# A PERFORMANCE MEASUREMENT SYSTEM FOR TRAINING SIMULATORS

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SUMMARY

Unscheduled power plant outages are very costly and waste energy because that electrical energy must then be transmitted over longer distances from other plants to the locality whose power station is out-of-service. Better trained plant operators as well as better designed plant control and safety systems are germaine in this day and age when our world's emphasis is on conservation of natural resources.

This paper presents a Performance Measurement System that can be utilized for optimizing operator training efforts along with collecting man-machine operational research data on a training simulator. This system was developed for the Electric Power Research Institute (EPRI) and further work on this project is continuing. This paper presents a basic introduction to the system, methodology incorporated in its design, data and results obtained, as well as future plans for the coming three-year term.

## I. INTRODUCTION

### 1.1 Background

Full-scale, real-time simulators have become a key element in the training of nuclear power plant operators. These simulators provide effective operational training without costly plant downtime and they permit training on important abnormal and emergency conditions which cannot be conducted on an operating plant. In addition to their direct training value, these simulators offer a unique opportunity to investigate important aspects of power plant operation. In 1975, the Electric Power Research Institute (EPRI) initiated a program to investigate the use of training simulators for the following purposes:

- To provide an empirical data base for statistical analysis of operator reliability and for allocation of safety and control functions between operators and automated controls.
- To develop a method for evaluation of the effectiveness of control room designs and operating procedures.
- To develop a system for scoring aspects of operator performance to assist in training evaluations and to support operator selection research.

This effort is directed by Dr. Randall W. Pack, Nuclear Engineering and Operations Department, EPRI, and is advised by a Utility Advisory Group (UAG) composed of representatives of utility companies owning or having on order a nuclear power plant simulator. Project participants include individuals and organizations with expertise in nuclear power plant operations and training, simulator design and construction, mathematical modeling of human operator performance, human factors engineering, and selection testing.

In the first phase of this program, EPRI contracted with The Singer Company, Simulation Products Division, to study the feasibility of a standardized performance measurement system using simulation techniques. Singer concluded that such a program is feasible and recommended that one or more prototype performance measurement systems be developed and implemented on selected current generation nuclear power plant simulators.

Subsequent to the Singer study, the Tennessee Valley Authority (TVA) expressed interest in participating in operator performance measurement research using the power plant simulators being constructed at the TVA Power Production Training Center at the Sequoyah Nuclear Power Plant site near Daisy, Tennessee. This Training Center, equipped with simulators for the Sequoyah PWR Nuclear Power Plant, the Browns Ferry BWR Nuclear Power Plant and the Cumberland fossil fueled plant, will provide all the facilities needed for a comprehensive program applying simulation techniques to the study of plant operations.

Having concluded that development of a performance measurement system is feasible and having identified simulator facilities that could be used for this purpose, EPRI initiated a one year project to develop a prototype Performance Measurement System for Training Simulators. Work was started on 1 May 1976 and the initial series of four exercises was pilot implemented on the Browns Ferry Simulator at the TVA Power Production Training Center during the week of 21 March 1977.

The one year feasibility demonstration project demonstrated that the Performance Measurement System has excellent potential for supporting research in the following areas:

- Training techniques and methodology
- Human factors aspects of control room design
- Personnel selection
- Operator reliability analysis

## 1.2 Applications of the System

The techniques for developing a Performance Measurement System described in this paper can be adapted to any current plant simulator. Data collection, performance evaluation, and research programs can be prepared in the fashion for any application - be it aircraft, chemical plant, or military trainer.

Simulator Performance Measurement Systems appear to be potentially very useful to the Navy training community. In the area of training evaluation, they offer the potential for quantitative, standardized evaluation of a ship or aircraft ASW team, a flight crew, or an air defense team. Not only could the operational readiness of the team be measured against a known standard, but the effectiveness of the training could be assessed by comparison of pre- and post-training evaluations. The use of an impartial instrument such as the simulator computer to assist with performance evaluations can also provide more consistent and useful measures of performance than those generated by human evaluators alone, especially in an environment where instructor turnover is relatively rapid.

For the Navy, tactical development requires data on man-machine performance, in the same manner that such data is needed for research in the EPRI Performance Measurement System. With a high fidelity simulation, the effectiveness of new tactics and hardware can be evaluated in the semi-controlled environment of the training simulator. Operator performance and hardware deficiencies can be identified precisely, and appropriate action initiated to correct these problems. In an era of funding restraints, the use of training simulators to develop such operational data appears to be much more cost-effective than the use of numerous large-scale fleet exercises. Additionally, data collected in real-time on the trainers is subject to far fewer perturbations than data collected at sea. Obviously use of sophisticated simulators will not eliminate the need for training exercises at sea, but a proper mix of simulator and at-sea exercises could result in improved tactical development data, gathered in a more cost-effective manner.

## 1.3 Project Status

The following summarizes the progress made on this project between January 1, 1977 and May 1, 1977.

