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June 1977

THIS PAPER WAS PREPARED FOR SUBMISSION TO:
Institute of Nuclear Materials Management 1977 Annual Meeting, Stouffer's National Center Hotel, Arlington, VA - June 29-July 1, 1977

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A MATERIAL CONTROL ASSESSMENT PROCEDURE*

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ABSTRACT

The material control system assessment procedure being developed by
the Lawrence Livermore Laboratory for the U.S. Nuclear Regulatory Commission is
reviewed. It consists of five major sections: Target Identification, Adversary
Sequence and Stimul Generation, Material Control System Response Determination,
Safeguard System Outcome Determination, and Safeguard System Utility Determina­
tion. When adopted, this procedure will minimize safeguards licensing problems
by providing compatibility with future performance based regulations, explicit
evaluation rules and requirements, well-defined trade-off structures, and user-
oriented and systematic evaluation and design tools.

Desirability of Formal Procedure

The purpose of a material control (MC) system at a nuclear facility is
to protect the public from the consequences of a diversion of special nuclear
material. For privately owned nuclear facilities in the U.S., The Nuclear
Regulatory Commission must insure that the anticipated performance of an MC
system is adequate prior to issuing an operating license. However, assessing
the ultimate performance of an MC system design is a complex problem, it is too
difficult for a regulator to determine acceptability by processing all of the
relevant information in his head informally. Moreover, the licensee applicant
and public interest groups would probably object to such an approach because of
the uncertainties involved. (The licensing of nuclear facilities is often under­
taken in an arena of acrimonious and bitter debate.) Consequently, the use of a
formal, systematic assessment procedure which would integrate the experience,
professional judgement, and understanding of experts in the fields of nuclear
materials control and nuclear regulatory operation would be highly desirable.

The material control assessment procedure being developed by the
Lawrence Livermore Laboratory for the NRC is such a procedure. It combines a
variety of powerful systems analysis tools with an innovative and comprehensive
structure and is specifically oriented to the use of performance based regul­
ations in the licensing process. In addition, it provides the NRC with the
means to consider many different points of view and develop a balanced viewpoint
from which to judge material control systems. This viewpoint can encompass not
only the MC and safeguard system effectiveness, i.e., preventing the diversion
of special nuclear material and the perpetration of malevolent acts upon society,
but the impact of the routine material control system operation upon the licensee
applicant and the public as well. A block diagram outlining the five major
procedure sections is shown in Figure 1. (The input block and two subordinate
sections are included for clarity.)

**This report was prepared for the U.S. Nuclear Regulatory Commission, Office
of Nuclear Regulatory Research under research order No. 66-77-012 and under
the auspices of the U.S. Energy Research and Development Administration,
Overview of the Assessment Procedure

The five procedure blocks can be grouped into three phases corresponding to any general system test. The first phase, the preparation of the test input, includes the Target Identification and Adversary Sequence and Stimuli Generation blocks. The second phase system test involves the Material Control System Response Determination block. The third phase of analyzing the test results consists of the Safeguard System Outcome Determination and the Safeguard System Utility Determination blocks. The procedure operations can be roughly summarized as follows.

When a material control system design is submitted to the NRC by a licensee applicant, the information contained in the submittal document is entered into the LLL/NRC Data Base. From the description of the facility's physical layout and process streams, the locations of special nuclear materials (targets) are identified in the Target Identification block and are classified as to their attractiveness to the adversary. Material acquisition adversary action sequences are then generated in the the Adversary Sequence and Stimuli block. In addition, stimuli generated by those material acquisition actions are developed for each sequence. (Stimuli are disturbances of facility system variables caused by the material acquisition actions of the adversary.) These sequences and stimuli are then passed along to the Material Control System Response Determination block as input for the MC system test. A probability distribution over the possible MC system responses are produced for each sequence. (It should be specifically noted that each sequence could have many different responses because of the uncertainties involved in the perpetration of adversary actions, the performance of MC components, the generation of stimuli, etc.) These MC system responses are then combined with physical protection inputs in the Safeguards System Outcome Determination block to generate the outcome of each diversion attempt. The block's outputs are also in the form of probability distributions over the possible outcomes because of the uncertainties involved. Finally, the diversion attempt outcomes are analyzed in the Safeguard System Utility Determination block to produce utility values or "figures of merit" upon which the acceptability of the material control system can be based.

Procedure Block Description

Because of space limitations, only the gross features of the procedure will be included here. Further details are available in References 1-5.

Input Information Block

As was noted above, the Input Information block consists of the Licensee Applicant Submittal Document (LASD) and the LLL/NRC Data Base. The block is structured to facilitate assessment procedure data handling by specifying the exact format for the applicant's LASD and providing a computer data base system for the NRC. The LASD consists of a facility physical layout, a process description, a material control system description, the description of the operational procedures, and the supporting data and specifications. The computerized LLL/NRC Data Base contains equipment models, material control component models, assessment procedure models and methodologies, NRC decision criteria, and supporting data.

