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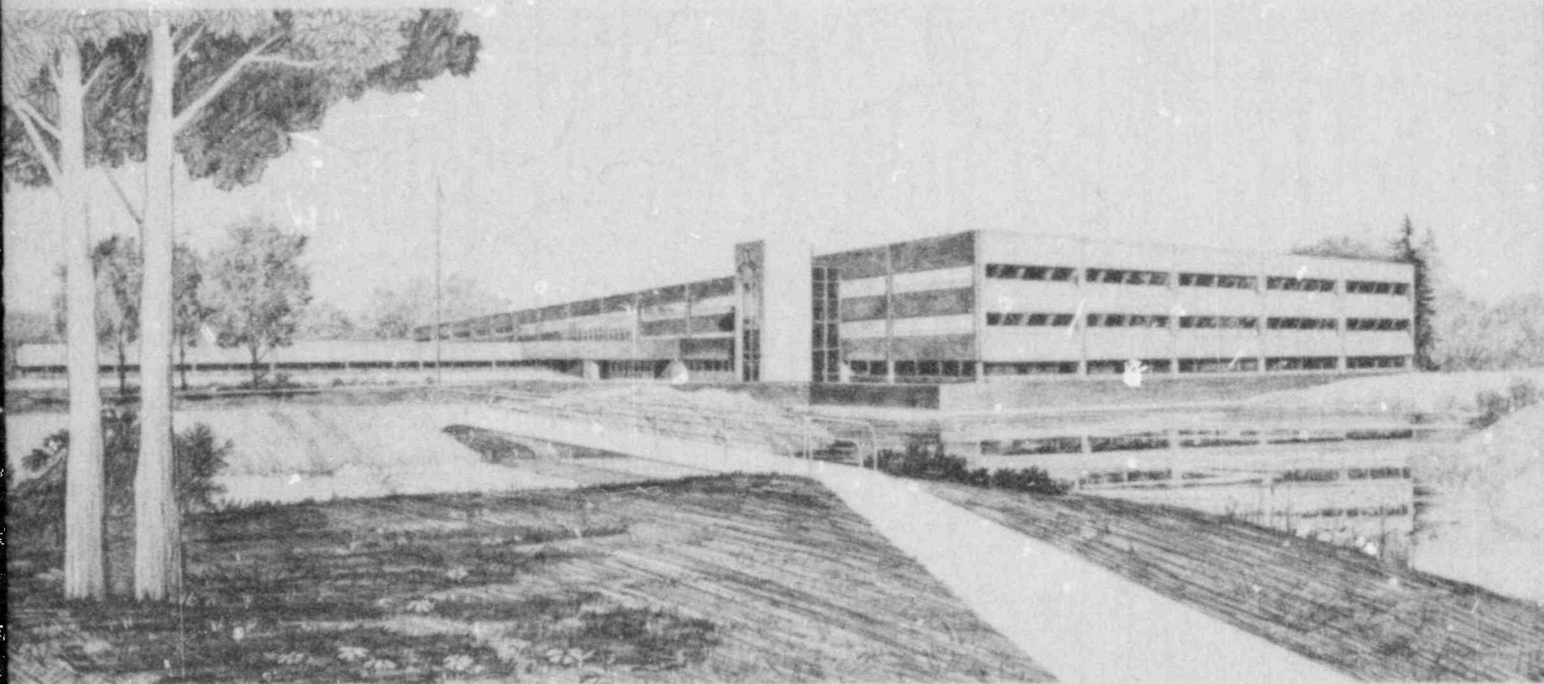

Idaho National Engineering Laboratory
Operated by the U.S. Department of Energy

Interactive Simulator Evaluation for CRT-Generated Displays

Harold S. Blackman
Walter E. Gilmore

December 1984

Prepared for the
U.S. Nuclear Regulatory Commission
Under DOE Contract No. DE-AC07-76IDO1570

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ABSTRACT

The United States Nuclear Regulatory Commission (USNRC) is sponsoring an on-going research program to develop methods of assessing various types of computer-generated displays currently being implemented in nuclear power plant control rooms. The purpose of this report is to present an interactive simulation technique for the evaluation of computer-generated displays. The independent variables for this experiment were transient type (six levels), and display type including the levels of star + control panel, bar + control panel, meter + control panel, pressure-temperature map + control panel, and control panel only. The dependent measures were deviations of parameter values comprising the safety functions at risk, percent of time these parameters were out of tolerance from onset of the transient, and accuracy of the operator path in transient mitigation. The results indicate that an interactive simulation method can be used to evaluate various display types, and that the workstation and computer/simulator is an effective configuration. The implications of these results for display evaluation and design are discussed.

FIN No. A6308—CRT-Generated Displays

SUMMARY

The present study is a continuation of research being conducted at the Idaho National Engineering Laboratory (INEL) to identify valid methods and data bases for evaluating cathode ray tube (CRT) display formats. To date, four methods employing operators from the Loss-of-Fluid Test (LOFT) reactor have been identified and studied; these are: signal detection paradigms (psychophysics), multidimensional rating scales, human engineering checklists, and noninteractive simulation. A fifth method recently developed, and the subject of this study is interactive simulation.

The purpose of this report is to describe the interactive simulation method developed to evaluate the effectiveness of computer-generated displays which are designed to enhance performance of the reactor operator. As with the past four studies in this series, the primary target of this evaluation technique is safety parameter displays (SPDs), although the results are applicable to most CRT-based displays. The evaluation method is based upon the expressed purpose of the SPD, using operator performance as the yardstick.

An experiment was conducted to obtain data using interactive simulation as a method for evaluating displays. The formats evaluated in this study are the same used in the noninteractive simulation method, and in the previous experiments. This provided the capability for comparing data gathered in the interactive simulation with data accumulated in the other methods. The four SPDs used in these experiments were named according to their format and structural characteristics: bars, stars, meters, and a pressure-temperature (P-t) map. An additional display for the interactive experiment served as the control panel. The control panel consisted of the required controls and parameter information necessary to control the plant through selected transients. This was the means by which the operator directly interacted with the plant simulator. The operator controlled the plant by pressing buttons and entering ratios, flows, etc. through the control panel's touch-sensitive panel. All subjects in the experiment operated the plant with the control panel. The treatment received by each subject consisted of the control panel plus an SPD or, in the case of the control treatment, soley the control panel. This technique specifically tested the efficiency of using deviation of plant parameters indicative of safety functions as dependent measures in evaluating a display aid. In addition, the effectiveness of operator action event trees (OAETs) as an objective way of scoring operator paths in transient mitigation was assessed. Both of these methods were found to be sensitive to differences in displays.

The comparison of the displays used in this experiment also illuminated an interesting finding. All the results, including trend data, have indicated that operators perform better when using the control panel only. That is, the addition of an extra top-level display (a safety parameter display) actually attenuated performance. These results must be interpreted with caution as the control panel display used in this experiment is a type of safety parameter display. Also, our control panel is not representative of designs found in control rooms today.

The control panel blended the initial set of necessary controls and indications to run the plant for the transient events selected. It was logically organized and placed all the parameters in close proximity (in a single CRT screen). So, in effect, this was an integration of control and display for the operator. However, adding a second display panel, the SPD, did create a decrement in performance. The root cause of this decrement in performance is not perfectly clear. It may be attributed to time-sharing between displays, experience with the SPD used, the experimental task, or other undetermined factors. Therefore, the major implication of this finding is that SPDs must have a thorough operational test to insure their effectiveness in nuclear power control rooms.

These experiments have shown that an interactive simulation method can be used to evaluate various display types concentrating on correction and follow of transient events. The workstation, computer hardware, computer software, and simulator configuration is an effective combination. Results can be obtained through experimental control and use of these facilities. The use of the OAET in this experiment has reinforced their use in collection of human performance data. The trees, in conjunction with a classification system, can be used to look at human performance and errors. This type of information could also make a logical bridge to the human in risk assessment.

ACKNOWLEDGMENTS

We would like to acknowledge O. R. Meyer and thank him for the overall technical assistance he provided. The efforts of R. E. Ford in display and transient development, as well as F. Cerven in consultation of power plant operations, equipment checkout, and program tracking are also appreciated. We would like to thank the operators from the Loss-of-Fluid Test reactor for their participation in this effort, and D. E. Jackson for his assistance in data collection. A special thanks is given to R. L. Smith, W. J. Swenson, J. R. Venhuizen, and D. G. Bannister for their contributions in software development, hardware configuration, and plant simulation.

A special acknowledgment is also due to the support we received from the Operator Evaluations Section and the Reliability and Statistics Branch at EG&G Idaho, Inc. N. F. Dudley of the Operator Evaluations Section provided extremely useful comments toward specifying the control panel. R. E. Wright and S. Z. Bruske, both of the Reliability and Statistics Branch developed the Operation Action Event Trees (OAETs). The study could not have been conducted without this expertise.

Thanks are also due to J. P. Jenkins, C. E. Overby, and J. Norberg of the Nuclear Regulatory Commission for their assistance and support in this research effort.

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FIGURES

TABLES

NOMENCLATURE

OAET	Operator action event tree
CRT	Cathode ray tube
INEL	Idaho National Engineering Laboratory
LOFT	Loss-of-Fluid Test
NRC	Nuclear Regulatory Commission
POM	Plant operating manual
P-t	Pressure-temperature
PWR	Pressurized water reactor
PZR	Pressurizer
S/G	Steam generator
SPD	Safety parameter display
T-hot	Hot leg temperature

INTERACTIVE SIMULATION EVALUATION FOR CRT-GENERATED DISPLAYS

INTRODUCTION

Purpose

The purpose of this report is to describe a method developed to evaluate the effectiveness of computer-generated displays designed to enhance reactor operator performance. As with the past four studies in this series, the primary target of this evaluation technique is safety parameter displays (SPDs), although the techniques are applicable to most CRT-based displays. The evaluation method is based upon the expressed purpose of the SPD, using operator performance as the yardstick.

The most general statement of purpose for the SPD is "to aid control room personnel during abnormal and emergency conditions in determining the safety status of the plant."[1,2,3,4] NUREG-0696 defines safety status in terms of the plant's safety functions which include but are not limited to the following (Reference 2):

- Reactivity control
- Reactor core cooling and heat removal from the primary system
- Reactor coolant system integrity
- Radioactivity control
- Containment integrity.

Specifically, the SPD must allow for the detection of abnormal plant conditions which ostensibly could be a threat to one or more individual safety functions. Detection is stated as the primary purpose of the SPD and has been the dependent measure for two of the experimental evaluation techniques in this series. Two additional but optional purposes are the (a) identification of abnormal conditions, and (b) correction and follow of actions (References 2 and 3).

An interactive technique was designed to test the concept of safety functions as dependent measures for the correction and follow of actions in transient mitigation, as well as the effectiveness of operator action event trees (OAETs) as objective methods of scoring operator paths in transient correction.

Background

The present study is a continuation of research being conducted at the Idaho National Engineering Laboratory (INEL) to identify valid methods and data bases for evaluating cathode ray tube (CRT) display formats. To date, four methods employing operators from the Loss-of-Fluid Test (LOFT) reactor have been identified and studied; these are: signal detection paradigms (psychophysics), multidimensional rating scales, human engineering checklists, and noninteractive simulation. A fifth method recently identified, also the subject of this study, is interactive simulation.