- The prototype Performance Measurement System was successfully pilot implemented at the Browns Ferry BWR Simulator. Four test exercises were run several times during the pilot implementation week. These test exercises were: Reactor Criticality, Plant Startup, SCRAM from High Power, and Main Steam Isolation Valve (MSIV) Closure.
- This paper contains the data and analysis for three of these exercises, namely: Reactor Criticality, Plant Startup, and SCRAM from High Power. These three exercises were carefully reviewed by General Physics and several computer program updates were made for each. It is believed that these three exercises are presently complete. The evaluation computer program for the MSIV exercise is currently nearing completion at the time of this writing.
- Human factors specialists from Lockheed Missiles and Space (LMSC) observed the man-machine interfaces associated with the exercises as they were being run on the Browns Ferry BWR Training Simulator. They also interviewed each of the participants following the exercises. The report of their findings is published in a report entitled "Pilot Study Performance Measurement System for Training Simulators," EPRI Project RP 769-1, 21-25 March 1977, by J. L. Seminara and S. K. Eckert, April, 1977.[1]
- Dr. Richard S. Barrett, Director of the Applied Psychology Division of

[1] These reports are included in a General Physics Report entitled "Electric Power Research Institute Project RP 769-1, Performance Measurement System for Training Simulators, Third Progress Report, GP-R-321, May 27, 1977, by C. F. Kupiec and R. D. Graves.

the Stevens Institute of Technology, observed the pilot implementation of this prototype system. He has prepared suggestions with regard to *research in operator selection and* presented them in a report entitled "Report of Observations Made on March 21 and 22 at the TVA Simulator."[1]

- Dr. Thomas D. Sheridan of MIT, a member of this project team, observed the pilot implementation exercises and has made suggestions regarding future evaluation exercises. He suggests that Casualty Identification and Control Drills (CICD's), of short time duration, be incorporated for some future exercises. Exercises of this sort would be a potential source of much operational research data because each CICD could be performed many times by many operators. He has also suggested drills of longer time duration to provide data relevant to the ANSI-N660[2] decision concerning the **reliability** of operator diagnosis and response as a function of time. Dr. Sheridan has prepared preliminary ideas for utilization of these exercises for future research.

- The computer data presented is also compared with the subjective instructor's evaluation for each of the test exercises. The instructor data proved invaluable in verification of the validity of the test exercises.

- The use of exercise videotaping was incorporated during the test exercises. This was a valuable review tool for the evaluator and operator both.

*Refer to Figure 1.*

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[1]These reports are included in a General Physics Report entitled "Electric Power Research Institute Project RP 769-1, Performance Measurement System for Training Simulators,"Third Progress Report, GP-R-321, May 27, 1977, by C. F. Kupiec and R. D. Graves.

[2]ANSI Standard N-660 "Criteria for Safety Related Operator Actions." The purpose of this proposed standard is to provide criteria to decide whether initiation or adjustment of a safety system provided to mitigate the consequences of a *design basis event may be accomplished by a* human operator or must be augmented by an automatic protection system.

### 1.4 Project Organization

In organizing this project, EPRI assembled a well-balanced team with expertise in several different fields to ensure that the prototype performance measurement system would, to the maximum extent practicable, achieve the program goals. The project organization, illustrated in Figure 2, includes expertise in nuclear power plant operations and training, simulator design and construction, mathematical modeling of human operator performance, human factors engineering, and selection testing.

Additionally, and of paramount importance to this development effort, the project is reviewed by a Utility Advisory Group (UAG) composed of representatives from utility companies which own or have on order a nuclear power plant training simulator. By having first-hand input from the UAG, other project participants can help to assure that the project is conducted in a manner useful in the utility companies.

The Utility Advisory Group is currently comprised of representatives from the following utility companies:

- Carolina Power and Light Company
- Consolidated Edison Company of New York
- Duke Power Company
- Pennsylvania Power and Light Company
- Tennessee Valley Authority
- Virginia Electric and Power Company
- *Washington Public Power Supply* System
- Arizona Public Sérvice Company

Additionally, representatives of the ANS-50 committee who are currently developing ANSI Standard N-660, Criteria for Safety Related Operator Actions, have recently begun formal interaction with the project team. *Empirical data generated from* simulator exercises can be of great value to this committee, and their participation is intended to assist the project in developing and providing this data in the appropriate form.

## II. COMPUTER EVALUATION PROGRAM METHODOLOGY, PROGRAM WRITING AND DEBUGGING

### 2.1 Methodology

The programming goals of the current EPRI project were set forth as follows:

- The construction of a real-time simulation module to collect and *permanently store on magnetic tape* the entire contents of the simulator I/O buffer at a rate

