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Physical Protection of Nuclear Facilities Quarterly Progress Report October - December 1978

REVISED VERSION

Leon D. Chapman, Editor

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PHYSICAL PROTECTION OF NUCLEAR FACILITIES QUARTERLY PROGRESS REPORT
October-December 1978

Revised Version

Leon D. Chapman
Editor

Date Published: March 1979

Sandia Laboratories
Albuquerque, New Mexico 87185
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PHYSICAL PROTECTION OF NUCLEAR FACILITIES

QUARTERLY PROGRESS REPORT

October-December 1978

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QUARTERLY PROGRESS REPORT

October-December 1978

SUMMARY

Activities this quarter included completion of a major portion of the Standardized Nuclear Unit Power Plant System (SNUPPS) facility characterization. Vital area analysis of a boiling water reactor (BWR) and a benchmark calculation for a pressurized water reactor (PWR) were also completed. Work was initiated this quarter on a computer-based fault tree development program which will hopefully reduce the time and manpower required to translate facility and operational information into fault tree logic.

A new computer code, ADPATH, which finds both theft and sabotage paths in a facility digraph and takes into account adversary direction of travel has been developed. Tests designed to fully exercise the theft path capabilities of ADPATH are currently being devised.

Preliminary work on an update processor for the BARRIER module of the Safeguards Engineering and Analysis Data-Base (SEAD) was undertaken. Work was also initiated on the development of a library of primitives, including schemas and program modules, that will be used in programs that access SEAD. This library will prevent duplication in software writing for the various SEAD modules.

Considerable time was spent this quarter in preparing for a demonstration of the Safeguards Automated Facility Evaluation (SAFE) methodology to Nuclear Regulatory Commission (NRC) staff members and management and the documentation of the SAFE process and related computer codes. Efforts to develop a capability which provides for the automatic identification of regions within SAFE continued. In addition, work was initiated on the development of a SAFE/SEAD interface.

FACILITY CHARACTERIZATION

In-House Activities

The major part of the characterization of the Standardized Nuclear Unit Power Plant System (SNUPPS) facility design was completed during this quarter. This characterization includes system descriptions for five important safety systems (auxiliary feedwater, residual heat removal, emergency electric power, reactor protection, and primary coolant system boundary), development of the sabotage fault trees, and identification of the areas where basic sabotage actions can be accomplished. The fault trees and location information have been computerized to facilitate future modification and analysis.

The SNUPPS characterization information will be used in several areas: (1) demonstration of the Safeguards Automated Facility Evaluation (SAFE) methodology, (2) the Nuclear Power Plant Design Concepts for Sabotage Protection program, (3) the Hazards to Nuclear Reactors from Nearby Transportation Accidents program, and (4) a fire protection study. The SNUPPS design is well-suited for use in these programs since it is a current design and since sufficient detailed information will be available prior to actual construction. Another advantage of SNUPPS is that detailed models have been built prior to construction, assuring that the as-built facility will closely follow the SNUPPS design. This is in contrast to other facilities where small piping and conduit (2 inches in diameter and smaller) are field routed and installed at the time of construction.

The sabotage fault trees for SNUPPS are based on information contained in the Safety Analysis Reports (SARs). As a result, the fault trees could be overly conservative. For loss-of-coolant accidents and transient incidents, the SARs do not give the minimum equipment necessary for safe shutdown under various conditions, which is the information desired. Rather, the SAR analyses assume that a specified set of equipment is operational and that this complete set becomes the necessary minimum.

The vital area analyses of operating power reactors continued this quarter with the completion of the analysis of a boiling water reactor (BWR) facility and a benchmark calculation for a pressurized water reactor (PWR) facility. Analyses were also performed for alternate configurations of two previously completed PWR facilities. This work is part of a joint effort with Los Alamos Scientific Laboratory (LASL) for the Nuclear Regulatory Commission (NRC), Office of Nuclear Reactor Regulation.

Transfer of the computer code, Set Equation Transformation System (SETS), to LASL and instructional support to provide the requisite knowledge and analytical capabilities necessary to use SETS continued this quarter. One PWR facility was used as a benchmark case; computer analysis for this case was performed satisfactorily at both LASL and Sandia.

