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Physical Protection of Nuclear Facilities
Quarterly Progress Report
April - June 1979

Leon D. Chapman, Editor

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Sandia Laboratories

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PHYSICAL PROTECTION OF NUCLEAR FACILITIES
QUARTERLY PROGRESS REPORT
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Sandia Laboratories
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PHYSICAL PROTECTION OF NUCLEAR FACILITIES

QUARTERLY PROGRESS REPORT

April-June 1979

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PHYSICAL PROTECTION OF NUCLEAR FACILITIES

QUARTERLY PROGRESS REPORT

April-June 1979

SUMMARY

Major activities during the third quarter of FY79 included (1) the vital area analyses of operating reactor facilities, (2) assistance to the Nuclear Regulatory Commission, Probabilistic Analysis Staff (NRC/PAS) for evaluation of the Three Mile Island accident, (3) further development and testing of the ADPATH (adversary paths) subroutine for finding single-target theft and multiple-target sabotage paths in a facility, (4) the continued design and coding of COBOL and FORTRAN interfaces for the Safeguards Engineering and Analysis Data-Base (SEAD), (5) improvements to the Brief Adversary-Threat Loss-Estimator (BATLE) model, the Estimate of Adversary Sequence Interruption (EASI) Graphics model, and the Safeguards Network Analysis Procedure (SNAP), and (6) application of the Safeguards Automated Facility Evaluation (SAFE) methodology to several nuclear facilities.

Vital area analyses of 11 pressurized water reactors (PWRs) and 9 boiling water reactors (BWRs) have been completed. This work, which is being performed in conjunction with Los Alamos Scientific Laboratory (LASL), has been greatly facilitated by the fact that LASL is now supplying computer-ready input and by the use of a new solution procedure.

At the request of NRC/PAS, Sandia Laboratories provided analytical support for the analysis of the Three Mile Island accident. Commencing on 31 March 1979, the SANDIA-ORIGEN computer code was used to predict the radionuclide inventory of the reactor core and the accompanying decay heat generation rates. Because of improved input methods and efficient code operation, results of the SANDIA-ORIGEN analysis were forwarded to Washington, D.C. within hours after the initial request was made.

The ADPATH subroutine, which is used in SAFE for identifying critical adversary paths within a facility, has been modified to provide the capability of determining single-target theft and sabotage paths for insiders and outsiders, as well as the path problem associated with a single sabotage team which attacks more than one target. Coding for a subroutine that will repeatedly call ADPATH to obtain start-to-target and target-to-target segments for sabotage paths is almost complete.

Work continued on the development of a detailed model of all Guard Tactics Simulator (GTS) guard and adversary procedures for the GTS engagement model. Considerable effort was expended this quarter on the resolution of certain anomalies concerning this model. Further improvements were also made to the SNAP model. Documentation which details the implementation of the GTS engagement model in SNAP and the application of SNAP using the GTS facility is being prepared.

Improvements continue to be made to the SAFE methodology. Recent changes have greatly facilitated data input by improving the methods used to digitize the facility layout drawing and by providing better utilization of the graphics capabilities of the system. Another area of improvement to SAFE is the development of a model for calculating guard response times. The SAFE methodology has been used to evaluate several nuclear facilities: the Allied-General Nuclear Services (AGNS) mixed-oxide facility and separations facility, a nuclear reactor, and the Standardized Nuclear Unit Power Plant (SNUPPS) facility.

FACILITY CHARACTERIZATION

In-House Activities

The principal activities related to the facility characterization task during this quarter were (1) the vital area analyses of operating reactor facilities, (2) the continued development of the Set Equation Transformation System (SETS) code, (3) assistance to Lawrence Livermore Laboratory (LLL) in its material control and accounting program, (4) the negotiation of a subcontract to support further development of the generic sabotage fault trees (GSFTs), (5) assistance to the Nuclear Regulatory Commission, Probabilistic Analysis Staff (NRC/PAS) for evaluation of the Three Mile Island accident, and (6) vital area importance determination.