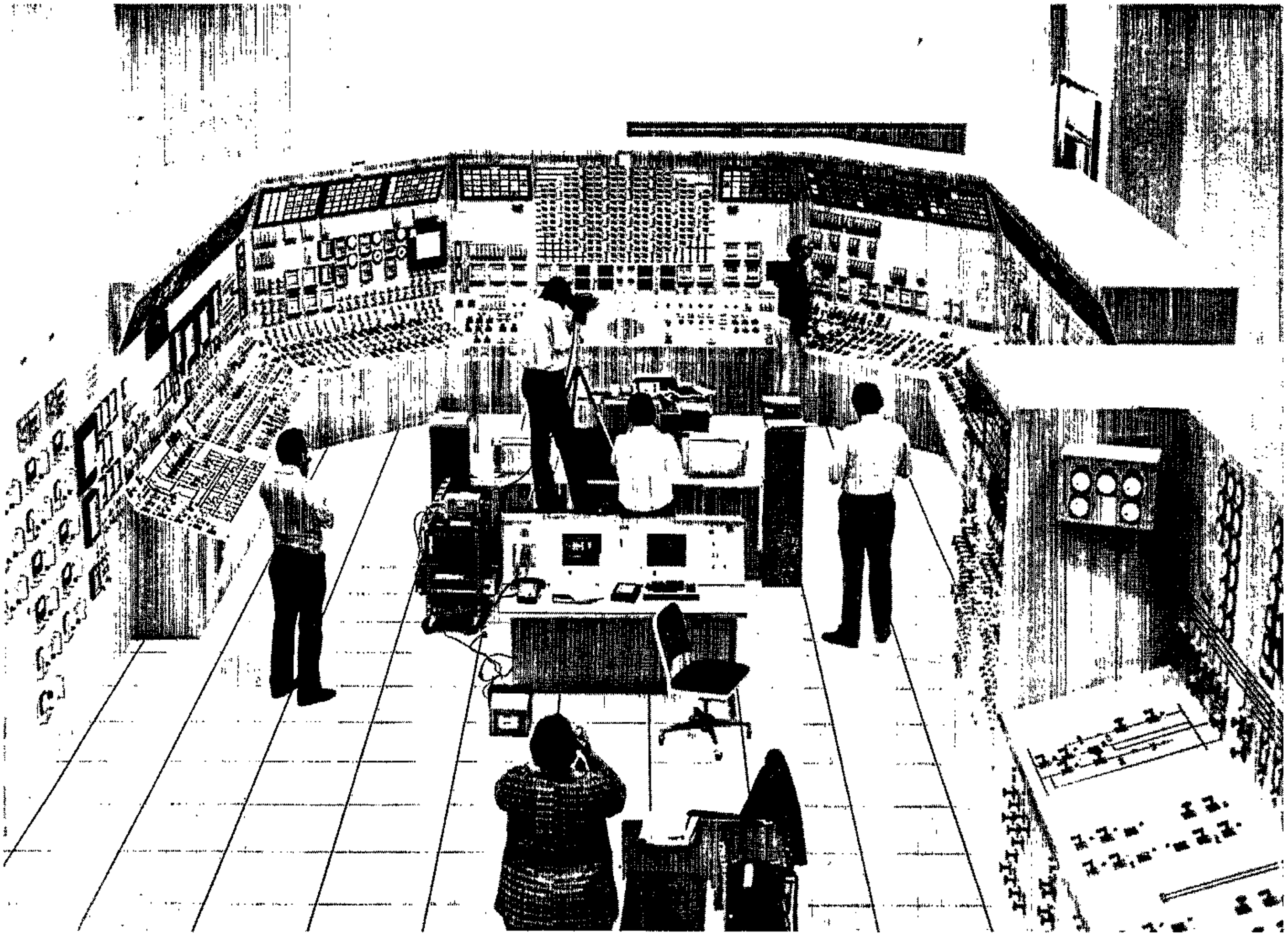

Figure 1. Brown's Ferry BWR Simulator Control Room at the TVA Power Production Training Center during the implementation of the Prototype Performance Measurement System.

| INDIVIDUAL/ORGANIZATION | PROJECT INVOLVEMENT |
| --- | --- |
| Dr. Randall W. Pack<br>• Nuclear Engineering and Operations Department, EPRI | • EPRI Project Manager |
| Utility Advisory Group (UAG)<br>• Representatives from utility companies which own or have on order nuclear power plant simulators | • Advise the project to ensure that the system is implemented in a manner that is most beneficial to utility companies |
| General Physics Corporation<br>• A leader in providing training services to the nuclear industry | • Responsible for EPRI implementation of the system |
| The Singer Company, Simulator Products Division<br>• A leader in the design and production of simulators for the military and for industry | • Provide expertise on simulator hardware and software |
| Dr. Thomas B. Sheridan<br>• Professor of Mechanical Engineering, Massachusetts Institute of Technology and Head of the Man-Machine Systems Laboratory at MIT.<br>• Has conducted extensive research on mathematical models of human operator performance. | • Advise the project to ensure that it is used effectively to support the development of operator models and the conduct of operator reliability research |
| Lockheed Missiles and Space Company<br>• Has extensive experience in human factors engineering for the aerospace industry.<br>• Has completed a study of human factors engineering aspects of nuclear power control room design. | • Advise the project to ensure that it is used effectively in support of research directed at improved control room design. |
| Dr. R. S. Barrett<br>• Professor, Stevens Institute of Technology<br>• Has developed and critiqued Selection Programs for numerous industrial clients, including utility companies. | • Advise the project to ensure that it is used effectively in support of personnel selection research |

Figure 2. Project Organization, Performance Measurement System for Training Simulators

sufficiently rapid to accurately determine the state of the particular piece of datum being sampled.

- The construction of a set of computer algorithms to evaluate training exercises using as a data base the data collected and stored on magnetic tape via the real-time data collection program.

In these data collection programs, a complete set of boolean and analog data is collected, which at a given instant of time represents the state of the several thousand switches, lights, meters, recorders, etc., present in the plant control room. The reason for collecting all of these data is that certain data will be utilized in research programs to identify man-machine operational characteristics while other data will be used in evaluating the operator's performance for the given exercise.

The principal function for maintaining a record of all data is to enable the research analyst to go back and evaluate other parameters at a later time if deemed necessary.

The research effort currently under way incorporates reviewing an operator's performance in detail so as to better define the man-machine operational strengths, as well as weaknesses. In this way, a better understanding of operator reliability can be obtained as well as the pin-pointing of plant control shortcomings. This type of data would be beneficial for control room design as well as identifying incorrect operational techniques.

## 2.2 Program Writing and Debugging

There are five basic steps in the construction of any computer program:

- Construct Algorithm
- Generate Computer Code
- Determine Input Data
- Determine Output Data
- Debug Exercises

The first step, "Construct Algorithm," is simply the construction of the logical rules by which one evaluates whatever one wishes to evaluate and is independent of any particular computer language. This is the most crucial step in the construction of an evaluation program and it is necessary that it be done in conjunction with a knowledgeable reactor operator instructor, preferably the person who drafted the exercise. Close cooperation between programmer and instructor on this step will result in a good evaluation program in a minimum amount of time.