The methods that have been developed vary in terms of experimental control, cost, time to perform, and fidelity to the real world. Table 1 gives a brief summary, reference, and comparison of the methods' attributes. The psychophysics study demonstrated sensitivity and control over all experimental variables, but was both costly and time consuming with low fidelity to the real world (the control room environment). The multidimensional rating scale was relatively inexpensive and efficient, incorporated a measure of operator preference, and demonstrated a stronger relationship or correlation to real-world performance data. The checklist method was also relatively inexpensive and efficient, and displayed still greater face validity. That is, it was closer to the real world in terms of perceived content. Questions on the checklist pertained directly to seven functional areas describing actual display features. However, the checklist and the multidimensional rating scale do not actually measure human performance. Instead, measurements are taken on the characteristics of the display, characteristics that are presumed to relate to maximizing human performance. The noninteractive method simulation was more objective and thus, more powerful because it measured actual operator performance with the display formats. This method was more costly and time-consuming than either of

Table 1. Comparison of evaluation methods' attributes

Authors	Title	Rated (1-low, 5-high) Reliability	Validity (Face)	Cost	Description
Peterson, R. J. Smith, R. L. Banks, W. W. Gertman, D. I.	An Empirical Examination of Evaluation Methods for Computer Generated Displays: Psychophysics, NUREG/CR-2916, EGG-2214, September 1982	5	1	3	Methods of evaluation were developed based upon perceptual aspects of displays and signal detection theory. Operators were asked to identify abnormal parameters on 3 SPD formats after 5 and 10 millisecond exposures. Later, operators were asked to identify and locate abnormal parameters following the same exposure times. These methods were sensitive to changes in performance elicited by differences in display formats.
Gertman, D. I. Blackman, H. S. Banks, W. W. Peterson, R. J.	CRT Display Evaluation: The Multidimensional Rating of CRT-Generated Displays, NUREG/CR-2942, EGG-2220, October 1982	3	2	1	A rating scale was developed to evaluate operator preference as a function of different display formats. Six dimensions; content density, content integration, format cognitive fidelity, cognitive processing, and general acceptance were embedded in the scale. The total scale was 155 items in length. Participants evaluated 3 display types. The subscale of content integration, and cognitive processing were sensitive to differences in display format.
Blackman, H. S. Gertman, D. I. Gilmore, W. E.	CRT Display Evaluation: The Checklist Evaluation of CRT Generated Displays, NUREG/CR-3557, EGG-2285, December 1983	5	4	1	A checklist instrument was developed to evaluate objective human factors requirements of displays. The checklist developed covers the following areas; quality of information, organization of data, labels and abbreviations, feedbacks and cues, CRT characters, scale characteristics, digital display characteristics, and column charts and graph characteristics. The total instrument was 93 items long, each designed with an subjectively determined weight. The checklist was sensitive to differences in display format.
Blackman, H. S. Gertman, D. I. Gilmore, W. E. Ford, R. E.	Noninteractive Simulation Evaluation for CRT-Generated Displays, NUREG/CR-3556, EGG-6265, December 1983	4	4	4	A noninteractive method of a simulator based evaluation of CRT generated displays was developed. Operators were tasked with the detection and identification of 18 simulated transients. Dependent measures were time to defections and correctness of transient identification. Four different display formats were used as stimulus materials. A workload task was implemented to simulate a control room environment. Results indicated that this type of method is appropriate for evaluating a display's capability to provide data for the detection and identification of transients.

Table 1. (continued)

Authors	Title	Rated (1-low, 5-high) Reliability	Validity (Face)	Cost	Description
Blackman, H. S. Gilmore, W. E.	Interactive Simulator Evaluation for CRT-Generator Displays, NUREG/CR-3767, EGG-2308	4	5	5	An interactive simulation technique was developed for the evaluation of CRT generated displays. Operators were tasked with control of the plant through transient events. A CRT-based, graphic control panel equipped with a touch screen served as the operators interface with the simulator. Four different display formats were used as stimulus materials. Dependent measures were deviations of parameter values comprising the safety functions at risk, percent of time these parameters were out of tolerance from onset of the transient, and accuracy of the operator path in transient mitigation. Results addressed the questions of transient correction and follow of actions, and found the method sensitive to differences in displays

the pencil and paper methods (multidimensional rating scale and checklist), but had excellent control of the experimental variables and also had a higher fidelity to the control-room environment. By comparison, the interactive simulation is the closest to the real control-room environment. It is the most objective and allows measurement of correction and follow of operator actions, but is also the most costly and time consuming of the techniques. However, it, as mentioned, provides not only the best data in terms of controlling experimental variables, but high fidelity to the control-room environment. Therefore, an experiment was conducted to obtain comparable data using interactive simulation as a method for evaluating displays.

The formats evaluated in this study are the same used in the noninteractive simulation method, and in the previous experiments. This provided the capability for comparing data gathered in the interactive simulation with data accumulated by the other methods. The four SPDs used in these experiments were named according to their format and structural characteristics: bars, stars, meters, and a pressure-temperature (P-t) map. An additional display for the interactive experiment served as the control panel. The control panel consisted of the required controls and parameter information necessary to control the plant through selected transients. This was the means by which the operator directly interacted with the plant simulator. The operator controlled the plant by pressing buttons and entering ratios, flows, etc. through the control panel's touch sensitive panel. All subjects in the experiment operated the plant with the control panel. The treatment received by each subject consisted of the control panel plus an SPD or, in the case of the control treatment, solely the control panel.

A description of the experiment and a discussion of the results are presented in this report. The experiment provided for a comparison of operator performance among the four SPD types to a control group which had no SPD to assist in control of the plant. In the experiment, a methodology was developed for evaluating displays where the subject works with the display in a dynamic interactive mode (as in an actual plant). Performance data against which the other methods can be validated were collected.

METHOD

Design

The independent variables for this experiment are transient type (six levels), and display type including the levels of star + control panel, bar + control panel, meter + control panel, pressure temperature map + control panel, and control panel only. Each subject received only one of the above treatments. However, all subjects attempted to mitigate a group of six transients presented in a random order. The dependent variables are deviations of parameter values including the safety functions at risk, percent of time these parameters were out of tolerance from onset of the transient, and accuracy of the operator path in transient mitigation. The variables were analyzed in two separate analyses of variance. The only comparisons made were planned orthogonal contrasts among the levels of the factor of display type. These comparisons and analyses are discussed in detail in the analyses section of this report.

Subjects

The subjects for this experiment, 20 total, are either currently or formerly certified LOFT operators. All subject's prior experiences include nuclear plant operations in the United States Navy. Their mean civilian and Navy operations experience level is approximately nine years. Ages of the subjects range from 26 to 39 years and all have 20/20 vision (actual or corrected) and normal color vision. The subject pool maximized the number of individuals who previously had participated in other evaluation experiments in this series.

Equipment and Experiment Work Station

The transient initiating events were recorded and stored on a Prime 550 computer. The data were displayed on two Lexidata 8100 graphics systems, one of which was equipped with a touch panel. The Lexidata System equipped with the touch panel was used to display the control panel which gave the subject necessary parametric information and the input capability to drive the simulator in an interactive mode. The second Lexidata System was used to display the SPD for the four experimental conditions. The two Lexidata CRTs were driven by the Prime computer through an interface with the LOFT simulator.

The Lexidata terminals were mounted in a control console located in the INEL Graphics Design Research Laboratory. Figures 1 and 2 give overhead and side views of the experimental work station. All aspects of the work station conform to the guidelines presented in NUREG 0700.

The training session was conducted with a training program developed using the authoring package Apple Pilot on an Apple IIe 128K personal computer equipped with an Apple III black and white CRT monitor, and dual 5-1/4-inch floppy disk drives. The self-paced training system was administered to the subjects via the same Apple IIe system configuration.

The operator's description of his/her actions during the experimental session was tape recorded using a cassette recorder and a remote microphone. The experimental task was conducted in an environment where ambient temperature, lighting, and noise were controlled to avoid undue environmental stress to the subjects. Particular emphasis was directed to the lighting conditions in order to avoid glare on the CRT screen.

Materials

A total of five displays were created for this experiment, all capable of interfacing with the LOFT simulator. Four of these displays are the SPDs star, bar, meter, and P-t map. The fifth display is the control panel. These displays are shown in Figures 3, 4, 5, 6, and 7, respectively. All five displays comply with currently acceptable human engineering guidelines.

A set of six transients were developed which correspond to four major types of accidents: (a) overheating, (b) overcooling, (c) overpressure, and (d) underpressure. The six transients are:

- Stuck open secondary relief valve
- Loss of primary coolant pumps
- Steam generator tube rupture.

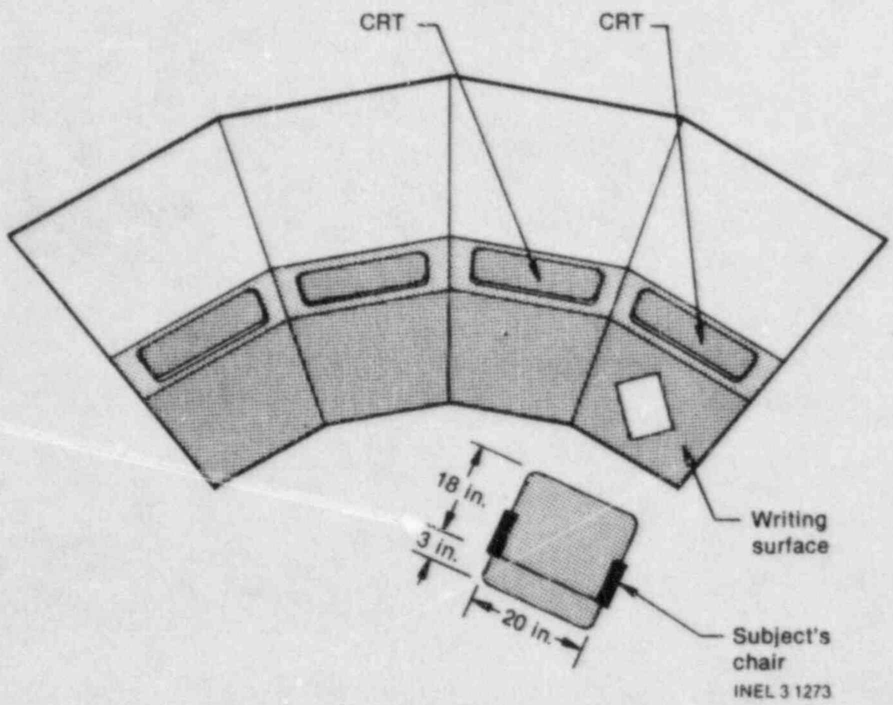

Figure 1. Overhead view of experiment work station.

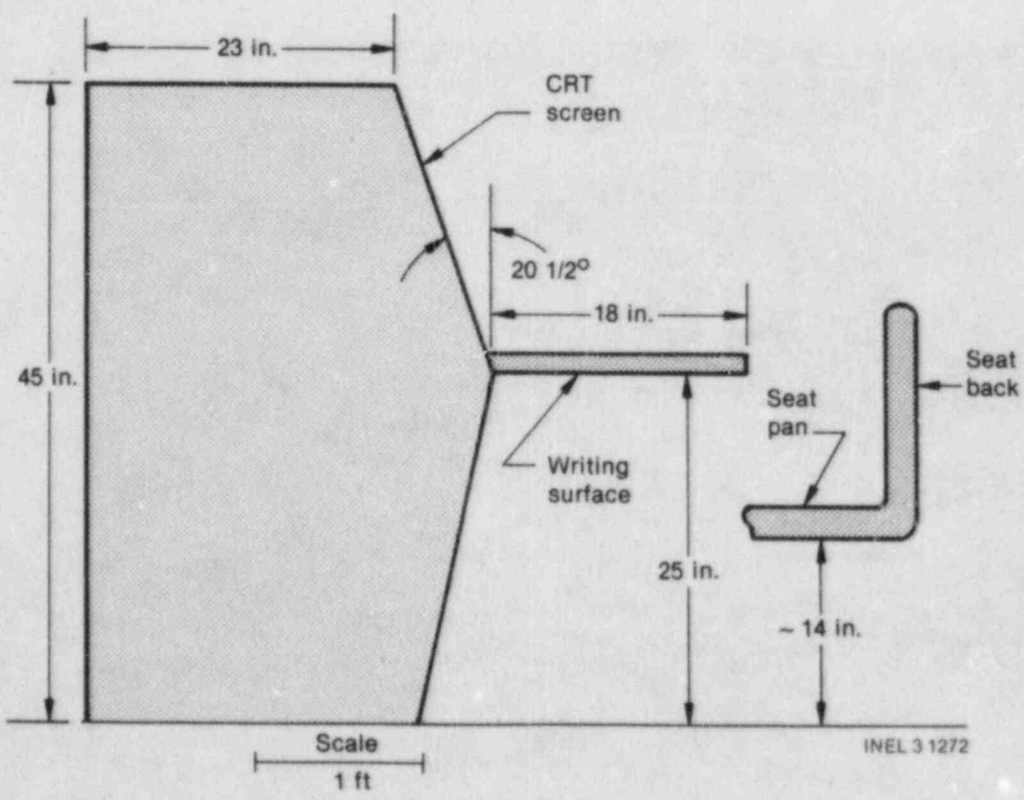

Figure 2. Side view of experiment work station.

