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THE AGGREGATED SYSTEMS MODEL
A TOOL FOR
NUCLEAR SAFEGUARDS DECISION-MAKING*

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ABSTRACT

Setting performance criteria for systems that safeguard special nuclear material (SNM) involves many considerations: characteristics of adversaries attempting to divert SNM, safeguards response to attempts, costs of safeguards systems, and the consequences of diverted SNM. This paper describes an Aggregated Systems Model which is designed to assist decision makers integrate and evaluate consistently these diverse factors. Results from applying the model to a hypothetical facility handling SNM are summarized. The paper also describes a new performance criterion designed to measure the effectiveness of a safeguard system in deterring adversaries.

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Summary

Lawrence Livermore Laboratory has developed quantitative tools to help the U.S. Nuclear Regulatory Commission (NRC) establish rules for safeguarding special nuclear material (SNM). This summary describes one of those tools, the Aggregated Systems Model (ASM), which is designed to aid the NRC in setting criteria for safeguard (S/G) systems. The ASM integrates many of the factors involved in the criteria decision-making process including characteristics of adversaries attempting to divert SNM, safeguards response to a diversion attempt, costs of safeguards measures and the consequences of diverted SNM.

Under the general title of setting safeguards criteria, we consider NRC decisions such as:

- Performance-based regulations: setting an acceptable performance level for individual components or for overall safeguards systems.
- Integrated safeguards evaluation: making tradeoffs between safeguards components with different functions to achieve the most effective safeguards system, possibly within cost constraints.
- Value-impact analysis: finding the socially optimal safeguards system with the best balance between the social need for safeguards and the social cost of the safeguards system.

The Aggregated Systems Model (ASM) - Overview

The ASM is a collection of models: Adversary Model, Facility Model, Safeguards Technology Model, Consequences Model, and a Social Utility Model.

The schematic below show these models together with the linkages between them. In the following we give a brief description of each of these models:

- Adversary Model: A probabilistic model of several kinds of adversaries incorporating their attempt frequency, resources, and plan of attack. The model explicitly considers an adversary's choice of strategy such as the pathway to SNM, number of tries and the quantity desired and his or her choice of tactics reflected in a decision to abort or continue a try if detected. The adversary is assumed to make these choices based on his/her own preferences for the possible outcomes such as capture, success or failure without capture.
- Facility Model: This describes the system designed to safeguard SNM and the likelihood that each adversary will be detected and interrupted by the safeguards system.
- Safeguards Technology Model: This element describes safeguards components that could be incorporated in the safeguard design and their associated cost. Alternative designs for sensitivity analysis are considered.
- Consequences Model: The consequences Model is a probabilistic statement of the effects of the malevolent uses of diverted SNM. Consequences were evaluated in terms of outcomes such as public fatalities, evacuation cost, deaths and damage at the facility.
- Social Utility Model: Diversion consequences and safeguards cost are expressed in common units using the utility model. This would allow a decision-maker to make explicit trade-offs, among lives lost, property damage, evacuation cost, and the cost of safeguards.

Application of ASM

To demonstrate the methodology outlined above, the ASM was applied to a hypothetical facility handling SNM. Decisions such as those mentioned above were analyzed and sensitivity analyses were also performed.

To demonstrate the use of the model, we briefly describe one of the results of the analyses. As an example of setting a performance criteria for a safeguards system, we examined the decision to set a constraint on the expected quantity of SNM diverted each year. The decision criterion is demonstrated graphically in Figure 2. The horizontal axis measures system performance for several system designs. In this example overall system performance is measured in terms of the expected SNM diverted per year. On the vertical axis, we measure three costs as a function of expected SNM for the various designs: Safeguards Cost (C_S), Diversion Cost (C_D) and Total Social Cost ($C_T = C_S + C_D$). The optimal level of performance is where C_T is lowest. In our example (strictly illustrative) minimum C_T occurs when 6 g/yards are diverted. To the left of 6 g/year C_D is lower, but the cost C_S of this decrease is substantial, causing C_T to rise rapidly. The ASM allows one to arrive at an optimum performance threshold (criteria) for particular performance measures.

Technical Highlights of the Analysis:

The analytical process has generated a variety of insights that aided in the model developments:

- 1 - Sensitivity analysis showed that the overall diversion risk is sensitive to repeated attempts by sophisticated insider adversaries. Therefore, the model allows the adversaries to choose the

number of tries, the amount of material to divert in each try and whether to abort the attempt when detected or not. This process is modeled as a Markov Process, the adversary makes the choice according to his/her preferences for the ultimate outcome.

- 2 - The analysis generated a set of performance measures to judge the system effectiveness in thwarting various adversary types. The choice among these measures is determined by the type of system being evaluated; e.g., while the performance of a Material Control and Accounting System can be judged by the probability of detecting an attempt or the expected time to detection; physical security can be evaluated using the probability of identifying and capturing the adversary.

- 3 - Because the model hypothesize that the adversary will not make an attempt if he/she perceived the safeguards to be strong enough, the analysis generate a measure of deterrence of a S/G system to various adversary types.

Concluding Remarks

In designing a tool for safeguards decision-making one must integrate a wide range of factors. The ASM provides a possible evaluation framework and shows how these factors are inter-related and how the quantitative information about them is used to make a decision. One should mention, however, that these analytical tools are designed to be an aid and not a replacement for the judgments of the regulators who make the ultimate safeguards decisions. As much of the information available is judgmental, the ASM gives

the regulator a tool to measure the sensitivity of the decision to this subjective information. The insights gained by using the model can guide data collection efforts for the safeguards decision-making process.