Vital Area Analyses

The vital area analyses of operating reactor facilities, which are being performed in conjunction with Los Alamos Scientific Laboratory (LASL) for the NRC Office of Nuclear Reactor Regulation, continued as the major activity during this quarter. LASL is now supplying the information needed for these analyses in a computer-ready input form rather than as marked-up GSFT forms. This change has greatly facilitated the vital area analyses. To date, analyses of 11 pressurized water reactors (PWRs) and 9 boiling water reactors (BWRs) have been completed.

SETS Code

A new procedure for the analysis of fault trees was implemented. A bottom-up substitution procedure is now being used rather than the top-down approach normally used in the SETS analysis. The development of this new procedure has greatly reduced the analyst and computer time required to complete a major portion of the vital area analysis. Analyses that formerly required days can now be accomplished in a few hours; computer run times have been reduced from minutes to seconds. As a result of LASL's contribution to data preparation and the improvement in analytical capability which was described above, the large backlog of facilities awaiting analysis is being eliminated.

Research continued during the quarter on the possibility of developing an In-Place Reduction (IPR) algorithm for the SETS program. In the current versions of SETS, the reduction of an equation is achieved in the following way:

1. The factored form of the equation is expanded into a disjunctive normal form (DNF) and the identities $A*A = A$ and $A*\overline{A} = 0$ are applied to each term. (The * represents the logical AND operator and the overline indicates the NOT operator.)
2. The DNF of the equation is simplified by applying the law of absorption ($A + A*B = A$) to remove superfluous terms in the expanded equation. (The + represents the logical OR operator.)
3. The DNF of the resulting equation is factored and the equation in factored form is stored. Equation storage is much more efficient in factored form than in DNF.

The steps described above, while implemented efficiently in SETS, involve expansion of the equation into a DNF. Often, the number of terms in the expanded equation before simplification is enormous; whereas, the number of terms after simplification can be quite manageable. Examples have been encountered where tens of millions of terms produced during the expansion of an equation are simplified to a few hundred terms in the final DNF of the equation. The problem then is the creation and manipulation of a very large number of terms, particularly when many of these terms will be deleted by absorption.

The IPR algorithm that Sandia is attempting to develop would achieve simplification of an equation in its factored form and avoid the expansion of some or all of the equation into a DNF. With such an algorithm, an equation which is not too large in its factored form to be entered into the computer could be simplified even though the expanded DNF of the equation exceeds the computer storage capacity.

Three Mile Island Assistance

A series of calculations was performed at the request of NRC/PAS to assist in the evaluation of the Three Mile Island accident. Commencing on 31 March 1979, the SANDIA-ORIGEN computer code was used to predict the radionuclide inventory of the reactor core and the accompanying decay heat generation rates. The SANDIA-ORIGEN code was originally developed for analyzing and characterizing a light water reactor (LWR) spent-fuel reprocessing facility and has since been used for a variety of fuel-cycle problems. The ease of input preparation and code operation allowed fast turnaround; the initial results were telephoned to PAS within a few hours after the request was made. Subsequent code runs were performed as requested for varying conditions and the output listings were flown to Washington, D.C. The development of the SANDIA-ORIGEN code and LWR fuel-cycle models allowed rapid response to NRC's request for detailed calculations related to the Three Mile Island accident.

LLL Digraph

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

Vital Area Importance

The classification of vital areas is an essential step in the design of a safeguards system. Identification of the relative importance of potential targets within a facility allows rational decisions to be made for the allocation of safeguards resources, i.e., guards, to protect these targets. Currently, vital areas are classified into two categories: Type I areas, which correspond to areas in which the adversary would only have to visit one location in order to be successful (singleton terms in the minimal equation), and Type II areas, which correspond to areas in which the adversary would have to visit more than one location to be successful (any other areas which appear in the minimal equation).

Research was initiated during this quarter on the application of game theoretic techniques 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. A seminar was held by Dr. Engelbrecht-Wiggans in which he presented the concepts of existing game theoretic techniques which might help to rank order targets within a nuclear power plant. This rank ordering of targets would permit a priority assignment of the response forces to protect the more critical areas of the facility.