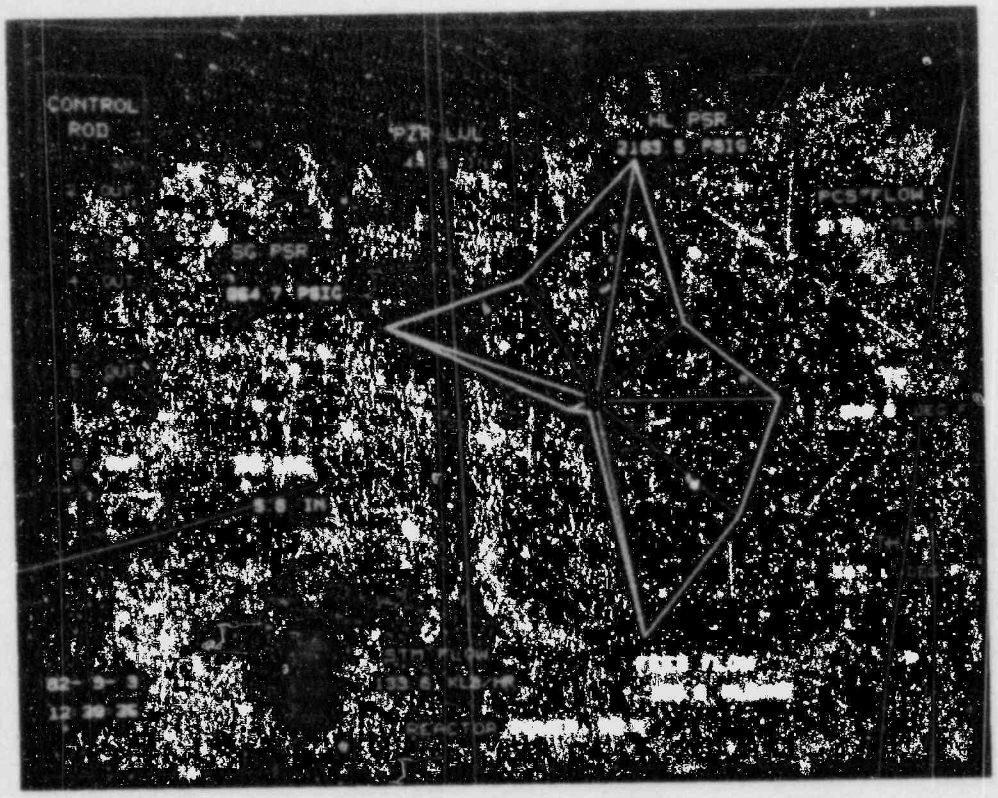

Figure 3. Star.

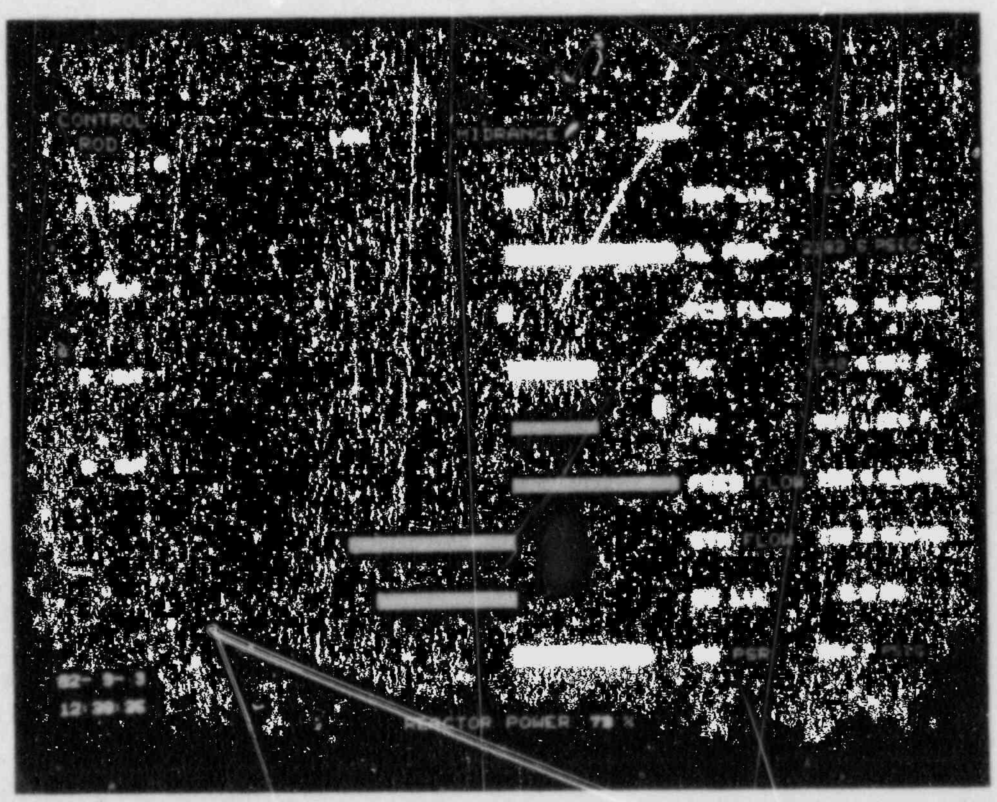

Figure 4. Bar.

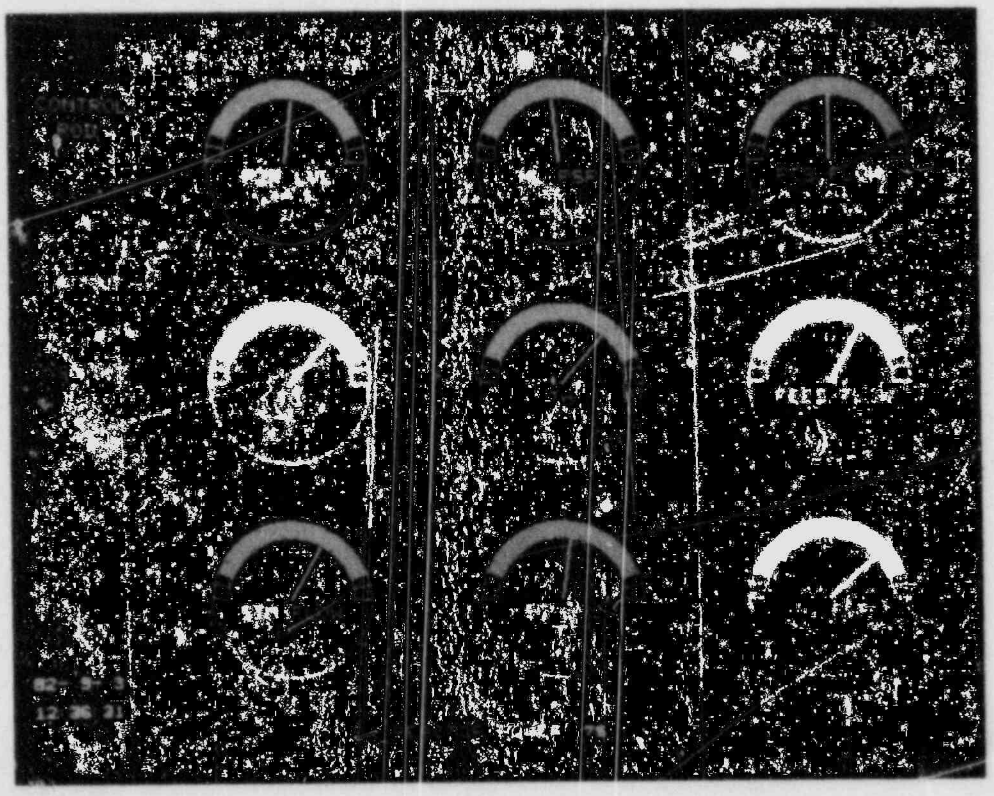

Figure 5. Meter.

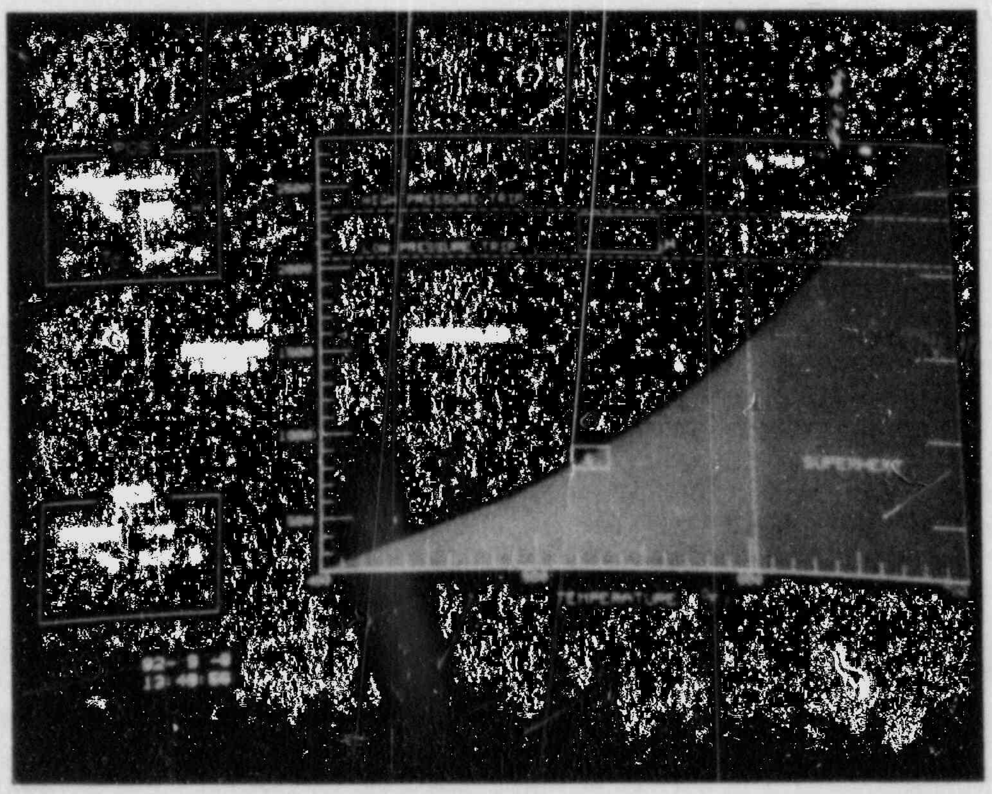

Figure 6. P-t map.

Figure 7. Control panel.

- Loss of main feedwater
- Main steam isolation valve closes
- Stuck open pressurizer spray valve.

These transients were evaluated for difficulty and ability to control, by an experienced operator and a human factors expert. The effort was directed at creating transients which presented a reasonable level of difficulty, but were controllable from the CRT control panel used in the experiment. After an iterative review, these goals were met. Operator action event trees were developed for each of these transients and were used by operations experts in the analysis of the subject's decision path. These trees are shown in Figures 8, 9, 10, 11, 12, and 13.

Procedure

Five experimental conditions existed in this experiment. Four of the five consisted of one SPD (either bar, star, meter, or P-t map) plus the control panel; the fifth consisted of only the control panel. Subjects were randomly assigned to one of the five experimental conditions.

Each subject was greeted by the experimenter and familiarized with the graphic display research facility and the overall purpose of the project. After being shown the Apple IIe computer, the subject began the self paced instructional program. The program is briefly described below, but may be found in its entirety in Appendix A.