Assistance was given to Lawrence Livermore Laboratory (LLL) in the use of SETS to solve large digraph problems which were developed within the LLL material control and accounting program. The digraphs led to very large equations involving complement events and hence represent a different class of problems from fault trees. This work indicates that there exists a need to extend and improve SETS to handle these types of problems.

Work was initiated on a computer-based fault tree development program. The goal is to reduce the time and manpower required to translate the facility design and operation information into fault tree logic. The initial criteria for the required computer code modules have been defined. It is anticipated that subcontractors will be used in various parts of the project, including development of the data-gathering system and adaptation of the generic sabotage fault trees for use in this code.

Contractual Support

During this quarter, Dikewood Industries completed their support activity for the facility characterization of the SNUPPS facility. A final report on their effort has been delivered to Sandia. This report contains systems descriptions, fault trees, location information, and other miscellaneous information developed during the study.

Falcon R&D continued their work on generic fault trees for interconnected, multiloop heat removal systems. Trees for two- and three-loop closed systems with full interconnection have been developed. The SETS analysis to obtain the minimal cut sets has required the use of all available sophisticated solution techniques. The application of these new generic fault trees to the SNUPPS auxiliary feedwater system to verify their practical applicability will begin during January 1979.

PATH-GENERATION/SELECTION METHODOLOGY

In-House Activities

ADPATH Tests

ADPATH is a new code which finds both theft and sabotage paths in a facility digraph (directed graph) where the delay times and detection probabilities may depend on the adversary's direction of travel. The new code represents a major improvement over MINDPT, which is the code currently used in SAFE to find sabotage paths in an undirected facility graph. The new code utilizes digraphs which require twice as many nodes as the previous graph model. This extension allows the user to specify alarms on either or both sides of each barrier and each target. Since each arc of the digraph has an associated direction in addition to its delay time and detection probability, passage through doors which are locked on only one side and transits through stairwells can both be treated to reflect their directional dependence. Accounting for directionality is absolutely essential to an accurate analysis of the theft problem since the thief must escape as well as gain access.

ADPATH solves the same sabotage problems as MINDPT. It differs from MINDPT in that a pathfinding algorithm developed by Ford has been substituted for Dijkstra's method. The results of extensive code-comparison tests, which were described in the April-June 1978 Quarterly Report, prompted the decision to make this algorithm substitution. Also, ADPATH eliminates several design features of MINDPT which were not optimal. All of the graphs used to test MINDPT have been converted into corresponding digraphs and analyzed by ADPATH. The ADPATH results agree with those produced by MINDPT.

Theft problems are considerably more complicated than sabotage problems, even in the special case which ADPATH treats. This special case is characterized by the elimination of the dependence of the removal path upon the access path. The elimination of path dependence is accomplished by assuming that an insider acts upon the barriers and the alarms, either before or after the thief does, in such a way as to provide the thief with minimum delay times and detection probabilities at all points along the thief's route. This assumption not only allows subpaths to be found independently but also constitutes an important critical case. A set of test problems has been devised to fully exercise the theft path capabilities of ADPATH; these tests are currently being performed.

COMPONENT FUNCTIONAL PERFORMANCE CHARACTERIZATION

In-House Activities

Safeguards Engineering and Analysis Data Base

The development of the Safeguards Engineering and Analysis Data-Base (SEAD) is sponsored jointly by the Department of Energy and NRC. SEAD provides a capability for the updating and retrieval of data from a data base which pertains to the performance of various physical protection systems. The principal activity during this reporting period was preliminary work on a system 2000 update processor for the BARRIER module of SEAD. This module will be used to update the Penetration Times Data Base (Chapter 16 of the Sandia Barrier Technology Handbook) as new data becomes available.

Work was also started on the development of a library of primitives for use in programs that will access SEAD. Primitives include schemas and program modules which are used to perform receiving functions. The first primitive developed is contained in SEADCLB, a COBOL library program which includes COBOL data definitions for all schemas in SEAD. Availability of a library of primitives will avoid duplication of effort in writing software for the various modules of SEAD.

Other activities included (1) initial studies of FORTRAN interfaces between SEAD and application programs which are part of the Safeguards Methodology Development effort and (2) preliminary studies of schemas appropriate for a Safeguards Bibliographic Data-Base module. In addition, a Tektronix Model 4025 computer terminal, which will enhance ease of maintenance of SEAD modules, was installed. This terminal is equipped with a form ruling option that provides complex updating capability to the nonprogrammer operator.

