms which are based on quantitative tests of item characteristics (such as No. 5, 6 and 7) to sense smaller defects can be estimated using a similar expression if the test is treated as an attribute-type measurement, or using another technique if the test is treated as a variable-type measurement.

Reference

C. G. Hough et al., "Example of Verification and Acceptance of Operator Data--Low Enriched Uranium Fabrication," Report No. BNWL-1852, Battelle Pacific Northwest Laboratories, August 1974.

EVALUATION AID FOR MOE NO. 2 - P_{AA1}

MOE Definition

P_{AA1} is the probability, given an abrupt loss of five formula kilograms of accessi' e SSNM in item form from the facility and a short-term, item-monitoring alarm, that the MC&A system correctly assesses the alarm to be valid within one hour.

Key MC & MA Task Force Goal Applicable to This MOE

MC 9: Maintain procedures and information sufficient to evaluate process conditions and material records so that they may provide for an assessment of alarms within one hour.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system for correctly assessing within one hour a short-term, item-monitoring alarm as being a valid alarm. The key factors to be considered for evaluation of this MOE are the procedures and records needed for assessing each alarm and the preparedness and past performance of facility personnel who assess the alarms. The evaluation of this MOE parallels that of P_{A1} in that each alarm which contributed to the evaluation of P_{A1} should be considered. In addition, the synthesis of data for P_{AA1} should follow that used for P_{A1}, except that instead of synthesizing P_A values for different item locations and alarms, the products of $P_A \times P_{AA}$ for each item location and alarm are synthesized. The result is the composite MOE for loss detection ($P_{D1} = P_{A1} \times P_{AA1}$), which can be divided by P_{A1} to obtain P_{AA1}. The main point of this synthesis approach is that each P_{AA} value is weighted by its corresponding P_A value; hence, the P_A and P_{AA} values for each item location and alarm are aggregated so as to properly produce the composite MOE for loss detection (P_{D1}).

Reliable performance of an alarm assessment within one hour is facilitated when action criteria, personnel responsibilities and assessment procedures are well defined and documented. The first evaluation step is to collect and review the available documentation. Depending on the extent of this documentation, the NRC assessment team may have to interview facility personnel to define the assessment procedures. Based on the assessment procedures which are expected to be followed, the next evaluation step is to determine how well the procedures work. Implementation of the procedures depends on the efficiency and completeness of the procedures, the availability of supporting records and the qualifications of facility personnel. Actual alarm assessments at the facility may be documented. Examination of 1) the alarm assessment procedures, 2) the supporting facility records, 3) the qualifications of the relevant facility personnel, and 4) the history of previous alarm assessments at the facility should provide the NRC assessment team with the data needed to judge the expected performance of each type of alarm assessment.

EVALUATION AID FOR MOE NO. 3 - P_{LA1}

MOE Definition

P_{LA1} is the probability, given an abrupt loss of five formula kilograms of accessible SSNM in item form from the facility and a validated short-term, item-monitoring alarm, that the MC&A system correctly assesses the loss in terms of 1) characterization of the loss, 2) identification of the loss mechanism and 3) determination of the appropriate follow-up actions within twenty-four hours.

Key MC & MA Task Force Goal Applicable to This MOE

MC 11: Provide procedures and maintain a capability when a loss is detected to rapidly: estimate the size of the loss, identify the loss mechanism, characterize any missing material, and identify those individuals with access to or responsibility for the missing material.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system for correctly assessing within 24 hours an abrupt five-formula-kilogram SSNM loss detected by short-term, item-monitoring measures. In contrast to the alarm assessment which deals with only a single issue (true or false alarm), a loss assessment deals with three broader issues. First, the loss should be characterized in terms of the form, quantity and other important attributes of the missing material, such as item identification and container description. In order to determine if the missing material is elsewhere in the facility and to determine if the loss is limited to only the location where the alarm was generated, all other accessible SSNM item locations in the facility should be checked for indications of gains or losses. Second, the loss mechanism needs to be identified in terms of whether the loss was accidental or intentional, how it occurred, and who was responsible. The loss characterization and loss mechanism identification should contribute directly to performance of the third issue, determination of the appropriate follow-up actions. If the loss were accidental, it would be appropriate to define corrective actions to prevent future accidents. If the loss were due to theft, then the appropriate action would be notification of security personnel who could prevent further removal of SSNM from the facility and initiate recovery of any SSNM already removed.

The above discussion describes the activities which should occur during a loss assessment. Evaluation of how well the loss assessment is likely to be performed by facility personnel requires examination of the same type of factors which are relevant to evaluation of alarm assessment capabilities. These factors include 1) the efficiency and completeness of the loss assessment procedures, 2) the availability of supporting facility records, 3) the qualifications of relevant facility personnel and 4) the history of previous loss assessments at the facility. Examination of these factors should provide the NRC assessment team with the data needed to evaluate loss assessment capability, and hence, to judge P_{LA1}.

EVALUATION AID FOR MOE NO. 4 - P_{A2}

MOE Definition

P_{A2} is the probability, given an abrupt loss of five formula kilograms of accessible SSNM in bulk form from any controllable unit of the facility, that bulk-material-monitoring measures generate an alarm within twenty-four hours.

Key MC & MA Task Force Goals Applicable to This MOE

MC 8(b): Detect within twenty-four hours, with high assurance, a loss of five formula kilograms of SSNM in bulk form accessible to theft from any controllable unit of a facility.

MC 14 Based upon procedures and analyses designed for detection with high assurance of a composite loss of five formula kilograms of SSNM in bulk form from any controllable unit of a facility, confirm each day the presence of SSNM accessible to theft.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system's bulk-material-monitoring measures to generate an alarm:

- within twenty-four hours
- after an abrupt loss
- of five formula kilograms
- of accessible SSNM
- in bulk form
- from any controllable unit of the facility.

In general, this MOE could apply to all SSNM bulk material in the facility. However, in order to reflect MC 8(b), it applies only to SSNM bulk material which is accessible to theft and to each controllable unit of the facility, not necessarily to the entire facility. The Task Force Report defines SSNM to be "not accessible to theft if it is a) not readily separable from other radioactive material and the combined materials have a total external radiation dose rate in excess of 100 rems per hour at a distance of 3 feet from any accessible surface without intervening shielding, b) locked in a vault-type room which is tamper-safed and under continuous electronic intrusion detection surveillance, or c) of a size and form which prohibits theft without rapid detection, such as a fuel assembly." A controllable unit is a facility subunit whose boundaries are defined so as to facilitate effective material control within the unit. Material control measures, such as material measurements and material transfer procedures, are provided at controllable unit boundaries.

The first step of an evaluation of this MOE is to identify the controllable unit boundaries and to determine the locations within each controllable unit where accessible SSNM bulk material is being stored or used. At each location, the bulk material can be characterized in terms of material form, mass, concentration, residence time at the location, and reason for being at the location. The next evaluation step is to determine what bulk-material-monitoring alarms, if any, are in operation to sense losses of this accessible SSNM material. These alarms will consist of some observed bulk material characteristic being compared with an expected one. A list of potentially applicable material characteristics together with the corresponding basis for the comparison are given below.

Material Characteristic	Basis for Comparison
1. Mass	Records, Process Yield Estimates
2. Appearance (color, grain size, etc.)	Earlier Observations of Similar Material, Photographs
3. Physical Property	Records, Physical Property Estimates
4. Chemical Property	Records, Chemical Property Estimates
5. Elemental Concentration	Records, Process Yield Estimates
6. Isotopic Concentration	Records, Process Yield Estimates
7. Use and Movement	Material Control Procedures, Production Control Procedures, Quality Control Procedures, Process Control Procedures
8. Transfer	Material Transfer Procedures

Alarms based on material characteristics No. 1 and 2 are more likely to be used because of their relative simplicity. However, alarms based on material characteristics No. 3, 4, 5 and 6 may be used if the necessary data is collected to support production control, quality control or process control activities. Alarms based on these material characteristics are sensitive to different theft scenarios, and in particular, to the use of different material substitution tactics to conceal theft.

Another key attribute of the alarms, in addition to the bulk material characteristic tested, is the fraction of the accessible SSNM material which is checked each day. The tests may be performed for all of the material, for random samples of each material form, or for random samples of certain material forms. If less than 100% of the material is tested for an alarm each day, then the sampling plan used for that alarm should be evaluated to determine its capability to sense material deficiencies. The resulting data collected in support of evaluating P_{A2} consist of

- locations of accessible SSNM bulk material
- characteristics of accessible SSNM bulk material
- sensitivity of applicable alarms to sense losses associated with different theft scenarios

All of these data need to be considered during the deliberations by the NRC assessment team members who evaluate P_{A2}. Using these data, the assessment team should estimate the probabilities that 5-formula-kilogram-SSNM losses from all of these accessible SSNM bulk material locations and plausible combinations thereof generate alarms. Then, using the probability values obtained, the team should synthesize a composite probability to obtain P_{A2} for the facility. The synthesis could be based on 1) the lowest probability obtained for any location or, combination of locations, 2) an unweighted average of probabilities, 3) a weighted average of probabilities where the weights are assigned by the team based on considerations such as material attractiveness or 4) a consensus judgement by the team.

Technical Issues

1. Multiple Controllable Units in Facility

Some facilities may be operated as a single controllable unit for MC&A purposes and others may be operated as several controllable units. For the former situation, P_{A2} is evaluated for the entire facility. For the latter situation, P_{A2} would be evaluated for each controllable unit; then, the NRC assessment team should synthesize a composite P_{A2} for the facility. The synthesis could be based on 1) the lowest P_{A2} obtained for any controllable unit, 2) an unweighted average, 3) a weighted average whose weights are assigned by the team, or 4) a consensus judgement made by the team. The composite P_{A2} is reported as the P_{A2} for Case 2.

2. Multiple Alarms in Controllable Unit

Material at some locations may be protected by more than one alarm. In this situation, the combined performance of the alarms needs to be estimated. For example, if two independent alarms, whose individual performances are represented by p' and p", are in operation, then the combined performance of the alarms would be represented by $p = p' + (1 - p')p''$. If the two alarms are not independent, the above estimate would represent an upper limit on their combined performance. The lower limit would be the larger of p' and p". Hence, the combined performance can be represented by the general expression

$$p = p' + f(1 - p')p''$$

where $p' \geq p''$ and $f = 1$ for independent alarms and $0 \leq f \leq 1$ for nonindependent alarms. The assessment team will have to estimate "f" based on the operation of a specific pair of alarms. The same rationale is applicable to more than two alarms.

