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PERFORMANCE MEASUREMENT SYSTEM FOR TRAINING SIMULATORS

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ABSTRACT

In May 1976, EPRI initiated a research project, RP769, "Performance Measurement System for Training Simulators," to design, install, and test run on the Browns Ferry Nuclear Power Plant training simulator, a system capable of automatic recording of statistical information on operator action and plant response. Four exercises were developed in the initial 15 month phase: reactor criticality, plant startup, scram from high power, and main steam isolation valve closure. Key variables and actions suitable for monitoring by the training simulator computer were identified and programmed for operator actions that the computer could not monitor, checklists were prepared in a format that minimized the subjectivity of the instructor's evaluation. Since that time, the programs have been refined significantly.

The performance measurement system is expected to become a useful tool for future EPRI research projects. However, the cost of training simulator time is high; to keep research program costs reasonable, the measurement system is being designed to be an integral part of operator training programs. Furthermore, enthusiastic cooperation in the development and improvement of the measurement system can be expected from the training staffs if they see the system as being directly useful in the training programs.

ORIGINS

Three studies played important roles in starting this project. The first was the Reactor Safety Study, WASH-1400, which, in one section, performed a human reliability analysis to estimate the influence of human errors on the unavailability of various safety systems and components. The principal author of that section, Alan D. Swain, made the following complaint:

N.D.

"An actuarial data base for human error rates in nuclear power plants does not exist. Although the AEC does collect information on human errors associated with abnormal power plant incidents, the data are not generally in a form usable for human reliability anaylsis." (p. III-59)

It was Dr. Swain's view (communicated separately) that a well-designed simulator based performance measurement system could help provide a satisfactory data base.

A second precursory study was performed under EPRI project RP501, "Human Factors Review of Nuclear Power Plant Control Room Design". In that study the human factors aspects of five representative nuclear power plant control rooms were evaluated using such methods as a check-list guided observation system, structured interviews with operators and trainers, direct observations of operator behavior, task analyses and procedure evaluation, and historical error analyses. The human factors aspects of design practices were illustrated, and many improvements in current practices were suggested.

The situation selected for analysis at the four PWR simulators visited was a steam generator tube leak or rupture. The emergency hypothesized was a leak that eventually required shutdown but was preceded by diagnostic activity and control action to avoid an immediate emergency trip. At the BWR simulator investigated, the subject for task analysis was a reactor vessel feedwater valve controller failure in which the controller failed open. The researchers found that the specific sequence of events was different in each simulation run because of the interdependencies of system variables and operator actions, and because of differences in operator actions allowed within the generalized procedures. They had difficulty with complete'y and accurately recording the variable values, plant conditions, and operator actions during the fast-moving sequences. The study team recommended that any future task analyses on training simulators be made with the assistance of the simulator computers for event documentation.

The third precursory study was performed by the Simulation Products Division of the Singer Company for EPRI, covering the following tasks:

- Surveyed automated simulator performance practices, past and present, in the U.S. and foreign electric utility industries, in the aerospace industry, and in the U.S. military;
- Identified options of which parameters are to be recorded and in what format records are to be stored;
- Investigated the type of simulator hardware and software modifications which are necessary to implement the performance measurement system;
- Developed an estimate of the cost and simulator downtime which would be required to install a performance measurement system.

The present project is a direct follow-on to that feasibility study.

Description of Measurement System

With need and feasibility established in the above studies, in May 1976 EPRI contracted with General Physics Corporation to implement the performance measurement system for four drills on the Browns Ferry training simulator.

The function of the performance measurement system is to collect and evaluate simulator data. Figure 1 illustrates the systems operation. During the conduct of a simulator exercise all control room data (meters, annunciator lights, switch and knob positions) are collected by a data collection program and stored on magnetic tape. This occurs concurrent with the normal operation of the simulator (i.e., "on line"). The data collection program is added to the basic simulation program to accomplish this data collection. This program must be written in assembly language for the Browns Ferry simulator, as that language is used in all the simulation programs on the simulator.

At the end of an exercise, there is a complete and permanent record of all the simulator data that was represented during the exercise. This data can then be used to compile any of a number of different types of printouts through the use of different computer programs. These programs are implemented "off-line", i.e., when the simulator computer is not being used to drive the simulator, or evaluation of the data can be done on a computer other than the one at the simulator. The evaluation programs are written in Fortran for ease of discussion, debugging, and transfer to other simulators or computers.

Evaluations for Training

Two evaluation programs are designed primarily for use by the simulator training staff, the event chronology and the error summary. The printouts contain listings of errors made by the operators; the computer has been programmed to watch for errors considered by a group of operators, trainers, and human factors researchers to have a significant chance of occurrence.

PMS Implementation

The second phase of EPRI research project RP769 is to implement the Performance Measurement System on all simulators at the TVA Training Center, Daisy, Tennessee - Browns Ferry (GE-BWR), Sequoyah (W-PWR), and Cumberland City (fossil). Additionally, the PWR exercises will be adapted to Duke Power's McGuire simulator.

EXERCISES

Selection

The Utility Advisory Group (composed of utilities which own or have on order a nuclear power plant training simulator) met in June 1978 and selected ten exercises for development on the Browns Ferry BWR simulator and ten for the Sequoyah PWR simulator. The exercises selected are listed in Tables 1.

During 1978, the scope of the project was extended to include the development of ten exercises on the TVA Cumberland Steam Plant simulator.

Because of the different interests and emphasis with fossil generation, compared to nuclear, a Fossil Utility Advisory Group was formed to advise this extension. As a result of that group meeting in December 1978, ten exercises were selected for development on the Cumberland City simulator. Those exercises are shown in Table 1.