The training program, consisting of four phases, began with familiarization of each control and display on the control panel. The subject was asked to locate each control and display, and answer questions regarding their information content. The second training section dealt with learning how to operate the control panel in terms of inputting flows and valve status changes using the touch screen. This involved operation of an input keypad as well as specific functions all located on the control panel. Each subject practiced inputting, clearing, and changing data on a live simulation. The third training section covered the specific SPD that each subject used in the experiment. The subjects were trained only on the SPD they would use; thus, the content of these sessions differed with the SPD type. A portion of this training included viewing ten different transients on the SPD. Prior to initialization, the transient being used was identified enabling the

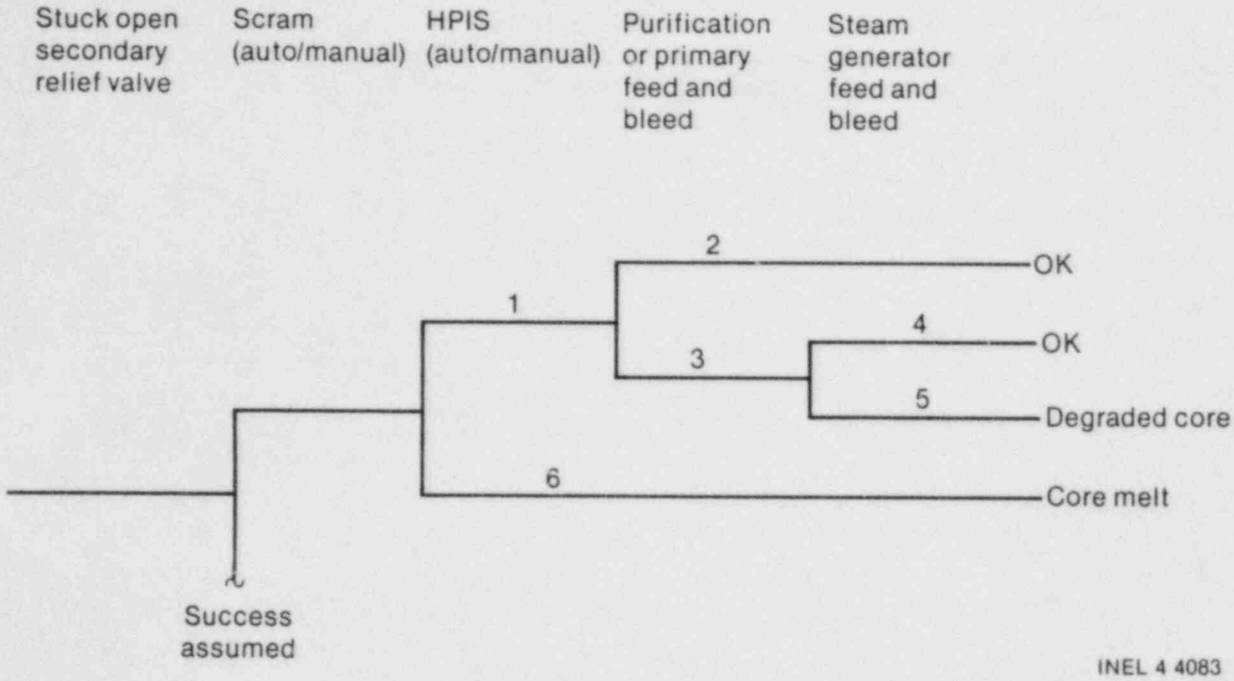

Figure 8. OAET—stuck open secondary relief valve: Transient 1.

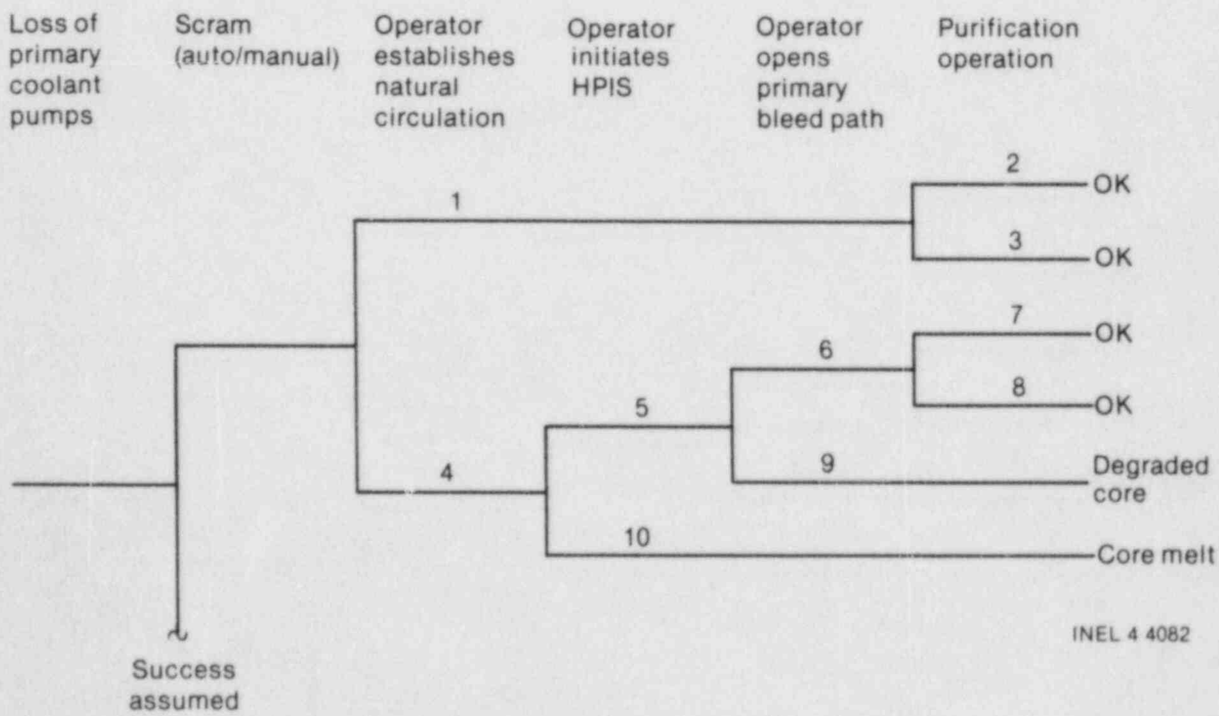

Figure 9. OAET—loss of primary coolant pumps: Transient 2.

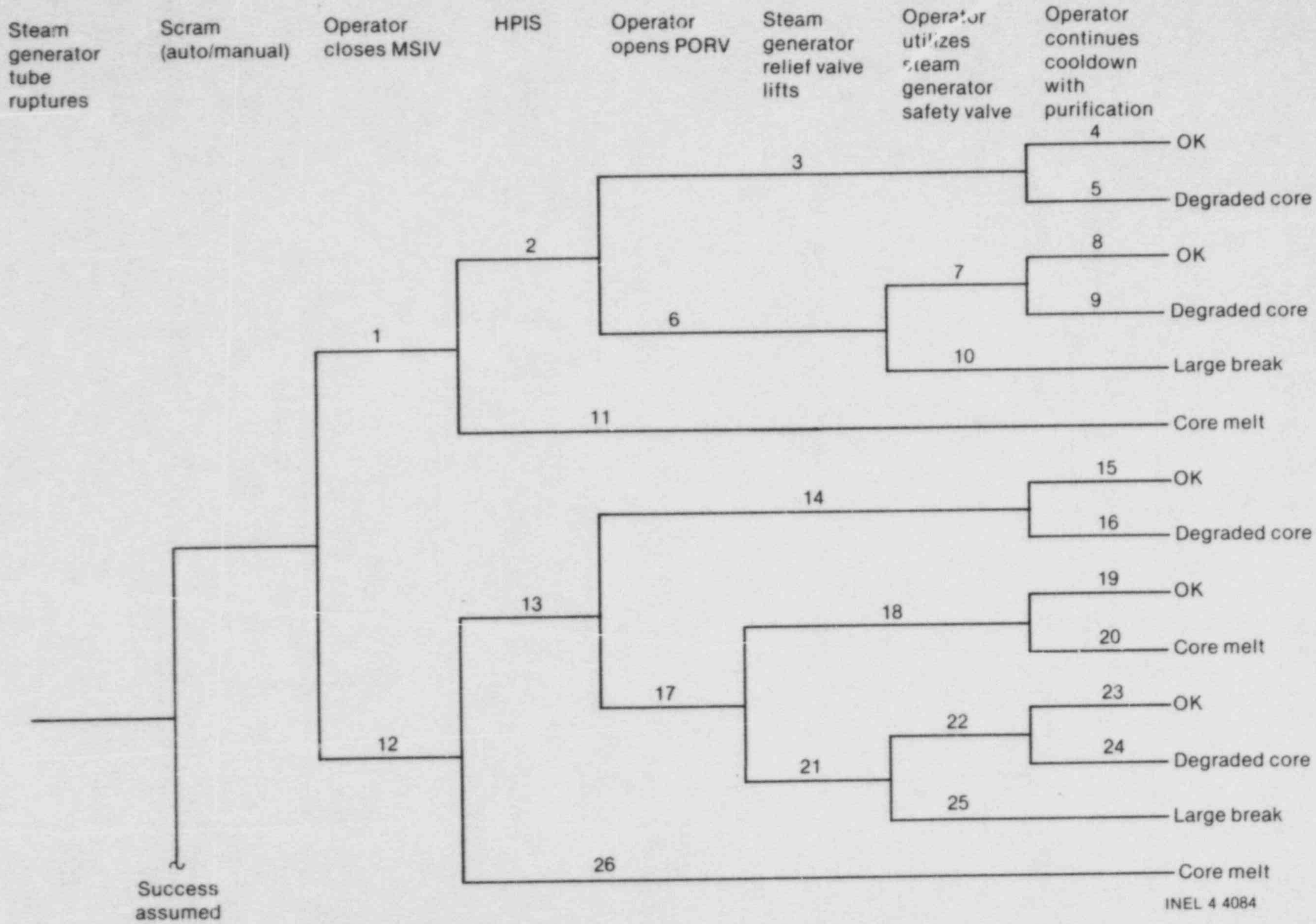

Figure 10. OAET—steam generator tube rupture: Transient 3.

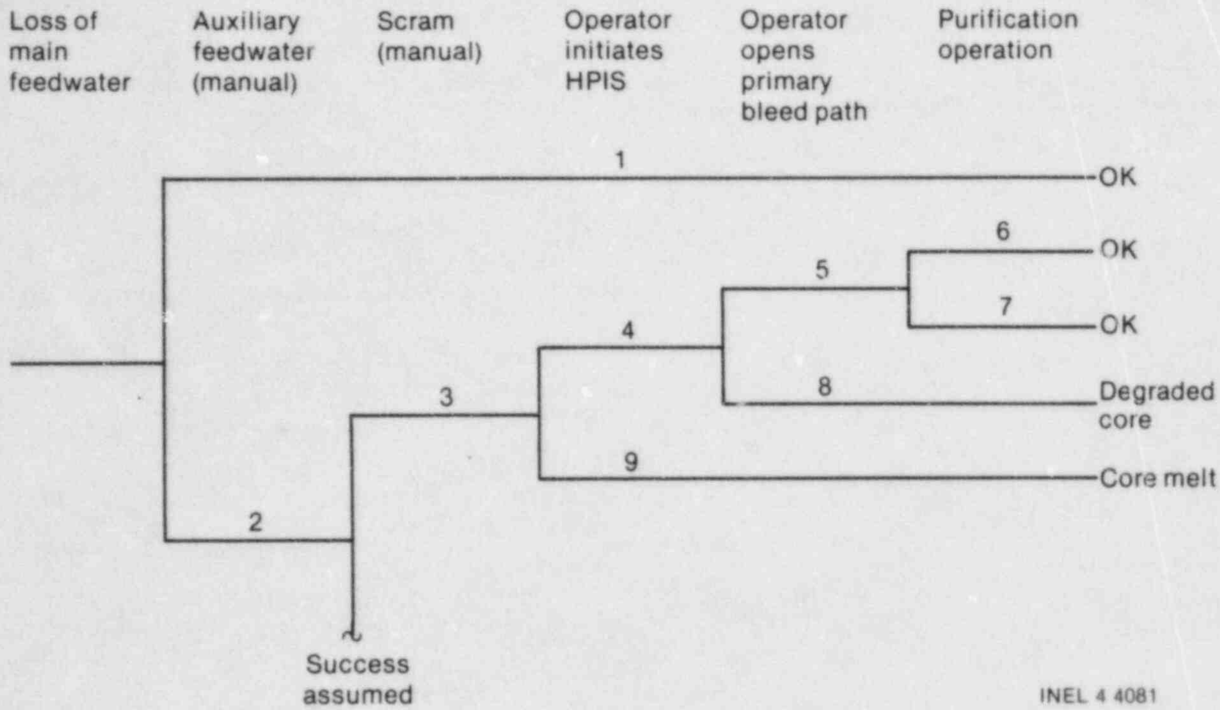

Figure 11. OAET—loss of main feedwater: Transient 4.