3. Sampling Plans for Individual Alarms

If all accessible SSNM bulk material covered by an alarm is not tested within 24 hours, but some fraction of it is, it will be necessary to evaluate the effectiveness of the sampling plan for that alarm. This evaluation should be done by a team member who is familiar with statistical sampling techniques. As an example, for alarms which are based on qualitative tests of material characteristics (such as No. 2), the effectiveness of an attribute sampling plan to sense gross defects can be estimated using the expression

$$p = 1 - (1 - n/N)^{M_o/M}$$

where p is the probability of sampling compromised material, n is the number of materials sampled, N is the total number of materials, M is the average material mass in formula kilograms and M_o is five formula kilograms. The effectiveness of sampling plans for alarms which are based on quantitative tests of material characteristics (such as No. 1, 3, 4, 5 and 6) to sense smaller defects can be estimated using a similar expression if the test is treated as an attribute-type measurement, or using another technique if the test is treated as a variable-type measurement.

Reference

C. G. Hough et al., "Example of Verification and Acceptance of Operator Data--Low Enriched Uranium Fabrication," Report No. BNWL-1852, Battelle Pacific Northwest Laboratories, August 1974.

EVALUATION AID FOR MOE NO. 5 - P_{AA2}

MOE Definition

P_{AA2} is the probability, given an abrupt loss of five formula kilograms of accessible SSNM in bulk form from any controllable unit of the facility and a short-term, bulk-material-monitoring alarm, that the MC&A system correctly assesses the alarm to be valid within one hour.

Key MC & MA Task Force Goal Applicable to This MOE

MC 9: Maintain procedures and information sufficient to evaluate process conditions and material records so that they may provide for an assessment of alarms within one hour.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system for correctly assessing within one hour a short-term, bulk-material-monitoring alarm as being a valid alarm. The key factors to be considered for evaluation of this MOE are the procedures and records needed for assessing each alarm and the preparedness and past performance of facility personnel who assess the alarms. The evaluation of this MOE parallels that of P_{A2} in that each alarm which contributed to the evaluation of P_{A2} should be considered. In addition, the synthesis of data for P_{AA2} should follow that used for P_{A2}, except that instead of synthesizing P_A values for different material locations and alarms, the products of $P_A \times P_{AA}$ for each material location and alarm are synthesized. The result is the composite MOE for loss detection ($P_{D2} = P_{A2} \times P_{AA2}$), which can be divided by P_{A2} to obtain P_{AA2}. The main point of this synthesis approach is that each P_{AA} value is weighted by its corresponding P_A value; hence, the P_A and P_{AA} values for each material location and alarm are aggregated so as to properly produce the composite MOE for loss detection (P_{D2}).

Reliable performance of an alarm assessment within one hour is facilitated when action criteria, personnel responsibilities and assessment procedures are well defined and documented. The first evaluation step is to collect and review the available documentation. Depending on the extent of this documentation, the NRC assessment team may have to interview facility personnel to define the assessment procedures. Based on the assessment procedures which are expected to be followed, the next evaluation step is to determine how well the procedures work. Implementation of the procedures depends on the efficiency and completeness of the procedures, the availability of supporting records and the qualifications of facility personnel. Actual alarm assessments at the facility may be documented. Examination of 1) the alarm assessment procedures, 2) the supporting facility records, 3) the qualifications of the relevant facility personnel, and 4) the history of previous alarm assessments at the facility should provide the NRC assessment team with the data needed to judge the expected performance of each type of alarm assessment.

EVALUATION AID FOR MOE NO. 6 - P_{LA2}

MOE Definition

P_{LA2} is the probability, given an abrupt loss of five formula kilograms of accessible SSNM in bulk form from any controllable unit of the facility and a validated short-term, bulk-material-monitoring alarm, that the MC&A system correctly assesses the loss in terms of 1) characterization of the loss, 2) identification of the loss mechanism and 3) determination of the appropriate follow-up actions within twenty-four hours.

Key MC & MA Task Force Goal Applicable to This MOE

MC 11: Provide procedures and maintain a capability when a loss is detected to rapidly: estimate the size of the loss, identify the loss mechanism, characterize any missing material, and identify those individuals with access to or responsibility for the missing material.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system for correctly assessing within 24 hours an abrupt 5-formula-kilogram SSNM loss detected by short-term, bulk-material-monitoring measures. In contrast to the alarm assessment which deals with only a single issue (true or false alarm), a loss assessment deals with three broader issues. First, the loss should be characterized in terms of the form, quantity and other important attributes of the missing material. In order to determine if the missing material is elsewhere in the controllable unit and to determine if the loss is limited to only the location where the alarm was generated, all other accessible SSNM bulk material locations in the controllable unit should be checked for indications of gains or losses. Second, the loss mechanism needs to be identified in terms of whether the loss was accidental or intentional, how it occurred, and who was responsible. The loss characterization and loss mechanism identification should contribute directly to performance of the third issue, determination of the appropriate follow-up actions. If the loss were accidental, it would be appropriate to define corrective actions to prevent future accidents. If the loss were due to theft, then the appropriate action would be notification of security personnel who could prevent further removal of SSNM from the facility and initiate recovery of any SSNM already removed.

The above discussion describes the activities which should occur during a loss assessment. Evaluation of how well the loss assessment is likely to be performed by facility personnel requires examination of the same type of factors which are relevant to evaluation of alarm assessment capabilities. These factors include 1) the efficiency and completeness of the loss assessment procedures, 2) the availability of supporting facility records, 3) the qualifications of relevant facility personnel and 4) the history of previous loss assessments at the facility. Examination of these factors should provide the NRC assessment team with the data needed to evaluate loss assessment capability, and hence, to judge P_{LA2}.

EVALUATION AID FOR MOE NO. 7 - P_{A3}

MOE Definition

P_{A3} is the probability, given an abrupt loss of five formula kilograms of SSNM in item form from the facility, that item-monitoring measures generate an alarm within the two-month period between physical inventories during which the loss occurred.

Key MC & MA Task Force Goals Applicable to This MOE

MC 10: Detect, with high assurance, the cumulative loss of five formula kilograms of SSNM from any controllable unit of a facility within the interval between physical inventories.

MC 15 Provide a high degree of assurance that the safeguards system has been effective in preventing the loss of five formula kilograms of SSNM from any controllable unit of a facility within the period between physical inventories.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system's item-monitoring measures to generate an alarm

- within the two-month period between physical inventories
- after an abrupt loss
- of five formula kilograms
- of SSNM
- in item form
- from the facility.

This MOE is similar to P_{A1}, which is applicable to sensing abrupt losses of SSNM items from the facility, except that while P_{A1} deals with sensing losses of "accessible" SSNM items within 8 hours, P_{A3} treats sensing losses of any SSNM items within the period between bimonthly physical inventories. A result of this difference between dealing with only "accessible" items versus any items is that the list of item locations compiled for evaluation of P_{A1} needs to be expanded to include all other SSNM item locations. Using the expanded list, the additional SSNM items should be characterized as before, and the item-monitoring alarms which are in operation to sense abrupt losses of these items within the two-month period should be identified and characterized. The resulting data base which consists of 1) the locations and characteristics of all SSNM items, and 2) the sensitivities of the applicable alarms to sense losses associated with different theft scenarios, should be considered during the NRC assessment team's deliberations to evaluate P_{A3}.

The two technical issues described for the evaluation of P_{A1} (multiple alarms and sampling plans) are applicable to the evaluation of P_{A3}.

EVALUATION AID FOR MOE NO. 8 - P_{R3}

MOE Definition

P_{R3} is the probability, given an abrupt loss of five formula kilograms of SSNM in item form from the facility and an intermediate-term, item-monitoring alarm, that the MC&A system correctly assesses the alarm to be valid and correctly assesses the loss in terms of 1) characterization of the loss, 2) identification of the loss mechanism and 3) determination of the appropriate follow-on actions within one day.

Key MC & MA Task Force Goal Applicable to This MOE

MC 11: Provide procedures and maintain a capability when a loss is detected to rapidly: estimate the size of the loss, identify the loss mechanism, characterize any missing material, and identify those individuals with access to or responsibility for the missing material.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system for correctly resolving within one day an intermediate-term, item-monitoring alarm. Resolution of the alarm involves two parts: assessment of the alarm to determine it is valid and assessment of the loss in terms of three issues: 1) characterization of the loss, 2) identification of the loss mechanism and 3) determination of the appropriate follow-on actions.

The starting point for evaluation of this MOE is the list of SSNM item locations, item characteristics and alarm characteristics for the facility. This list, which was prepared for evaluation of P_{A3}, includes all of the alarms which the MC&A system should be prepared to assess. The procedure for performing each of these alarm assessments needs to be determined. These procedures should be reviewed for efficiency and completeness, and the availability of records required for the assessments should be examined. The personnel who perform the assessments need to be identified. Any past assessments of these alarms by facility personnel should be reviewed. Based on the results obtained during examination of 1) the efficiency and completeness of the alarm assessment procedures, 2) the availability of supporting facility records, 3) the qualifications of the relevant facility personnel, and 4) the history of previous alarm assessments at the facility, the NRC assessment team should have the data needed to judge the first part of alarm resolution.

The second part of alarm resolution involves the above-mentioned three issues addressed by a loss assessment. First, the loss should be characterized in terms of the form, quantity and other important attributes of the missing items, such as item identification and container description. In order to determine if the missing material is elsewhere in the facility and to determine if the loss is limited to only the location where the alarm was generated, all other SSNM item locations in the facility should be checked for indications of gains or losses. Second, the loss mechanism needs to be identified in terms of whether the loss was accidental or intentional, how it occurred, and who was responsible. The loss characterization and loss mechanism identification should contribute directly to performance of the third issue, determination of the appropriate follow-up actions. If the loss were accidental, it would be appropriate to define corrective actions to prevent future accidents. If the loss were due to theft, then the appropriate actions would be notification of security personnel who could prevent further removal of SSNM from the facility and initiate recovery of any SSNM already removed.

The above discussion describes the activities which should occur during a loss assessment. Evaluation of how well the loss asssessment is likely to be performed by facility personnel requires examination of the same type of factors which are relevant to evaluation of alarm assessment capabilities. These factors include 1) the efficiency and completeness of the loss assessment procedures, 2) the availability of supporting facility records, 3) the qualifications of the relevant facility personnel, and 4) the history of previous loss assessments at the facility. Examination of the above factors for evaluation of loss assessment capability together with the corresponding factors for evaluation of alarm assessment capability should provide the NRC assessment team with the data needed to judge P_{R3}.