The exercises selected for development were designed to provide a balanced mix to support several different goals of the project. First was the requirement to support regular training in normal evolutions, normal but infrequent evolutions, accident events, and specific licensing requirements. Additionally, the mix of exercises is designed to support research in the areas of operator reliability, safety functions, and selection testing. The exercises selected represent a balanced attempt to meet all these objectives.

Development

The Electric Power Research Institute project has been expanded to develop Performance Measurement System (PMS) programs for a total of forty exercises on the Browns Ferry, Sequoyah, McGuire, and Cumberland simulators. In order to accomplish this development in an efficient, uniform fashion some standard format and progression for exercise development is required. The following instructions detail the steps involved for the development of an exercise to the point where it is turned over to the programmer:

Exercise Definition

The development of an exercise must start with a clearly defined idea of what plant evolutions are to be involved. The exercise must cover a discrete facet of plant operation suitable for evaluation and compatible with available initial conditions in the simulator. Ideally the exercise will follow operating and emergency procedures with a single correct path of operator actions which delivers the plant in the desired condition (i.e. Reactor Startup). Be alert for steps in which there are multiple paths to accomplish a given requirement. Those cases must be specifically noted in order to account for that variability of action in the programming.

Exercise Description

A. Operator Actions.--The operator/instructor providing the initial input for the exercise development must think through the selected exercise and follow it through the procedures to develop a complete list of all Operator Actions which are expected or required. This must include every switch manipulation performed by the operator in the conduct of the procedures.

B. Controlled Variables.--The operator/instructor next must define each plant parameter over which the operator exercises manual control during the exercise such as pressure, level, temperature, etc.

C. Milestone Events.--Next consider any significant milestones in the procedure/exercise which should be noted. If in doubt, list it. This should cover such things as:

> Commenced rod withdrawal, shifted ______ to automatic, reactor critical, turbine paralleled to grid, etc.

This list should also include a note on how the milestone can be detected on the simulator.

D. Error List.--The next stage of development is perhaps the most difficult. The operator/instructor must now go through the proposed sequence of events in the exercise and identify every potential error in the student operators sequence of actions. To make it manageable, list only reasonable errors for the given exercise, i.e., actions out of sequence, wrong switch, failure to ______, etc. Errors such as spilled coffee or inadvertent manual initiation of Safety Injection are usually inappropriate. To aid in programming, these errors must be further grouped into System or Process designations with amplifying data.

E. Instructor Check List.--Concurrent with the development of the above error list, compile a check list of operator functions which cannot be detected from the recorded data. These functions such as "check" and "verify" are important indicators of operator performance which unfortunately cannot be monitored by the PMS. This check list will serve as a guide for the instructor to insure he notes these important actions are accomplished.

Program Writing

With the listings of Operator Actions, Controlled Variables, Milestone Events, and Error List, the programmer should be able to write the Performance Measurement System evaluation program for the exercise under development. Recognize of course that considerable liasion will still be necessary to clarify unforeseen questions about the exercise.

Error Codes

To facilitate programming and later research data analysis, a Uniform System and Process System was devised to code errors and events. Where possible system or process designations are parallel across all three simulators. The system code I=7 refers to the Turbine/Generator in all exercises. Similarly, error 21-2 (I-J) refers to the same Reactor Water Level control error in all BWR exercises. This uniform error coding is designed to make it easier to compare data between exercises and between simulators by allowing analysis based on distributions of the occurrence of "I" system errors and individual "I-J" errors.

Evaluation

Initial attempts at using the Performance Measurement System to score operator performance met with severe difficulties. Although there is general agreement that all errors are not equally significant, attempts to scale errors, saying error X is worse than error Y met with considerable disagreement. The ranking of errors depends on many situational and personal variables which are perceived differently by various judges. The result was significant variation in scaling between even two judges for a given set of errors.

Pilot Approach

In the pilot development of the program, errors were assigned to category A, B, C, or D based on probable consequences. Class A represented worst case safety related accidents while D ranged to include very minor procedural errors. In addition to these four type groups, a numerical rank ordering was assigned over the range 1 to 20 for use in numerical evaluation of operator performance. This method generated argument because of the roughness inherent in a 4 class or 1 to 20 scaling. Additionally, the scaling of safety related errors with economic errors developed into a very sensitive issue.

Current Approach

To allow a finer classification of error and avoid the safety vs. economic controversy, current efforts are to implement a multi-attribute disutility scaling. In effect the safety and economic considerations are separated and a given error is ranked according to its consequences in each of several areas considered individually. The areas under development are:

A - Certain Safety Effects
B - Probable Safety Effects
C - Certain Economic Effects
D - Probable Economic Effects
E - Personal Consequences

A given error is not assigned as A, B, C, D, or E. Rather every error has a disutility (or adverse consequence) in each area.

Example -

Error - Failure to pull rods when loading turbine.

A	B	C	D	E		
0	2	0	3	1	=	02031

Meaning - 0 - No definite safety violation.
2 - Potential violation of tech spec (temp limit).
0 - No definite cost.
3 - Potential trip → 1 hr delay → $10 K.
1 - Negative comment by Supervisor.

This method, devised by Dr. Thomas Sheridan of MIT, is designed to allow a classification of errors without requiring an apriori ranking of the safety and economic consequences, while allowing later statistical evaluation of consequences in all areas. Extension to fossil operators will require modification of A and B categories. The system is quite complex and a detailed explanation will not be attempted here.

This "multi-attribute" method of categorization provides more information than a "single attribute" method in which a given error can be in only one category. The computer can search the error data for those errors which are at or above a certain level on one scale while at the same time at or above a certain level on another scale, etc.

Further, by judging both "certain" and "potential" consequences as above, we get estimates of both the upper limit and the 90th percentile of a distribution, enough to specify the shape in the critical range of the consequence-frequency distribution associated with the given error. For "personal reputation" errors such specificity does not seem warranted.