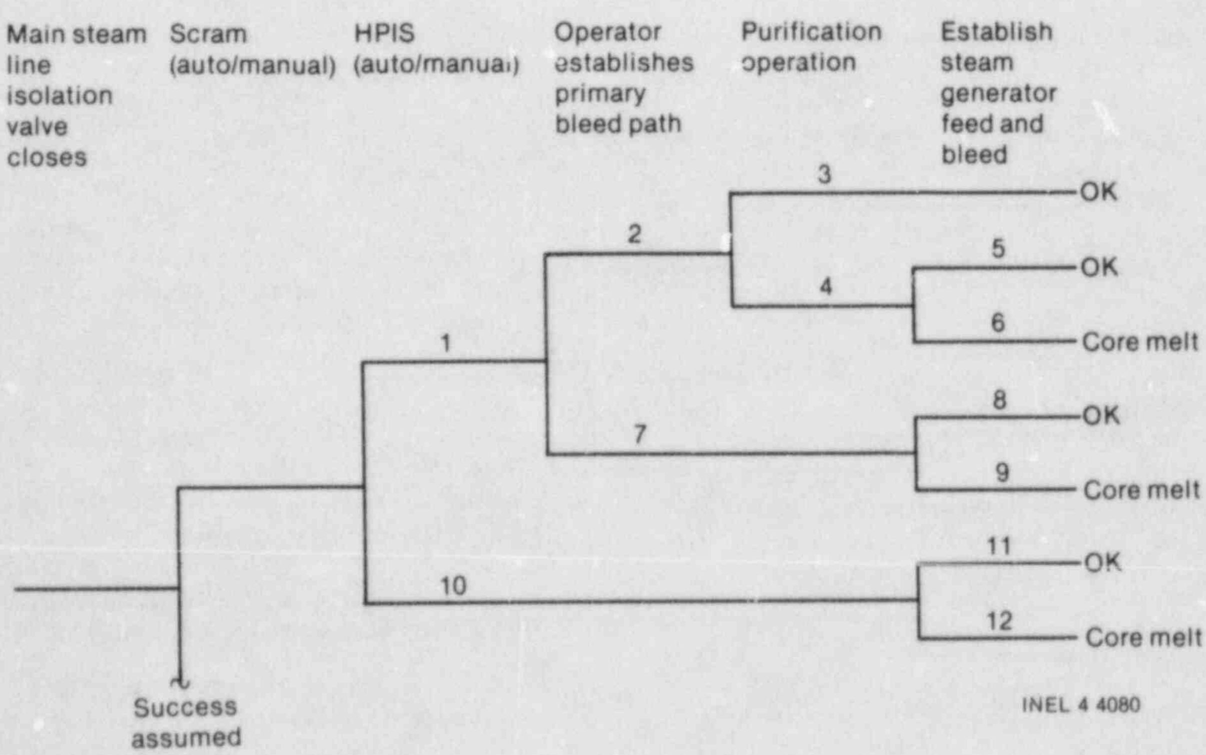

Figure 12. OAET—main steam isolation valve closes: Transient 5.

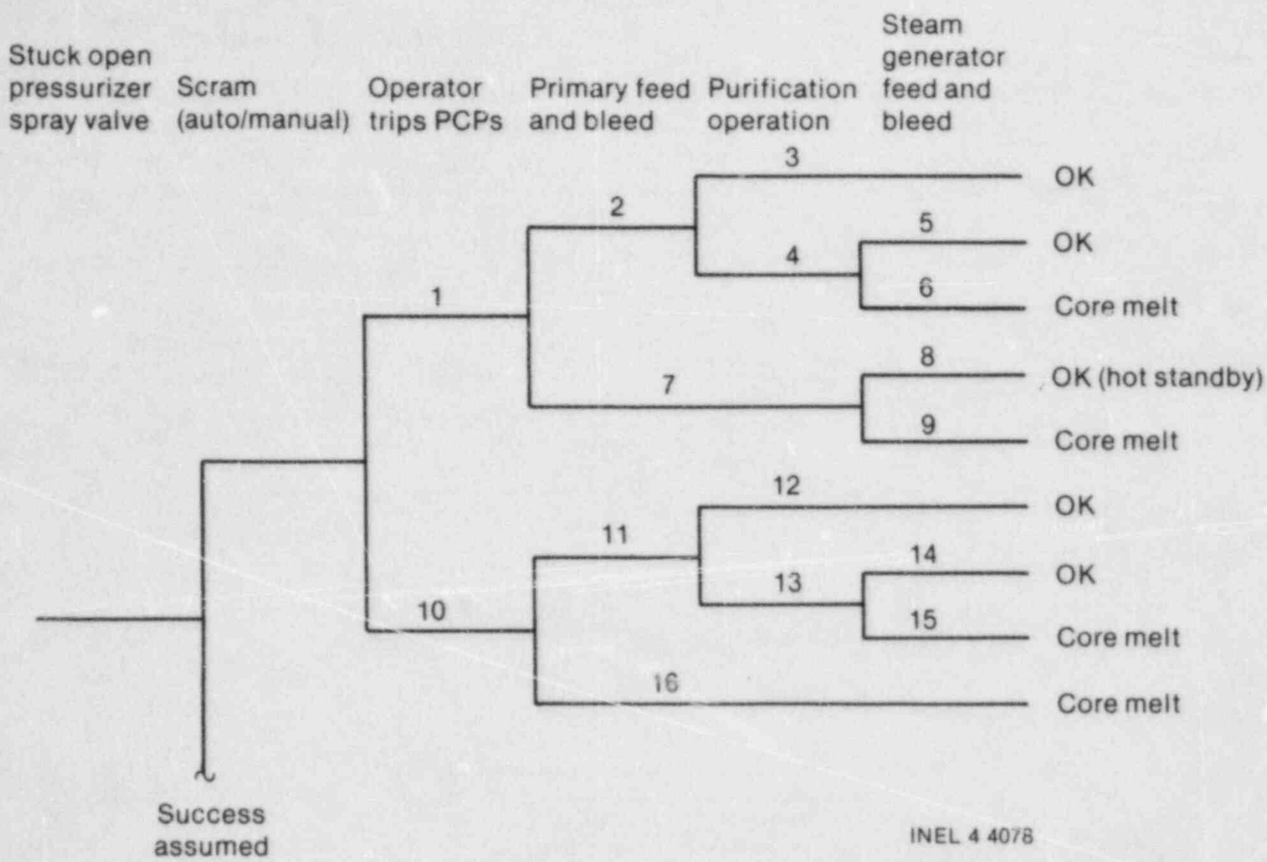

Figure 13. OAET—stuck open pressurizer spray valve: Transient 6.

subject to study the plant's reactions on the SPD. Questions were answered regarding the transient, and the transient was replayed (once only) for clarification purposes. During phase four of the training program, the subjects were read instructions regarding the experimental tasks they would be expected to complete. This section is duplicated below to give the reader a better understanding of the experimental task.

> "Your task in this experiment will be to attempt to mitigate the transient as it unfolds. You will be tape recorded as you work through the transient and you must verbalize each action as you take it and why you are taking it. In doing so, you should identify what you think the transient is as you take your control actions.
>
> "Your performance will be scored on the basis of two measures: how well your solution to the transient fits the ideal model, and how well you control the safety functions jeopardized by the transient in terms of operating limits for various parameters.
>
> "A set of plant operating manuals (POMs) have been provided for your use and you may refer to them at any time you deem necessary.
>
> "You may work on the transient until you feel the plant is on its way to stable conditions, thirty minutes have passed in real time, or the plant simulation model has exceeded its limits. Please inform the experimenter when you have completed the training."

At this time the experimenter read the following instructions to the subjects:

> "Remember that your task is to mitigate the transient which occurs, bringing the plant to stable conditions. You must verbalize each action you take and why you are taking it including what you think the transient is. Do you have any questions? We will now begin."

The experimenter then turned the tape recorder on, selected the transient as dictated by the randomized transient list on the subject sheet, and verbalized the transient number upon initialization of that transient.

Scoring

Safety Function Evaluation. A prerequisite to using the violation of safety functions as a dependent measure in this simulation experiment was the identification of specific parameters to be tracked and their associated setpoints. This process was based on expert opinion and accepted plant values as found in the Plant Operating Manuals (POMs) and Technical Specifications. The parameters and their setpoints were selected in terms of standards available for reactor operation, behavior under simulation, and through plant safety analyses.

Of the five major safety functions defined earlier in this report, only two were challenged by our set of test transients. These are reactor core cooling and heat removal from the primary system, and reactor coolant system integrity. The parameters associated with these safety functions were initially identified as listed below.

For reactor core cooling and heat removal from the primary system, they were:

- Power level
- Steam generator (S/G) level
- Pressurizer (PZR) pressure
- Hot leg temperature (T-hot).

For reactor coolant system integrity, they were:

- Pressurizer (PZR) level
- Subcooling greater than 25 degrees.

A three step iterative review process was performed to validate these parameters and to develop their associated setpoints. These parameters and associated setpoints were observed through each of the six test transients, first with no operator actions, and then with operator actions taken as dictated by proper procedures. Next, these same parameters and associated setpoints were reviewed by qualified reactor operators familiar with the LOFT plant on which the simulation is based. Finally, a review by LOFT safety analysis personnel to insure consistency with known plant behavior was performed. This process yielded the final set of parameters and setpoints for each transient. A table detailing these values appears in Appendix B.

For measurement purposes, each parameter was tracked by the computer for each operator as s/he attempted to mitigate the transients. Mean deviation scores were calculated for each of the parameters and for the percent of time spent outside of the determined setpoint ranges. In this way, numeric scores were created reflecting the operator's ability to maintain control over the safety functions.

Operator Action Event Tree (OAET) Analyses. The third dependent variable for this experiment is the quality of the operator's actions in mitigation of the transient. To help provide a more objective means of evaluating the operator's performance, OAETs were developed for each of the six test transients. The OAET (Figures 8-13) served as the basis for the scoring of the operator's action sequence. Action protocols were produced for each subject containing each action they took and when they took it. A sample of these protocols is presented in Table 2.

Table 2. Sample subject action protocol

Control Identification	Action	Time
Steam stop	Shut	12:38:08
PCS pump	On	12:38:29
Keypad touch	1	
Main feed bypass	% open	12:39:42
Keypad touch	1	
Keypad touch	0	
Main feed bypass	% open	12:41:00
Keypad touch	1	
Keypad touch	0	
Steam bypass	% open	12:41:20
Steam stop	Open	12:41:44
ACC fan status	On	12:42:04
Keypad touch	5	
Steam bypass	% open	12:42:38
Keypad touch	8	
Keypad touch	1	
Steam bypass	% open	12:43:21
Keypad touch	0	
Steam bypass	% open	12:43:53
Keypad touch	1	
Keypad touch	5	
Main feed bypass	% open	12:44:07
Keypad touch	2	
Keypad touch	5	
Main feed bypass	% open	12:44:29

The scoring scheme used required the scorer to classify each action as being desirable, ineffective, or undesirable in conjunction with being defined or not being defined by the OAET. Two judges classified each item. Items were discussed until a consensus was reached between the judges. The judges were operator licensing examiners. Essentially, Figure 13 captures the essence of what we were attempting to measure. Figure 14 presents the relationship of time and plant instability for the various branch points of an operator's action. This represents the operator's action as a continuum rather than the simple dichotomy of the OAET. Six categories were developed relating to the three branches of Figure 13. These categories are listed in Table 3. The scorer's task was to fit each action to one of these six categories.