Contractual Support

Neutralization

Human Parameters -- Members of the security force at Allied-General Nuclear Services (AGNS), Barnwell, South Carolina, were used as subjects for tests related to acquisition of human factor data for neutralization models which were developed by Applied Psychological Services, Inc. (APS). These tests were conducted during the week of 16 October 1978. Data collection forms for each criterion of the tests have been developed by APS; these criteria include

1. Coordination--Tasks which require physical ability, muscular coordination, training, body flexibility, body bending, and body twisting. Example: Jumping down a flight of stairs.
2. Balance--Tasks which require gross body control and balance. Example: Walking along a narrow wall.
3. Mental Flexibility--Tasks which require novel solutions, use of imaginative approaches to the solution of a problem, rapid adjustment to unexpected situations, and mental flexibility. Example: Determination of how an unusual act may be performed, e.g., how to defeat a security alarm system.
4. Information Processing--Tasks which require mental integration of information which has been provided and prediction of the outcome. Example: Determination of what to do in the case of an attack on the site based on personnel strength, position, and available weapons.
5. Mental Adaptability--Tasks which (1) require perception of clues, things which do not make good sense, inconsistencies, or things which are inappropriate and (2) display the individual's alertness to details in the surroundings. Example: Perceiving something wrong in a visitor's actions.
6. Cohesiveness--Tasks which require a feeling for the reactions of others and their attitudes. Example: Judging how another guard will react to a work order.
7. Reasoning--Tasks which require logical thinking, systematic thinking, the ability to see relationships among the facts, and common sense. Example: Determining the best order in which to do something.
8. Muscular Agility--Physical tasks which require gross nimble, speedy, and quick body movement. Example: Chasing an intruder through a maze of equipment.

9. Aspiration--Tasks which require achievement of a difficult goal. Example: Achieving marksmanship scores which are somewhat higher than those previously attained.
10. Identification--Tasks which require the subordination of personal goals to those of the group in order to accomplish the group's goal. Example: Working overtime (without pay) to help other guards complete a task.
11. Stress--Tasks which require completion within strict time limits or under pressure. Example: Meeting work deadlines or accomplishing tasks within scheduled time limits even when other pressures have been placed on the guard.
12. Social Interaction--Tasks which require interaction with others, cooperation, group planning, and joint activity. Example: Working as part of a team to search an area.

An example of the instructions which are given to the supervisors is shown in Figure 1.

In addition to AGNS personnel, 22 members of the Philadelphia police force were also administred the APS test. No problems were encountered during the tests.

Analysis of the data which resulted from the AGNS and Philadelphia tests has been started. To date, the following analyses have been completed:

1. Calculation of the mean and standard deviation of the test scores for the current male guard force sample at AGNS,
2. Calculation of the mean and standard deviation of the test scores for females on the AGNS guard force,
3. Calculation of the mean and standard deviation of the test scores of guard trainees at AGNS,
4. Calculation of the biserial correlation between scores and criterion data for the male guard sample at AGNS, and
5. Calculation of mean and standard deviation of the test scores for the Philadelphia police officer sample.

The following statistics remain to be calculated by subtest:

1. Percentile distributions, and
2. T-tests of the significance of difference between the Philadelphia police officer sample and the AGNS samples.

The final report, which will cover the test content, test administration, and analysis of test data, will be completed in January 1979 and will conclude the APS work in data collection for neutralization.

Your task is to judge how well Guard ____________________ performs various tasks. To provide this information you should:

1. Read over and make sure you understand the definitions of each task before you rate the guard. If you do not understand the definition, or if you have any questions, please ask for clarification.
2. Read the first definition in the task definition list and decide how well you think Guard ____________________ performs tasks of this type.
3. Enter your response on the answer form in the row labeled "coordination." Use the scale shown below in making your judgment.

0	10	20	30	40	50	60	70	80	90	100
Very Poorly		Below Average		About Average			Above Average		Almost Perfectly	

The scale is also on the card which the administrator has placed in front of you.

