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Author(s): Leon D. Chapman

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Responsible NRC Individual and NRC Office or Division:

Richard C. Robinson, Safeguards Research Branch, SAFER:RES

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PREPARED BY
Sandia Laboratories
Albuquerque, New Mexico 87115

DISTRIBUTION:
S. Levine, RES
C. Beck, RES
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PHYSICAL PROTECTION OF NUCLEAR FACILITIES

Progress Report

May 1979

Prepared by

Leon D. Chapman

Safeguards Methodology Development Division 4416

Sandia Laboratories

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PHYSICAL PROTECTION OF NUCLEAR FACILITIES

Progress Report

SUMMARY

New Activities

New activities during May included (1) efforts to apply game theory techniques in order to expand the scope of the vital area classification work, (2) the implementation of additional analytical and statistical output routines for the Safeguards Network Analysis Procedure (SNAP), and (3) the initiation of a contract with Science Applications, Inc. (SAI) to further develop generic sabotage fault tree (GSFT) methods for identifying vital areas and equipment at nuclear power facilities.

Continuing Activities

Facility characterization work during May concentrated on the vital area analyses of operating reactor facilities and the analysis of the Lawrence Livermore Laboratory (LLL) digraph, which was developed as part of the LLL material control and accounting program. During this month, analysis continued on six pressurized water reactors (PWRs) and two boiling water reactors (BWRs). In addition to these activities, a briefing on the vital area analysis methodology was presented to the Advisory Committee on Reactor Safeguards (ACRS).

Other continuing activities included (1) coding and documenting of the single-target adversary and multiple-target sabotage paths which can be solved using ADPATH (adversary paths), (2) the design of COBOL maintenance interfaces for the Safeguards Engineering and Analysis Data-Base (SEAD), (3) the development of further improvements to the Brief Adversary-Threat Loss-Estimator (BATLE) model, (4) the

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resolution of certain anomalies concerning the Guard Tactics Simulator (GTS) engagement model, and (5) the implementation of additional capabilities for SNAP.

Significant progress continued to be made within the Automation of System Evaluation program. Additional modifications and improvements have been made to the Safeguards Automated Facility Evaluation (SAFE) methodology. For example, the SAFE pathfinding routines have been modified to allow SAFE to handle larger facililty graphs, and a model for calculating guard response times is being developed.

The SAFE methodology is presently being used to evaluate an Allied-General Nuclear Services (AGNS) mixed-oxide facility, an AGNS separations facility, and the Standardized Nuclear Unit Power Plant System (SNUPPS) facility. Work is progressing smoothly on these evaluation tasks.

FACILITY CHARACTERIZATION

In-House Activities

The principal activities during May were (1) the vital area analyses of operating reactor facilities, (2) the analysis of the LLL digraph, and (3) the start of a contract with SAI to improve the generic sabotage fault tree technique.

The vital area analyses of operating reactor facilities are being performed jointly with Los Alamos Scientific Laboratory (LASL) for the Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation (NRC/NRR). The following list gives the status of these analyses at the end of this reporting period:

PWR	3	Locations corrected, analysis redone
PWR	6	Complete analysis done
PWR	7	Fault tree and locations corrected, complete analysis done

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PWR 9 Fault tree corrected, analysis redone

PWR 10 Fault tree corrected, analysis redone

PWR 11 Complete analysis done

BWR 8 Further corrections made in May, analysis redone

BWR 9 Analysis started

The complete analysis consists of a plot of the fault tree, inversion of the event-location transformation list to give a list of the events in each location, solution of the fault tree in terms of locations, i.e., Type I and Type II vital areas, and a list of event sequences which occur in Type I vital areas. The reruns of the BWR analyses begun in April due to LASL-specified changes have all been completed.