Weights for the six categories were subjectively assigned by the experimenter. These weights are presented in Table 3. The rationale for scoring was based not only upon the relative consequences of the three branches, desirable actions, ineffective actions, and undesirable actions, but on whether or not the action was tree defined, indicating it was contained in the procedures. Undesired, tree-undefined actions were assigned the lowest weight (-3). These actions had the greatest potential negative consequences and were not a part of the standard procedures. Undesired, tree-defined actions were assigned a weight of -2. Other actions which also had the potential of a negative consequence were a part of the procedure, but were taken at an inappropriate time. Ineffective actions whether tree defined or not were assigned a weight

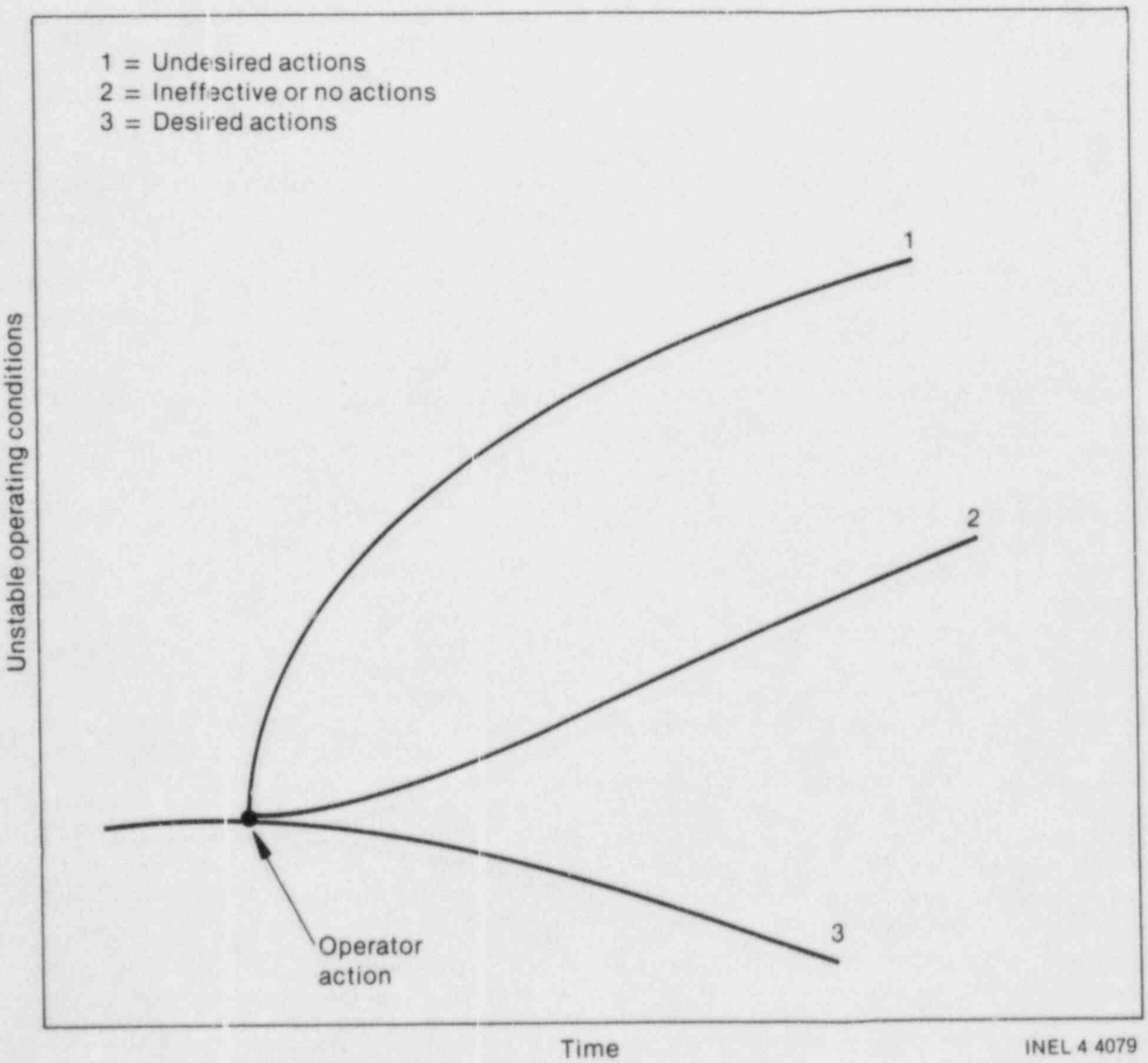

Figure 14. Relationship of time and plant instability for operator action.

of -1. A negative weight was assigned because these actions would not improve the situation. No differentiation was made between tree defined and tree undefined because of the lack of a difference in likely consequences. Tree-undefined, desired actions were weighted a positive score of 2 since they would improve the situation but were not a part of the procedures. Tree-defined, desired actions were given the highest positive weight (3). These actions would improve the situation and were a part of the standard procedure. The experimenter summed the weights to determine an overall category-based score for each transient. In addition to the classification of actions, the scorers were asked to assign a percentage score of transient solution "goodness." The maximum score was 100%, the minimum 0%. These two scores presented an accurate description of how well the operator was able to mitigate the transient and bring the plant to stable conditions.

Table 3. Categories of action classification weights

Category Number	Description	Weight
1	Undesired, tree-undefined action	-3
2	Undesired, tree-defined action	-2
3	Ineffective, tree-undefined action	-1
4	Ineffective, tree-defined action	-1
5	Desired, tree-undefined action	2
6	Desired, tree-defined action	3

ANALYSES

Four major analyses were conducted on the data described. The first two analyses were made with the dependent measures of plant parameter deviation, and time out of limits. These analyses were run using a one-way analysis of variance (ANOVA) with the planned orthogonal comparisons listed in Table 4 below. The analyses were run by transient for each plant parameter indicative of the safety function being compromised by that transient. Separate analyses were conducted for parameter deviation and percent time out of bounds. Only those analyses resulting in statistically significant effects are reported in the results section.

Table 4. Planned orthogonal comparisons for ANOVAS

Control Panel	Bar	Star	Meter	P-t Map
4	-1	-1	-1	-1
0	-1	-1	-1	3
0	-1	-1	2	0

The second two analyses were made with the dependent measures of category-based score and percentage score of operator performance. These analyses were 5 (display type) by 6 (transient) repeated measures ANOVA, with the same planned orthogonal comparisons for the factor of display type as in the previous analyses. One analysis was conducted for the category-based score and one analysis for the percentage score. Comparisons of interest are discussed in the results section.

RESULTS

The analyses of the safety functions via plant parameters yielded two significant effects from the six transients investigated. For Transient 1, a stuck open secondary relief valve, power level gave a significant difference in the comparison of control panel only vs. the combination of all other display types. The mean scores indicate that the control panel group had a smaller deviation of power level than the other groups. The orthogonal comparisons, means, and standard deviations are presented in Tables 5 and 6, respectively. The second significant effect was found for T-hot on transient 5, main steam isolation valve closes. Here the difference occurred between the P-t map vs. the combination

Table 5. ANOVA table for safety functions: Transient 1 power level deviation score

	Coefficient	Standard Error	T-Value	Significance
Control panel vs. bar, star, P-t map, and meter	12.75	5.033	2.53	$p < 0.05$
P-t map vs. bar, star, and meter	-3.25	3.90	-0.834	NS
Meter vs. bar and star	-1.25	2.76	-0.453	NS

of the bar, star, and meter display. The comparisons and measured standard deviations may be found in Tables 7 and 8, respectively.

The analyses of operator's performance in terms of the OAET will now be discussed. Tables 9 and 10 present the results for the category-based scoring. Table 9 contains the ANOVA, and Table 10, the means and standard deviations. The major comparison of interest is between the control vs. all other display types. This comparison reached statistical significance and, upon examination of the means, it is seen that the control panel only group performed significantly better than the others. Evaluating the two other comparisons along with the mean scores, the subjects are shown to have done equally well with the star, meter, and P-t meter, while substantially better with the bar, and even better with the control panel only. There were no statistically significant differences achieved between the displays on the scorer's subjective scores, although the means followed the same pattern. Therefore, these analyses are not contained in this report.

Table 6. Means and standard deviations safety functions: Transient 1 power level deviation score

	Mean	Standard Deviation
Control	5.75	2.63
Bar	9.25	1.26
Star	8.50	3.00
P-t map	9.75	0.50
Meter	8.25	2.75

Table 7. ANOVA table for safety functions: Transient 5 hot leg temperature percent time out

	Coefficient	Standard Error	T-Value	Significance
Control panel vs. bar, star, P-t map and meter	-0.081	0.215	-0.378	NS
P-t map vs. bar, star and meter	0.354	0.166	2.13	$p < 0.05$
Meter vs. bar & star	0.001	0.117	0.002	NS

Table 8. Means and standard deviations for safety functions: Transient 5 hot leg temperature percent time out

	Mean	Standard Deviation
Control	99	1.7
Bar	99	0.52
Star	99	0.21
P-t map	88	21.4
Meter	99	0.36

Table 9. ANOVA table for category classification score

	Coefficient	Standard Error	T-Value	Significance
Control panel vs. bar, star, P-t map and meter	-174.42	70.83	-2.46	$p < 0.05$
P-t map vs. bar, star and meter	32.42	54.86	0.59	NS
Meter vs. bar & star	13.04	38.79	0.34	NS

Table 10. Standard deviations for category classification score

	Mean	Standard Deviation
Control	93.71	69.94
Bar	69.96	45.95
Star	40.00	27.74
P-t map	42.00	23.15
Meter	48.46	74.79

DISCUSSION

The purpose of this report is to describe the effectiveness of the evaluation technique developed at INEL in evaluating computer-generated displays. The technique specifically tested the efficiency of using deviation of plant parameters indicative of safety functions as dependent measures in evaluating a display aid. In addition, the effectiveness of OAETs as an objective way of scoring operator paths in transient mitigation was assessed. Critical safety functions as measured by plant parameters yielded differences for two of the six transients studied in this experiment. One of those findings was consistent with the OAET scoring method, while the other was not. This method is sensitive to differences in the display aids. However, it is subject to the operator's style in operating a plant. That is, if a given operator reacts quickly rather than more slowly, this variable is significantly effected while the end result of stabilizing the plant is not. Thus, when using a tracking system such as this, it is important that the operators realize they are being scored as absolute numbers representing the operating range, and how long they remain outside that range. It is equally important to realize that this forces a behavior change and may temporarily change the operator's style in operating a plant. Care must be taken to select transients that will challenge safety functions, and that have parameters trackable and visible to the operator. This study, as well as others,[5,6] has clearly demonstrated the applicability of this technique in measuring performance.

The second method of measuring performance in this study was the use of OAETs. The major contention with the OAETs has been their dichotomous nature. That is, the operator either takes a specific action or s/he does not. As previously discussed, we do not feel this adequately addresses the realm of possible operator actions. The use of an action classification system allows the OAET to serve as the basis while accounting for the continuum of possible operator actions in performance terms. Our system of classification did yield significant differences among the displays, demonstrating its sensitivity.

The evaluation of operator actions is a meaningful way to assess the effectiveness of displays, procedures, and prior knowledge. Adequate control of procedures, and prior knowledge in this experiment allowed the systematic examination of the SPDs relative effectiveness in aiding the operator to determine what course of actions to take to bring the plant to stable operating conditions. Examinations of these actions are a face valid and credible manner of SPD evaluation.

The comparison of the displays used in this experiment also revealed an interesting finding. All the results, including trend data, have indicated that operators performed better when using the control panel only. That is, the addition of an extra top-level display (a safety parameter display) actually attenuated performance. These results are not directly generalized to the nuclear power plant control room. The control panel used in this experiment is unlike any control panel presently found in today's control rooms, and was intended only to allow the operator to control the plant. In fact, the control panel display used in this experiment is a type of safety parameter display. The SPD as defined in NUREG-0835, NUREG-0696, and Supplement 1 to NUREG-0737 (References 1, 2, and 3), is an integrated, concise display of the minimum set of the critical plant parameters. The control panel blended the initial set of necessary controls and indications to run the plant for the transient events selected. It was logically organized, and placed all the parameters in close proximity (in a single CRT screen). So, in effect, this was an integration of control and display for the operator. But the purpose of this research was to test the concept of interactive simulation to evaluate SPDs, which, in fact, the control panel enabled us to do.

The reported decrement in performance could be attributed to a number of different factors including training, treatments, or what we believe to be the most likely, time sharing between tasks. What follows is a discussion of the possible implications of this and an evaluation of the independence of SPDs in the control room. However, it is emphasized that these effects may not at all be present in a real control room situation.

We assert that the addition of second display panel caused the operator to time share between the two displays, creating a decrement in performance. This phenomenon is supported by a model developed by Norman and Bobrow,[7] which shows that the ability to share attention is related to the cognitive resources required by the tasks. The number of tasks, as well as their associated complexity must also be considered. It is crucial that the design features of a machine and the operator's ability to execute time-shared tasks are balanced.[8,9] This raises the question, for whom is the SPD intended? If it is intended for operator use, care must be taken to prevent degradation of performance. Overwhelming operators and crews with tasks and information is certainly undesirable, especially if such a situation causes more errors and lowers performance.[10] On the other hand, operator performance may not be a factor if a shift supervisor, or other person not directly involved with controlling the plant, makes use of the display as a top level indicator of plant status.