4. Repeat this procedure until Guard ____________________ has been evaluated on all 12 task types. Refer to the task definitions as often as necessary when you make your judgments. Feel free to ask the administrator any questions which occur during your work.
5. You may enter any number from "0" to "100" for any task description. Please remember that most people do not do well or poorly on everything they do. Accordingly, you will probably want to use a variety of numbers as you rate the guard on the various task types.
6. When you have finished go back over your work and make sure that each number reflects your best possible evaluation of Guard ____________________ on each task.

Figure 1. Example of Supervisor's Instructions

EVALUATION METHODOLOGY

In-House Activities

Automation of System Evaluation

SAFE Demonstrations -- A demonstration of the SAFE methodology was presented to Jay Durst, NRC Office of Regulatory Research, during October. This demonstration covered the SAFE procedure from the digitization phase to path analysis. In addition, assistance was also given to B. Hatter and J. Bartlett, NRC Office of Nuclear Material Safety and Safeguards, in their preparation of a demonstration of SAFE for NRC management and staff members. Discussions concerning the equipment required by SAFE, the input data, and the organization and content of the presentation were held, and the facility digitization process and the SAFE analysis procedure were thoroughly reviewed. Also, a demonstration of the possible use of a video camera and monitor system to be used during presentations of SAFE was arranged.

Various line-printers that are compatible with the Tektronix 4051 have been examined in order to provide a recommendation to NRC as to what type of line-printer would be compatible. One requirement for the line-printer is that it have the capability to print from the Tektronix 4051 as well as from the Sandia NOS time-sharing system. The line-printer would be useful to print out large data files from SAFE instead of printing them at the terminal. Equipment currently in use at Sandia Laboratories includes a Texas Instrument Model 810 printer and a Tektronix 4641 printer. Both of these printers require a Tektronix 4051 Option 10 printer interface/RS232.

SAFE Documentation -- The SAFE modules for which general descriptions have been documented include facility characterization, target identification, pathfinding, path evaluation, adversary neutralization, general SAFE input and output, and an example of an application of SAFE to a generic facility. In the application example, emphasis is placed upon use of SAFE to gain information and insights about the facility and the dependence of the facility security upon specific parameters (barrier delays, probability of detection of a sensor, guard response time, etc.).

A flowchart which illustrates the execution of SAFE from the user's point of view is shown in Figure 2. It also shows the flow of control and makes clear what options are available and what occurs once