Contractual Support

Science Applications, Inc. (SAI) is now under contract to support the further development of the GSFT method for identifying vital areas and equipment at nuclear facilities. The three principal tasks in the program are

1. To review the current GSFTs in order to identify problem areas associated with their application to specific facilities,
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. The main topics of discussion to date include (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

During this quarter, final tests were made to verify recent modifications to the subroutine ADPATH (adversary paths), and documentation for ADPATH was completed. The ADPATH code is now available for use in determining single-target theft and sabotage paths for insiders or outsiders in a facility digraph model. This code is an improvement over the MINDPT code since it not only solves the same sabotage path problems as MINDPT but also solves theft path problems as well. In addition, ADPATH has the added feature that any of these paths can start anywhere within the facility, thus allowing scenarios in which the adversaries can be either insiders or outsiders; moreover, the paths belong to a more realistic facility model. The digraph reflects directional dependencies of delay times and detection probabilities and is capable of detailed modeling of multiple-alarm systems at a single location.

Multiple-Target Sabotage Paths

An algorithm has been developed to solve the path problem associated with a single sabotage team which attacks more than one target. In this case, the problem is to determine in what order and along what path a given set of targets should be visited in order for the adversary to minimize the probability of interruption.

In order to illustrate this technique, assume that a facility digraph is given with the usual delay times and detection probabilities associated with the arcs and nodes. Also assume that a subset of k targets $T = T_1, T_2, . . . , T_k$ is given along with appropriate response times of $RT = RT_1, RT_2, . . . , RT_k$, $k \geq 2$. Now consider all k! possible orderings of the targets in T. For each ordering, consider a shortest-time path which passes from the start nodes through each target in order. Each target has a corresponding response point which lies a guard-response-time earlier on this path. The last (latest) of these response points, P, lies just before (or possible right on) the target T . Between target T and the preceding target, say T_m, the adversary must switch from detection probability minimization to time minimization. The minimum interruption probability path for this target ordering is formed by (1) a minimum detection probability path from the start nodes through each target in order up to T_m, (2) a minimum detection probability path from T_m up to a point Q whose time away from T is the same as that of the last response point, P, and (3) a minimum time path from Q to target T and on through all of the remaining targets in order. The optimal path is that path which has the least probability of interruption for all possible orderings of the targets. Note that the definition of the transition point Q ensures that time minimization does not begin until the adversary is close enough to all of the remaining targets.

Coding has almost been completed for a subroutine that will repeatedly call ADPATH to obtain start-to-target and target-to-target segments of these sabotage paths. The run time for this code is $O(k!)$, where $O(k!)$ means order of $k!$ The user of this code should limit the problems to which it is applied to $k \leq 6$; otherwise, excessive computer run-times may be encountered.

COMPONENT FUNCTIONAL PERFORMANCE CHARACTERIZATION

In-House Activities

Safeguards Engineering and Analysis Data-Base

The design of COBOL maintenance interfaces required for all of the Safeguards Engineering and Analysis Data-Base (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 Safeguards Automated Facility Evaluation (SAFE) methodology has been developed and debugged. Some optimization work on the COBOL and FORTRAN interfaces has been started, and initial steps have been taken to document these activities. Also, preliminary steps in the integration of SEAD with SAFE were undertaken.

Updating of the old BARRIER data base has been completed. Retrieval of the updated barrier information is now possible using SAFE by means of an interface which links SEAD and SAFE. The work on SEAD which was described above is being jointly funded by NRC and the Department of Energy (DOE).

SAFEREF, which has been designed, developed, and implemented under DOE funding as a module of SEAD, is a bibliography of all Sandia and contractor reports which deal with facility safeguards (the cutoff date for these reports is 30 September 1978). Maintenance software has been written which allows additions to be made to the module as reports are published; deletions can also be made as reports become obsolete. Progress has been made to retrieve from SAFEREF a subset of those reports which were supported by NRC funding. This would provide a current list of reports to meet the requests for documents related to NRC safeguards activities at Sandia.