Techniques might also be employed to better integrate new displays in the control-room. Multimodel (visual, tactile, auditory) presentations have been shown to reduce workload, although they are not well understood.[11,12]

Certain types of training can also improve performance with shared tasks. Rieck, Ogden, and Anderson[13] demonstrated that the amount of dual task practice is a major determinant of subsequent dual task performance. Thus, training involving the shared tasks will improve performance, suggesting that simulator training has a great deal of importance. Overall, it is evident that care must be taken to fully integrate the man and machine in the system.

Methods Applicability

These experiments have shown that an interactive simulation method is an effective means of evaluating various display types concentrating on correction and follow of transient events. The method could also be easily used to evaluate various displays usability in the detection and recognition of transients. The workstation, computer hardware, computer software, and simulator configuration is a productive combination. The transfer of this method to full-scope simulators would be straightforward. A full scope simulator would also enable the evaluator to examine the full integration of the SPD into the control room. This method can also be used as a template to compare utility demonstration or tests of their SPD implementation. The use of the OAET in this experiment has reaffirmed their usefulness in the collection of human performance data. The trees, in conjunction with a classification system, can be used to look at human performance and errors. This type of information could also make a logical bridge to the human in risk assessment.

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APPENDIX A

INTERACTIVE SIMULATION TRAINING PROGRAM

APPENDIX A

INTERACTIVE SIMULATION TRAINING PROGRAM

Print of lesson NAMES

```
PR:1S
D:N$(20)
T:Please type in your name.
a:$n$
*q1
t:
t:$n$ , the control panel you will be
:using is composed of five major
:instrument and control groups. These
:are secondary coolant system, reactor
:control, reactor coolant system,
:emergency core cooling, and purifica
:tion system.
u:return
j:a1
*return
t:
t:PRESS RETURN TO CONTINUE
as:
g:es
e:
*al
t:How many major instrument and control
:groups make up the control panel?
a:
m:5!five
ty:correct
tn:$n$ , incorrect try again.
jn:q1
u:return
*q2
t:In addition, a numeric input by
:keypad is located in the lower right
:hand portion of the screen. This key
:pad will be used to set rates and
:speeds for the various pearameters. The
t:operation of this key pad and all
:controls will be explained later in
:this session.
u:return
t:Where is the key pad located on the
:control panel?
a:
m:lower$right!
ty:correct
tn:$n$ , incorrect try again.
jn:q2
u:return
*z1
t:The selected functions of the various
:controls are shown by a white
:backlight. Deselected functions are
:shown by a cyan backlight. Therefore,
t:if the off button for the PCS Pumps is
:white, and the on button is blue the
:PCS pumps are off. All control
:functions are indicated in this
:fashion.
u:return
t:is the main feed pump indicated as on
:or off on the control panel?
a:
m:on!running
ty:correct
tn:$n$ , incorrect try again.
jn:z1
u:return
t:We will begin by familiarizing you
:with all the controls, and displays on
:the control panel. The first system we
:will consider is the secondary coolant
:system.
t:
t:
*q3
t:The secondary coolant system is
:composed of 20 controls and displays.
:Your task is to find each of these
:controls and displays, and to record
:the operational state using the
:keyboard following the control/display
:name.
u:return
t:Your task in this series of questions
:is to _________ each control and
:display, and to _________ the operational
:state following the control/display
:name.
a:
m:find&record!enter
ty:correct
tn:$n$ , incorrect try again.
jn:q3
u:return
t:The first subgroup in the secondary
:coolant system are those controls/dis
```

```
:plays dealing with the steam generator.
t:The first item is:
t:
*q4
t:STM Generator Level
a:
m:8
ty:correct
tn:$n$ , incorrect try again.
jn:q4
*q5
t:STM Generator Pressure
a:
m:808
ty:correct
tn:$n$ , incorrect try again.
jn:q5
*q6
t:STM Generator Temperature
a:
m:519
ty:correct
tn:$n$ , incorrect try again.
jn:q6
*q7
t:Stm Gen Lvl Control
a:
m:auto!automatic
ty:correct
tn:$n$ , incorrect try again.
jn:q7
*q8
t:STM Generator Blowdown
a:
m:shut!closed!off
ty:correct
tn:$n$ , incorrect try again.
jn:q8
u:return
t:The next subgroup deals with STM Flow
:these are:
t:
t:
*e5
t:STM Flow
a:
m:167
ty:correct
tn:$n$ , incorrect try again
jn:e5
*e6
t:STM Bypass
a:
m:O
ty:correct
tn:$n$ , incorrect try again.
jn:e6
*e7
t:STM Stop
a:
m:open!on
ty:correct
tn$n$ , incorrect try again.
jn:e7
*e8
t:STM Flow Control
a:
m:58
ty:correct
tn:$n$ , incorrect try again.
jn:e8
u:return
t:The next text deals with Main Feed.
:These are:
t:
t:
*q9
t:Main Feed Flow
a:
m:167
ty:correct
tn:$n$ , incorrect try again.
jn:q9
*q10
t:Main Feed Bypass
a:
m:O!0%
ty:correct
tn:$n$ , incorrect try again.
jn:q10
*q11
t:Main Feed Isolation
a:
m:open!on
ty:correct
tn:$n$ , incorrect try again.
jn:q11
*q12
t:Main Feed Control
a:
m:33!33%
ty:correct
tn:$n$ , incorrect try again.
jn:q12
*q13
t:Main Feed Pump
a:
m:on!running
```

```
ty:correct
tn:$n$ , incorrect try again.
jn:q13
u:return
t:The next subgroup is concerned with
:the condensate receiver. These are:
t:
t:
*q14
t:Cond. RCVR Level
a:
m:32
ty:correct
tn:$n$ , incorrect try again.
 jn:q14
*q15
t:Cond. RCVR Pressure
a:
m:300
ty:correct
tn:$n$ , incorrect try again.
jn:q15
*q16
t:Cond. RCVR Temperature
a:
m:417
ty:correct
tn:$n$ , incorrect try again.
jn:q16
u:return
t:The last subgroup is the Aux Feed.
t:These are:
t:
t:
*q18
t:Aux Feed Pump
a:
m:off!stop
ty:correct
tn:$n$ , incorrect try again.
jn:q18
*e2
t:Aux Feed Isolation
a:
m:shut!closed!off
ty:correct
tn:$n$ , incorrect try again.
jn:e2
u:return
t:The second system is the reactor
:control system which is composed of
:four controls and displays. These are:
t:
t:
*q20
t:Reactor Status-Trip
a:
m:no!indication!off!blank
ty:correct
tn:$n$ , incorrect try again.
jn:q20
*e4
t:Reactor Status-PCT PWR
a:
m:80!80%
ty:correct
tn:$n$ , incorrect try again.
jn:e4
*q21
t:Positive Indicators (Rods 2,4,6 and
:8)-inches
a:
m:54!54 inches
ty:correct
tn:$n$ , incorrect try again.
jn:q21
*q22
t:Reactor Scram
a:
m:none!no!indication!off!blank
ty:correct
tn:$n$ , incorrect try again.
jn:q22
*q23
t:Rod Drive
a:
m:hold
ty:correct
tn:$n$ , incorrect try again.
jn:q23
u:return
t:The third system is the reactor
:coolant system which is composed of
:thirteen controls and displays. These
:are:
t:
t:
*q24
t:PZR Level
a:
m:45
ty:correct
tn:$n$ , incorrect try again.
jn:q24
j:25
*s5
ty:correct
tn:$n$ , incorrect try again.
```

e:
*q25
t:PZR Pressure
a:
m:2185
u:s5
jn:q25
*q26
t:PZR Temperature
a:
m:652
u:s5
jn:q26
*q27
t:PORV
a:
m:shut!off
u:s5
jn:q27
*q28
t:PZR Spray
a:
m:auto!automatic
u:s5
jn:q28
*q29
t:PZR Heaters
a:
m:auto!automatic
u:s5
jn:q29
*q30
t:PORV Isolation
a:
m:open!on
u:s5
jn:q30
*q31
t:Hot Leg Temperature
a:
m:564
u:s5
kn:q31
*q32
t:Cold Leg Temperature
a:
m:535
u:s5
jn:q32
*q33
t:PCS Pumps
a:
m:on!running
u:s5
jn:q33
*q34
t:PCS Flow
a:
m:3800
u:s5
jn:q34
*q35
t:Hot Leg Drain
a:
m:0
u:s5
jn:q35
*q36
t:Cold Leg Drain
a:
m:0
u:s5
jn:q36
u:return
t:The fourth system is the Emergency
:Core Cooling which contains nine
:controls and displays. These are:
t:
t:
*q37
t:Coolant Source
a:
m:none!not selected
u:s5
jn:q37
*q38
t:HPIS Pump A
a:
m:off
u:s5
jn:q38
*q39
t:HPIS A Flow
a:
m:0
u:s5
jn:q39
*q40
t:HPIS A Isolation
a:
m:shut!closed
u:s5
jn:q40
*q41
t:HPIS Pump B
a:
m:off
u:s5

```
jn:q41
*q42
t:HPIS B Flow
a:
m:0
u:s5
jn:q42
*q43
t:HPIS B Isolation
a:
m:shut!closed!off
jn:q43
*q44
t:Downcomer Isolation
a:
m:shut!off!closed
u:s5
jn:q44
*q45
t:Cold Leg Isolation
a:
m:shut!off!closed
u:s5
jn:q45
u:return
t:The fifth system is the Purification
:System which is composed of six
:controls and displays.
t:
t:
*q46
t:HPIS ti Purif Sys
a:
m:shut!closed!off
u:s5
jn:q46
*q47
t:PURIF Flow
a:
m:0
u:s5
jn:q47
*q48
t:PURIF Inlet
a:
m:shut!closed!off
u:s5
jn:q48
*q49
t:PURIF Pump
a:
m:off!closed!not running
u:s5
jn:q49
*q50
t:PURIF Throttle
a:
m:0
u:s5
jn:q50
*q51
t:PURIF Outlet
a:
m:shut!off!closed
u:s5
jn:q51
u:return
e:
```

Print of lesson CONT

```
*q1
t:In this experiment, the mimic screen
:also allows the operator to control
t:various plant parameters. You will be
:asked not only to observe plant
:status, but the screen will provide a
t:capability for control input as well.
:There is a touch sensitive panel
:placed over the screen that will
t:signal an audible "beep" when buttons
:are manipulated.
u:return
j:q2
*return
t:
t:PRESS RETURN TO CONTINUE
as:
g:es
e:
*q2
t:Additional feedback is provided to
:the operator in the form of color
:coding the controls and changes in
:numeric data.
u:return
t:There are two types of controls
:presented on the screen. One type
:permits the actual selection of
:numeric values for selected parameters
:.
t:The letter type gives the operator
:the
:option for selecting whether a
:specific component should be "ON",
:"OFF", "OPEN", "SHUT", or "AUTO". or
:in the case of the reactor control
:rods, "IN", "HOLD", and "OUT".
```