Data Collection Architecture

The initiation of the data collection program causes the following dynamic evaluation of the Input/Output variables. Every second the computer forms a data string consisting of all Digital Outputs (DO), Analog Outputs (AO), and Analog Inputs (AI), collected once during that second, and all Digital Inputs (DI) formed from a logical "or" of the 4 previous quarter seconds of those DI's. The "Data string" is then compared to a reference string and if any DI or DO changes during that second, or if there is a 3% (full scale) change between the reference and analog values, the data string is written on magnetic tape. If the data string is written to magnetic tape, the entire DI and DO section of the reference string are replaced by their corresponding values in the data set. If any AI or AO in the reference string differs by more than 3% from the value in the data string, that specific value is replaced by the data string value. To avoid once per second data collection, certain multipoint recorders and process computer lights have been masked from the comparison, but are stored on the magnetic tape.

Data Collection Initiation

The data collection program is a self-contained assembly language program which is initiated through push-button control at the instructor's console. Simulator hardware relationships are shown in Figure 2. To collect data, a magnetic tape is mounted on Magnetic Tape Drive #1, and placed "on-line" at the "load" point. When data collection is desired, the instructor depresses the "Par Print" button, located at his console. This action causes the "Par Print" light, to be lit, and initiates the data collection program. To terminate the data collection, the instructor again depresses the "Par Print" button which turns off the corresponding light and causes an "End of File" to be written on the magnetic tape. The data collection program is then ready to collect data for another scenario.

Data Collection Attributes

The current data collection program provides significant advantages over previous data collection for the following reasons. First, the instructor now maintains control over the data collection, determining when and for how long to collect data. Secondly, "Backtrack" and "Freeze", two important instructor's tools, are available during the data collection process. Thirdly, the data compression described in the architecture section permits the data collection program to be active for longer periods of time. Currently, a 4:1 data compression has been realized, however, because of the dynamic nature of the compression, more active scenarios have less data compression.

Minicomputer Evaluation

To evaluate the data collection tape in a reasonably short time after simulator performance, and the return of those results to the instructor was a cornerstone of the Performance Measurement System (PMS). The TVA computers could not perform background processing of the data tapes concurrent with the simulator training. Therefore, to do the evaluation required the reconfiguration of the computer from simulation to the Real Time monitoring mode, the evaluation of the data tape, and, finally, the return to the simulation mode. Additionally, because the simulators were in use for most of the day, the time available to evaluate data tapes or to write the evaluation software programs was extremely limited.

To resolve those problems, a mini-computer with a disc operating system which could be programmed to read the data tapes and evaluate the results was purchased. A Digital Equipment Corporation (DEC) 11-34 machine with a magnetic tape drive and two 5 Megabyte discs was chosen. The DEC machine was purchased principally because of its widespread usage and its capability with the McGuire simulator (also a DEC machine).

The principal advantage of the new system is the ability to evaluate a data tape immediately after exercise completion. Additionally, other advantages have been evidenced including instructor control of the evaluation program, and a generalized file structure for errors and events, and the capability for data storage and analysis.

The interactive nature of the disc operating system, coupled with an indirect command program structure permits a simulator instructor to sit down at the computer and determine which evaluation program to run. The indirect command file leads the instructor through those steps necessary to start the evaluation, and performs checks to insure that the instructor correctly utilizes the system. In this way, the need for technical assistance to perform the evaluation is avoided. The indirect command file is so general that it permits all simulator instructors to utilize the same program but performs different branches depending upon the simulator type (BWR, PWR, or FOS) and the scenario to be evaluated.

The file structure of the DEC machine has also allowed filing by system and simulator, all expected errors in all the scenarios. These errors are in the code previously described. Sample error files are shown in Table 2. This format removes the tediousness of rewriting the same message for different scenarios, permits the access of errors across scenario boundaries and saves significant computer memory during evaluation. In addition to storing the error messages, five elements of a multi-attribute list are stored with those error messages. In this way, the occurrence of an error (system number and error number) within that system, provides a direct pointer to that error message and multi-attribute description of the severity of that error.

In a similar manner, all exercise evaluation programs have been stored in separate files, each accessed by the simulator type and exercise number. Therefore, the identification of that simulator and exercise scenario, in the indirect command file, is used as a pointer to which performance measurement program is to be run. This file architecture is also used in the proposed data-base structure, to support the researchers, as shown in Figure 1.

TRAINING APPLICATION

Two evaluation programs are designed primarily for use by the simulator training staff, the event chronology and the error summary. The pr outs contain listings of errors made by the operators; the computer has been programmed to watch for errors considered by a group of operators, trainers, and human factors researchers to have a significant chance of orrurrence. A sample printout is shown in Appendix A.

The first portion of the printout is the event chronology. This lists milestone events and errors in a chronological order. The second part is an error summary, wherein errors are categorized by type error, system, and number of occurrences. The performance summary, from the pilot implementation program, has been deleted due to the aforementioned disagreements. Until the complex, but statistically valid, multi-attribute disutility scaling system is implemented; no grading is assigned.

During the pilot implementation runs, the human factors researchers debriefed each of the subjects. At the conclusion of the structured interview portion of the debriefing, the test subjects were asked to provide frank opinions regarding advantages and disadvantages foreseen for the performance measurement system. This questioning revealed a highly favorable attitude towards the purposes of the measurement program. The major advantages highlighted were:

- The program gives the trainer another evaluation tool, one which is more objective than the instructor. This tool cannot be relied on too heavily since some subjective observations made by the instructor, which cannot be measured by a computer, are important.

