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Physical Protection of Nuclear Facilities Quarterly Progress Report October-December 1976

Leon D. Chapman,
Editor

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PHYSICAL PROTECTION OF NUCLEAR FACILITIES

QUARTERLY PROGRESS REPORT

October - December, 1976

Leon D. Chapman
Editor
Systems Analysis Division I
Sandia Laboratories
Albuquerque, NM 87115

PREPARED FOR THE U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REGULATORY RESEARCH
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Contributors

Kenneth G. Adams
David E. Bennett
Harold A. Bennett
Sharon L. Daniel
Dennis Engi
Louann M. Grady
Diane B. Holdridge
Bernie L. Hulme
Richard D. Jones
Robert G. Roosen
Dallas W. Sasser
Amado A. Trujillo
G. Bruce Varnado

Technical Staff Members
of Sandia Laboratories

Leon D. Chapman
Editor

CONTENTS

	<u>Page</u>
I. Summary	6
II. Evaluation Methodology Development	6
A. In-House Activities	6
A.1 Critical Location Identification	7
A.2 Path Selection Techniques	8
A.3 Path Evaluation Methods	10
A.4 Sub-System Functional Modeling	15
B. Contractual Involvements	17
B.1 TRW Physical Security Model	17
B.2 Neutralization	18
B.3 Safeguards Network Symbolology	19
B.4 Evaluation of Human Attributes	19
III. Facility Characterization	20
A. In-House Activities	20
B. Contractual Involvements	23
IV. Characterization of Physical Protection Components and Constraint Sets	23
A. In-House Activities	23
B. Contractual Involvements	24

PHYSICAL PROTECTION OF NUCLEAR FACILITIES

QUARTERLY PROGRESS REPORT

October - December, 1976

I. SUMMARY

Activities for the first quarter of FY 77 included the preparation of presentations on the Physical Protection of Nuclear Facilities Program for the NRC review committee (November 16, 17, 19, 1976) at Sandia Laboratories, Livermore, California. Also, a draft program plan on the Protection of Nuclear Materials for both fixed facilities and in-transit systems was submitted to the NRC.

Other activities have focused primarily on the development of evaluation methodologies. These efforts have included the development of a computer graphics implementation of EASI (Estimate of Adversary Sequence Interruption), engagement model developments, ISEM (Insider Safeguards Effectiveness Model) documentation, pathing algorithm improvements, and facility characterization methodology improvements.

A large effort has been expended in defining and interfacing with possible contractual support involvements. Areas of these involvements include a generic safeguards data base, fault tree analysis techniques, physical protection modeling, human attribute definitions, neutralization modeling, and safeguards network symbology models.

II. EVALUATION METHODOLOGY DEVELOPMENT

A. IN-HOUSE ACTIVITIES

Currently, evaluation of Physical Protection Systems for nuclear facilities is thought to consist of the following steps:

- (1) Identification of critical locations within the facility requiring physical protection,
- (2) Selection of paths leading to critical locations for detailed analysis,
- (3) Evaluation of safeguards system effectiveness along the path, and
- (4) Identification of potential system improvements.

The activities in evaluation methodology development in the first three steps are outlined in this report. Since Step 4 cannot be exploited until models are developed in Steps 1 thru 3, there will be no discussion of Step 4 in this report. However, a related topic entitled, "Sub-System Functional Modeling" is included.

A.1 CRITICAL LOCATION IDENTIFICATION

Fault Tree Analysis

It has become clear that for specific sites within a given class of facilities (say LWRs) fault trees could be developed automatically using the Set Equation Transformation System (SETS) provided the following are available:

- (1) The top of a generic fault tree for the entire class of sites, and
- (2) A library of sub-fault-trees which further develop the basic events in (1) to some level of detail for any specific site.

An analyst could be shown how to construct a SETS user program that would read selected items from the library of sub-fault-trees and unite them with the generic fault tree to form any site-specific tree. An alternative currently possible without modification of SETS is to develop one all inclusive fault tree which must be pruned to make it site-specific.

The mechanics of the symbolic manipulation required for this task seems to be straightforward. The big difficulty lies in a

development of (1) and (2) (or an all inclusive tree) that is "complete", i.e., capable of representing all of the sites in the given class and doing so in sufficient detail.

A.2 PATH SELECTION TECHNIQUES

Graph Theoretic Techniques

Developmental work has continued with the graph theoretic techniques, specifically with the Dijkstra shortest path algorithm which has been implemented on the Tektronix 4051 intelligent graphics terminal. Though the 4051 is quite powerful, it does face limitations on the size of the graph that it can successfully handle; the largest problem is on the lower ranges of realistic problems.