EVALUATION AID FOR MOE NO. 9 - P_{A4}

MOE Definition

P_{A4} is the probability, given an abrupt loss of five formula kilograms of SSNM in bulk form from any controllable unit of the facility, that bulk-material-monitoring measures generate an alarm within the two-month period between physical inventories during which the loss occurred.

Key MC & MA Task Force Goals Applicable to This MOE

MC 10: Detect, with high assurance, the cumulative loss of five formula kilograms of SSNM from any controllable unit of a facility within the interval between physical inventories.

MC 15 Provide a high degree of assurance that the safeguards system has been effective in preventing the loss of five formula kilograms of SSNM from any controllable unit of a facility within the period between physical inventories.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system's bulk-material-monitoring measures to generate an alarm

- within the two-month period between physical inventories
- after an abrupt loss
- of five formula kilograms
- of SSNM
- in bulk form
- from any controllable unit of the facility.

This MOE is similar to P_{A2}, which is applicable to sensing abrupt losses of SSNM bulk material from any controllable unit, except that while P_{A2} deals with sensing losses of "accessible" SSNM bulk material within 24 hours, P_{A4} treats sensing losses of any SSNM bulk material within the period between bimonthly physical inventories. A result of this difference between dealing with only "accessible" bulk material versus any bulk material is that the list of bulk material locations compiled for evaluation of P_{A2} needs to be expanded to include all other SSNM bulk material locations. Using the expanded list, the additional SSNM bulk material should be characterized as before, and the bulk-material-monitoring alarms which are in operation to sense abrupt losses of this material within the two-month period should be identified and characterized. The resulting data base which consists of 1) the locations and characteristics of all SSNM bulk material, and 2) the sensitivities of the applicable alarms to sense losses associated with different theft scenarios, should be considered during the NRC assessment team's deliberations to evaluate P_{A4}.

The three technical issues described for the evaluation of P_{A2} (multiple controllable units, multiple alarms and sampling plans) are applicable to the evaluation of P_{A4}.

EVALUATION AID FOR MOE NO. 10 - P_{R4}

MOE Definition

P_{R4} is the probability, given an abrupt loss of five formula kilograms of SSNM in bulk form from any controllable unit of the facility and an intermediate-term, bulk-material-monitoring alarm, that the MC&A system correctly assesses the loss in terms of 1) characterization of the loss, 2) identification of the loss mechanism and 3) determination of the appropriate follow-on actions within one day.

Key MC & MA Task Force Goal Applicable to This MOE

MC 11: Provide procedures and maintain a capability when a loss is detected to rapidly: estimate the size of the loss, identify the loss mechanism, characterize any missing material, and identify those individuals with access to or responsibility for the missing material.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system for correctly resolving within one day an intermediate-term, bulk-material-monitoring alarm generated for any controllable unit of the facility. Resolution of the alarm involves two parts: assessment of the alarm to determine it is valid and assessment of the loss in terms of three issues: 1) characterization of the loss, 2) identification of the loss mechanism and 3) determination of the appropriate follow-on actions.

The starting point for evaluation of this MOE is the list of SSNM bulk material locations, bulk material characteristics and alarm characteristics for each controllable unit. This list, which was prepared for evaluation of P_{A4}, includes all of the alarms which the MC&A system should be prepared to assess. The procedure for performing each of these alarm assessments needs to be determined. These procedures should be reviewed for efficiency and completeness, and the availability of records required for the assessments should be examined. The personnel who perform the assessments need to be identified. Any past assessments of these alarms by facility personnel should be reviewed. Based on the results obtained during examination of 1) the efficiency and completeness of the alarm assessment procedures, 2) the availability of supporting facility records, 3) the qualifications of the relevant facility personnel, and 4) the history of previous alarm assessments at the facility, the NRC assessment team should have the data needed to judge the first part of alarm resolution.

The second part of alarm resolution involves the above-mentioned three issues addressed by a loss assessment. First, the loss should be characterized in terms of the form, quantity and other important attributes of the missing material. In order to determine if the missing material is elsewhere in the controllable unit and to determine if the loss is limited to only the location where the alarm was generated, all other SSNM bulk material locations in the controllable unit should be checked for indications of gains or losses. Second, the loss mechanism needs to be identified in terms of whether the loss was accidental or intentional, how it occurred, and who was responsible. The loss characterization and loss mechanism identification should contribute directly to performance of the third issue, determination of the appropriate follow-up actions. If the loss were accidental, it would be appropriate to define corrective actions to prevent future accidents. If the loss were due to theft, then the appropriate actions would be notification of security personnel who could prevent further removal of SSNM from the facility and initiate recovery of any SSNM already removed.

The above discussion describes the activities which should occur during a loss assessment. Evaluation of how well the loss assessment is likely to be performed by facility personnel requires examination of the same type of factors which are relevant to evaluation of alarm assessment capabilities. These factors include 1) the efficiency and completeness of the loss assessment procedures, 2) the availability of supporting facility records, 3) the qualifications of the relevant facility personnel, and 4) the history of previous loss assessments at the facility. Examination of the above factors for evaluation of loss assessment capability together with the corresponding factors for evaluation of alarm assessment capability should provide the NRC assessment team with the data needed to judge P_{R4}.

EVALUATION AID FOR MOE NO. 11 - P_{A5}

MOE Definition

P_{A5} is the probability, given an abrupt loss of five formula kilograms of SSNM from any accounting unit of the facility, that a bimonthly material balance generates an alarm within thirty days after the end of the two-month period during which the loss occurred.

Key MC & MA Task Force Goals Applicable to This MOE

MA 6: Detect, with high assurance, based upon a periodic measured physical inventory, a loss of five formula kilograms of SSNM from a facility, or, if not achievable for an entire facility, from smaller accounting units comprising the entire facility. Establish, for the latter case, controls to preclude theft by the same adversary from two or more accounting units and to preclude falsification of records of more than one accounting unit by any individual having access to material.

MA 14: Provide for bimonthly physical inventories, based on measurements, to provide a highly reliable record of quantities and locations of all SSNM at a facility. Reconcile and adjust book inventories to the results of the physical inventory within 30 days from its beginning.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system's bimonthly material balance to generate an alarm:

- within 30 days after the end of the two-month accounting period
- after an abrupt loss during the accounting period
- of five formula kilograms
- of SSNM
- from any accounting unit of the facility.

This MOE applies to losses of SSNM, in item and bulk form, from any accounting unit. An accounting unit is a facility subunit whose boundaries are defined to facilitate effective material accounting within the unit. Physical security measures, such as physical barriers and personnel access controls, material control measures, such as material transfer procedures, and material accounting measures, such as mass and concentration measurements, are provided at accountable unit boundaries.

The Task Force Report states that MA 6 requires the uncertainty (LEID) associated with a bimonthly material balance to be less than 3 formula kilograms. With an alarm threshold set at 3 formula kilograms, this requirement theoretically provides an alarm probability for a 5-formula-kilogram loss of 0.9 and a false alarm probability of 0.05. A member of the NRC assessment team who is familiar with the determination of LEID and the variation of alarm probability with LEID and alarm threshold should perform this part of the evaluation.

Technical Issue--Multiple Accounting Units in Facility

Some facilities may be operated as a single accounting unit for MC&A purposes, and others may be operated as several accounting units. For the former situation, P_{A5} is evaluated for the entire facility. For the latter situation, P_{A5} would be evaluated for each accounting unit; then, the NRC assessment team should synthesize a composite P_{A5} for the facility. The synthesis could be based on 1) the lowest P_{A5} obtained for any accounting unit, 2) an unweighted average, 3) a weighted average whose weights are assigned by the team, or 4) a consensus judgement made by the team. The composite P_{A5} is reported as the P_{A5} for Case 5.

EVALUATION AID FOR MOE NO. 12 - P_{R5}

MOE Definition

P_{R5} is the probability, given an abrupt loss of five formula kilograms of SSNM from any accounting unit of the facility and a bimonthly material-balance alarm, that the MC&A system correctly assesses the alarm to be valid and correctly assesses the loss in terms of 1) characterization of the loss, 2) identification of the loss mechanism and 3) determination of the appropriate follow-up actions within twenty days.

Key MC & MA Task Force Goals Applicable to This MOE

MA 7: Provide the capability to conduct, on a demand basis, physical inventories based on measurements to provide a record of quantities of SSNM at a facility and to provide results as soon as possible, but no later than twenty days from the day on which the demand was made.

MA 8: Establish and maintain a capability to localize a loss to its source, to identify the loss mechanisms, and to characterize the lost material.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system for correctly resolving within 20 days a bimonthly material-balance alarm generated for any accounting unit of the facility. For the purpose of evaluating this MOE, it is assumed that a demand inventory is performed for the accounting unit where the alarm was generated. Resolution of the alarm involves two parts: assessment of the alarm by performing a physical inventory and corresponding material balance to determine the alarm is valid and assessment of the loss in terms of 1) characterization of the loss, 2) identification of the loss mechanism and 3) determination of the appropriate follow-up actions. Performance of both the alarm assessment (by inventory) and the loss assessment relies mainly on the facility's procedures and personnel. Examination of the 1) efficiency and completeness of the assessment procedures, 2) the availability of supporting measurement capabilities and records, 3) the qualifications of the relevant facility personnel and 4) the history of previous assessments of this type at the facility should provide the NRC assessment team with the data needed to judge P_{R5}.

EVALUATION AID FOR MOE NO. 13 - P_{A6}

MOE Definition

P_{A6} is the probability, given a protracted loss of five formula kilograms of SSNM in item form from the facility during the two-month period between physical inventories, that item-monitoring measures generate an alarm within the same period.

Key MC & MA Task Force Goals Applicable to This MOE

MC 10: Detect, with high assurance, the cumulative loss of five formula kilograms of SSNM from any controllable unit of a facility within the interval between physical inventories.

MC 15: Provide a high degree of assurance that the safeguards system has been effective in preventing the loss of five formula kilograms of SSNM from any controllable unit of a facility within the period between physical inventories.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system's item-monitoring measures to generate an alarm

- within the two-month period between physical inventories
- after a protracted loss
- of five formula kilograms
- of SSNM
- in item form
- from the facility.