- An instructor is hesitant to tell utility management that a trainee won't make it. The measurement system offers a standard by which to make such a decision. If a trainee consistently makes sixteen errors per exercise and the norm is only one or two, then the instructor can use the hard copy of the exercise results to convince the utility.

- Instructors may be influenced by their likes and dislikes among trainees. There is a tendency to give the "nice guy" trainee a break. Other trainees that you dislike may be downgraded unfairly. An instructor also often equates good performance with an operating style most like his own; e.g., he operates the boards like I think I would. An objective measurement system eliminates these factors.

- Instructors can disagree over the effectiveness of a trainee. The computer could help settle such differences.

- The measurement system could pinpoint errors or deficiencies that the operator is not aware of. He can then avoid these problems in the real plant.

- The measurement program may help us find out whether an individual has supervisory capacity, whether he can make decisions, and if he has confidence in himself.

- The program may lead to layout changes on the board; perhaps making more compact control boards.

RESEARCH APPLICATIONS

Data Base

General Physics Corporation is reconfiguring the PMS software to (a read on a PDP-11 the time history tapes which are produced on the training simulators, (b) produce the training output on paper and (c) create files of summary performance data for later analysis by several training and research groups. The object of this task is to insure that the initial data base structure is as convenient as possible for later analysis processing. The purpose of this section is to present the present requirements and design of a data base structure for PMS data storage and evaluation.

The data base requirements are outlined in terms of (A) the type of data, (B) the use of data, (C) data indexing for analysis and (D) software functions for analysis.

A. Type of Data

Data will be derived from PWR, BWR, and Fossil Fuel Simulator plant evolutions and training exercises with embedded CICD's and additional task "complicating" factors. The complicating, or task loading factors might or might not be inserted by an instructor to keep a trainee challenged. The following kinds of data will be created:

- Errors by system, specific error and time of occurrence.
- Multiple attribute profiles.
- Operator response time (and correctness) to alarms and events.
- Continuous variable performance.
- Sequence and time of all control manipulations.

B. Use of Data

As seen at this time, the data will be used for the following purpose:

- By Trainers for feedback immediately after the end of a simulator training session.
- By Training Management (possibly) to evaluate class performance and training program effectiveness.
- By Researchers for:
  - Empirical measurement development and improvement.
  - Human reliability analyses (N660).
  - Control room design improvement.
  - Operator selection studies.

C. Data Indexing for Analysis

The training feedback output has been developed (for initial purposes) and is beyond the scope of this paper. An initial list of data indexing requirements for analysis by researchers has been proposed. These requirements show the number of different ways that data need to be subdivided for analysis. Therefore, the data base access and indexing requirements are defined, and the data base structure and file architecture should make it convenient to do so.

The potential requirements for data base access and indexing for training management use have also been proposed. These requirements are introduced because of past experience. When the benefits of data on each simulator run are discovered, and trainers have confidence in the system, then the training community will suggest other uses of the system. The data base structural design should recognize this as a possible future requirement so it will be convenient to incorporate.

D. Software Functions for Analysis

Data processing requirements can be divided into four major functions, (1) performance measurement evaluation (2) file status and management (3) analysis preparation and (4) data analysis.

The performance measurement evaluation programs exist at this time and perform the necessary analyses and calculations to read the time history tapes and exercise text files and generate the training output. It is planned to upgrade these programs further to allow extraction of specific data and provide additional inputs such as instructor comments.

File status and management programs are being developed to perform the obvious tasks of managing and organizing the massive file structure. Security must also be provided to determine who can do what with which files.

While performance data are collected and stored in output files sequentially, analysis programs require data to be organized in arrays by dependent, independent and covariables. The purpose of an analysis preparation program is to organize the data for each specific analysis and they might call the analysis program as a subroutine.

Data analysis programs will either read data from core or from disk files and produce listings of results. Available or required programs will need to be reviewed by each researcher to establish specific needs.

Many of the analyses are available in pre-programmed statistical packages that can be purchased at significantly less cost than programming them from scratch. There are some cautions, however. Each of the more popular packages contain slightly different features and standard disclaimers (i.e., use at your own risk). There are many different models and experimental designs that are assumed (or employed) by these canned programs and there are some features (such as Ridge regression and removal of effects of repeated measures) that are not included.

The selection and implementation of data analysis programs will be an ongoing task in itself. The issue of data analysis programs is raised here only to preview the possible requirements so that our whole processing approach is organized, and the work on data file structures will be done with an eye toward the upcoming requirements.

N-660

One of the tasks of the project is to collect data to support development of the American National Standard "Criteria for Safety-Related Operator Actions", usually referred to as the ANSI N-660 Standard. In support of this task the project team has followed the evolution of the standard, attended several working group sessions and presented to that group the potential and limits regarding use of PMS data to support N-660. The current mood is that the standard must spring from some objective data in order to be accepted. The current EPRI research project and a similar, more limited, effort by Westinghouse currently afford the only sources of such data. Final standard development will be keyed to data collection in those projects or require a retreat to subjective estimates.

Exercise selection for the project adequately supports this task with major accidents being studied on both BWR and PWR simulators. Additionally, the Development of Casualty Identification and Control Drills (CICD's) will provide a useful data base for this task area. The goal is to provide initial statistical data to the committee by late spring 1979.

Watts Bar FSAR

A corrolary to the N-660 involvement is a possible application of project PMS data to resolution of an NRC question on TVA's Watts Bar Nuclear Plant Final Safety Analysis Report (FSAR). The question concerns operator response time to a loss of Component Cooling Water to Reactor Coolant Pump oil coolers with the danger of subsequent pump overheating and rotor bearing seizure. If operator intervention is disallowed in the analysis for a period of 30 minutes, the current NRC leaning on operator action, the Reactor Coolant Pumps must be designed and tested to operate for that period without failure or additional automatic protective functions must be initiated by the loss of Component Cooling. Initial tests indicate operator diagnosis and response occurs within about 2 minutes. It is hoped a data base can be assembled to indicate the unreasonableness of the 30 minute limit.