The interaction between Sandia Laboratories and LLL on the analysis of very large digraphs continued this month. Sandia suggested a new method for finding solutions to the LLL digraphs, which are developed as part of the LLL material control and accounting program for NRC. The digraphs are composed of two parts, one dealing with the material accounting function and one dealing with the physical security function. The material accounting digraph was solved using the Set Equation Transformation System (SETS); however, the physical security digraph was too large for direct solution. The new suggested solution method involves the development of a set of system equations from the digraph and a subsequent transformation of the variables. This technique produces a more compact representation of the original digraph, and the new set of equations can then be solved using SETS. LLL is proceeding with the application of the new method in order to complete the analysis of an example digraph.

A briefing on the vital area analysis methodology was given to the ACRS on 23 May 1979. The subcommittee was particularly interested in the capability to determine the minimum protection requirements for a facility. This information can be developed from the complement of the location solution to the sabotage fault tree. The subcommittee was also quite interested in the Sandia/LASL cooperative effort to apply the vital area analysis procedures to operating facilities.

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Vital Area Importance

The classification of vital areas is an essential step in the design of a safeguards system. Identification of levels of differing importance in potential targets allows rational decisions to be made on the allocation of safeguards resources, e.g., guard responses. Currently, vital areas are classified into two categories: Type I areas, which correspond to singleton terms in the minimal equation, and Type II areas, which include any other areas which appear in the minimal equation.

Research was initiated during this reporting period on the application of game theory to expand the scope of vital area classification systems. The goal is to provide a technique which allows a more discriminating measure to be used to classify potential target areas. The research centers on the application of probabilistic values to the game which arises from viewing the terms of the minimal equation as the minimal winning coalitions of a simple, monotonic (but not superadditive) game in characteristic function (Von Neuman-Mogenstern) form. Probabilistic values are a generalization of the concepts which gave rise to the Shapley value and Banzhof index, which have been familiar to game theorists for some time. Recent research in reliability theory has rediscovered these measures, although from a different perspective. The current task will reconcile these two areas and apply recent advances in game theory to the reliability case.

Contractual Support

Science Applications, Inc. is now under contract to Sandia to support the further development of the generic sabotage fault tree method for identifying vital areas and equipment at nuclear power facilities. The three principal tasks in the program are

1. To review the current GSFTs to identify problem areas in their application to specific facilities,

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2. To assure comprehensive applicability, and
3. To identify events or portions of the trees which are not used or are unimportant.

These tasks form the basis for the development of a computer-assisted, automated fault tree development capability. During the two meetings held this month with SAI personnel, topics of discussion centered on (1) whether the GSFTs should cover both hot and cold shutdown, (2) the difficulties in modeling multi-train cooling systems, and (3) the development of a general model or method for representing system failure criteria. A formal interface has been established so that the experience developed at LASL in applying the current GSFTs can be made available to SAI.

PATH-GENERATION/SELECTION METHODOLOGY

IN-HOUSE ACTIVITIES

Single-Target Adversary Paths

A document entitled, "ADPATH: An Adversary Path Subroutine," was written during May. This report discusses the facility digraph model, the specific path problems that can be solved by ADPATH (single-target theft and sabotage problems), the assumptions made for ADPATH and the rationale behind these assumptions, the methods used to call the ADPATH subroutine, example problems, and the solution process and code performance.

Multiple-Target Sabotage Paths

The coding of a subroutine for multiple-target sabotage paths is nearing completion. This subroutine repeatedly used ADPATH to obtain start-to-target and target-to-target segments of sabotage paths that involve more than one target. The objective is the same as in other codes, i.e., to minimize the probability of interruption. This new code, together with ADPATH, will provide a capability for finding the adversary paths of greatest concern in nuclear facility protection,

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namely, those paths with minimum probability of interruption which are used by an adversary to visit either one theft target or a small number of sabotage targets (six or less).

COMPONENT FUNCTIONAL PERFORMANCE CHARACTERIZATION

In-House Activities

Safeguards Engineering and Analysis Data-Base

The design of COBOL maintenance interfaces required for all of the SEAD modules was completed during this reporting period, and a substantial amount of COBOL coding to support this activity was written. Also, a prototype FORTRAN interface between SEAD and the SAFE methodology has been developed and debugged. Preliminary steps in the integration of SEAD with SAFE were undertaken. Some optimization work on the COBOL and FORTRAN interfaces has been started. Initial steps were taken to document these activities.