This MOE is similar to P_{A3}, which is applicable to sensing losses of SSNM items from the facility during the period between bimonthly inventories, except that while P_{A3} deals with abrupt losses, P_{A5} treats protracted losses. Specifically, P_{A6} should reflect the MC&A system's capability to sense multiple losses of small quantities of SSNM before the cumulative loss exceeds 5 formula kilograms. The SSNM item locations and characteristics identified for evaluation of P_{A3} can be used for evaluation of P_{A6}. The alarms applicable to each item location need to be evaluated to determine their capability to sense multiple small losses which total 5 formula kilograms during a 2-month period. The sensitivities of these alarms to sense cumulative losses during a 2-month period for different theft scenarios, complete the data base needed for evaluation of P_{A6}.

The two technical issues described for the evaluation of P_{A1} (multiple alarms and sampling plans) are applicable to the evaluation of P_{A6}.

EVALUATION AID FOR MOE NO. 14 - P_{R6}

MOE Definition

P_{R6} is the probability, given a protracted loss of five formula kilograms of SSNM in item form from the facility during a two-month period between physical inventories and an intermediate-term, item-monitoring alarm, that the MC&A system correctly assesses the alarm to be valid and correctly assesses the loss in terms of 1) characterization of the loss, 2) identification of the loss mechanism and 3) determination of the appropriate follow-on actions within one day.

Key MC & MA Task Force Goal Applicable to This MOE

MC 11: Provide procedures and maintain a capability when a loss is detected to rapidly: estimate the size of the loss, identify the loss mechanism, characterize any missing material, and identify those individuals with access to or responsibility for the missing material.

Discussion

The evaluation of this MOE is similar to and, in some situations, may be identical to that of MOE NO. 8 - P_{R3}.

EVALUATION AID FOR MOE NO. 15 - P_{A7}

MOE Definition

P_{A7} is the probability, given a protracted loss of five formula kilograms of SSNM in bulk form from any controllable unit of the facility during the two-month period between physical inventories, that bulk-material-monitoring measures generate an alarm within the same period.

Key MC & MA Task Force Goals Applicable to This MOE

MC 10: Detect, with high assurance, the cumulative loss of five formula kilograms of SSNM from any controllable unit of a facility within the interval between physical inventories.

MC 15: Provide a high degree of assurance that the safeguards system has been effective in preventing the loss of five formula kilograms of SSNM from any controllable unit of a facility within the period between physical inventories.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system's bulk-material-monitoring measures to generate an alarm

- within the two-month period between physical inventories
- after a protracted loss
- of five formula kilograms
- of SSNM
- in bulk form
- from any controllable unit of the facility.

This MOE is similar to P_{A4}, which is applicable to sensing losses of SSNM bulk material from any controllable unit during the period between bimonthly inventories, except that while P_{A4} deals with abrupt losses, P_{A7} treats protracted losses. Specifically, P_{A7} should reflect the MC&A system's capability to sense multiple losses of small quantities of SSNM before the cumulative loss exceeds 5 formula kilograms. The SSNM material locations and characteristics identified for evaluation of P_{A4} can be used for evaluation of P_{A7}. The alarms applicable to each material location need to be evaluated to determine their capability to sense multiple small losses which total 5 formula kilograms during a 2-month period. The sensitivities of these alarms to sense cumulative losses during a 2-month period for different theft scenarios, complete the data base needed for evaluation of P_{A7}.

The three technical issues described for the evaluation of P_{A2} (multiple controllable units, multiple alarms and sampling plans) are applicable to the evaluation of P_{A7}.

EVALUATION AID FOR MOE NO. 16 - P_{R7}

MOE Definition

P_{R7} is the probability, given a protracted loss of five formula kilograms of SSNM in bulk form from any controllable unit of the facility during a two-month period between physical inventories and an intermediate-term, bulk-material-monitoring alarm, that the MC&A system correctly assesses the alarm to be valid and correctly assesses the loss in terms of 1) characterization of the loss, 2) identification of the loss mechanism and 3) determination of the appropriate follow-on actions within one day.

Key MC & MA Task Force Goal Applicable to This MOE

MC 11: Provide procedures and maintain a capability when a loss is detected to rapidly: estimate the size of the loss, identify the loss mechanism, characterize any missing material, and identify those individuals with access to or responsibility for the missing material.

Discussion

The evaluation of this MOE is similar to and, in some situations, may be identical to that of MOE NO. 10 - P_{R4}.

EVALUATION AID FOR MOE NO. 17 - P_{A8}

MOE Definition

P_{A8} is the probability, given a protracted loss of five formula kilograms of SSNM from any accounting unit of the facility during a two-month period between physical inventories, that a bimonthly material balance generates an alarm within thirty days after the end of the period.

Key MC & MA Task Force Goals Applicable to This MOE

MC 6: Detect, with high assurance, based upon a periodic measured physical inventory, a loss of five formula kilograms of SSNM from a facility, or, if not achievable for an entire facility, from smaller accounting units comprising the entire facility. Establish, for the latter case, controls to preclude theft by the same adversary from two or more accounting units and to preclude falsification of records of more than one accounting unit by any individual having access to material.

MA 14: Provide for bimonthly physical inventories, based on measurements, to provide a highly reliable record of quantities and locations of all SSNM at a facility. Reconcile and adjust book inventories to the results of the physical inventory within 30 days from its beginning.

Discussion

The evaluation of this MOE is similar to and, in some situations, may be identified to that of MOE NO. 11 - P_{A5}.

EVALUATION AID FOR MOE NO. 18 - P_{R8}

MOE Definition

P_{R8} is the probability, given a protracted loss of five formula kilograms of SSNM from any accounting unit of the facility during a two-month period between physical inventories and a bimonthly material-balance alarm, that the MC&A system correctly assesses the alarm to be valid and correctly assesses the loss in terms of 1) characterization of the loss, 2) identification of the loss mechanism and 3) determination of the appropriate follow-up actions within twenty days.

Key MC & MA Task Force Goals Applicable to This MOE

MA 7: Provide the capability to conduct, on a demand basis, physical inventories based on measurements to provide a record of quantities of SSNM at a facility and to provide results as soon as possible, but no later than twenty days from the day on which the demand was made.

MA 8: Establish and maintain a capability to localize a loss to its source, to identify the loss mechanisms, and to characterize the lost material.

Discussion

The evaluation of this MOE is similar to and, in some situations, may be identical to that of MOE No. 12 - P_{R5}.

EVALUATION AID FOR MOE NO. 19 - P_{A9}

MOE Definition

P_{A9} is the probability, given a protracted loss of five formula kilograms of SSNM from any accounting unit of the facility during a twelve-month period, that analysis of the bimonthly, material-balance data for the period generates an alarm within two months after the end of the period.

Key MC & MA Task Force Goal Applicable to This MOE

MA 15: Identify, establish cause, and take corrective action for bimonthly and cumulative yearly inventory differences that exceed their associated limits of error. Monitor and maintain material accounting systems so that the long-term (greater than one year) behavior of plant inventory differences does not exhibit a trend which is significantly different from zero.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system to sense cumulative five-formula-kilogram SSNM losses which occur during a 12-month period by analysis of bimonthly, material-balance data for any accounting unit of the facility. Determination and comparison of a cumulative inventory difference (CID) and its limit of error (LECID) after each bimonthly material balance is a conventional means to sense protracted losses. A LECID of 3 formula kilograms would theoretically provide an alarm probability for a 5-formula-kilogram loss of 0.9 and a false alarm probability of 0.05. Trend analysis of periodic material balance data has been and continues to be an area of active investigation. Evaluation of this MOE should be done by an assessment team member who understands the determination of CID and LECID as well as trend analysis and its continuing development.

EVALUATION AID FOR MOE NO. 20 - P_{R9}

MOE Definition

P_{R9} is the probability, given a protracted loss of five formula kilograms of SSNM from any accounting unit of the facility during a twelve-month period and a long-term, material-balance alarm, that the MC&A system correctly assesses the alarm to be valid and correctly assesses the loss in terms of 1) characterization of the loss, 2) identification of the loss mechanism and 3) determination of the appropriate follow-up actions within three months.

Key MC & MA Task Force Goal Applicable to This MOE

MA 15: Identify, establish cause, and take corrective action for bimonthly and cumulative yearly inventory differences that exceed their associated limits of error. Monitor and maintain material accounting systems so that the long-term (greater than one year) behavior of plant inventory differences does not exhibit a trend which is significantly different from zero.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system for correctly resolving within 3 months a long-term, material-balance alarm generated for any accounting unit of the facility. Resolution of this type of alarm can present a challenge to any MC&A system. The possible low rate of loss (<5 formula grams per shift) or possible long time since the loss occurred or some combination of both can make the investigative process difficult to carry out successfully. Although the alarm may originate in a single accounting unit, resolution of the alarm may require consideration of other accounting units as well as consideration of shipper-receiver differences over the same time period. Evaluation of this MOE will likely reflect factors relevant to evaluation of many other MOEs and should be performed by the most experienced members of the NRC assessment team.

EVALUATION AID FOR MOE NO. 21 - P_{A10}

MOE Definition

P_{A10} is the probability, given a loss of a SSNM item during shipment, that a shipper-reciever comparison generates an alarm within twenty-four hours after the shipment arrives at the facility.

Key MC & MA Task Force Goal Applicable to This MOE

MA 4: Verify, within one working day of the receipt of a shipment, the presence and integrity of all items and containers of SSNM in the shipment.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system's shipper-receiver comparisons to sense loss of any SSNM item from an incoming shipment within 24 hours after it arrives at the facility. Reliable performance for this MOE requires an established procedure for checking the identification and number of all incoming items against their shipping list as well as checking the seal integrity of all containers. In some situations, checks for gross defects by weight measurements or NDA may be appropriate. Records of when these procedures are carried out and by whom should be maintained up to date.

EVALUATION AID FOR MOE NO. 22 - P_{AA10}

MOE Definition

P_{AA10} is the probability, given a loss of a SSNM item during shipment and a shipper-receiver-comparison alarm, that the MC&A system effectively supports a joint shipper-transporter-receiver effort to correctly assess the alarm to be valid within one hour.