The second step, "Generate Computer Code," is a FORTRAN realization of the evaluation algorithm. In other words, the algorithm is cast in a language the computer understands. The evaluation exercises written for this project were written in Extended FORTRAN IV except for certain data transforming subroutines which had to be written in Assembly Language. The structure of the code for the four programmed exercises is not identical in that to some extent programming these exercises was a learning process for the programmer. In the programming of future exercises, it is suggested that a technique called "structured programming" be adhered to as closely as possible. In this technique, the code is generated from top to bottom in such a manner that each block of code has only one entry point, one exit point and no unconditional branches. This means that each block of code is independent instead of interdependent as is the case in most computer programs and can be debugged easily.

In the third step, "Determine Input Data," is lumped together a number of substeps: (1) the simulator instructor and the programmer must decide together what data is required to evaluate each step of the exercise. This data could be a switch position, a lamp output, a rod position, a meter indication, or a combination of one or more of the above. After these determinations have been made, the programmer must consult with the simulator manufacturer to determine where in the I/O buffers this data resides and in what form. For example, a certain piece digital datum needed may be bit 13 of the 631 word of the I/O. After the locations and forms of the data are obtained from the simulator manufacturer, the programmer must determine how to translate this data into a FORTRAN representation. A number of standard FORTRAN callable assembly language subroutines have been written to accomplish this. For example, the standard subroutine TEST BITS will process any number of bits of an I/O word and return to the FORTRAN program the boolean representation of those bits.

The fourth step, "Determine Output Data," is really only a programming step in the sense that the program must produce a printout of error messages and scores. The form of the programs used to produce the printouts is now standard. However, in spite of this, a large amount of time and programming effort is expended in producing the printouts. This is because a given exercise can have a large number N of possible errors associated with it. A printout requires 6N FORTRAN error statements. Currently we are devising a method for the follow-on project which will use N free form error messages as input data to a standard print subroutine. The standard print subroutine would utilize the alphanumeric string manipulation capabilities of FORTRAN via the encode/decode subroutines. The use of this method will greatly reduce the time and effort currently spent on this step of the programming.

The last step, "Debug Exercise," is another one which requires close cooperation between the programmer and simulator instructor. First, the input data to this evaluation program should be printed out and closely inspected to ensure that the I/O locations were correct and that the data subroutines are interpreting the data correctly. Next, the evaluation program should be run using data from exercises which are expected to be error free and exercises which contain known errors. The printouts from these exercises should then be carefully scrutinized by both simulator instructor and programmer and any discrepancies noted. The errors which are found are usually simple and easy to correct. However, in exercises which contain complex process control blocks, nonprogramming errors can occur which indicate the process is being misevaluated. Major revision of the code may then be necessary. It is for this reason that the use of structured programming techniques is recommended. If the program is structured, the offending block of code will be logically independent of other program blocks and can be easily reprogrammed.

## III. PILOT IMPLEMENTATION DATA AND RESULTS

### 3.1 Schedule

Pilot Implementation of the Performance Evaluation System was performed during the week of March 21, 1977. It took place at the Browns Ferry simulator at the TVA Power Production Training Center. This consisted of conducting each of the four pilot exercises utilizing TVA operators, a training coordinator from Washington Public Power Supply System and members of the General Physics training organization. The four exercises utilized in this pilot implementation were:

- Criticality (Individual Exercise)
- SCRAM (Individual Exercise)
- Startup (Group Exercise)
- Main Steam Isolation Valve Closure (Group Exercise)

1. Reactor Criticality (Individual Exercise

   SCENARIO

   The reactor is shutdown by approximately -1%Δk/k. Seven control rods must be sequentially withdrawn to achieve criticality. During this time, the reactor operator must follow correct control manipulations to enable the reactor to achieve criticality. The exercise is terminated when the reactor vessel water temperature is increased by approximately 10°F.

2. Reactor Scram From Power Operation (Individual Exercise)

   SCENARIO

   The plant is operating at ≈ 50% power. After several minutes of steady state operation, the generator trips due to a single phase fault between the generator and the generator breaker in the switchyard. The operator must respond to this trip and the resultant reactor scram without help from additional operators. The plant will not be restarted. The exercise is terminated upon being ready to restart or commence cooldown.

3. Plant Startup (Group Exercise)

   SCENARIO

   Reactor is critical at 10% power with approximately 3 Bypass Valves open. Reactor water level is in manual control with the "A" Reactor Feed Pump in service. The main turbine has been on the turning gear for two hours in preparation for startup following turbine maintenance.

   Startup and synchronize the Unit in accordance with correct procedures. Use the simulator telephone to request the performance of evolutions required outside the control room. The reactor operator is responsible for the operation of the reactor including water level and reactor auxiliaries. The Turbine operator is responsible for all evolutions. Record the events in the Daily Journal.

4. Main Steam Isolation Valve Closure (Group Exercise)

   SCENARIO

   The plant is operating at full power. After several minutes of operation, the generator trips due to a single phase fault between the generator and the generator breaker in the switchyard. The crew (2 operators) must respond to this trip and the resultant reactor scram and Main Steam Isolation. The objective is to verify the safe shutdown of the reactor and turbine and to stabilize control of the reactor pressure and water level. The plant will be cooled down in the isolated condition. The exercise is terminated when cooldown has been established.

3.2 Scope

The principal purpose of this Pilot Implementation was to demonstrate the feasibility of the Performance Evaluation System. It was also utilized to obtain further information on the potential uses of the system for training and research. In addition, valuable data was also obtained to improve each of the four exercises.