Edison Electric Institute Selection Study

The Performance Measurement System will be used as a validation tool in a large operator selection study conducted by Personnel Decisions Research Institute under Edison Electric Institute funding. Additional work by consultants on the EPRI project deals with application of a PMS to a minicomputer driven part-task simulator for possible selection testing applications in addition to part-task training.

U. S. Navy

Recognizing the unique advantages of a computer based Performance Measurement System as a training evaluation tool, the U. S. Navy is negotiating for installation of a PMS on their Fast Frigate 1200 psi Steam Plant Simulator. Especially attractive in that environment of high personnel and instructor turnover is a standardized, objective, hard copy evaluation to uniformly access trainee performance and training program effectiveness.

SUMMARY

In summary the Performance Measurement System promises to be a valuable tool for assisting the staff on all types of training simulators. Further, it provides unique opportunities for data collection on many facets of operator-system interface for research, design, and regulatory applications.

Table 1. Exercises for Development

BWR	PWR	FOSSIL
1. REACTOR SCRAM	1. REACTOR TRIP	1. UNIT TRIP
2. REACTOR STARTUP	2. REACTOR STARTUP	2. BOILER STARTUP
3. PLANT STARTUP	3. TURBINE STARTUP	3. TURBINE STARTUP
4. MSIV CLOSURE	4. FEEDWATER STARTUP	4. UNIT STARTUP (TO 400 MW)
5. EMERGENCY SHUTDOWN	5. STEAM GENERATOR TUBE RUPTURE	5. LOAD ESCALATION (FROM 400 MW TO 1300 MW)
6. LOCA (SMALL BREAK)	6. LOCA	6. LOAD REDUCTION (FROM 1300 MW TO 400 MW)
7. LOCA (LARGE BREAK)	7. OVERALL PLANT STARTUP	7. UNIT SHUTDOWN (FROM 400 MW)
8. PLANT SHUTDOWN	8. SOLID OPERATION	8. LOSS OF MAIN FEED PUMP
9. FEEDWATER MALFUNCTIONS	9. POWER OPERATION CVCS	9. LOSS OF PRIMARY AIR FAN
10. RECIRCULATION PUMP TRIP	10. POWER ESCALATION	10. TUBE LEAK

Table 2. Sample BWR Error Files

08. BWR -- RHR SYSTEM

1XXXXXFAILED TO START A RHR PUMP.
2XXXXXFAILED TO START THE CORRESPONDING RHRSW PUMP.
3XXXXXFAILED TO OPEN THE SUPPRESSION POOL SPRAY AND RECIRC VALVE.
4XXXXXFAILED TO POSITION RHRSW HX FCV FOR 3000 GPM (INITIAL).
5XXXXXFAILED TO OPEN THE SUPPRESSION POOL RECIRC AND TEST ISOLATION VALVE.
6XXXXXFAILED TO STOP B, AND D, RHRSW PUMPS.
7XXXXXFAILED TO SATISFY CONTAINMENT SPRAY SWITCH INTERLOCK.
8XXXXXFAILED TO STOP THE CORE SPRAY PUMPS.
9XXXXXFAILED TO STOP SOME LPCI MODE PUMPS.
10XXXXXFAILED TO START THE RHRSW PUMP PRIOR TO OPENING THE HX OUT VLV.
11XXXXXFAILED TO MAINTAIN PROPER RHR FLOW IN SUPP POOL COOLING MODE OF OPERATION.
12XXXXXFAILED TO PRESS RHR RESET PUSHBUTTON FOR CONTAINMENT SPRAY.
13XXXXXFAILED TO USE PROPER RHR LOOP.
14XXXXXFAILED TO OPEN INBOARD CONTAINMENT SPRAY VALVE.
15XXXXXFAILED TO OPEN OUTBOARD CONTAINMENT SPRAY VALVE.

12. BWR -- NUCLEAR INSTRUMENTATION

1XXXXXFAILED TO SHIFT RECORDERS TO IRM FROM APRMS.
2XXXXXFAILED TO INSERT ALL SRM DETECTORS.
3XXXXXFAILED TO INSERT ALL IRM DETECTORS.
4XXXXXRECEIVED SRM HIGH ALARM.
5XXXXXRECEIVED IRM HIGH ALARM.
6XXXXXFAILED TO BYPASS FAILED SRM.
7XXXXXFAILED TO SWITCH SRM CHART RECORDER TO OPERATIONAL CHANNEL.
8XXXXXFAILED TO BYPASS FAILED IRM.
9XXXXXFAILED TO BYPASS THE RWM.
10XXXXXFAILED TO BYPASS FAILED APRM CHANNEL.
11XXXXXFAILED TO MAINTAIN IRM'S GREATER THAN DOWNSCALE TRIP.
12XXXXXFAILED TO MAINTAIN IRM'S GREATER THAN 15%.
13XXXXXFAILED TO MAINTAIN IRM'S LESS THAN 85%.
14XXXXXFAILED TO MAINTAIN IRM'S LESS THAN ROD BLOCK TRIP (108%).
15XXXXXFAILED TO MAINTAIN IRM'S LESS THAN SCRAM TRIP.
16XXXXXRETRACTED IRM DETECTORS.