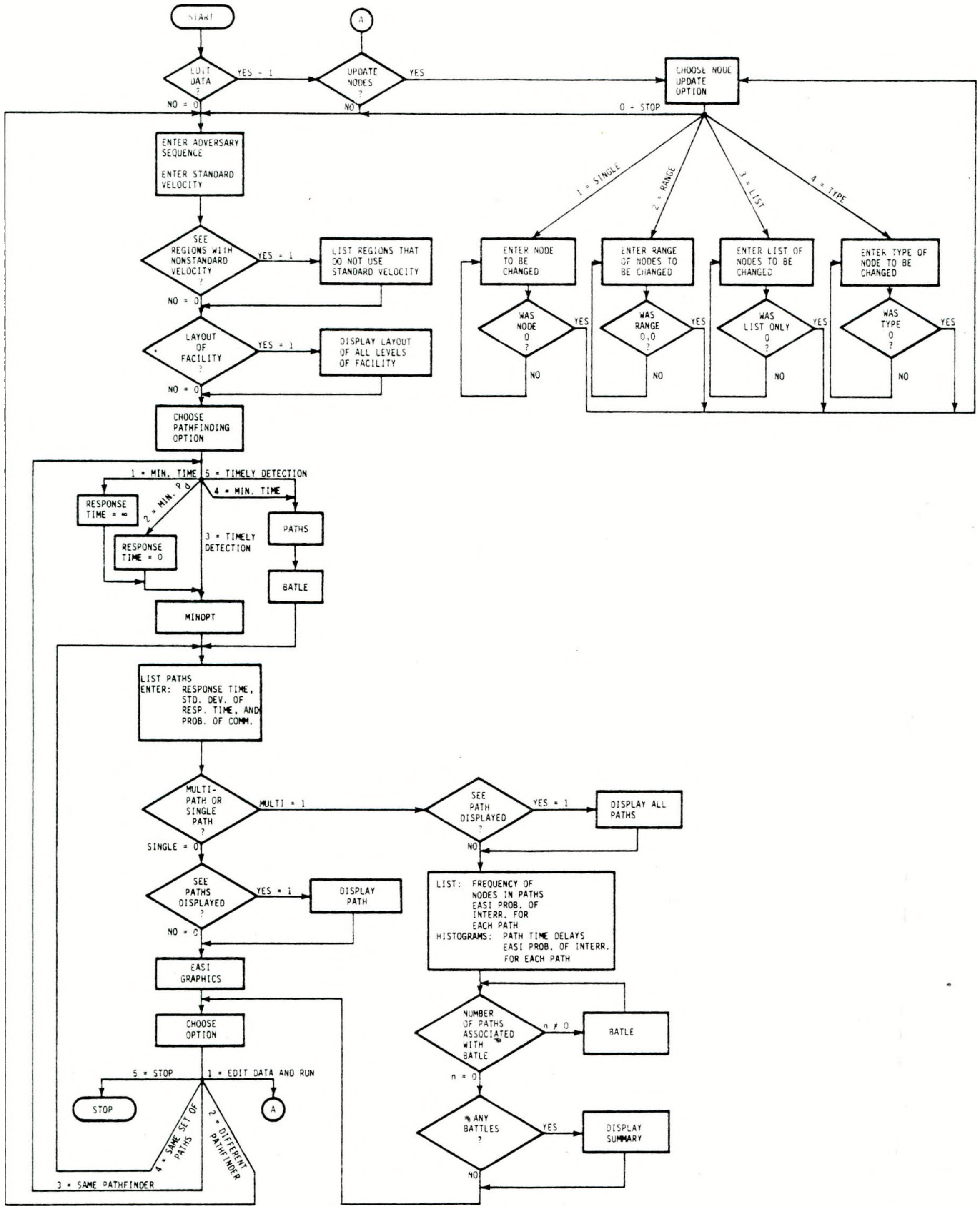

Figure 2. Flowchart of User's Options in SAFE

an option is chosen. A second flowchart, which is system oriented, has been constructed but, because of its complexity, is not included in this report. This flowchart shows the transfer of control from program to program, the use of data files, and the use of procedure file control variables.

Documentation of the SAFE computer codes continues. Comments have been added to these codes, and simplifying changes have been made. After changes are made to the code, it is necessary to verify that these changes have been made correctly.

SAFE Program Modifications -- The output of SAFE on a terminal was adjusted so that the output will fit within 72 columns. This enhancement will allow output to be written on the Tektronix 4051 terminal without wrap-around occurring. This change was made in anticipation of the demonstration to NRC staff members.

The display of pathfinding options of SAFE have been changed from computer subroutine names to descriptive names. For example, the interactive SAFE response

Choose Pathfinding Routine Wanted:

1 = KSPTH

2 = MINDPT

3 = PATHS

has been changed to read

Choose Pathfinding Option Wanted:

Deterministic (MINDPT)

1. Minimum time over path
2. Minimum detection probability over path
3. Minimum timely detection
   (Detection with sufficient time for guard response)

Stochastic (PATHS)

4. Minimum time
5. Minimum timely detection

It was felt that these descriptive names were more understandable. To accomplish this change, program modifications were necessary in order to automatically perform the listed options.

Additional work during this quarter was devoted to automating the identification of regions in SAFE. Currently the user is burdened with the tedious task of picking out each region in a facility, identifying all of the nodes and barriers in each region, and supplying this information to SAFE. A network of computer codes is presently being written to provide the capability to build this region information automatically with some minimal assistance from the user.

The modules which perform the automatic processing of the facility to determine regions have been completed. Other modules which will allow the user to examine the region output for verification, to make corrections, and to provide information which the automatic processes were unable to provide are yet to be written. The modules, as illustrated in Figure 3, will now be described.