Updating of the old BARRIER data base has been completed. Retrieval of the updated barrier information will be possible from SAFE. All of the data-base work is being jointly sponsored by NRC and the Department of Energy (DOE).

EVALUATION METHODOLOGY

In-House Activities

Model Development

Expansion of the BATLE Model -- Improvements continue to be made to the BATLE model. Attrition rates are being greatly expanded to reflect weapon type and range, cover, posture, and illumination. These parameters can be altered for each player at any time, and corresponding attrition rates can be computed. Two additional weapon categories have been added to BATLE; these categories are semiautomatic rifles and submachine guns. An ambush capability has also been

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added to the model. The user now specifies whether an ambush occurs and, if so, which side has the advantage and the length of the firing time.

Automation of System Evaluation

Modifications of SAFE -- A number of modifications and improvements have been made to SAFE. The SAFE pathfinding routines have been modified in order to allow SAFE to handle larger facility graphs. Both the deterministic and stochastic pathfinding codes have been adapted. The execution time for these modified codes is not substantially greater than it is for the unmodified codes.

SAFE-SNAP Interface -- Consideration has been given to the establishment of a formal interface between the SAFE and SNAP models. There are some straightforward connections between the SAFE facility model and the SNAP facility model; however, there are also some significant differences between these two models. Specifically, large regions in SAFE, e.g., the region outside of a building, but inside a fence, must be divided into smaller areas in order to represent the spaces in the SNAP model. These smaller spaces are required in order to sufficiently describe the guard and adversary tactics. It has been recommended that a program be developed which will help the user create the SNAP models through the use of computer graphics.

Guard Arrivals within SAFE -- Another area of improvement to SAFE is the development of a model for calculating guard response times. In order to select critical timely detection paths, SAFE requires the input of guard response times to the targets which have been identified for a facility. A loose interpretation of the response time to a target is the time required for the guards to arrive at the specific target given a response force call-up. Timely detection implies that the adversary is detected with sufficient time remaining to interrupt the adversary before the adversary's goal is achieved.

Currently, the response times are merely estimates provided by the analyst. Techniques which will aid the analyst in estimating such response tim re being considered. Related models are also being examined for new ideas.

One approach to this problem is to allow the user to input guard positions graphically and then to calculate the shortest time paths to the facility targets using existing path routines and a modified facility graph. The facility graph for the guards would be different from the graph for the adversaries in that the guards would only pass through regular doors and would likely have easy access throughout the entire facility. As an example, let t_i, g_i be the ith target and ith guard, respectively. In this case, the following information might be produced:

$t_i \backslash g_i$	1	2	3	4
1				
2	Shortest time for g_i to get to t_i			
3				
4				
⋮				

The shortest time required to get a guard to t_i would be the minimum time in row i. The shortest time to get k guards to t_i would be the maximum of the k smallest entries in row i. In the process of developing this methodology, the user might also produce the following tables:

t_i	Guard nearest t_i
1	
2	
3	
4	
⋮	

g_i	No. of targets nearest to g_i
1	
2	
3	
4	
⋮	

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Note that the extent to which the times vary in the shortest-time-to-targets matrix can be used with the two tables given above to determine how well-dispersed the guards are in the facility.

The minimal times required to get the guards to the various targets also provide a time estimate for the actual physical paths to the targets. However, when an adversary is detected, a guard is not likely to respond directly to a target and may not travel along the shortest path to the target. These minimal times merely provide a lower bound for the time that must be provided after the detection of an adversary action. These lower bounds will provide the analyst a basis for estimating response times. In any case, the analytical results should always be examined for sensitivity to the chosen response times.

SAFE Applications -- The AGNS mixed-oxide (MOX) facility and separations facility have been digitized and the data sent to AGNS for review. Both of these data sets have been returned; there were some corrections to the MOX facility. These corrections have been made and the analysis is continuing and should be completed in the near future.