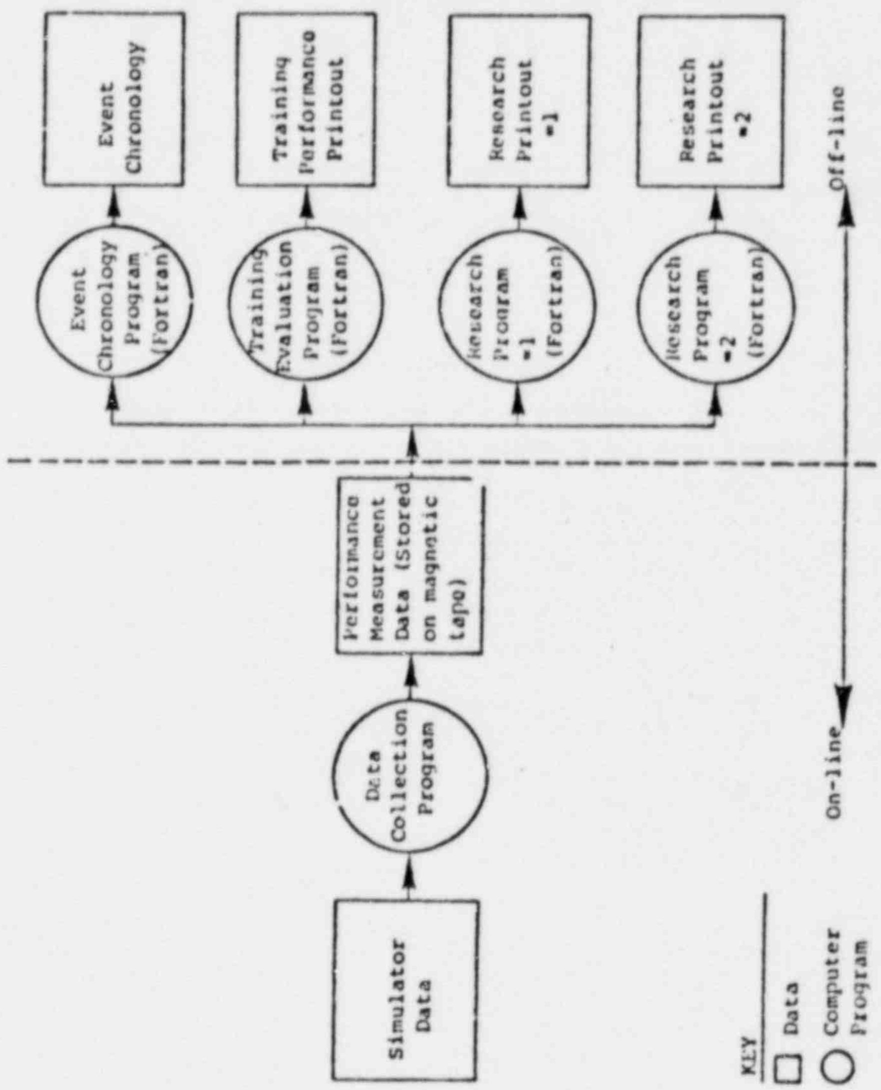

Figure 1 Structure of the Performance Measurement System

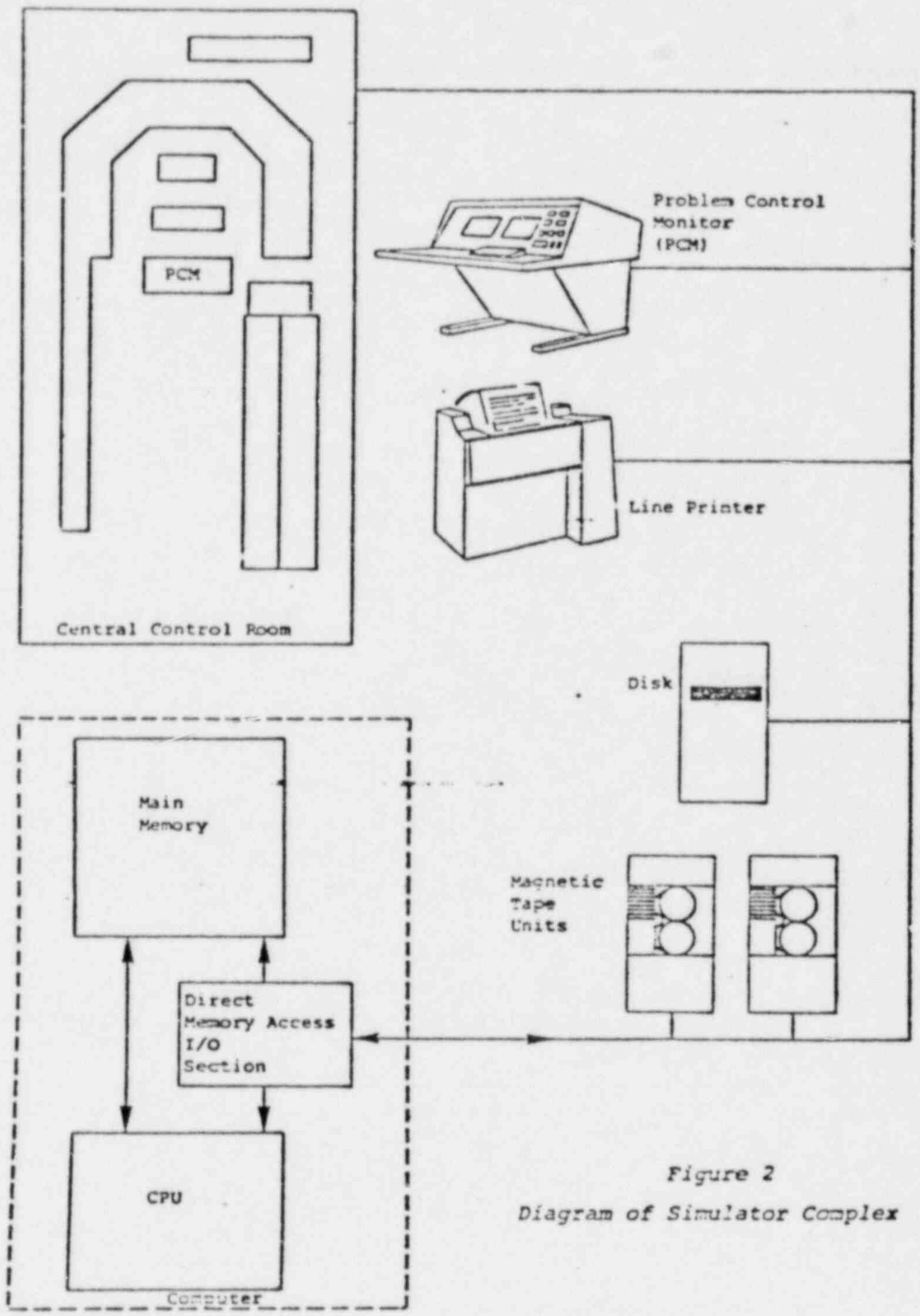

Figure 2
Diagram of Simulator Complex

E P R I

P E R F O R M A N C E   M E A S U R E M E N T

S Y S T E M

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PERFORMANCE MEASUREMENT SYSTEM
DEVELOPED FOR THE ELECTRIC POWER RESEARCH
INSTITUTE BY GENERAL PHYSICS CORPORATION
OCTOBER, 1978

DATE:25-SEP-78
RUN : 1

E V E N T / E R R O R   C H R O N O L O G Y

S E Q U O Y A H   S I M U L A T O R

S T E A M   G E N E R A T O R   T U B E   R U P T U R E

TIME HR:MIN:SEC	EVENT OR ERROR
00:00:00	START OF EXERCISE.
00:01:34	STEAM GENERATOR TUBE RUPTURE INTIATED.
00:01:35	FAILED TO CONTROL STEAM GENERATOR #1 WATER LEVEL < 38%.
00:01:35	FAILED TO CONTROL STEAM GENERATOR #2 WATER LEVEL < 38%.
00:01:35	FAILED TO CONTROL STEAM GENERATOR #3 WATER LEVEL < 38%.
00:01:35	FAILED TO CONTROL STEAM GENERATOR #4 WATER LEVEL < 38%.
00:02:08	FAILED TO SELECT BOTH SOURCE RANGE RECORDERS AFTER P-6 PERMISS..
00:03:34	PLACES TWO ADDITIONAL CHARGING PUMPS IN SERVICE.
00:04:41	COMMENCE POWER DECREASE.
00:04:41	FAILS TO ISOLATE BLOWDOWN (PRIOR TO POWER DECREASE).
00:04:41	REDUCED TURBINE POWER IN EXCESS OF 2% PER MINUTE.
00:06:57	FAILED TO MAINTAIN VOLUME CONTROL TANK LEVEL > 20%.
00:09:56	COMPLETE REACTOR SHUTDOWN.
00:09:57	FAILED TO SELECT MANUAL ROD CONTROL.
00:09:57	RETURNED STEAM GENERATOR #1 WATER LEVEL < 38%.
00:09:57	FAILED TO CONTROL STEAM GENERATOR #1 WATER LEVEL > 28%.
00:09:57	RETURNED STEAM GENERATOR #2 WATER LEVEL < 38%.
00:09:57	FAILED TO CONTROL STEAM GENERATOR #2 WATER LEVEL > 28%.
00:09:57	RETURNED STEAM GENERATOR #3 WATER LEVEL < 38%.