This week of simulator exercises was successfully completed at the Browns Ferry simulator. All of the scheduled exercises were completed and the following was accomplished with each exercise:

1. As each exercise was conducted, operational data was collected on magnetic tape. These magnetic tapes were subsequently utilized as data input into the computer program utilized to evaluate the reactor operator performance.

2. During each simulator exercise, one or more experienced evaluators observed the operation and completed an evaluator checklist as the exercise was conducted. It was intended that these subjective evaluations provide a preliminary assessment of how the system performance data correlates with the observations of these experienced observers.

   The subjective instructor evaluations will be used as a rough comparison against the computer results. The details of the computer printout is the subject matter of section 3.3.

3. Each exercise was videotaped, which proved to be most beneficial during the post-exercise interviews and evaluation of each operator's performance on the simulator.

4. A post-exercise operator interview was conducted by the human factors, selection testing, and modeling consultants. The purpose of this interview was to get data on the operator's opinions of these exercises along with his judgement of the relative difficulty of the tasks required for performance.

The section which follows includes the details of the computer printout employed in the reactor operator performance evaluation.

3.3 Computer Printout for the Pilot Implementation Exercises

For the purpose of illustration, the complete computer printout facsimile from the first computer graded exercise carried out at the Browns Ferry simulator is presented in this section in Figures 3(a)(b)

A performance summary for each of the pilot implementation runs carried out during this program is presented in section 3.4 along with the instructor evaluation summary for each exercise.

At this time, however, let's consider the information tabulated in Figures 3 (a)(b) Note that the information presented therein is done so in several different ways. This is done so as to enable the instructor to evaluate the student's performance quickly and easily. The following data tabulations are compiled in each computer printout.

1. Event/Error Chronology

   The chronological tabulation of key events along with the errors incurred is tabulated first. Each error is identified according to its type (namely, A, B, C or D). A listing of this type enables the instructor to obtain a broad overview of the student operator's performance in the exercise. Figure 4 includes the compilation of the classification of errors considered in these exercises.

2. Performance Summary

   This portion of the computer printout tabulates the total number of errors incurred along with the maximum possible score and actual score achieved for the exercise. For example, in Figures 3(a)(b) computer printout for the criticality exercise, the operator was responsible for one C-Type error and several D-Type errors in the neutron monitoring portion of his total exercise. The performance summary portion of the computer printout tabulates the criticality

EVENT/ERROR CHRONOLOGY
INDIVIDUAL EXERCISE/REACTOR CRITICALITY
BROWNS FERRY SIMULATOR

Date: 3/21/77
Run I1-1

| TIME HR:MIN:SEC | EVENT OR ERROR | TYPE |
|---|---|---|
| 00:00:00 | Start the Exercise | |
| 00:02:41 | Operator Commences Rod Withdrawal | |
| 00:07:28 | * Failed to Conduct Rod Overtravel Test | B |
| 00:09:44 | * Failed to Conduct Rod Overtravel Test | B |
| 00:18:11 | * Failed to Conduct Rod Overtravel Test | B |
| 00:24:29 | Reactor Critical | |
| 00:28:42 | * Failed to Maintain IRM Greater than 15% | D |
| 00:29:11 | * Withdraw SRM Detectors Prior to IRM Band 3 | C |
| 00:29:18 | * Failed to Shift SRM Recorders to Slow | D |
| 00:29:18 | * Failed to Maintain IRM Less than 85% | D |
| 00:29:27 | * Failed to Maintain IRM Less than 85% | D |
| 00:44:29 | Reactor Adding Heat | |
| 01:01:43 | * Calculated Heat-up Rate Incorrectly | D |
| 01:01:43 | End of Exercise | |

PERFORMANCE SUMMARY
INDIVIDUAL EXERCISE/REACTOR CRITICALITY

| TASK | TOTAL NUMBER ERRORS OF EACH CLASS A | B | C | D | POSSIBLE SCORE | SCORE | % |
|---|---|---|---|---|---|---|---|
| I. System Operation | | | | | | | |
| 1. Neutron Monitoring | 0 | 0 | 1 | 4 | 35 | 27 | 77.1 |
| 2. CRD (Control Rod Drives) | 0 | 3 | 0 | 0 | 28 | 13 | 46.4 |
| 3. RPS (Reactor Protection) | 0 | 0 | 0 | 0 | 3 | 3 | 100.0 |
| II. Process Control | | | | | | | |
| 1. RCS Temperature Control | 0 | 0 | 0 | 0 | 26 | 26 | 100.0 |
| 2. Reactivity/Power Control | 0 | 0 | 0 | 0 | 18 | 18 | 100.0 |
| 3. RX Water Level Control | 0 | 0 | 0 | 0 | 15 | 15 | 100.0 |
| III. Administrative | 0 | 0 | 0 | 1 | 10 | 7 | 70.0 |

| TIME FACTORS | MEAN (MINUTES) | THIS EXERCISE (MINUTES) |
|---|---|---|
| 1. Start to Achieve Criticality | 0 | 24 |
| 2. Criticality to Point of Adding Heat | 0 | 20 |
| 3. Total Exercise | 0 | 61 |

Figure 3 (a). Computer Printout for Criticality Exercise Showing Event/Error Chronology, Performance Summary and Time Factors