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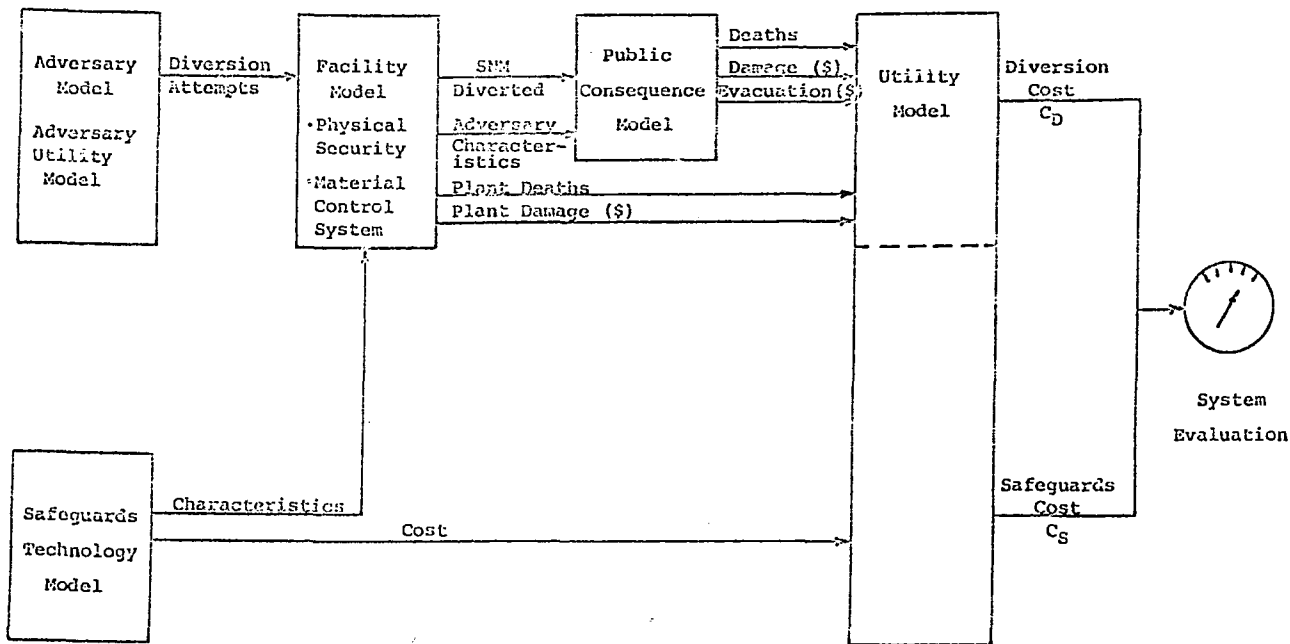
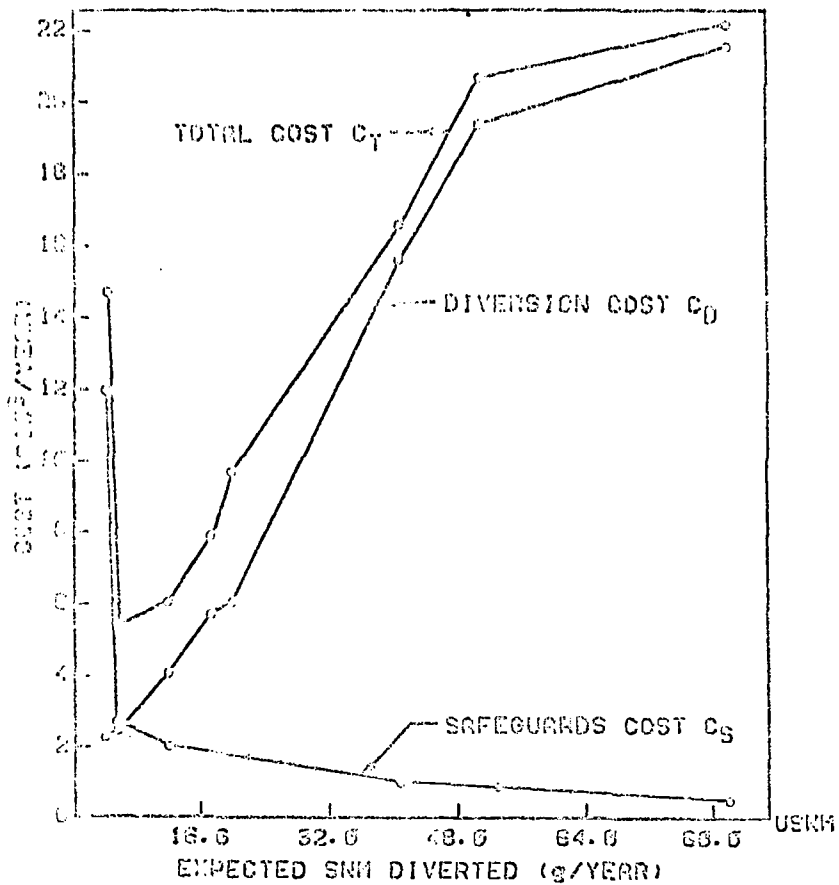


FIGURE 1. Aggregated Systems Model Overview



PERFORMANCE GRAPH:
 COST VERSUS EXPECTED SNM DIVERTED
 PER YEAR

FIGURE 2