Another shortest path algorithm based upon T.A.J. Nicholson's^{*} ideas has been tested. A computer graphics display utilizing Nicholson's shortest path algorithm was observed at a visit to Duke Power Company of Charlotte, North Carolina. The original algorithm was developed to find shortest routes for cabling within a facility. This has been converted to find minimum time or detection probability routes for nuclear facilities; however, when it was compared to Dijkstra's algorithm in its current refined form, it was found to use more memory and to require longer execution times.

Two improvements to the sabotage pathfinding subroutine produced savings in run time. After the Dijkstra search finds the lengths of the shortest paths from off-site to each target, a retrace is done to identify the actual paths that are shortest.

^{*} Nicholson, T.A.J., "Finding the Shortest Route Between Two Points in a Network," Computer Journal, May 1966 - February 1967, p. 275-280.

Previously this involved extra arithmetic. A scheme whereby a predecessor of a node along a shortest path is stored in a vector during the Dijkstra search was developed. Then, without any arithmetic, the shortest paths are retraced by simply following a chain of predecessors. This saved 2 percent in run time on our largest test problem and 40 percent on the smallest.

The second change was to reverse the direction of the Dijkstra search. Instead of searching separately from each target back to off-site, the new procedure searches once from off-site finding shortest paths to all other nodes in the sabotage graph. On the largest test problem (a realistic one) the run time was reduced by a factor of ten (from 4.20 seconds to 0.45). This makes dynamic pathfinding feasible.

Alternatives to shortest time or minimum detection probability paths are needed since a measure for a path could be the adversary's success probability as estimated by simulation. It is quite possible that the adversary's success probability is maximized along a path which is not shortest in the measures of time or detection probability. If, however, one had a list of the k shortest paths, then simulations could be carried out to provide a rank ordering of these paths according to adversary success probability. (Notice that this does not necessarily find paths with maximum probability of success.)

The general algorithm for k^{th} shortest paths does not seem to lend itself directly to our sabotage or theft graphs because it admits (i) paths with loops and (ii) paths with two consecutive arcs in the same region as candidates for second, third, ..., shortest paths.

A special version of this general algorithm tailored to our graphs for $k = 2$ has been developed and will be investigated. Extensions to arbitrary k are being considered.

A.3 PATH EVALUATION METHODS

ISEM

Documentation is being prepared for the Insider Safeguards Effectiveness Model which essentially consists of two papers which are in the process of being published. "Simulation of Personnel Control Systems Using the Insider Safeguards Effectiveness Model (ISEM)" addresses the modeling philosophy behind ISEM and discusses its basic features. "Insider Safeguards Effectiveness Model (ISEM) - Sandia User's Guide - Version I" provides a detailed description of the inputs, assumptions, logic, and outputs, as well as sample evaluations and sensitivity analyses. Both of these documents are expected to be published in the near future. This work has been supported primarily by ERDA related safeguards programs at Sandia.

EASI

A simple, easy to use method, called Estimate of Adversary Sequence Interruption (EASI) has been developed to evaluate physical security system performance under specified conditions of threat and system operation. The method calculates the probability of interrupting the adversary along a specified path based upon the following physical protection functions: (1) detection, (2) adversary delay, (3) communications, and (4) guard response time. The evaluation can be performed on a hand-held programmable calculator.

Documentation on this evaluation method has been approved by NRC Research Staff and will be published in January 1977. To facilitate the use of EASI on a trial basis, a user's manual has been developed. A rough draft is currently under review by the NRC Research Staff.

Some improvements in the SR-52 calculator program for EASI have been made. Some of these are: the number of sensors is no longer limited, changes can be made in response time and communication probability with each sensor location, the number of programming steps has been reduced by nearly a factor of two. In addition, programs for EASI on the currently available Hewlett-Packard programmable calculators have been developed. A rough draft of a report documenting these improvements has been prepared.

A versatile computer graphics application of EASI has been developed, and additional options are contemplated. In the current version, facility and adversary path attributes are entered at a graphics terminal, and the probability of adversary sequence interruption is calculated. A variety of graphical plotting options are available. Probability of sequence interruption can be plotted as a function of response force time, or probability of detection at some sensing device, etc. In addition, probability of sequence interruption can be plotted as a function of two variables yielding a surface on a three dimensional space as shown in Figures 1 and 2. A number of pairs of variables such as response force time and probability of communication, response force time and time delay for a barrier, time delay for a barrier and probability of detection, etc. are available. All of these plotting options are very useful because they graphically display the sensitivities of components along the adversary's path. It is anticipated that eventually this graphics technique, which requires a user supplied adversary path, will be linked with an adversary path generating technique.