00:09:57	FAILED TO CONTROL STEAM GENERATOR #3 WATER LEVEL > 28%.
00:09:57	RETURNED STEAM GENERATOR #4 WATER LEVEL < 38%.
00:09:57	FAILED TO CONTROL STEAM GENERATOR #4 WATER LEVEL > 28%.
00:10:00	FAILED TO SELECT MANUAL FEED CONTROL.
00:10:11	FAILED TO MAINTAIN PRESSURIZER LEVEL ABOVE 25%.
00:10:26	TRIPS GENERATOR OUTPUT BREAKERS.
00:10:26	FAILED TO MAINTAIN STEAM GENERATOR #1 WATER LEVEL > 10%.
00:10:26	FAILED TO MAINTAIN STEAM GENERATOR #2 WATER LEVEL > 10%.
00:10:26	FAILED TO MAINTAIN STEAM GENERATOR #3 WATER LEVEL > 10%.
00:10:26	FAILED TO MAINTAIN STEAM GENERATOR #4 WATER LEVEL > 10%.
00:10:30	RETURNED STEAM GENERATOR #1 WATER LEVEL > 10%.
00:10:30	RETURNED STEAM GENERATOR #2 WATER LEVEL > 10%.
00:10:31	RETURNED STEAM GENERATOR #3 WATER LEVEL > 10%.
00:10:31	RETURNED STEAM GENERATOR #4 WATER LEVEL > 10%.
00:10:41	EXCEEDED A 100 DEG/HR. COOLDOWN RATE.
00:12:42	RETURNED COOLDOWN RATE TO < 100 DEG./HR..
00:13:19	RETURNED PRESSURIZER LEVEL ABOVE 25%.
00:13:41	COMMENCE COOLDOWN AND PRESSURE DECREASE.
00:14:23	RETURNED VOLU[illegible]NTROL TANK LEVEL > 20%.
00:16:03	FAILED TO MAINTA[illegible]SSURIZER LEVEL ABOVE 25%.
00:16:42	EXCEEDED A 10[illegible] COOLDOWN RATE.
00:17:19	RETURN[illegible]ER LEVEL ABOVE 25%.
00:17:45	FAILED TO MA[illegible]ESSURIZER LEVEL ABOVE 25%.
00:18:42	RETUR[illegible]RATE TO < 100 DEG./HR..
00:20:42	EXCEEDED A [illegible]00 DEG[illegible] COOLDOWN RATE.
00:22:42	RETURNED COOLDOWN RATE TO < 100 DEG./HR..
00:23:02	RETURNED PRESSURIZER LEVEL ABOVE 25%.
00:38:16	ISOLATED UPPER-HEAD INJECTION ACCUMULATORS TOO SOON.
00:40:58	FAILED TO MAINTAIN VOLUME CONTROL TANK LEVEL > 20%.
00:43:22	RETURNED VOLUME CONTROL TANK LEVEL > 20%.
00:58:43	ISOLATED COLD LEG ACCUMULATORS TOO SOON.