EVALUATION METHODOLOGY

In-House Activities

Model Development

Expansion of the BATLE Model -- Improvements have been made to the Brief Adversary-Threat Loss-Estimator (BATLE) model. Attrition rates have been greatly expanded to reflect weapon type and range, cover, and posture of the target. Two additional weapon categories have been added to the model: semiautomatic rifles and submachine guns. An ambush or first-shot capability has also been added that allows the user to specify whether a first shot is fired and, if so, which side fires the shot and the length of the firing time. Another modification will allow the user to alter the effects of the training degradation rule, if so desired.

EASI Graphics -- Another option has been added to the Estimate of Adversary Sequence Interruption (EASI) Graphics package. This option allows the user to examine the probability of system win as a function of the system variables for a specific facility analysis. The probability of system win is defined as the product of the probability of interruption and the probability of neutralization, i.e., the probability that the defenders are able to subdue the adversary. The probability of interruption is obtained from EASI, while an estimate of the probability of neutralization can be obtained from BATLE. The new option regards the probability of neutralization as another variable of the system and provides the capability of plotting the probability of system win as a function of the probability of neutralization and one of the other variables of the system (response time, probability of communications, task time, or probability of detection).

Automation of System Evaluation

Modifications of SAFE -- The SAFE digitizing program called Graphical Representation through Interactive Digitization (GRID) has been modified to allow the user to place the facility layout drawing on the digitizing table without regard to its orientation on the table.

Previously, it was quite easy to misalign the drawing, resulting in a significant loss of accuracy in digitizing. This new feature should make digitizing more convenient. In conjunction with this modification, several other changes were made in order to reduce the amount of input data required and to provide better utilization of the graphics capabilities for inputting data.

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 the time required to run the unmodified codes.

SAFE-SNAP Interface -- Consideration has been given to the establishment of a formal interface between the SAFE and SNAP models. This provision would be useful to the analyst in making an aggregate or global evaluation of the physical protection system using SAFE followed by a more detailed scenario evaluation using SNAP. The same facility data base could then be utilized by both SAFE and SNAP. This interface would reduce the effort required to apply SNAP. 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 times are 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 \ 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 to t_i
1	
2	
3	
4	
.	
.	
.	

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

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.

<u>SAFE Applications</u> -- During this quarter, four facilities have been evaluated using SAFE. The Allied-General Nuclear Services (AGNS) mixed-oxide (MOX) facility and separations facility have been digitized and the data forwarded to AGNS for review. Both of these data sets have been returned; minor corrections were necessary to the MOX facility data. These corrections have been made, and the analysis is continuing.

A nuclear reactor which was digitized earlier this year is still being reviewed. This facility represents the largest facility for which SAFE has been used to perform an evaluation. The facility graph consists of 413 nodes, 2920 arcs, and 8 levels. Because of the size of this graph, it has been necessary to make some modifications to the current version of SAFE. These modifications have resulted in a program which can be handled within the limits of the Sandia NOS time-sharing computer system.

A representative of Savannah River Operations visited Sandia for the purpose of applying the SAFE methodology to a facility which is being studied at Savannah River. A fairly comprehensive analysis of this facility was accomplished in 1-1/2 days.

Preparation of the Standardized Nuclear Unit Power Plant System (SNUPPS) facility for analysis has been completed. This preparation has included the vital area analysis and the conversion from blueprints to a computer representation using SAFE. A few more corrections to the SNUPPS facility have also been made, and 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.

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 the 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 development effort in this area will be initiated in the near future.

Contractual Support

Safeguards Network Analysis Procedure

A detailed model of all Guard Tactics Simulator (GTS) guard and adversary procedures was developed in accordance with the definition provided by NRC. This model has been executed for various scenario alternatives which provide information concerning the behavior of the system. A detailed briefing was held at Pritsker and Associates 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.

Considerable effort was expended this quarter 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. Work has also been done toward including global variables and force flags in SNAP. 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.

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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