The input block structure makes the applicant-NRC submission interface
more efficient for several reasons. First, the LASO contains only the information required for the material control assessment. Secondly, the explicit and standardized format saves time and money in the preparation of such a submittal. Finally, the computerized data base reduces the effort required of the NRC licensing personnel in the implementation of the assessment procedure.

Target Identification Block

The purpose of the Target Identification block is to eliminate unimportant targets from the detailed analyses following this block. A list of all location for special nuclear material is generated from the description of facility layout and process streams. The criticality safety analysis is also well suited for this. A multiattribute utility (MAU) model is used to classify the target materials. A utility value for each target is calculated, based upon several attributes of the material. (An example of a model which could be used for a plutonium reprocessing facility is described in References 3 and 4. For more on multiattribute utility models, see References 6 and 7.) Basically, the utility value is a "figure of merit" representing this attractiveness of the material to the adversary. Only those targets which are classified as critical or important are passed on for the material control system testing. (The criteria upon which these classifications will be based will be determined in conjunction with the NRC.)

Through the use of the multiattribute utility model, target identification is made systematic yet flexible. The MAU model can incorporate subjective expert judgements above the adversary's values and the real value of different materials in a formal and mathematical manner. In addition, the model's value structure (which results from these judgements) can be easily and explicitly varied to represent the different adversaries or the more complete information concerning adversaries which becomes available through NRC-sponsored threat analysis. This allows sensitivity analyses to be easily made in order to check basic assumptions and results. Similarly, the model can be easily modified to adapt to new situations that may arise such as the addition of a new material or a new type of process. Finally, licensing uncertainty is reduced because the target evaluations are made uniformly for all license applications.

Adversary Sequence and Stimuli Generation Block

The purpose of the Sequence and Stimuli Generation block is to produce the specific adversary action inputs necessary for the material control system test. As the first step, a Boolean logic "reachability" computer code is used to determine all of the possible material acquisition paths which connect targets and material acquisition points. The process stream interconnection description is used as input. Next, graphical logic tools called digraphs are used to represent the adversary's interactions with the facility's physical plant, process, and material control systems while he is attempting to divert material along these acquisition paths. (See Reference 2) Such interactions will produce disturbances in the systems variables which are called stimuli. These are identified for each adversary material acquisition action. At each acquisition point, diversion fault trees are then synthesized directly from the digraphs by a computer code for many different types of diversion attempts. Cut sets for each diversion fault tree are subsequently generated by an extremely efficient computer code. (These cut sets are the collections of a adversary actions which
must occur in order for the diversion, the fault tree's "top event", to occur.*) Stimuli from the digraphs are then matched with the actions in each cut set. Finally, the cut set actions and their stimuli are time-ordered into adversary action sequences, and statistics describing the actions and sequences are generated.

The MC system test input preparation is greatly aided by the application of new techniques, tools, and automation. For example, the reachability code can handle complex situations accurately and quickly which might be difficult or impossible for an unaided analyst to do at all. In addition, the digraphs are extremely flexible in their application and can be adapted to new facility systems which are developed quite readily. Digraphs for specific types of equipment and processes can also be standardized and kept in the data base ready for future use, reducing analyst efforts and avoiding the "reinventing the wheel." Most importantly, computer codes can be used to synthesize the diversion fault trees** automatically from the digraphs to effect a great saving in time and money.

Material Control System Response Determination Block

The material control system testing is accomplished through the use of the Material Control System Simulator (MCSS) program developed at the Lawrence Livermore Laboratory. (See References 8 and 9) MCSS is a high level discrete event simulation program in which the program blocks represent the problem elements functionally, i.e., the performances of problem elements such as sensors or a pulse columns are described by summaries of more detailed models, simulations, or tests which can be directly validated. When the MCSS program is set up for the material control system test (See Figure 2), it models the facility process, the adversary action sequences (one at a time); and the material control system (which consists of material control components and logic). When (in simulated time) the facility process (elements) allows adversary actions (elements) to occur, stimuli are generated for each action according to the summaries describing the adversary action and the process models. (For example, an adversary diverts a small portion from storage of a batch material transfer. The low level in the storage tank is one stimuli.) The opening of a valve is another. Wherever the stimuli are monitored by material control components, signals are generated according to the probabilistic performance characteristics for those monitor components. These signals are processed in turn by the material control system logic to produce the material control responses. Many replications are made for each sequence in order to determine the probability distributions over the possible MC system responses as functions of time. The simulation process is repeated until all of the sequences passed from the previous block have been tested. (Several procedures which minimize the number tests required are employed but are not discussed here because of space limitations.)

*) In order to prevent the cut sets from becoming too numerous for efficient MC system testing, portions of the tree which are determined to be of negligible importance will be eliminated or reduced by computer code. In addition, cut sets with actions or sequences of actions which are determined to be too difficult or unlikely (also by use of a computer code) will not be retained for test inputs.