Preparation of the SNUPPS facility for analysis has been completed. A few more corrections to the SNUPPS facility have been made. The data have been transferred to the NOS time-sharing system. Region data that define the facility graph have been generated through the use of the Automated Region Extraction Algorithm (AREA). A physical protection system has been defined for the facility, and the appropriate data have been entered. The facility is now ready for critical-path selection. A problem has been encountered in that the facility information results in a large-sized problem, and the path-selection routines do not load into the normal maximum-sized partition available on the NOS system. Attempts are being made to modify the computer codes to reduce the core requirements so that larger problems such as the SNUPPS problem can be run during regular working hours.

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Advisory Committee on Reactor Safeguards (ACRS) Briefing -- A briefing on an application of the SAFE methodology to a reactor was given to ACRS on 23 May 1979. This briefing was part of a series of briefings presented to ACRS to describe the major safeguards research projects conducted for the NRC Office of Nuclear Regulatory Research (NRC/RES).

Symposium on Safeguards and Nuclear Material Management

The European Safeguards Research and Development Association (ESARDA) conducted the 1st Annual Symposium on Safeguards and Nuclear Material Management in Brussels, Belgium, on 25-27 April 1979. The majority of the roughly 100 papers that were presented at this meeting related to nuclear material accounting. This emphasis on nuclear material accounting is consistent with the role of ESARDA in support of activities of the International Atomic Energy Agency (IAEA), which are, in essence, exclusively of an accounting nature.

A paper was presented which describes the evolution of safeguards methodologies at Sandia, under the sponsorship of NRC/RES, for evaluating the effectiveness of physical protection systems. Based on the content of the papers which were even peripherally related to the modeling of physical protection systems, it is clear that the Sandia developmental effort in this area is years ahead of any similar efforts in other countries. Moreover, since it is currently beyond the scope of IAEA responsibilities, physical protection assurances are relegated to domestic authorities. Consequently, in the absence of domestic pressures for authorities to provide physical protection assurance, it is doubtful that any substantial developmental effort in this area will be initiated in the near future.

Contractual Support

Safeguards Network Analysis Procedure

A detailed model of all GTS guard and adversary procedures was developed in accordance with the definition provided by NRC. This

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model has been executed for various scenario alternatives which provide information concerning the behavior of the system. A detailed briefing which outlined all aspects of the new GTS engagement model and its application to various adversary attack scenarios was presented to NRC personnel in May.

The majority of the effort this month centered on the resolution of certain anomalies concerning the GTS engagement model. Due to the definition of the various attrition probabilities and the overall structure of the GTS, a time-step procedure was required. Certain anomalies were identified in adapting this time-step procedure and were discussed at a recent NRC briefing. These anomalies have been resolved through the implementation of specific hard-coded additions to the existing routines.

Implementation of the virtual memory processing scheme is progressing satisfactorily. This scheme will allow any size SNAP model to be executed within the Sandia NOS core constraints. Implementation has also been initiated on the inclusion of global variables and force flags. Global variables may be used instead of numeric values in various fields in SNAP data statements. The user can change the values of global variables during simulation executions, thus allowing dynamic definition of system parameters. For example, illumination levels in various portions of the facility can be varied during the simulation through the use of global variables. Force flags, which are set by the user, are associated with each force in the network; a maximum of 60 force flags can be associated with each force. These flags can be set active or disabled and will permit more detailed decision logic in the actions of the various forces.

A statistic has been added to the general performance statistics of SNAP which provides the probability of interruption for a given scenario simulation. This new statistic reflects the probability that a particular adversary force will contact an opposing guard force. An engagement need not be initiated in the calculation of this statistic.

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A routine has been designed to assist in the preparation of SNAP data input files. The routine has been coded for the facility model portion of the input data.

A report which details the application of SNAP using the GTS facility has been completed. This report provides details on the facility, the guard tactics, and the adversary attack scenarios which are included in the model, as well as output results for the simulation of the scenarios of interest.

Technical documentation has also been started which will provide details of the implementation of the GTS engagement model in SNAP. Since the implementation is highly complex, detailed documentation is essential for effective future development efforts.

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