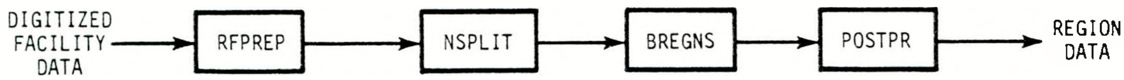

Figure 3. Sequence of Modules for Automated Identification of Regions

1. RFPREP--Processes facility data to determine which nodes lie on which lines. Reports information that may indicate improper digitization.
2. NSPLIT--Splits every node that lies on a line into two nodes so that one node is placed on each side of the line. Also moves the node into the interior of the regions in which it lies.
3. BREGNS--Builds regions by starting with a single node in a region and connecting as many nodes to it as possible with straight-line paths that do not cross any facility lines (walls, etc.). Repeats the process by using each node added to the region as a starting point and is continued until there are no more nodes to add to the region.
4. POSTPR--Deletes regions that contain only a single node. Also deletes regions that contain only outer boundary nodes of the facility. Checks to see if any region contains both of the pair of split nodes that represent a single node on a line. If such a case is found, the region information is

appropriately modified so that only one node remains. Collapses all split node pairs into the original node from which they were created.

The modules in this sequence have been tested on digitized facilities and have performed well. This sequence should handle all one-level facilities for which the facility data are complete and accurate. In a facility that has more than one level, interconnecting regions that define passageways from one level to another are not automatically generated. Another module will be written to allow the user to furnish information for the addition of such regions.

If the facility data are incomplete or inaccurate, which may result in incorrect formation of regions, the user should be provided with means to update the original facility data, after which the data may be processed again. Such user capabilities should be made available before the network is completed.

Automatic region identification should make SAFE easier to use and should drastically reduce the time required to prepare facility information for analysis.

SAFE/SEAD Interface -- Work has begun this quarter on the direct interaction between SAFE and SEAD. When completed, this link will automatically tie the barrier nodes in the SAFE facility representation to the penetration time delay for the barriers that are (or will be) stored in the data base. The initial effort has mainly involved establishing a format for interaction between SAFE and SEAD and outlining requirements to be fulfilled by the interface.

Neutralization

BATLE -- A steady-state version of the Brief Adversary-Threat Loss-Estimator (BATLE) has been implemented on the Texas Instruments TI-59 programmable calculator. The program requires three magnetic cards for input and program execution. The first card calculates attrition rates for guards and adversaries based on training, weapon type, cover, illumination level, distance between combatants, and the APS psychological modification factor. The second card calculates the unnormalized probabilities of entering the possible absorption states (zero guards or zero adversaries) from a given initial state. This calculation is made using a recursion relation. The program on the third card normalizes the probabilities, calculates probabilities of win for guards and adversaries, and calculates expected numbers of guards or adversaries given a win. Because of storage limitations, only certain combinations of guard and adversary force sizes can be handled. Acceptable force sizes are summarized in Table I.

TABLE I

Acceptable Force Sizes for TI-59 Version of BATLE

Size of Larger Force	Corresponding Size of Smaller Force
6	1,2,...,6
7,8	1,2,3,4,5
9,10,11	1,2,3,4
12,13,...,17	1,2,3
18,19,...,27	1,2
28,29,...,56	1

Fixed-Site Neutralization Model -- A document has been completed which describes the input to the Guard Tactics Simulator (GTS) example which was constructed during the Fixed-Site Neutralization Model (FSNM) tutorial on 23 September 1978. The input to FSNM will be modified to incorporate suggestions from NRC staff members and to exercise the FSNM with more realistic GTS examples. Prior to the exercise, the decision logic in FSNM will be altered to reflect a process which can be either stochastic or deterministic. Subsequently, a modest number of replications will be made to study the effects of statistical variability within the model. The final product of this effort will be a document which describes the use of FSNM in modeling GTS scenarios.

Efforts to convert the FSNM code to the CDC 7600 computer are nearly complete. Incompatibility of the FORTRAN systems has been eliminated, and assignment of data arrays to large core memory is complete. It appears that it will soon be possible to load the entire FSNM code into the CDC 7600. The PLEX preprocessor, which prepares input data for the FSNM code, is presently being tested through the use of data which have been used by Sandia to test FSNM at other installations.

Contractual Support

Neutralization

Human Parameters -- The final report which documents the integration of human parameters into Sandia's BATLE model was completed by APS and delivered to Sandia. This report* explains the logic of the model and the results of sensitivity studies which were performed.

BATLE is a small-force engagement model which can be used to simulate a battle between a security force and an adversary force. The principal information required by BATLE is the attrition rates for the guards and adversaries. These data are calculated by BATLE based on user-specified input data. Originally, BATLE only considered factors related to training, weapons, cover, and range. The work performed by APS was directed toward incorporating human factors data into the BATLE model.