00:58:49 AFFECTED GENERATOR ISOLATED.

00:58:55 END OF EXERCISE.

00:58:55 FAILED TO SHUT MAIN FEED VALVE.
00:58:55 FAILS TO SHIFT AUXILIARY STEAM SUPPLY TO #4 STEAM GENERATOR.

DATE:25-SEP-78
RUN: .

E R R O R   S U M M A R Y

S T E A M   G E N E R A T O R   T U B E   R U P T U R E

S E Q U O Y A H   S I M U L A T O R

I. SYSTEM OPERATION

2. CHEMICAL AND VOLUME CONTROL.

NUMBER OF OCCURANCES	ERROR
1	PLACES TWO ADDITIONAL CHARGING PUMPS IN SERVICE.

3. ROD CONTROL.

NUMBER OF OCCURANCES	ERROR
1	FAILED TO SELECT MANUAL ROD CONTROL.

4. MAIN AND AUXILIARY FEED.

NUMBER OF OCCURANCES	ERROR
1	FAILED TO SELECT MANUAL FEED CONTROL.
1	FAILED TO SHUT MAIN FEED VALVE.

6. MAIN STEAM.

NUMBER OF OCCURANCES	ERROR
1	FAILS TO ISOLATE BLOWDOWN (PRIOR TO POWER DECREASE).
1	FAILS TO SHIFT AUXILIARY STEAM SUPPLY TO #4 STEAM GENERATOR.

7. TURBINE AND GENERATOR (AUXILIARIES).

NUMBER OF OCCURANCES	ERROR
1	REDUCED TURBINE POWER IN EXCESS OF 2% PER MINUTE.

9. SAFETY INJECTION.

NUMBER OF OCCURANCES	ERROR
1	ISOLATED COLD LEG ACCUMULATORS TOO SOON.
1	ISOLATED UPPER-HEAD INJECTION ACCUMULATORS TOO SOON.

11. ELECTRICAL DISTRIBUTION.

N O   E R R O R S   I N   T H I S   A R E A .

12. NUCLEAR INSTRUMENTATION.

NUMBER OF OCCURANCES	ERROR
1	FAILED TO SELECT BOTH SOURCE RANGE RECORDERS AFTER P-6 PERMISS..

II. PROCESS CONTROL.

21. PRESSURIZER LEVEL.

NUMBER OF OCCURANCES	ERROR
3	FAILED TO MAINTAIN PRESSURIZER LEVEL ABOVE 25%.
3	RETURNED PRESSURIZER LEVEL ABOVE 25%.

22. PRESSURIZER PRESSURE.

N O   E R R O R S   I N   T H I S   A R E A .

23. R.C.S. TEMPERATURE.

NUMBER OF OCCURANCES	ERROR
3	EXCEEDED A 100 DEG/HR. COOLDOWN RATE.
3	RETURNED COOLDOWN RATE TO < 100 DEG./HR..

24. STEAM GENERATOR LEVEL.

NUMBER OF OCCURANCES	ERROR
1	FAILED TO CONTROL STEAM GENERATOR #1 WATER LEVEL < 38%.
1	FAILED TO CONTROL STEAM GENERATOR #2 WATER LEVEL < 38%.
1	FAILED TO CONTROL STEAM GENERATOR #3 WATER LEVEL < 38%.
1	FAILED TO CONTROL STEAM GENERATOR #4 WATER LEVEL < 38%.
1	FAILED TO CONTROL STEAM GENERATOR #1 WATER LEVEL > 28%.
1	FAILED TO CONTROL STEAM GENERATOR #2 WATER LEVEL > 28%.
1	FAILED TO CONTROL STEAM GENERATOR #3 WATER LEVEL > 28%.
1	FAILED TO CONTROL STEAM GENERATOR #4 WATER LEVEL > 28%.
1	RETURNED STEAM GENERATOR #1 WATER LEVEL < 38%.
1	RETURNED STEAM GENERATOR #2 WATER LEVEL < 38%.
1	RETURNED STEAM GENERATOR #3 WATER LEVEL < 38%.
1	RETURNED STEAM GENERATOR #4 WATER LEVEL < 38%.
1	FAILED TO MAINTAIN STEAM GENERATOR #1 WATER LEVEL > 10%.
1	FAILED TO MAINTAIN STEAM GENERATOR #2 WATER LEVEL > 10%.
1	FAILED TO MAINTAIN STEAM GENERATOR #3 WATER LEVEL > 10%.
1	FAILED TO MAINTAIN STEAM GENERATOR #4 WATER LEVEL > 10%.
1	RETURNED STEAM GENERATOR #1 WATER LEVEL > 10%.
1	RETURNED STEAM GENERATOR #2 WATER LEVEL > 10%.
1	RETURNED STEAM GENERATOR #3 WATER LEVEL > 10%.
1	RETURNED STEAM GENERATOR #4 WATER LEVEL > 10%.

25. STEAM GENERATOR PRESSURE.

N O   E R R O R S   I N   T H I S   A R E A .