Key MC & MA Task Force Goal Applicable to This MOE

MC 9: Maintain procedures and information sufficient to evaluate process conditions and material records so that they may provide for an assessment of alarms within one hour.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system to effectively support a joint shipper-transporter-receiver effort to correctly assess within 1 hour an alarm, which indicates one or more items of an incoming shipment may be missing or may have been compromised, to be valid. Reliable performance for this MOE requires established procedures to be followed by each of the parties involved as well as rapid communications between the parties to be possible at all times. Although successful performance of the alarm assessment may require successful performance by all of the parties, the evaluation of this MOE should only consider the performance of the MC&A system being assessed to support the joint effort. If such alarms have occurred at the facility in the past, the facility's performance history for these alarm assessments should be considered.

EVALUATION AID FOR MOE NO. 23 - P_{LA10}

MOE Definition

P_{LA10} is the probability, given a loss of a SSNM item during shipment and a validated short-term, shipper-receiver-comparison alarm, that the MC&A system effectively supports a joint shipper-transporter-receiver effort to correctly assess the loss in terms of 1) characterization of the loss, 2) identification of the loss mechanism and 3) determination of the appropriate follow-up actions within twenty-four hours.

Key MC & MA Task Force Goal Applicable to This MOE

MC 11: Provide procedures and maintain a capability when a loss is detected to rapidly: estimate the size of the loss, identify the loss mechanism, characterize any missing material, and identify those individuals with access to or responsibility for the missing material.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system to effectively support a joint shipper-transporter-receiver effort to correctly assess within 24 hours a validated alarm, which indicates that one or more SSNM items of an incoming shipment may be missing or may have been compromised, in terms of 1) characterization of the loss, 2) identification of the loss mechanism and 3) determination of the appropriate follow-up actions. Reliable performance for this MOE requires established procedures to be followed by each of the parties involved as well as rapid communications between the parties to be possible at all times. Although successful performance of the loss assessment may require successful performance by all of the parties, the evaluation of this MOE should only consider the performance of the MC&A system being assessed to support the joint effort. If such losses have been detected at the facility in the past, the facility's performance history for these loss assessments should be considered.

EVALUATION AID FOR MOE NO. 24 - P_{A11}

MOE Definition

P_{A11} is the probability, given a loss of five formula kilograms of SSNM from a shipment, that a shipper-receiver comparison generates an alarm within ten days after the shipment arrives at the facility.

Key MC & MA Task Force Goal Applicable to This MOE

MA 5: Detect, with high assurance, within a period of ten days of receipt of a shipment, a loss of five formula kilograms of SSNM from the shipment.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system's shipper-receiver comparisons to sense loss of 5 formula kilograms of SSNM from any incoming shipment within 10 days after it arrives at the facility. One key factor is the uncertainty (LESRD) or limit of error on the shipper-receiver difference for each shipment. Measurement uncertainties of both the shipper and receiver contribute to LESRD. Hence, neither can control LESRD alone. The evaluation of this MOE for the MC&A system being assessed should be based on its relative contribution to LESRD for individual shipments. A LESRD of 3 formula kilograms of SSNM would provide a 0.9 probability of sensing a 5-formula-kilogram loss with a false alarm probability of 0.05. Another key factor is the timeliness of the facility to obtain chemical analyses of U or Pu concentrations. In particular, can the measurements be performed in 10 days or less? An NRC assessment team member, who is familiar with material assay measurements and determination of LESRD should evaluate this MOE.

EVALUATION AID FOR MOE NO. 25 - P_{R11}

MOE Definition

P_{R11} is the probability, given a loss of five formula kilograms of SSNM from a shipment and a shipper-receiver-comparison alarm, that the MC&A system effectively supports a joint shipper-receiver-referee effort to correctly assess the alarm to be valid and to correctly assess the loss in terms of 1) characterization of the loss, 2) identification of the loss mechanism and 3) determination of the appropriate follow-up actions within thirty days after the shipment arrives at the facility.

Key MC & MA Task Force Goal Applicable to This MOE

MA 10: Identify and reconcile shipper-receiver differences which are statistically significant at the 95% confidence level for individual items or containers and for an entire shipment, except for shipments which have a difference of 50 grams or less. Statistically significant differences should be resolved during the inventory interval in which they are identified, if possible, and not later than thirty days from the date of receipt.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system to effectively support a joint shipper-receiver-referee effort to correctly assess an alarm, which indicates that a 5-formula-kilogram or larger loss of SSNM from a shipment may have occurred, to be valid and to correctly assess the loss in terms of 1) characterization of the loss, 2) identification of the loss mechanism and 3) determination of the appropriate follow-up actions, with both alarm and loss assessments being completed within 30 days after the shipment arrives at the facility. Reliable performance for this MOE requires established procedures to be followed by each of the parties involved as well as rapid communication and possible sample exchanges between the parties. Although successful performance of these two assessments may require successful performance by all of the parties, the evaluation of this MOE should only consider the performance of the MC&A system being assessed to support the joint effort. Emphasis should be placed on consideration of procedures, how well they are executed and what examples exist of past performance. The team should examine any available independent or round-robin results for chemical analyses as well as past performance in investigating, identifying and correcting suspected measurement biases.

Reference

W. L. Delvin, "An Evaluation of Shipper/Receiver Differences Involving Shipments of Plutonium Dioxide," Report No. HEDL-TME 78-40, Hanford Engineering Development Laboratory, May 1978.

EVALUATION AID FOR MOE NO. 26 - P_{A12}

MOE Definition

P_{A12} is the probability, given a cumulative loss of five formula kilograms from any combination of shipments to and from the facility during a twelve-month period, that analysis of the shipper-receiver comparison data for the period generates an alarm within two months after the end of the period.

Key MC & MA Task Force Goal Applicable to This MOE

MA 11: Monitor the cumulative shipper-receiver difference on all correspondent accounts and on the combination of all receipts and shipments of SSNM to ensure that the cumulative differences for any period of twelve consecutive months do not exceed five formula kilograms.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system to analyze shipper-receiver difference data for a 12-month period to sense within 2 months after the end of the period cumulative losses of 5 formula kilograms of SSNM from any combination of shipments to and from the facility. The key factor is the uncertainty (LECSRD) or limit of error in the cumulative shipper-receiver difference for the 12-month period. Measurement uncertainties of both shippers and receivers contribute to LECSRD. Depending on the particular facility being assessed, several shipper and several receiver facilities may be involved. The degree to which shipper-receiver differences for single shipments are reconciled correctly will have a direct influence on the performance of a facility's MC&A system for this MOE.

EVALUATION AID FOR MOE NO. 27 - P_{R12}

MOE Definition

P_{R12} is the probability, given a cumulative loss of five formula kilograms of SSNM from any combination of shipments to and from the facility during a twelve-month period and a long-term, shipper-receiver-comparison alarm, that the MC&A system effectively supports a multi-party effort to correctly assess the alarm to be valid and to correctly assess the loss in terms of 1) characterization of the loss, 2) identification of the loss mechanism and 3) determination of the appropriate follow-up actions within three months.

Key MC & MA Task Force Goal Applicable to This MOE

MA 11: Monitor the cumulative shipper-receiver difference on all correspondent accounts and on the combination of all receipts and shipments of SSNM to ensure that the cumulative differences for any period of twelve consecutive months do not exceed five formula kilograms.

Discussion

The evaluation of this MOE is similar to that for MOE NO. 25 - P_{R11}, except that several shipper facilities, several receiver facilities and several referees may be involved.

EVALUATION AID FOR MOE NO. 28 - P_{AA13A}

MOE Definition

P_{AA13A} is the probability, given no loss but a non-MC&A alarm, that the MC&A system correctly assesses the alarm to be false within one hour in terms of loss of five formula kilograms or more of accessible SSNM in item form from the facility.

Key MC & MA Task Force Goal Applicable to This MOE

MC 9: Maintain procedures and information sufficient to evaluate process conditions and material records so that they may provide for an assessment of alarms within one hour.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system to correctly assess non-MC&A alarms within one hour using item-monitoring measures to investigate possible losses of accessible SSNM items from the facility. Evaluation of this MOE is similar to that of MOE NO. 2 - P_{AA1}.

EVALUATION AID FOR MOE NO. 29 - P_{AA13B}

MOE Definition

P_{AA13B} is the probability, given no loss but a non-MC&A alarm, that the MC&A system correctly assesses the alarm to be false within twenty-four hours in terms of loss of five formula kilograms or more of accessible SSNM in bulk form from each controllable unit of the facility.

Key MC & MA Task Force Goal Applicable to This MOE

MC 11: Provide procedures and maintain a capability when a loss is detected to rapidly: estimate the size of the loss, identify the loss mechanism, characterize any missing material, and identify those individuals with access to or responsibility for the missing material.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system to correctly assess non-MC&A alarms within twenty-four hours using bulk-material-monitoring measures to investigate possible losses of accessible SSNM bulk material from each controllable unit of the facility. Evaluation of this MOE is similar to that of MOE NO. 6 - P_{LA2}.

EVALUATION AID FOR MOE NO. 30 - P_{AA14}

MOE Definition

P_{AA14} is the probability, given no loss but a non-MC&A alarm, that the MC&A system correctly assesses the alarm to be false within twenty days in terms of loss of five formula kilograms or more of SSNM from each accounting unit of the facility.

Key MC & MA Task Force Goal Applicable to This MOE

MA 7: Provide the capability to conduct, on a demand basis, physical inventories based on measurements to provide a record of quantities of SSNM at a facility and to provide results as soon as possible, but no later than twenty days from the day on which the demand was made.

Discussion

The purpose of this MOE is to represent the performance of the MC&A system to correctly access non-MC&A alarms within twenty days using a material balance based on a demand inventory to investigate possible losses of SSNM from each accounting unit of the facility. Evaluation of this MOE is similar to evaluation of the alarm assessment associated with MOE NO. 12 - P_{R5}.