The most practical way to incorporate the desired human effects was to modify the attrition rates (A for adversaries and G for guards) calculated by BATLE. This modification is accomplished in subroutine PSYCHO by the calculation of modification factors for the A and G values which are a function of four effects: (1) radiation effect (RADE), (2) visual effect (VISE), (3) stress effect (STRE), and (4) cohesiveness effect (COHE).

A summary block diagram of the total PSYCHO subroutine is shown in Figure 4. PSYCHO is entered only once to calculate the guard attrition rate modifier and once to calculate the adversary attrition rate modifier for each BATLE simulation run, regardless of the length of the simulated battle.

The attrition rate modifier is determined by averaging the four effects, or the three effects if no nuclear event is involved. Control is then returned to BATLE.

Within BATLE, program changes were made to accomplish the multiplicative degradation effect. A variable PSY is returned by PSYCHO for

---

*Arthur I. Siegel and J. Jay Wolf, Human Effects Aspects In Simulating Hostile Attacks Against Nuclear Facilities II. Development and Testing of Psychosocial Subroutine for the Brief Adversary Threat Loss Estimator (BATLE) Model, Applied Psychological Services, Inc., Wayne, Pennsylvania, September 1978.

each of the entries made per run (one for guards, one for adversaries). For each entry, PSY is calculated as a function of selected parameters:

$$PSY = PSYCHO\ (-, -, -, -)$$

In the PSY calculation for the adversary, PSYCHO uses four guard parameters to reflect the effects of these parameters on the marksmanship of the guards and thus on the attrition rate of the enemy. Modification of the attrition factors in BATLE is provided by

$$A = A \bullet PSY_a$$

The final calculation is

$$G = G \bullet PSY_g$$

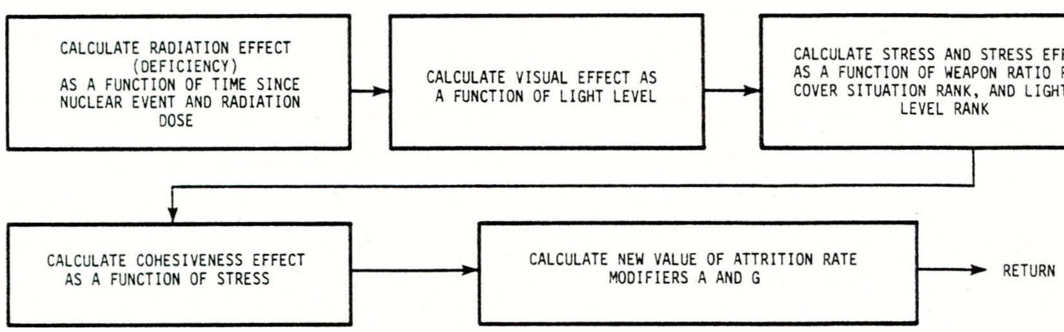

Figure 4. Block Diagram of the PSYCHO Subroutine

Following program correction and testing, APS conducted a series of sensitivity tests with the BATLE/PSYCHO model. As a base case, a battle with five guards defending against three adversaries was simulated. Both sides used shotguns and had no cover. Some of the results obtained through the use of human effects include the following:

1. A large increase in radiation dose to the personnel on one side resulted in a reduction of the PSY factor (which later reduced the rate-of-death values for the opposing side) by about 30 percent. It also increased the battle duration by about 30 percent and decreased the probability of win for the irradiated side from 0.81 to 0.66 for a battle conducted in full illumination.

2. The most significant radiation effects occurred 15 minutes after irradiation.
3. An increase in illumination level (without irradiation) over the total allowed range for either side increased the PSY factor for the personnel on the same side by about 45 percent and decreased the battle duration by about 30 percent.
4. For the adversaries, an increase in illumination level of the adversary throughout the total allowed range decreased the probability of win for the adversaries from 0.19 to 0.07 (63 percent) and, conversely, increased the probability of win for the guards from 0.81 to 0.93.
5. For the guards, an increase in illumination level of the guards throughout the allowed range decreased the probability of win for the guards from 0.81 to 0.61 (24.7 percent) and increased the probability of win for adversaries from 0.19 to 0.39.

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