Figure 1. EASI Output, Example 1

Figure 2. EASI Output, Example 2

System Evaluation

An effort has been initiated to link facility characterization, path generation and facility evaluation into a procedure that could be accomplished quickly and achieve meaningful results. To accomplish part of the facility characterization process, it is necessary to be able to represent the layout of a facility on a computer graphics terminal in a direct and efficient manner. Through discussion with ultimate users of such a program, it was determined that the most immediate requirement was for an automated approach to this facility characterization. Elementary programs for facility characterization have been written and have undergone successive revisions and improvements; this has primarily been done for the Tektronix 4051. As a result of these investigations, a Talos Cybergraph system has been ordered to allow facility data to be taken directly from blueprints. Until this is received, other manual digitizing facilities are being utilized and the data relayed back to the 4051 for final processing.

A simple demonstration interactive program has been developed using the Tektronix 4081 intelligent graphics terminal and a host Sandia CDC 6600 computer. Schematic representations of the physical layout of specific fixed-sites can be generated by selecting portals, barriers, hardware nodes, etc. from a menu displayed on the screen. After they are generated, the schematic representations could be transferred to permanent storage in the host computer and called up for display on other graphic terminals, for example, the Tektronix 4014 or Tektronix 4051. This approach takes advantage of the increased graphics capability available on the Tektronix 4081 terminal.

Interactive Gaming

Techniques for an interactive gaming approach to adversary-defender action and response are being developed. It is envisioned that several terminals can be artificially linked so that information can be passed back and forth and thus simulate an adversary-defender interaction analogous to the real situation.

A.4 SUB-SYSTEM FUNCTIONAL MODELING

In support of the above evaluation methods the following efforts in component functional modeling and human attributes are reported:

Communication

A feasibility study has been initiated for the development of a subsystem model of the communications function. This work involves the definition of a communications response index which might be used to characterize the effectiveness of the procedures proposed for summoning support from reserve guard forces. One possible approach to the specification of a quantitative probability communications response index is to establish validity of analogs to the several "security" indices used by the utility industry to characterize interconnection reliability. One approach would be to establish an analog between the decision process used by a fixed-site security controller in calling-up reserve guard forces and the decision process used by a power system controller in starting-up stand-by generating capacity. If the validity of the analog can be established, then many of the algorithms that have proved to be effective for the utility industry to characterize "system" security indices should be adaptable to and in the specification of a communications response index. Some preliminary survey work has been started on physical security procedures used at power system "security" control centers.

Neutralization

A model which can be utilized to characterize a battle between guards at a nuclear facility and their would-be adversaries has been developed. The model is stochastic in nature and can be used to find analytical expressions for the battle measures of interest; typically, the win probabilities and the expected time duration of the battle. To characterize the process, the model incorporates the distributions of the times to incur casualties and the distributions of interarrival times of reinforcements. The analytical solutions provided by the model readily facilitate sensitivity analyses.

A paper entitled, "A Small-Scale Engagement Model with Arrivals; Analytical Solutions", provides documentation for the model. This paper is expected to be published by March, 1977.

Human Attributes

An important component in a physical protection system is the human resource within the system. In order to evaluate system effectiveness, it is necessary to judge the qualities and abilities of the human elements within the system. Because the guard force is an essential human element in the physical security function, a methodology for guard performance evaluation must be developed. Before developing such methodology, it would be advantageous to identify those characteristics and attributes the guard personnel should possess based upon the necessity to execute and perform required tasks. If it is postulated that such guards might be involved in an engagement with the adversary, the qualities required cannot be ascertained by observation of guard forces presently available, as such events have never occurred. Therefore, it may be necessary to delineate these qualities by analogy with qualities

possessed by personnel involved in similar tasks. These might be based on professional judgment of human qualities and capabilities. Once these characteristics and attributes are identified, methods must be developed to measure them in a guard force. These measurements should be based upon consideration of use and validity of results.

The desirable characteristics and attributes of guards should be enforced and enhanced by training programs. The type and scope of this training will impact the methods developed for evaluation. It is necessary to understand how this training might be accomplished and what its relationship to total guard effectiveness is.

Discussions concerning guard evaluations methodology have been held with individuals involved in the selection, training, and evaluation of personnel involved in similar occupations. Meetings with police departments, private guard forces, and educational institutions have taken place because it is felt that these organizations might possess information that would be useful in the guard force problem. Initial contacts have indicated the primary instrument presently being utilized for evaluation is based upon subjective judgments of peers and supervisory personnel. In the case of the police, the new employee is subjected to a probationary period before being fully accepted as an officer. Continuing evaluations are made by observations of performance in actual job situations plus performance in continuing training programs.