DATA SHEET NO. 1--FOR USE WITH EVALUATION AIDS FOR MOE NO. 1 (P_{A1}), 2 (P_{AA1}), 3 (P_{LA1}), 7 (P_{A3}), 8 (P_{R3}), 13 (P_{A6}), 14 (P_{R6}), 28 (P_{AA13A})

MC&A ACTIVITY: Item Monitoring SSNM: Accessible Items in Facility

ITEM LOCATION	ITEM TYPE	MATERIAL FORM	NUMBER OF ITEMS	QUANTITY OF SSNM	OTHER ITEM CHARACTERISTICS	ALARM ID	TEST TYPE	TEST FREQUENCY	FRACTION OF ITEMS TESTED	ALARM CRITERIA	OTHER ALARM CHARACTERISTICS

DATA SHEET NO. 2--FOR USE WITH EVALUATION AIDS FOR MOE NO. 7 (P_{A3}), 8 (P_{R3}), 13 (P_{A6}), 14 (P_{R6})

MC&A ACTIVITY: Item Monitoring SSNM: Nonaccessible Items in Facility

ITEM LOCATION	ITEM TYPE	MATERIAL FORM	NUMBER OF ITEMS	QUANTITY OF SSNM	OTHER ITEM CHARACTERISTICS	ALARM ID	TEST TYPE	TEST FREQUENCY	FRACTION OF ITEMS TESTED	ALARM CRITERIA	OTHER ALARM CHARACTERISTICS

DATA SHEET NO. 3--FOR USE WITH EVALUATION AIDS FOR MOE NO. 4 (P_{A2}), 5 (P_{AA2}), 6 (P_{LA2}), 9 (P_{A4}), 10 (P_{R4}), 15 (P_{A7}), 16 (P_{R7}), 29 (P_{AA13B})

MC&A ACTIVITY: Bulk Material Monitoring SSNM: Accessible Bulk Material in Controllable Unit No.__

BULK MATERIAL LOCATION	PROCESS OR STORAGE TYPE	MATERIAL FORM	QUANTITY OF SSNM	TIME AT LOCATION	OTHER MATERIAL CHARACTERISTICS	ALARM ID	TEST TYPE	TEST FREQUENCY	FRACTION OF MATERIAL TESTED	ALARM CRITERIA	OTHER ALARM CHARACTERISTICS

DATA SHEET NO. 4--FOR USE WITH EVALUATION AIDS FOR MOE NO. 9 (P_{A4}), 10 (P_{R4}), 15 (P_{A7}), 16 (P_{R7})

MC&A ACTIVITY: Bulk Material Monitoring SSNM: Nonaccessible Bulk Material in Controllable Unit No.__

BULK MATERIAL LOCATION	PROCESS OR STORAGE TYPE	MATERIAL FORM	QUANTITY OF SSNM	TIME AT LOCATION	OTHER MATERIAL CHARACTERISTICS	ALARM ID	TEST TYPE	TEST FREQUENCY	FRACTION OF MATERIAL TESTED	ALARM CRITERIA	OTHER ALARM CHARACTERISTICS

APPENDIX B

DESCRIPTION OF ASSESS COMPUTER CODE

PROGRAM ASSESS

Purpose of the Module

ASSESS is the main program to assess the performance of the Material Control and Accounting (MC&A) system in responding to the four adversary goals.

Linkage

This routine calls: EVAL, TREPRT, WEIGHT

Common Block Utilization

WLEVEL is used for the variables: *W1(), *W2(), *W3(), *W4() VALUE *V1(), *V2(), *V3(), *V4(), *PERF

Technical Description

A tree structure is used to assess the performance of the safeguard system. In this scheme, there are four levels below the top. Values are entered for the 30 MOE's at level 4. All other hierarchical elements are evaluated. Evaluations are done by subroutine EVAL progressing from the lower levels upward to the top. The weights for each hierarchcal element are given default values in a DATA statement. These numbers may be altered by entering (via the input unit) revised weights for all elements at any level.

FUNCTION BIGW (N)

Purpose of the Module

BIGW calculates the overall normalizing constant for EVAL when the multiplicative evaluation is used.

Parameters

N = Number of weights to be considered
*BIGW = Functional value of the normalizing factor

Linkage

This routine is called by: EVAL

Common Block Utilization

WGHTS is used for the variables: W(), SUMW

Technical Description

If the sum of the weights is 1.0 (or within .001 of 1.0) the routine assumes that the function is the additive form and the overall normalizing(BIGW) = 0.0.

If the sum of the weights is less than 1.0 then BIGW is greater than 0.0.

If the sum of the weights is greater than 1.0 then BIGW is between -1.0 and 0.0.

FUNCTION EVAL (W1,V1,W2,V2,W3,V3,NUM)

Purpose of the Module

VAL determines the funtional value for an hierarchical elements using subordinate level weights and values.

Parameters

W1,2,3 = Weights for 3 subordinate elements
V1,2,3 = Values for 3 subordinate elements
NUM = Number of subordinate nodes in the structure
*EVAL = Functional value for this element

Linkage

This routine is called by: ASSESS

This routine calls: BIGW

Common Block Utilization

WGHTS is used for the variables: *W(), *SUMW

Technical Description

EVAL is a trichotomous function. The form of the function used is dependent on the weights of the subordinate elements. The three types of evaluations are:

Minimum value - If the weights are all equal to 1, then the value of the function is the minimum of all subordinate values.

Simple product - If the weights are all equal to 0, then a simple product evaluation is made.

Multiplicative - For all other cases, a multiplicative function is used. In this case, the function BIGW is called.

SUBROUTINE TREPRT (IOUT)

Purpose of the Module

TREPRT prints the weight and value for each hierarchical element using the prescribed tree structure.

Parameters

IOUT = Output unit number

Linkage

This routine is called by: ASSESS

Common Block Utilization

WLEVEL is used for the variables: W1(), W2(), W3(), W4()

VALUES is used for the variables: V1(), V2(), V3(), V4(), PERF

SUBROUTINE WEIGHT (IW, WGT, IN)

Purpose of the Module

WEIGHT assigns r.w weights at a given level.

Parameters

IW	=	Level of the element weights to be altered
WGT	=	Array of weights to be assigned to elements
IN	=	Input unit number

Linkage

This routine is called by: ASSESS

Common Block Utilization

WLEVEL is used for the variables: +W1(), +W2(), +W3(), +W4()

INPUT/OUTPUT DESCRIPTION

The input and output files are ASCII code, with 80 character input records and output records of 132 characters. The source code was written on the DEC 10 system at SAI and the disk was used as both input and output units. The first two statements after the DATA statements are OPEN statements, unique to the DEC 10, and are used together with a DATA statement to declare the input and output unit numbers, which are called IN and IOUT, respectively. For other systems, the two OPEN statements must be replaced by an appropriate I/O unit declaration. For example, if the card reader is unit 5 and the printer is unit 6, then the two OPEN statements must be removed with the DATA statement:

```
     DATA IN, IOUT / 12, 13 /
```

which would be replaced by

```
     DATA IN, IOUT / 5, 6 /
```

INPUT DATA DESCRIPTION

For each run, the input data consists of three types of records- title, revised weights and initial values for level 4 hierarchical elements.

TITLE - The first record of every run contains the title of the run and may contain up to 58 characters.

REVISED WEIGHTS - This set of records is optional. The weights at any level may be altered by entering a record containing up to 16 fields. The first field is the level to be altered and is formatted as an I2 field. The next 15 fields, which are formatted as I3 fields, are the revised weights expressed in hundredths (no decimal points). For example, if the weights .45,.30,.15,.10 are to entered for level 1, the input record would appear as:

01 45 30 15 10

All weights between 00 and 100 are acceptable. If the weights for level 4 are to be altered, two records will be required. the first record contains the level (04, formatted I2) followed by the first 15 weights (formatted I3). The second record again contains the level (04, formatted as I2) followed by the last 15 weights (formatted I3).

INITIAL VALUES - This set of data consists of three records. The first record contains the integer value, 0, and is used as a flag. The next two records each contain 15 fields formatted as I3. These 30 values (which should be between 00 and 99, inclusive) are the initial values entered at level 4. An example of this data set might be:

```
00
 30 40 33 45 55 43 30 33 20 20 20 10 90 99 90
 10 22 34 55 56 76 87 89 65 45 87 98 98 88 57
```

In this example 87, which is treated as .87 in the analysis, is the value entered in the 22nd hierarchical element of level 4.

OUTPUT DATA DESCRIPTION

The output data requires a record width of 132 characters and is standard FORTRAN output where the first character of each record is a carriage control character. There are two types of output. The first data set is a list of the weights and values for each hierarchical element of the tree structure.

The second data set for each run is a graphic display of the tree structure. The performance evaluation for the system is given at the top of the tree. For levels 1, 2 and 3, the weight followed by the value is given for each hierarchical element. The last three rows of numbers are the initial values entered into level 4. Level 4 weights are not included in this data set but are available for the first output data set.

APPENDIX C

FORTRAN LISTING OF
ASSESS COMPUTER CODE

```
      PROGRAM ASSESS
C
C*ABSTRACT:ASSESS assesses the MC & A system performance to achieve
C          goals of MC and MA task force.
C
C*PURPOSE: ASSESS is the main program to assess the performance of
C          the Material Control and Accounting (MC&A) system in
C          responding to the four adversary goals.
C
C*AUTHOR:  J. Bibko   27 May 1980
C
C*TYPE:    Main Program
C
C*PARAMETER DESCRIPTIONS:
C          'NONE'
C
C*CALLED BY:
C          'NONE'
C
C*CALLS TO:
C          EVAL, TREPRT, WEIGHT
C
C*COMMON BLOCKS:
C          WLEVEL
C             *W1(), *W2(), *W3(), *W4()
C          VALUE
C             *V1(), *V2(), *V3(), *V4(), *PERF
C
C*TECHNICAL DESCRIPTION:
C          A tree structure is used to assess the performance of the
C          safeguard system. In this scheme, there are four levels
C          below the top.  Values are entered for the 30 MOE's at
C          level 4. All other hierarchical elements are evaluated.
C          Evaluations are done by subroutine EVAL progressing
C          from the lower levels upward to the top.
C             The weights for each hierarchcal element are given
C          default values in a DATA statement. These numbers may
C          be altered by entering (via the input unit) revised
C          weights for all elements at any level.
C
C
      COMMON /WLEVEL/ W1(4), W2(9), W3(14), W4(30)
      COMMON /VALUE/ V1(4), V2(9), V3(14), V4(30), PERF, TITLE(17)
      DIMENSION  WGT(30)
      DATA IN, IOUT / 12, 13 /
      DATA W1    .4, .3, .2, .1 /,
     1     W2 / 1.0, .5, .5, .5, .35, .45, .2, 1.0, .5 /,
     2     W3 / .6, .4, .6, .4, .9, .6, .4, .9, 6*1.0 /,
     3     W4 / 27*0.0, .6, .4, 0.0 /
C
C--OPEN INPUT AND OUTPUT FILES ON DISK.
      OPEN (UNIT=IN,DEVICE='DSK',ACCESS='SEQIN',FILE='VALINP.DAT')
      OPEN (UNIT=IOUT,DEVICE='DSK',ACCESS='SEQOUT',FILE='VALOUT.DAT')
C
C--INPUT THE TITLE OF THE RUN.
 1001 CONTINUE
      READ (IN, 5000,END=9990) TITLE
 5000 FORMAT (17A4)
      WRITE (IOUT,6000) TITLE
 6000 FORMAT (1H1, 17A4 ///)
C
C--INPUT NEW WEIGHT VALUES.
 1000 CONTINUE
      READ (IN,5005) IW, (WGT(I), I = 1, 15)
 5005 FORMAT (I2, 15F3.2 )
      IF ( IW .LE. 0 .OR. IW .GT. 4 )                  GO TO 1010
```