ERROR SUMMARY
INDIVIDUAL EXERCISE/REACTOR CRITICALITY

## I. SYSTEM OPERATION

1. Neutron Monitoring:

| TIME HR:MIN:SEC | ERROR | TYPE |
|---|---|---|
| 00:28:42 | * Failed to Maintain IRM Greater than 15% | D |
| 00:29:11 | * Withdrew SRM Detectors Prior to IRM Range 3 | C |
| 00:29:18 | * Failed to Shift SRM Recorders to Slow | D |
| 00:29:18 | * Failed to Maintain IRM Less than 85% | D |
| 00:29:27 | * Failed to Maintain IRM Less than 85% | D |

2. CRD:

| TIME HR:MIN:SEC | ERROR | TYPE |
|---|---|---|
| 00:07:28 | * Failed to Conduct Rod Overtravel Test | B |
| 00:09:44 | * Failed to Conduct Rod Overtravel Test | B |
| 00:18:11 | * Failed to Conduct Rod Overtravel Test | B |

3. RPS:

| TIME HR:MIN:SEC | ERROR | TYPE |
|---|---|---|

No Errors in This Task

## II. PROCESS CONTROL

1. RCS Temperature Control:

| TIME HR:MIN:SEC | ERROR | TYPE |
|---|---|---|

No Errors in This Task

2. Reactivity/Power Control:

| TIME HR:MIN:SEC | ERROR | TYPE |
|---|---|---|

No Errors in This Task

3. RV Water Level Control:

| TIME HR:MIN:SEC | ERROR | TYPE |
|---|---|---|

No Errors in This Task

## III. ADMINISTRATIVE

| TIME HR:MIN:SEC | ERROR | TYPE |
|---|---|---|
| 01:01:43 | * Calculated Heat-up Rate Incorrectly | D |

Figure 3 (b). Computer Printout for Criticality Exercise Showing Error Summary

| CATEGORY | CLASSIFICATION OF ERROR |
|---|---|
| A. | Error which would have very serious consequences with regard to reactor safety and operation.<br><br>Criteria:<br><br>(1) Operation that results in violation of a Technical Specification safety limit.<br><br>(2) Operation that results in an unscheduled release of radioactive materials to the environs.<br><br>(3) Operation that results in equipment damage rendering the plant unavailable. |
| B | Error which may have, or may lead to, serious consequences with regard to reactor safety and operation or may substantially reduce safety margins.<br><br>Criteria:<br><br>(1) Operation that invalidates any assumption in the Safety Analysis.<br><br>(2) Operation that results in the violation of a Technical Specification Limiting Condition for Operation.<br><br>(3) Operation that, if uncorrected, could result in a violation of a Technical Specification Safety Limit.<br><br>(4) Operation that, if uncorrected, could result in equipment damage rendering the plant unavailable. |
| C | Error which interrupts or causes degraded plant operation but does not affect or threaten reactor safety.<br><br>Criteria:<br><br>(1) Operation that results in the initiation of an Abnormal Operational Transient.<br><br>(2) Operation that violates an approved station procedure.<br><br>(3) Operation that results in the activation of an automatic protective system. |
| D | Errors which, unto themselves, do not degrade plant operations directly but which are indicative of faulty judgement or lack of attention to detail and, if uncorrected, may cause or become an error of another category.<br><br>Criteria:<br><br>(1) Operation that, if uncorrected, could result in actuation of an automatic protective system.<br><br>(2) Operation that, if uncorrected, could result in the violation of a Technical Specification Limiting Condition of Operation.<br><br>(3) Operation inconsistent with accepted "good operating practices."<br><br>(4) Operation outside of boundaries of "normal operation."<br><br>(5) Operation that violates an approved station procedure. |

Figure 4. Classification of Errors

exercise tasks according to three major categories. These are:

I. System Operation
II. Process Control
III. *Administrative*

This is quite useful in that it allows the instructor/evaluator to tell at a glance which major areas that the operator-in-training may have had exhibited difficulty.

3. Time Factors

A separate tabulation of the important operational times is tabulated chronologically to identify how long it took the operator to accomplish the assigned task.

4. Error Summary

A complete error summary identified according to assigned task as well as type of error is also tabulated at the end of the computer printout. It is felt that the printout in this manner enables the instructor to review the student's performance in a clear, well-organized manner.

### 3.4 Pilot Implementation Exercise Data

There were 20 runs carried out to test the feasibility of the performance measurement system for training simulators. These runs included the four exercises *discussed in section* 3.1.

As was shown in section 3.3, the computer printout data outlines the reactor operator's performance in several different ways.

At this time, let us consider the overall data as compiled during these pilot implementation runs which is currently complete. This data is compiled in a tabular form which compares the objective computer grade with the subjective evaluator's grade for the test exercises. The following figures identify the comparison in performance grading between the two techniques:

- Figure 5, Grading Comparison for the Criticality Exercises
- Figure 6, Grading Comparison for the SCRAM Exercises
- Figure 7, Grading Comparison for the Startup Exercises

A brief perusal of these data discloses that the computer data correlates reasonably well with the subjective evaluations made by the instructor for that particular exercise. However, there are several exceptions to this close correlation in which the instructor evaluation and the computer evaluation are separated by more than *several percent*.

Although it was not the original intention of this report to evaluate these differences between the two sets of grades, it is believed that in actual practice such differences could arise and would necessarily have to be examined.

Section 3.5 which follows will consider the results of this data evaluation and examine the strengths and possible shortcomings of the computer evaluation technique.

### 3.5 Pilot Implementation Exercise - Results and Analysis

1. *Analysis of the Criticality Exercises*

From the computer printout of the performance summary as compared to the instructor evaluation as shown in Figure 5, the major areas of grading differences were in Neutron Monitoring, Control Rod Drive, and Administrative sections.