B. CONTRACTUAL INVOLVEMENTS

B.1 TRW PHYSICAL SECURITY MODEL

The task within the TRW contract which applies their Physical Security Code to a typical Nuclear Facility, the Allied General Nuclear Services (AGNS) Reprocessing Plant, is continuing. Problems

involved in securing required data from AGNS were resolved. A meeting at the AGNS facility November 30 thru December 2, 1976, with TRW, AGNS, and Sandia personnel allowed TRW to secure the necessary data and familiarize themselves with the facility. A subsequent meeting at AGNS on December 21, 1976 gave TRW an opportunity to present the data to be utilized in their model for review and comment by AGNS and Sandia personnel. A small number of clarifications were made in the data at that time. A draft of the TRW final report demonstrating their model will be completed in early March.

B.2 NEUTRALIZATION

Neutralization, an integral part of a safeguards system, is that which deals with the halting of unauthorized acts. The events which can be thought to be generally embraced by the neutralization process are listed below in their approximate chronological order of occurrence.

- Deployment of the on-site guards at the scene of the perceived threat,
- Warnings to the adversary to surrender,
- Adversary response to warnings,
- Armed engagement(s),
- Arrival and deployment of the response force, and
- Conclusion of the engagement(s) and reorganization of the site security forces.

Discussions with potential subcontractors have been ongoing pursuant to the construction of a safeguards neutralization model. The modeling effort has been envisioned as consisting of two fundamental tasks. One of the tasks involves the construction of the model itself, including the interfacing of inputs with outputs via the appropriate logic. The second task consists of the construction

of an experimental design which could, in principal, be used to measure the input parameters and to provide insights into the validity of the model. Clearly, these tasks should be coordinated to insure a high level of interaction.

B.3 SAFEGUARDS NETWORK SYMBOLOGY

Safeguards systems models can be considered as an integrated set of elements that characterize the facility, the adversary force, and the defender force. If a set of standard elements can be defined, then models of different facilities and different force structures could be developed by restructuring the interrelationships between the elements. Thus, specific situations would be modeled through the interconnections of the standard elements and the parameterization of the variables that describe those elements.

Discussions have been conducted regarding the development of a safeguards network symbology. The objective of this effort is to develop a network modeling and analysis technique that can be used to evaluate safeguards system effectiveness. A concept paper has been submitted to and reviewed by Sandia and the approach appears to be promising.

B.4 EVALUATION OF HUMAN ATTRIBUTES

Preliminary contacts have been made with two possible contractors, who are involved in developing methods of evaluating human attributes. Discussions have indicated the scope of the problem that is to be considered by them and the type of product expected. A concept paper will be submitted by each documenting how the task is perceived.

B.5 COMMUNICATIONS

Discussions were held to determine the availability and interest of consulting personnel with expertise in the power system "security"

area. The specific question addressed was, "which algorithms used by the utility industry might be analogous to those required for communications response evaluation?"

III. FACILITY CHARACTERIZATION

A. IN-HOUSE ACTIVITIES

The facility characterization subtask provides information on the physical description of potential sabotage and theft targets, critical locations, and potential sabotage consequences for the facilities of interest. During this quarter a general approach was developed for the characterization process, priorities and schedules were established for review of the facilities, and characterization was begun on the fuel reprocessing plant.

The characterization process is being conducted in the following steps:

- (1) Identify and quantify sources of radioactive material within the facility,
- (2) Rank the sources in terms of potential hazard,
- (3) Develop fault trees for theft and sabotage,
- (4) Identify critical systems from the fault trees,
- (5) Translate the fault trees into location trees, and
- (6) Identify critical locations from the location trees.

The procedure set for ranking the sources in terms of potential hazard differs for the theft and sabotage analyses. For sabotage, all sources of radioactivity at the facility will be considered and the following steps will be used:

- (1) Identify the primary ways of releasing the material to the environment,
- (2) Estimate the release fraction for each release mechanism,

- (3) Estimate the consequences of release from each source, and
- (4) Rank the sources in order of increasing consequences.

For theft, the sources of strategic quantities of SNM are of interest and the ranking procedure to be followed is:

- (1) Determine means of removal,
- (2) Determine removal rates for various removal techniques, and
- (3) Rank the sources in order of increasing removal rates.

Analysis based upon this ranking procedure will require close coordination with LLL involving the material control aspects. Ranking the sources helps guide the analysis by indicating which systems or events should be considered first and how far the analysis should be carried to adequately define the facility vulnerability. Eventually, all sources must be considered if the analysis is to be complete, but we want to concentrate initially on those likely to contribute most to public risk.