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```
      CALL WEIGHT ( IW  WGT, IN )
      GO TO 1090
C
C--INPUT THE INITIAL 30 VALUES.
 1010 CONTINUE
      READ (IN,5010) (V4(I),I = 1, 30)
 5010 FORMAT ( 15F3.2 / 15F3.2 )
      LEVEL = 4
      WRITE (IOUT,6010) LEVEL, (W4(I),V4(I), I = 1,30)
 6010 FORMAT ( 1H , ' LEVEL', I2/ 7(1X,F4.2,',',F3.2,3X) )
C
C--COMPUTE THE 14 VALUES AT LEVEL 3.
         TV1 = EVAL ( 0.0, V4(1), 0.0, V4(2), D1, D2, 2 )
         TV4 = EVAL ( 0.0, V4(4), 0.0, V4(5), D1, D2, 2 )
         V3(1) = EVAL ( W4(1), TV1, W4(3), V4(3), D1, D2, 2 )
         V3(2) = EVAL ( W4(4), TV4, W4(6), V4(6), D1, D2, 2 )
      DO 1005 I = 3, 9
         I1 = 2 * I + 1
         I2 = I1 + 1
         V3(I) = EVAL ( W4(I1), V4(I1), W4(I2), V4(I2), D1, D2, 2 )
 1005 CONTINUE
         TV21 = EVAL ( 0.0, V4(21), 0.0, V4(22), D1, D2, 2 )
         V3(10) = EVAL ( W4(21), TV21, W4(23), V4(23), D1, D2, 2 )
      DO 1006 I = 11, 13
         I1 = 2 * (I+1)
         I2 = I1 + 1
         V3(I) = EVAL ( W4(I1), V4(I1), W4(I2), V4(I2), D1, D2, 2 )
 1006 CONTINUE
      V3(14) = V4(30)
      LEVEL = 3
      WRITE (IOUT,6010) LEVEL, (W3(I),V3(I), I = 1,14)
C
C--COMPUTE THE 9 VALUES AT LEVEL 2.
      V2(1) = EVAL ( W3(1), V3(1), W3(2), V3(2), D1, D2, 2 )
      V2(2) = EVAL ( W3(3), V3(3), W3(4), V3(4), W3(5), V3(5), 3 )
      V2(3) = EVAL ( W3(6), V3(6), W3(7), V3(7), W3(8), V3(8), 3 )
      DO 1020 I = 4, 9
         I5 = I + 5
         V2(I) = V3(I5)
 1020 CONTINUE
      LEVEL = 2
      WRITE (IOUT,6010) LEVEL, (W2(I),V2(I), I = 1,9)
C
C--COMPUTE THE 4 VALUES AT LEVEL 1.
      V1(1) = EVAL ( W2(1), V2(1), W2(2), V2(2), D1, D2, 2 )
      V1(2) = EVAL ( W2(3), V2(3), W2(4), V2(4), D1, D2, 2 )
      V1(3) = EVAL ( W2(5), V2(5), W2(6), V2(6), W2(7), V2(7), 3 )
      V1(4) = EVAL ( W2(8), V2(8), W2(9), V2(9), D1, D2, 2 )
      LEVEL = 1
      WRITE (IOUT,6010) LEVEL, (W1(I),V1(I), I = 1,4)
C
C--COMPUTE THE PERFORMANCE COEFFICIENT.
      PERF = 0.0
      DO 1030 I = 1, 4
         PERF = PERF + V1(I)*W1(I)
 1030 CONTINUE
      WRITE (IOUT, 6020) PERF
 6020 FORMAT ( ///1H , 'MC8A SYSTEM PERFORMANCE = ', F3.2 //// )
      CALL TREPRT ( IOUT )
      GO TO 1001
C
C--NORMAL TERMINATION
 9990 CONTINUE
      END
```

```
      FUNCTION BIGW ( N )
C
C*ABSTRACT:BIGW calculates the overall normalizing constant for EVAL.
C
C*PURPOSE: BIGW calculates the overall normalizing constant for EVAL
C          when the multiplicative evaluation is used.
C
C*AUTHOR:  J. Bibbo   27 may 1980
C
C*TYPE:    Numerical
C
C*PARAMETER DESCRIPTIONS:
CIN        N      = Number of weights to be considered
COUT       BIGW   = Functional value of the normalizing factor
C
C*CALLED BY:
C          EVAL
C
C*CALLS TO:
C          'NONE'
C
C*COMMON BLOCKS:
C          WGHTS
C             W(), SUMW
C
C*TECHNICAL DESCRIPTION:
C          If the sum of the weights is 1.0 (or within .001
C          of 1.0) the routine assumes that the function is the
C          additive form and the overall normalizing(BIGW) = 0.0.
C               If the sum of the weights is less than 1.0
C          then BIGW is greater than 0.0.
C               If the sum of the weights is greater than
C          1.0 then BIGW is between -1.0 and 0.0.
C
C
      COMMON /WGHTS/ W(3), SUMW
C
C--CALCULATE THE SUM OF THE WEIGHTS.
      BK = 0.0
      DO 1000 I = 1, N
         IF (W(I) .EQ. 1.0 )                GO TO 9000
 1000 CONTINUE
      DIF = SUMW - 1.0
      IF ( ABS(DIF) .LT. 1.0E-3 )           GO TO 9010
      IF ( SUMW .LT. 1.0 )                  GO TO 1020
C
C--SUMW > 1.0 THEREFORE -1.0 < BIGW < 0.  TRY BIGW = -.5
         BK = -.5
         ADJ = BK
         IFLAG = 0
         GO TO 1030
C
C--SUMW < 1.0
 1020 CONTINUE
         BK = 1.0
         IFLAG = 1
C
C--EVALUATE SIDES OF 1 + BK = PROD(1 + BK * W(I))
 1030 CONTINUE
         SL = 1.0 + BK
         SR = 1.0
         DO 1035 J = 1, N
            SR = SR * (1.0 + BK*W(J))
 1035    CONTINUE
         IF ( ABS ( SR - SL ) .LT. 1.0E-4 )         GO TO 9010
         IF ( IFLAG .EQ. 1 )                        GO TO 1040
```

```
            ADJ = .5 * ADJ
            IF ( SR .LT. SL )              BK = BK + ADJ
            IF ( SR .GT. SL )              BK = BK - ADJ
            GO TO 1030
 1040     CONTINUE
            IF ( SR .GT. SL )                                GO TO 1050
               BK = BK + BK
               GO TO 1030
 1050       CONTINUE
               IFLAG = 0
               ADJ = .25 * BK
               IF ( BK .EQ. 1.0 )           ADJ = .5
               BK = BK - ADJ
               GO TO 1030
C
C--SPECIAL CASE WHERE BIGW = -1.0
 9000 CONTINUE
          BK = -1.0
C
C--NORMAL RETURN
 9010 CONTINUE
      BIGW = BK
      RETURN
      END
```

```
      FUNCTION ZVAL ( W1,V1,W2,V2,W3,V3,NUM)
C
C#ABSTRACT:EVAL deterimines the funtional value for an element.
C
C#PURPOSE:EVAL deterimines the funtional value for an hierarchical
C         elements using subordinate level weights and values.
C
C#AUTHOR:  J. Bibbo   27 May 1980
C
C#TYPE:    Numerical Evaluation
C
C#PARAMETER DESCRIPTIONS:
CIN       W1,2,3 = Weights for 3 subordinate elements
CIN       V1,2,3 = Values for 3 subordinate elements
CIN       NUM    = Number of subordinate nodes in the structure
COUT      EVAL   = Functional value for this element
C
C#CALLED BY:
C         ASSESS
C
C#CALLS TO:
C         BIGW
C
C#COMMON BLOCKS:
C         WGHTS
C          *W(), *SUMW
C
C#TECHNICAL DESCRIPTION:
C         EVAL is a trichotomous function.  The form of the function
C         used is dependent on the weights of the subordinate
C         elements.  The three types of evaluations are:
C*
C         Minimum value - If the weights are all equal to 1, then
C                         the value of the function is the mini-
C                         mum of all subordinate values.
C8
C         Simple product - If the weights are all equal to 0, then
C                          a simple product evaluation is made.
C8
C         Multiplicative - For all other cases, a multiplicative
C                          function is used.  In this case, the
C                          function BIGW is called.
C*
C
C
      COMMON /WGHTS/ W(3), SUMW
      DIMENSION V(3), TVAL(3)
      DO 1000 I = 1, 3
         W(I) = 0.0
         V(I) = 0.0
 1000 CONTINUE
      GO TO ( 1030, 1020, 1010 ), NUM
 1010 CONTINUE
         W(3) = W3
         V(3) = V3
 1020 CONTINUE
         W(2) = W2
         V(2) = V2
 1030 CONTINUE
         W(1) = W1
         V(1) = V1
C
C--CHECK THE SUM OF THE WEIGHT TO DETERMINE TYPE OF EVALUATION.
      SUMW = 0.0
      DO 1040 I = 1, NUM
         SUMW = SUMW + W(I)
```

```
 1040 CONTINUE
          R = FLOAT(NUM)
       IF ( SUMW .EQ. 0.0 )              GO TO 1060
       IF ( SUMW .EQ. FLOAT(NUM) )       GO TO 1070
C
C--FIND THE NORMALIZING FACTOR AND EVALUATE THE FUNCTION.
       WN = 0.0
       IF ( ABS ( SUMW-1.0 ) .GT. 1.0E-3 )       WN = BIGW ( NUM )
       PROD = WN*WN
       SEVAL = 0.0
       DO 1050 I = 1, 3
          TVAL(I) = W(I)*V(I)
          PROD = PROD * TVAL(I)
          SEVAL = SEVAL + TVAL(I)
 1050 CONTINUE
       EVAL = SEVAL
       IF ( ABS (WN) .LT. 1.0E-3 )         GO TO 9990
       EVAL = SEVAL +
     1        WN*(TVAL(1)*TVAL(2) + TVAL(1)*TVAL(3) + TVAL(2)*TVAL(3))
     2            + PROD
       GO TO 9990
C
C--SUMW = 0 --- USE THE SIMPLE PRODUCT EVALUATION.
 1060 CONTINUE
          PROD = 1
          DO 1065 I = 1, NUM
             PROD = PROD * V(I)
 1065     CONTINUE
          EVAL = PROD
          GO TO 9990
C
C--SUMW = NUM ----USE THE MINIMUM VALUE EVALUATION.
 1070 CONTINUE
          AMIN = 55.0
          DO 1075 I = 1, NUM
             IF ( V(I) .LT. AMIN )              AMIN = V(I)
 1075     CONTINUE
          EVAL = AMIN
C
C--NORMAL RETURN
 9990 CONTINUE
       RETURN
       END
```

POOR ORIGINAL