After a discussion with the instructor/evaluator concerning this exercise the following facts became apparent:

a. With regard to the neutron *monitoring system, it was* difficult for the instructor to continually determine if all of the IRM detectors were properly on scale.

b. In regards to shifting the SRM recorders to slow speed prior to detector retraction, it was felt by the operator that this task was likely to be forgotten because of other tasks which were more pressing.

c. With regard to the control rod drive section, the computer evaluation program only considered *one method of determining* if the rod had been properly overtravel tested. In reality however, there is more than one way to validly overtravel test the rod. The computer program is being updated to reflect the ways the rod can be overtravel tested.

| EXERCISE NUMBER | (1) 3/21/77 #1 | | (2) 3/21/77 #2 | | (3) 3/22/77 #1 | | (4) 3/23/77 #1 | | (5) 3/23/77 #2 | |
|---|---|---|---|---|---|---|---|---|---|---|
| COMPUTER GRADE / SUBJECTIVE EVAL. GRADE | Comp. | Subj. Eval. | Comp. | Subj. Eval. | Comp. | Subj. Eval. | Comp. | Subj. Eval. | Comp. | Subj. Eval. |
| I. SYSTEM OPERATION | | | | | | | | | | |
| 1. CRD | 46.4 | 60 | 46.4 | 100 | 46.4 | 100 | 100 | 100 | 100 | 90 |
| 2. NMS | 77.1 | 80 | 97.1 | 100 | 100 | 100 | 74.3 | 100 | 100 | 90 |
| 3. RPS | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| SUBTOTAL | 65.2 | 72.4 | 75.8 | 100 | 77.2 | 100 | 86.4 | 100 | 100 | 90.5 |
| II. PROCESS CONTROL | | | | | | | | | | |
| 1. Reactivity/Pwr. Control | 100 | 90 | 100 | 100 | 100 | 100 | 88.9 | 100 | 100 | 80 |
| 2. Vessel Level Control | 100 | 100 | 100 | 100 | 93.3 | 90 | 100 | 100 | 100 | 100 |
| 3. RCS Temp. Cont. | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| SUBTOTAL | 100 | 97 | 100 | 100 | 98.3 | 100 | 96.6 | 100 | 100 | 90.5 |
| III. ADMINISTRATIVE | 70 | 90 | 70 | 100 | 100 | 90 | 70 | 100 | 70 | 90 |
| SUBTOTAL | 70 | 90 | 70 | 100 | 100 | 90 | 70 | 100 | 70 | 90 |
| TOTAL | 80.7 | 84.4 | 85.9 | 100 | 88.1 | 98.1 | 89.6 | 100 | 97.8 | 91.9 |

Figure 5. Reactor Criticality Exercise

| EXERCISE NUMBER | (1) 3/21/77 #1 | | (2) 3/21/77 #2 | | (3) 3/22/77 #1 | | (4) 3/23/77 #1 | | (5) 3/24/77 #1 | |
|---|---|---|---|---|---|---|---|---|---|---|
| COMPUTER GRADE / SUBJECTIVE EVAL. GRADE | Comp. | Subj. Eval. | Comp. | Subj. Eval. | Comp. | Subj. Eval. | Comp. | Subj. Eval. | Comp. | Subj. Eval. |
| I. SYSTEM OPERATION | | | | | | | | | | |
| 1. Main Turbine | 51.9 | 50 | 74.1 | 80 | 100 | 100 | 100 | 80 | 77.8 | 90 |
| 2. Feedwater System | 52.2 | 50 | 52.2 | 90 | 87 | 100 | 87 | 70 | 52.2 | 100 |
| 3. Reactor Protect. | 100 | 80 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 4. Nuc. Instrum. | 66.7 | 60 | 66.7 | 90 | 100 | 100 | 33.3 | 100 | 100 | 80 |
| 5. Gen,/Electrical | 57.1 | 90 | 57.1 | 100 | 57.1 | 100 | 57.1 | 60 | 57.1 | 100 |
| 6. RWCU | 100 | 30 | 100 | 70 | 100 | 100 | 100 | 70 | 100 | 90 |
| 7. Recirc. System | 12.5 | 70 | 12.5 | 90 | 12.5 | 100 | 12.5 | 100 | 12.5 | 90 |
| SUBTOTAL | 65.1 | 60.7 | 70.8 | 89.1 | 87.7 | 100 | 82.1 | 78.6 | 74.5 | 93.1 |
| II. PROCESS CONTROL | | | | | | | | | | |
| 1. RV Press. Cont. | 100 | 90 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 2. RV Wtr. Lev. Cont. | 100 | 60 | 100 | 90 | 100 | 100 | 100 | 90 | 100 | 100 |
| 3. Reactivity/Power Control | 100 | 100 | 50 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| SUBTOTAL | 100 | 78.5 | 92.9 | 95.7 | 100 | 100 | 100 | 95.7 | 100 | 100 |
| III. ADMINISTRATIVE | 0 | 0 | 100 | 90 | 100 | 100 | 100 | 100 | 100 | 100 |
| SUBTOTAL | 0 | 0 | 100 | 90 | 100 | 100 | 100 | 100 | 100 | 100 |
| TOTAL | 70.8 | 62.8 | 75.9 | 90.3 | 90.5 | 100 | 86.1 | 82.2 | 80.3 | 94.5 |