u:return
t:The actual sequence for controlling
:and operating these two types of
:controls will now be discussed.
:First, you will be introduced to the
t:procedure for selection and input of
:numeric values. In the lower right
t:hand corner of the screen is a
:numeric keypad similar in layout to a
:touchtone key pad. This key pad will
:serve as an input device for the
t:selection of desired flow rates in gpm
:and valve status in percent open for
:specific controls on the screen.
u:return
t:The steps for accomplishing this task
:can best be described using a brief
:example. First, locate the control
t:labeled :Steam Bypass'' in the
:Secondary Coolant System. Now, suppose the digital
:indication in the window is currently
t:set at ''0'' gpm and you want to bring
:the flow up to 25 gpm for this pump.
t:
t:THIS VALUE IS ENTERED BY PRESSING
t:THE BUTTONS IN THE SEQUENCE ''2'',and ''5''
u:return
t:After this sequence, the input window
:located immediately above the first
:row of numeric keys on the key pad
:will display the value entered.
t:
t:The ''cl'' button, on the key pad, can be pressed if
:you are not satisfied with the value
:shown and a new value can be entered
:following the sequence previously
:discussed.
t:For example, if you decided to
:change flow to 27, you would press
:''cl'' followed by ''2'',and ''7''. You are now
t:ready to change the flow rate to 27
:gpm after verifying the value
:displayed in the input window is
:correct.
u:return
t:This is accomplished by simply
:pressing the box. Any location within
:the boundaries of the box can be
:pressed to achieve input.
u:return
t:immediate feedback is received by the
:display of the new updated value in
:the Control Box for ''Steam Bypass'' and
:the removal of the value shown in the
t:input window is transferred to the
:control box window to update the
:numeric value previously displayed.
t:
t:At this time we would like you to
:practice making such changes. Please
:make a change in the following
:controls:
t: STM FLOW CONTROL
t: MAIN FEED BYPASS
t: HOT LEG DRAIN
u:return
t:In this section you will be
:introduced to the operation of the
:second type of controls. This
t:category includes the control boxes
:with the ''OFF-ON'', ''SHUT-OPEN''
t:combinations and including other
:specialized buttons for controlling
:the plant. The procedure for
:controlling various parameters of
t:this nature can best be described
:using a brief example.
u:return
t:First locate the AUX FEED PUMP in the
:Secondary Coolant System. This
:control should be in an off condition
:which is indicated by the utilization
t:of a white and cyan color coding
:scheme.
t:Therefore, current operational mode
:indicating AUX FEED PUMP is in a non-
:operating condition is conveyed by the
:white backlight displayed on the ''OFF''
:key, and subsequently the cyan
t:backlight displayed on the ''ON'' key.
u:return
t:These colors will toggle back and
:forth as a function of operational
:mode. In other words; white indicates
:an active mode whereas cyan indicates
t:a passive or nonoperational mode.
t:
t:IT IS CAUTIONED THAT PATIENCE BE
:OBSERVED WHEN MANIPULATING THESE
:CONTROLS DUE TO A LAG TIME FOR THE
:SYSTEM TO RESPOND.
u:return
t:For example, if the operational
:setting for a control were off and the
:desired setting were to turn the
:control ''ON'', the following sequence

```
t:will usually be observed: a toggle in
:the color code will occur by which the
:"ON", button will code white followed
:by a rebound to cyan for a moment,
:then switch back to white and remain
t:at this setting until another change
:in operational mode.
u:return
t:At this time, a training session will
:be conducted to familiarize you with
:the specific controls designated to be
:manipulated in the manner just
:described. In order to fully acquaint
t:you with controls of this type you
:will be asked to input data for
:various controls.
u:return
t:      STM GEN LVL CONTROL
t:      MAIN FEED PUMP
T:      PORV
T:      PCS PUMPS
T:      HPIS PUMP A, flow = 25gpm
T:      COLD LEG ISOLATION
T:      PURIF INLET
T:      ROD DRIVE
T:      REACTOR SCRAM
u:return
```

Print of lesson DISP

```
pr:is
t:Please type in the letter of the
:display type you will be using.
t:A. control panel
t:B. bar, star, meter, or P-t map
a:
m:a!A
g:es
jy:fh
t:Your last section of training will
:familiarize you with safety
:parameter display that you will use in
:this experiment. Keep in mind that
t:the purpose of this experiment is to
:determine if the SPD does enhance your
:performance of detecting and
:identifying transient, and mitigating
t:those transients to a "safe" plant
:condition. Therefore, it is
:imperative that you use the SPD as an
:aid to you in accomplishing these
:tasks.
u:return
t:This training has two parts. The
:first is a brief description of the
:SPD you will use, and the second is
t:the viewing of sixteen known
:transients to acquaint you with the
:characteristics of the SPD.
u:return
j:d4
*return
t:
t:PRESS RETURN TO CONTINUE
as:
g:es
e:
*d4
t:At this time please type in the
:letter of the display type you will be
:using
t:
t:
t:A.  Bars
t:
t:B.  Stars
t:
t:C.  Meters
t:
t:D.  P-t map
d:f$(30)
a:$f$
g:es
j(f$-"A"):bars
j(f$-"B"):stars
j(f$-"C"):meters
j(f$-"D"):P-t
*bars
u:color
:reac
t:The bars display uses a central line
:to indicate the normal value.
:Parameter deviations from this value
t:are shown as bars to the left or right
:of normal. High and low range values
:were shown as vertical lines.
u:return
t:Parameter descriptions and digital
:values are on the right of the
:display. As parameter values reach
:the intermediate and out of limit
:barriers the bar indicator and digital
:values on the display change to the
:appropriate color. Notice that the
:primary coolant system parameters are
t:grouped at the top with the secondary
:system parameters at the bottom.
u:return
```

j:fine
*color
t:Each of the parameters on the display
:will give you the following color
:coded information.
t:
t:
t:Normal Operation- The setting is the
:center region for a given parameter
:level and is communicated to the
:operator with a green color code.
t:Numeric characters will also be
:green. The color green tells the
:operator to proceed and that parameter
:condition is satisfactory.
u:return
t:Intermediate Limits- The setting is
:immediately above or below a given
:parameter for normal operation, but
:not exceeding the extreme areas for
t:being out of limits. The condition is
:interpreted to the operator with a
:yellow color code. Numeric characters
:will also be yellow. The color code
t:yellow conveys caution to the operator
:and tells him a recheck is necessary.
u:return
t:Out of Limits- The setting is either
:above or below a given parameter of
:the range of intermediate limits. The
:condition is interpreted to the
:operator with a red color code.
t:Numeric characters will also be red.
:The color red alerts the operator and
:informs him that corrective action
:must be taken.
u:return
e:
*reac
t:The display also gives you reactor
:power in percent at center bottom, and
:control rod status in a box at the
:left margin.
e:
*Stars
u:color
u:reac
t:The star display represents parameter
:values as positions on the spokes of
:circle. A small inner circle
:represents range minimums while an
t:outer circle represents range
:maximums.
t:Current value spoke positions are
:tied together to form a nine-sided
:polygon. Digital values and parameter
:descriptions are shown around the
:outside of the maximum range ring.
u:return
t:background rings show the intermediate
:and out of range positions, with the
:digital parameter indications changing
:color as previously described.
u:return
j:fine
*Meters
u:color
u:reac
t:The meter display represents
:parameter values as needle positions
:on nine meters drawn on the cathode
:ray tube. The green, yellow, and red
t:ranges were shown on the meters with
:only the color corresponding to the
:current parameter value lit. Digital
:values (color coded as described) and
:parameter descriptions were inside
t:each meter.
u:return
j:fine
*P-t
u:color
t:Obtain the three figures on the P-t
:map from the experimenter. Figure 1
:shows the PT diagram with information
:pertinent to normal operation. In
:this mode, the reactor is at power
t:when it is presented on the screen.
:Figure 2 is displayed when there is a
:scram condition and the primary
:coolant pumps are in operation. The
:scram condition also exists in Figure
t:3, but in this case, the primary
:coolant pumps are off.
u:return
t:In general,each P-t map shown in the
:figures include a saturation curve
:which applies to both primary and
:secondary steam conditions. Above the
t:saturation line is the subcooled water
:region; below it is the superheated
:steam region.
t:Digital information for the Primary
:Coolant System (PCS) and the
:Secondary Coolant System (SCS) are
:presented adjacent to the P-t map.
:The box labeled PCS provides the
t:operator with numerical values for

:Pressure, Hot Leg Temperature, and
:Cold Leg Temperature.
t:The SCS box presents a value for
:pressure and steam temperature.
u:return
t:The P-t map, regardless of operation
:mode, show a data point for pressure
:and temperature in the Hot Leg Primary
:System (denoted with an "H" cursor),
t:and a point for pressure and
:temperature in the Secondary System
:(denoted with an "S" cursor). A
:pressure temperature point is
:established for the Cold Leg Primary
t:System (denoted with a "C" cursor)
t:when the reactor is in one of the
:scram conditions as illustrated in
:Figures 2 and 3. The "C" cursor is
t:not evident in Figure 1 since it only
:manifests itself when the plant is in
:a scram condition.
u:return
t:A box or window is enclosed around
:the "H" and "S" cursor in Figure 1.
:This window represents boundaries for
:normal operation around the cursor
:points.
t:These boundaries were established to
:account for minor plant variation, and
:power level.
t:Normal power operation could be
:anywhere within this window and be
:acceptable. The windows are dynamic
:in that they are functionally related
t:to reactor power levels. There are
:many conditions that will result in
:the cursor ("H" and "S") leaving the
:box. The position then becomes out of
:specification for Hot Leg Temperature
t:and Pressure ("H") or Secondary System
:Temperature and Pressure("S").
u:return
t:Immediately after the cursor leaves
:the box, a series of data trails will
:track its position on the P-t map.
t:The data trails consist of a string
:of dots for the "H" and "S" cursors
:with plus signs ("+") for the "C"
:cursor. These trails are illustrated
t:in Figures 2 and 3.
u:return
t:A set of dashed trip lines are also
:presented on the P-t map for the
:critical mode. These lines are
:replaced with a set of pressure relief
:lines under the scram modes (see
t:Figures 2 and 3).
t:The critical mode in Figure 1
:illustrates the location of the trip
:lines. The high pressure trip is
:located at 2346 psig, and the low
t:pressure trip is at 2059 psig. In
:addition, there is a T-hot trip at 603
:degrees F. The lines for Figures 2
t:and 3 are set at 2410 psig for PCS
:pressure relief and at 1088 psig for
:SCS pressure relief.
u:return
t:The cursors are color coded depending
:on their relative positions to these
:lines and windows. The color coding
:scheme is that which was previously
:described.
u:return
*fine
t:Tell the experimenter that you have
:completed this portion of the training
:and are ready for the transients.
u:return
*fh
t:Your task in this experiment will be
:to attempt to mitigate the transient
:as it unfolds. Your will be tape
:recorded as you work through the
t:transient and you must verbalize each
t:action as you take it and why you are
:taking it. In doing so you should
:identify what you think the transient
:is as you take your control actions.
u:return
t:Your performance will be scored on
:the basis of two measures. How well
:your solution to the transient fits
:the ideal model, and how well you
t:control the safety functions
:jeapordized by the safety in terms of
:operating limits for various
:parameters
u:return
t:A set of P.O.M.s have been provided
:for your use and you may refer to them
:at any time you deem necessary.
t:
t:
t:You may work on the transient until
:you feel the plant is on its way to
:stable conditions, one half hour has
:past in real time, or the plant
:simulation model has failed.
t:Please inform the experimenter that
:you have completed the training.
u:return

APPENDIX B

TABLE OF SETPOINTS FOR PARAMETERS BY TRANSIENT

APPENDIX B

TABLE OF SETPOINTS FOR PARAMETERS BY TRANSIENT

Transient Name and Number	Reactor Status	Power Level (%)	Steam Generator (in.)	Pressurizer Pressure (psig)	Hot Leg Temperature (T-hot) (°F)	Pressurizer Level (in.)	Subcooling Greater Than 25 Degrees (°F)
1. Stuck open secondary relief valve	Before scram	75	—	—	—	—	—
	After scram	0	—	>1500 ≤1670	—	—	—
2. Loss of primary coolant pumps	Before scram	—	—	—	—	—	—
	After scram	0	—	—	>541 <503	—	—
3. Steam generator tube rupture	Before scram	—	—	>2100	—	—	—
	After scram	0	—	<1100	—	>18 <70	≥20
4. Loss of main feedwater	Before scram	—	>-5 <13	<2210	<525 <565	≥37 ≤51	—
	After scram	0	>-32	—	—	—	—
5. Main steam isolation valve closes	Before scram	—	>-5 <13	<2340	>525 <565	≥37 ≤51	—
	After scram	0	—	—	>503 <541	—	—
6. Stuck open pressurizer spray valve	Before scram	—	—	>2050	—	—	—
	After scram	0	—	—	—	<70	≥20

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The United States Nuclear Regulatory Commission (USNRC) is sponsoring an on-going research program to develop methods of assessing various types of computer-generated displays currently being implemented in nuclear power plant control rooms. The purpose of this report is to present an interactive simulation technique for the evaluation of computer-generated displays. The independent variables for this experiment were transient type (six levels), and display type including the levels of star + control panel, bar + control panel, meter + control panel, pressure-temperature map + control panel, and control panel only. The dependent measures were deviations of parameter values comprising the safety functions at risk, percent of time these parameters were out of tolerance from onset of the transient, and accuracy of the operator path in transient mitigation. The results indicate that an interactive simulation method can be used to evaluate various display types, and that the workstation and computer/simulator is an effective configuration. The implications of these results for display evaluation and design are discussed.

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