```
      SUBROUTINE TREPRT ( IOUT )
C
C*ABSTRACT:TREPRT prints the weights and values using tree structure.
C
C*PURPOSE: TREPRT prints the weight and value for each hierarchical
C          element using the prescribed tree structure.
C
C*AUTHOR:  J. Bibbo   29 May 1980
C
C*TYPE:    Output
C
C*PARAMETER DESCRIPTIONS:
CIN        IOUT   = Output unit number
C
C*CALLED BY:
C          ASSESS
C
C*CALLS TO:
C          'NONE'
C
C*COMMON BLOCKS:
CNAME      WLEVEL
C              W1(), W2(), W3(), W4()
CNAME      VALUES
C              V1(), V2(), V3(), V4(), PERF
C
C
C
      COMMON /WLEVEL/ W1(4), W2(9), W3(14), W4(30)
      COMMON /VALUE/ V1(4), V2(9), V3(14), V4(30), PERF, TITLE(17)
      DATA STAR / '****' /
      WRITE (IOUT, 6000)
 6000 FORMAT (1H1, 39X, 'HIERARCHICAL STRUCTURE FOR ASSESSMENT OF MC&A',
     1' SYSTEM PERFOMANCE', //// )
      WRITE (IOUT, 6001) (STAR, I = 1, 7), PERF
 6001 FORMAT ( 1H ,57X,6A4,A1 / 1H ,57X,25H*  PERFORMANCE OF MC&A  * /
     1                           1H ,57X,25H*  SYSTEM AGAINST FOUR  * /
     2                           1H , 57X,25H*    ADVERSARY GOALS     * /
     3                           1H , 57X, 1H*,9X,F4.2,10X,1H* )
      WRITE (IOUT, 6005) (STAR, I = 1, 32)
 6005 FORMAT ( 1H ,57X,6A4,A1 / 2( 1H , 69X,1H* / ), 1H , 20X,24A4,A2 )
      WRITE (IOUT, 6010)
      WRITE (IOUT, 6010)
 6010 FORMAT ( 1H ,20X,1H*,47X,1H*,26X,1H*,21X,1H* )
      WRITE (IOUT, 6020) (STAR, I = 1, 20)
 6020 FORMAT ( 1H , 12X, 4A4,A1, 31X,4A4,A2, 4X, 2(5X, 4A4,A1 ) )
      WRITE (IOUT, 6030) (W1(I), V1(I), I = 1, 4)
 6030 FORMAT ( 1H ,12X,17H  ABRUPT THEFT    , 31X,18H PROTRACTED THEFT ,
     1    9X, 17H    THEFT FROM    , 5X, 17H       HOAX       /
     2 1H , 12X, 17H  FROM FACILITY   , 31X,18H  FROM FACILITY    ,
     2  9X,17H     SHIPMENT     , 5X,17H    (NO LOSS)     /
     3  1H , 12X,4H    ,F4.2,1H,F3.2,5H     ,31X,4H    ,F4.2,1H,F3.2,
     3  5X,1H ,4X, 2( 5X, 4H    ,F4.2,1H,,F3.2,5H     ) )
      WRITE (IOUT, 6020) (STAR, I = 1, 20)
      WRITE (IOUT, 6040) (STAR, I = 1, 19)
 6040 FORMAT ( 2( 1H ,20X,1H*,47X,1H*,26X,1H*,21X,1H*/ ),
     1 1H , 9X, 6A4, 26X, 4A4,A3, 8X, 4A4,A3, 8X, 2A4,A2 )
      WRITE (IOUT,6050)
      WRITE (IOUT,6050)
 6050 FORMAT (10X,1H*,22X,1H*,26X,1H*,17X,1H*, 5( 8X, 1H* ) )
      WRITE (IOUT, 6060) (STAR, I = 1, 20)
 6060 FORMAT ( 1H , 6X, 2A4, 15X, 3A4, 15X, 3A4, 6X, 6(1X,2A4) )
      WRITE (IOUT, 6070)
 6070 FORMAT (1H , 5X, 10H  SHORT    , 11X, 14H INTERMEDIATE , 13X,
     114H INTERMEDIATE ,5X,1H , 2( 27H  LONG      SHORT     INTER    )/
     2 1H , 5X,10H  TERM     , 11X, 14H      TERM     , 13X,
     2 14H      TERM     , 5X, 1H , 6( 9H  TERM    ) )
```

```
      WRITE (IOUT, 6080) (W2(I), V2(I), I = 1, 9)
 6080 FORMAT (1H , 5X,1H , F4.2,1H,, F3.2, 1H , 11X, 3H   , F4.2, 1H,,
     3   F3.2, 3H   , 13X, 3H   , F4.2, 1H,, F3.2, 3H   , 5X, 1H ,
     3    6( F4.2, 1H,, F3.2, 1H  ) )
      WRITE (IOUT, 6060) (STAR, I = 1, 20)
      WRITE (IOUT,6090)
      WRITE (IOUT,6090)
      WRITE (IOUT,6090)
 6090 FORMAT ( 1H , 9X, 1H*, 22X, 1H*, 26X, 1H*, 9X, 6(8X, 1H*) )
      WRITE (IOUT,6100)(STAR, I = 1, 13 )
 6100 FORMAT (1H , 5X, 2A4,A2, 2(8X,4A4,A3), 6(8X,1H*) )
      WRITE (IOUT,6110)
      WRITE (IOUT,6110)
      WRITE (IOUT,6110)
 6110 FORMAT ( 1H ,5X, 1H*, 13(8X, 1H* ) )
      WRITE (IOUT, 6120) (STAR, I = 1, 28)
 6120 FORMAT ( 2H  , 14(2A4,1X) /
    2    2H  , 2(18H   IM       BMM     ), 9H   MB    , 9H   IM     ,
    3    9H   BMM    , 2(9H    MB     ), 3(9H    SRC    ), 2(9H  NMAA   ))
      WRITE (IOUT, 6130) (W3(I), V3(I), I = 1, 14)
 6130 FORMAT ( 2H  ,14(F4.2,1H,F3.2,1H  ) )
        WRITE (IOUT, 6140) (STAR, I = 1,28)
 6140 FORMAT ( 2H  , 14(2A4,1X) / )
      WRITE (IOUT, 6150) V4(1),V4(4),(V4(I),I=7,21,2),(V4(J),J=24,30,2)
      WRITE (IOUT, 6150) V4(2),V4(5),(V4(I),I=8,22,2),(V4(J),J=25,29,2)
 6150 FORMAT ( 1H , 14(F6.2, 3X) )
      WRITE (IOUT, 6160) V4(3), V4(6), V4(23)
 6160 FORMAT ( 1H , 2(F6.2, 3X), 65X, F4.2 // )
      WRITE (IOUT, 6170) TITLE
 6170 FORMAT ( 1H , 37X, 17A4 )
C
C--NORMAL RETURN
 9990 CONTINUE
      END
```

POOR ORIGINAL

```
      SUBROUTINE WEIGHT ( IW, WGT, IN )
C
C*ABSTRACT:WEIGHT assigns new weights at a given level.
C
C*PURPOSE: WEIGHT assigns new weights at a given level.
C
C*AUTHOR:  J. Bibbo   28 May 1980
C
C*TYPE:    Input Module
C
C*PARAMETER DESCRIPTIONS:
CIN        IW     = Level of the element weights to be altered
CIN        WGT    = Array of weights to be assigned to elements
CIN        IN     = Input unit number
C
C*CALLED BY:
C          ASSESS
C
C*CALLS TO:
C          'NONE'
C
C*COMMON BLOCKS:
CNAME      WLEVEL
C             +W1(), +W2(), +W3(), +W4()
C
C
      COMMON /WLEVEL/ W1(4), W2(9), W3(14), W4(30)
      DIMENSION WGT(30)
      GO TO ( 1010, 1020, 1030, 1040 ), IW
 1010 CONTINUE
      DO 1015 I = 1, 4
         W1(I) = WGT(I)
 1015 CONTINUE
      GO TO 9990
 1020 CONTINUE
      DO 1025 I = 1, 9
         W2(I) = WGT(I)
 1025 CONTINUE
      GO TO 9990
 1030 CONTINUE
      DO 1035 I = 1, 14
         W3(I) = WGT(I)
 1035 CONTINUE
      GO TO 9990
 1040 CONTINUE
      DO 1045 I = 1, 15
         W4(I) = WGT(I)
 1045 CONTINUE
      READ (IN,5000) IW, (WGT(I), I = 16, 30)
 5000 FORMAT ( I2, 15F3.2 )
      IF ( IW .LE. 0 )                  GO TO 9990
      DO 1046 I = 16, 30
         W4(I) = WGT(I)
 1046 CONTINUE
      GO TO 9990
C
C--NORMAL RETURN
 9990 RETURN
      END
```

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A method for assessing the performance of a material control and accounting (MC&A) system in an operating nuclear fuel processing facility has been developed. The performance criteria inherent in the assessment are 16 key goals established by NRC's 1978 Material Control and Material Accounting Task Force. The top level of the assessment structure consists of four adversary goals (abrupt theft, protracted theft, theft from shipment and hoax) against which MC&A system performance is assessed. The bottom level of the structure consists of operational functions of a MC&A system: alarm generation, alarm assessment and loss assessment. Measures of effectiveness (MOEs) have been defined for each function. A complete MC&A assessment involves the evaluation of 30 MOEs by an assessment team. Methods for synthesizing these MOEs to produce assessments of MC&A performance at intermediate levels of the structure and to produce an overall performance assessment are described and have been computerized. Example MC&A synthesis exercises are presented.

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