Figure 6. SCRAM Exercise

| EXERCISE NUMBER | (1) 3/22/77 #1 | | (2) 3/24/77 #1 | |
|---|---|---|---|---|
| COMPUTER / SUBJECTIVE GRADE / EVAL. GRADE | Comp. | Subj. Eval. | Comp. | Subj. Eval. |
| I. SYSTEM OPERATIONS | | | | |
| 1. Main Turbine | 74.2 | 90 | 79.7 | 100 |
| 2. Main Generator | 87.2 | 100 | 30.8 | 80 |
| 3. Auxiliary Electrical | 47.6 | 90 | 47.6 | 100 |
| 4. Control Rod Drive | 100 | 100 | 100 | 100 |
| 5. Reactor Level Control | 100 | 100 | 100 | 90 |
| SUBTOTAL | 76.8 | 93.5 | 66.7 | 94.8 |
| II. PROCESS CONTROL | | | | |
| 1. Turbine Control | 63.6 | 100 | 63.6 | 100 |
| 2. Reactivity/Power Control | 96.8 | 100 | 67.7 | 100 |
| 3. Vessel Level Control | 87.0 | 100 | 87.0 | 90 |
| 4. Generator Control | 27.3 | 100 | 27.3 | 90 |
| SUBTOTAL | 69.5 | 100 | 62.6 | 96.6 |
| III. COORDINATION OF OPERATIONS | 50 | 100 | 100 | 100 |
| SUBTOTAL | 50 | 100 | 100 | 100 |
| IV. ADMINISTRATIVE | 100 | 100 | 100 | 100 |
| SUBTOTAL | 100 | 100 | 100 | 100 |
| TOTAL | 71.5 | 96.7 | 68.4 | 96.6 |

Figure 7. Startup Exercise

d. In regards to the administrative task of calculating the heatup rate correctly, there were also some grading differences. The computer calculated the average heatup rate over the exercise duration. Some of the operators however, calculated the instantaneous heatup rate at the exercise termination.

2. Analysis of SCRAM Exercises

From the computer printout of the performance summary as compared to the instructor evaluation, as shown in Figure 6, the major areas of grading differences were in Nuclear Instrumentation, Generator/Electrical, Reactor Water Cleanup (RWCU), and Recirculation System.

Following a detailed discussion with the instructor performing the operator evaluations, the following facts were apparent:

a. Some of these SCRAM exercises were terminated early by the instructor simply because the operator had the plant conditions well under control and was obviously handling this situation correctly. The Performance Evaluation System, however, required that the exercise be entirely complete for it to be properly evaluated.

b. What seemed to be a technical difficulty with the simulator may also have been the cause for nuclear instrumentation grading differences. It was noticed during operations that some nuclear instrumentation indications were not functioning normally.

c. Incomplete familiarity with all of the items to be evaluated under each section of the evaluation form also gave rise to further grading discrepancies in the areas of the Generator/Electrical, RWCU, and Recirculation System sections of this SCRAM exercise.

3. Analysis of the Startup Exercises

Technical difficulties with the data tapes of two of the four startup exercises caused them to be incomplete. Hence, only two startup exercises were considered as having valid results. In these two exercises, the same variations between the computer results and the evaluator results as shown in

Figure 7 occurred in the Main Turbine, Main Generator, Auxiliary Electrical, Turbine Control, Reactivity Power Control, and General Control sections.

The startup exercise is a difficult exercise, not only for the operator in training to perform, but also for the instructor to properly evaluate. The difficulty of this particular exercise is perhaps best described by the operators who actually participated in this program.

Four test subjects evaluated the Plant Startup operational sequences for error potential. The Plant Startup exercise tasks which were perceived as being most error-prone are as follows:

a. Checks Units Auxiliary Transformer voltage prior to 4 KV transfer.
b. Maintains transfer voltmeter balanced during turbine loading.
c. Selects and withdraws correct control rods.
d. Maintains reactor vessel level between 28 and 38 inches.
e. Correctly determines the first stage bowl temperature.
f. Verifies that chest warming is off.
g. Verifies lift pump on until > 990 RPM.

## 3.6 Concluding Remarks

1. Improvement of the Instructor's Capability

The fact that the computer evaluation is so complete and exacting, it not only evaluates the operator in training, but it also tends to measure the performance of the instructor's evaluation as well.

It is difficult, if not impossible, for the evaluator to monitor all of the parameters which the computer can do easily, however, with a little practice employing the use of the computer printout results, the instructor will tend to become much more aware of those areas of evaluation which he must concentrate on to become more effective in his evaluation capabilities.

2. Videotape Monitoring of the Pilot Implementation Exercises

It was also learned during these pilot implementation exercises that the videotape replay of the completed exercise proved invaluable. It not only provided a tool to review the operational exercises, but it also became a mechanism for the student to observe himself in action.

3. Research Project Utilizing Empirical Data Collected During the Performance Measurement System Exercises

The types of exercises best suited for research purposes would most likely be equally well suited for enhancing training endeavors. The important goal in this regard would be to obtain a comprehensive data base. This can be best accomplished by having viable exercises on both BWR and PWR simulators which provide researchers with needed data in such areas as:

- Quantitative modeling of operator performance and reliability.
- Human factors aspects of control room design.
- Man-machine relationships that would contribute to the development of future control board designs.
- Personnel selection research.

4. Project Continuation

In conclusion, the proposed project continuation for implementing the Performance Measurement System for the next 3 years is divided into four tasks as shown below.

- Task 1: Develop 10 Additional Exercises for the Browns Ferry BWR Simulator
- Task 2: Develop 10 Performance Measurement System Exercises for a PWR Simulator
- Task 3: Adapt Exercises to a Second PWR or BWR Simulator
- Task 4: Conduct Research Projects Utilizing Empirical Data Collected During the Performance Measurement System Exercises

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