**) While not a new safeguards tool, fault tree analysis does enable the analyst to systematically and exhaustively produce all of the material acquisition sequences. This capability is an obvious asset.
The MCSS program is well suited for MC system testing in licensing, for it can determine the performances of systems which have complex structures and can only be characterized probabilistically. Moreover, the program generates the performance values directly which are necessary to check compliance with the performance based regulations. The MCSS program is also extremely flexible because it can model widely different systems or scenarios easily. (This is especially valuable in the design of an MC system by the applicant or the testing of modifications or updates to a LASD by NRC.) However, the program is also very simple because it is a functional simulation program, i.e., it is not necessary to run very complicated and detailed simulation models such as a second order differential equation model of a piece of chemical process equipment in conjunction with each MCSS run. Only the relevant summary information about the equipment's behavior is necessary. Because the program is written in Fortran, it is easily transferrable. Importantly, the program is user and MC system problem-oriented because the simulation language details are suppressed in the practical implementation of the program.

**Safeguard System Outcome Block**

This block generates the statistics describing the outcome parameters of the diversion attempt. The MC system responses and the responses of the physical protection system** are combined with the material acquisition sequences in a functional simulation model to produce diversion attempt outcomes. Similarly to MCSS, the details of the MC system and physical protection system responses and the adversary sequences are summarized, and probability distributions over the possible outcomes are generated through simulation for each sequence.

The determination of the safeguard system outcome provides the flexibility and assurance of total safeguard system testing because the material control and physical protection systems are interdependent and must be evaluated accordingly. An MC system design which is optimal by itself may lead to a sub-optimal safeguard system design by not accounting for the physical protection system design. Hence, the evaluation of the overall safeguard system must be made. This evaluation can also be very useful during the design of the MC and physical protection systems, for trade-offs between the performances of the two systems can be explored.

**Safeguard System Utility Determination Block**

All of the many different aspects factors of MC system performance and operations are integrated in this block in order to determine its acceptability. It is here that its performance through the safeguard system effectiveness*** is evaluated in the light of the impact of the routine operations of the MC system upon the applicant and the public. However, because the applicant can reasonably be expected to submit only designs that he feels are operationally accept-

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* These outcome parameters are the attributes of the system effectiveness multiattribute utility model in the following block.

** The modeling of physical protection systems and the development of physical protection evaluation techniques is the responsibility of the Sandia, Albuquerque Laboratories under a NRC Office of Nuclear Regulatory Research Program.

*** Safeguard system performance varies with that of the material control system for a fixed level of physical protection.
able, the licensing process will probably not use the portion of the model which measures the impact of the operation upon the applicant. It is included expressly for the purpose of explicitly informing the licensee applicant what the trade-off structure is. (See below).

The determination of the system effectiveness is accomplished by a multiattribute utility model (MAU) which produces utility values which can be used in the application of performance based regulations. This model considers such outcome parameters as the amount of special nuclear material diverted, the number of plant personnel and bystander deaths resulting from the diversion attempt, the dollar damage to the facility, and the point of the adversary's apprehension. It also factors in the adversary perception effects (i.e., the attractiveness and deterrent effects produced by the material control system) and the probability that diversions would even be attempted.* The value structure (which determines the trade-off) in this MAU model will be developed in conjunction with the NRC.

The overall safeguard system utility values are produced by an additional MAU model which includes such additional factors as the capital cost of the material control system, the derating of the facility caused by the routine operation of the system, the number of production days lost due to false alarms and failures, the increased costs to the public, civil liberties, radiological releases and the public perception of security. This value structure (which determines the trade-offs) will be developed in conjunction with the NRC.

The use of the MAU models in this block will facilitate licensing by reducing uncertainty: the NRC, the applicant, and the public all know the "rules". The models provide specific and systematic measures of performances which are compatible with the future performance based regulations, and the trade-offs among the many system performances and operation parameters are clearly stated. In addition, the models are flexible so that they may accept new situations and issues which may arise in the future.

In summary, the above discussions show that the application of this procedure will minimize the safeguards licensing problems by providing compatibility with future performance based regulations, explicit evaluation rules and requirements, well-defined trade-off structures, and user-oriented and systematic evaluation and design tools.

References


* This value of the probability of diversion attempts will be determined by NRC.


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SAFEGUARD SYSTEM

DETERMINATION

PHYSICAL PROTECTION INPUTS

MATERIAL CONTROL COMPONENT PERFORMANCES

MATERIAL CONTROL SYSTEM RESPONSE DETERMINATION

ADVERSARY SEQUENCE AND STIMULI GENERATION

INPUT INFORMATION

TARGET IDENTIFICATION

ANALYSIS OF TEST RESULTS

MC SYSTEM TEST

TEST INPUT PREPARATION

FIGURE 1. Material Control Assessment Procedure

FIGURE 2. MCSS Test Simulation