The development of fault trees describing the ways sabotage or theft could be accomplished is a major component of the characterization effort and will receive primary emphasis in this task. Information will also be collected on plant layout, structural characteristics, and any other facility data required to support the methodology development and application.

A cursory examination of the data requirements for the TRW Physical Protection Model to determine how the use of that model might impact the facility characterization effort has been made. The basic requirements for understanding the facility process, operation, system functions, and physical characteristics are similar to those for the graph theoretic analysis and simulation model used in earlier Sandia studies. The amount of data input to the TRW model is, however, considerably greater because many of the parameters are computed from component characteristics by the model. In the models Sandia has used previously, many parameters are

assigned or computed outside the model and supplied as input. It does not appear that the use of the TRW model would require significantly different information than presently gathered for other models.

Characterization of the facilities will be initiated in the following order:

- (1) Fuel reprocessing facilities,
- (2) Plutonium fuel manufacturing facilities,
- (3) Process scrap and waste treatment facilities, and
- (4) Power reactors.

A study of each facility is anticipated to require approximately six months. The reprocessing facility study is underway, the fuel manufacturing study will begin in February, 1977, and the process scrap and waste treatment study will begin in March, 1977. The characterization of LWR Power Reactors is well in hand as a result of previous studies so that complete fault trees will not have to be developed. Review of proposed off-shore designs will begin in May to determine whether the vulnerability of such units is significantly different from conventional LWRs.

Initial efforts have dealt with the characterization of a nuclear fuel reprocessing facility. The Barnwell Nuclear Fuel Plant (BNFP) will be used as the basic structural model for the reprocessing plant with possible changes in layout and process details to reflect more representative designs. The significant sources of radioactivity have been identified and sabotage fault trees are being developed. A plant tour was made to gather detailed information on the facility and to discuss specific questions with plant personnel.

The portion of the task covering quantification of the radioactivity sources for BNFP has begun this quarter. The Oak Ridge National Laboratory Generation and Depletion Computer code (ORIGEN) will be used to calculate

the radionuclide inventory of the sources. Release fraction data for the major sources is being developed from the literature. This information will be used as input to the consequences model computer program (COMO).

B. CONTRACTUAL INVOLVEMENTS

Support contracts are being established with two firms, Falcon Research and Development, and Dikewood Industries, to aid in the characterization process. These contractors will perform fault tree analysis on portions of the systems and will collect detailed information on the operations of the facilities, locations of vital components, and physical characteristics. Sandia personnel are working closely with the contractors to assess progress and assure that their efforts are properly directed.

The Dikewood Contract (1.5 man-year rate) was initiated in December to support the reprocessing facility characterization study. Preliminary fault trees for major sources of radioactivity and for a small number of basic plant systems have been developed by Dikewood personnel. The Falcon Contract (1 man-year rate) will be initiated in mid-January to support the fuel manufacturing facility characterization study. Falcon personnel are in the process of collecting information for use in the study. The process scrap and waste treatment characterization for the facilities discussed above will be supported on these same contracts if contractor performance is satisfactory.

IV. CHARACTERIZATION OF PHYSICAL PROTECTION COMPONENTS AND CONSTRAINT SETS

A. IN-HOUSE ACTIVITIES

A hierarchy of elemental levels has been developed to facilitate the assembly of a generic safeguards hardware data base. The basic

unit of the hierarchy lies at the individual component level. A series of higher level static models can then be constructed until an interface is reached with simulation techniques at the functional level (detection, assessment, communication, delay, and neutralization).

The relationships between human elements and the neutralization process appear to be as nebulous as they are significant. An attempt at integrating the human element into neutralization is a necessary task if implementation of a neutralization model is a desired goal. This task can be decomposed into three separate parts.

- List the human attributes to be integrated,
- Develop tools to measure the attributes, and
- Provide a mapping from the attribute set into the model parameter set.

An attempt is underway to identify the fundamental driving forces behind human behavior. It is hoped that this will help improve our ability to predict in those parts of the problem that include human actions (e.g., adversary characterization and guard responses). A simple model for human behavior has been identified and preliminary tests will be initiated to better understand human behavior.

B. CONTRACTUAL INVOLVEMENTS

After consultation with several possible contractors, we have decided to negotiate a contract for the development of the generic data base. This will require extensive consultations between contractor personnel and Sandia Laboratories personnel. The "human element" problem has been discussed with possible subcontractors, and they are in the process of preparing concept papers.

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