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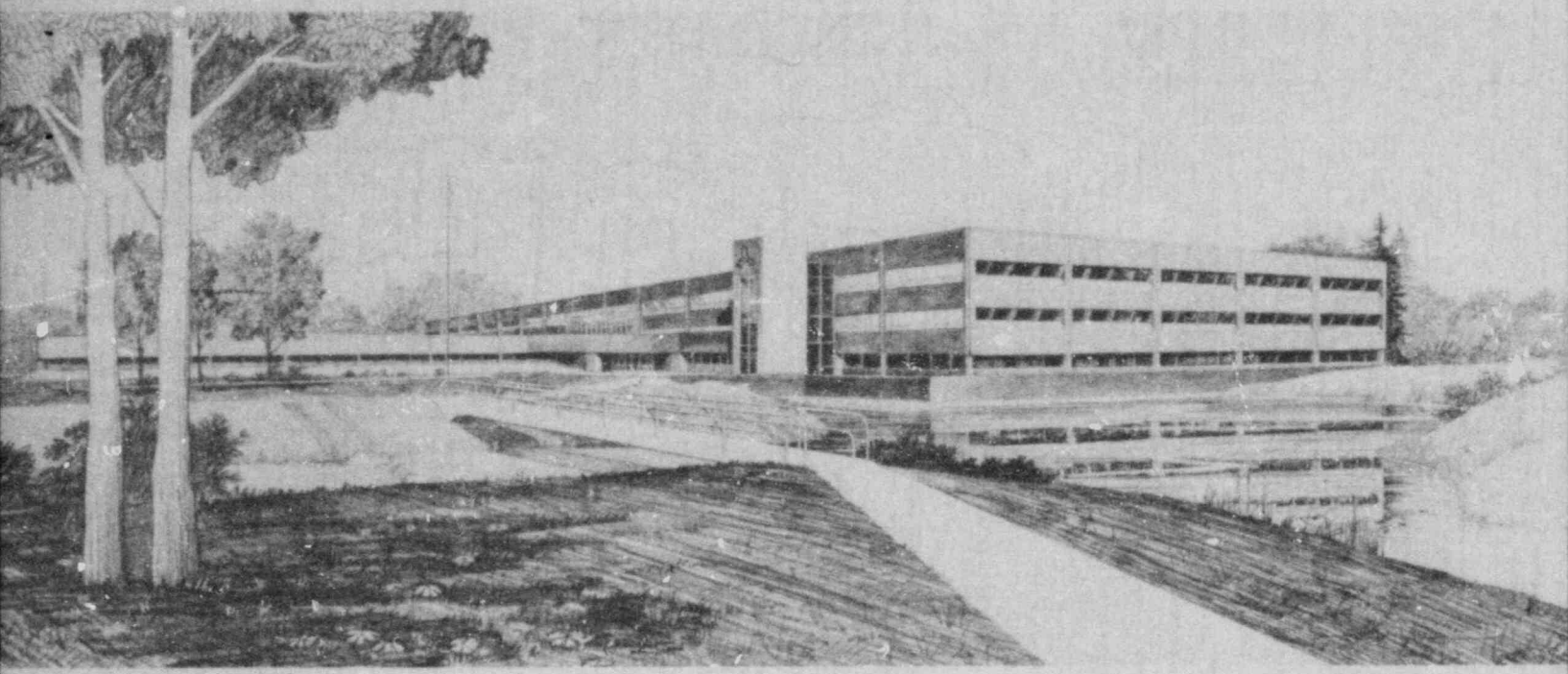

Idaho National Engineering Laboratory
Operated by the U.S. Department of Energy

Identification and Assessment of Anticipated Major Changes in Control Rooms

Robert E. Ford
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Prepared for the
U.S. Nuclear Regulatory Commission
Under DOE Contract No. DE-AC07-76ID01570

EG&G Idaho

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U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

and

National Technical Information Service
Springfield, Virginia 22161

NUREG/CR-3975
EGG-2339
Distribution Category: RX

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FIN No. A6390

ABSTRACT

This report fulfills the objective of the Advanced Control Room Concepts Project to identify the major changes and establish the appropriate categories in nuclear power plant control room designs so that a continuum of changes can be identified. A modified Delphi Technique was used for conferring with control room experts to identify the possible control room changes or concepts, and to identify the category into which these concepts belong. The results of the first Delphi conference round were then structured into a multilevel hierarchy. The top level, or focus, of this hierarchy is the control room man-machine system. The second level is the identified categories; the third level consists of modifiers to the second level; and the bottom, or fourth, level is the concepts or changes. The second round of the Delphi conference asked the panel to pairwise compare groups of related concepts as to the likelihood of their being used in a backfit or future generation control room. The results of the second Delphi conference round ranks the possible changes from the most likely to the least likely for both the related group of changes and for the top level, the control room man-machine system.

EXECUTIVE SUMMARY

Nuclear power plant control rooms in the United States are in a state of actual, or impending change. These changes in control rooms derive from a perception of needs for improvement as reported by the President's Commission on Three Mile Island, the Nuclear Regulatory Commission, the Electric Power Research Institute, and others. This impetus towards changes arrives at a time when man-machine technology offers a much greater number of options for satisfying control room needs than existed when currently operating nuclear power plants were designed. These options derive primarily from the growth in digital computer technology, but also from the arts and sciences of systems engineering and human factors.

The objective of the Advanced Control Room Concepts Project is to identify the criteria and guidelines needed for the regulatory assessment of these control room changes which will appear in backfits and in new designs for the next generation of nuclear power plants. This report identifies the major changes and establishes appropriate functional categories for these changes, so that a search for appropriate criteria and guidelines can begin.

Identification of changes to occur within the next 3-10 years is a forecasting activity. Since 3-10 years is a relatively short time frame and since many changes have been initiated, a forecasting method based upon extrapolation of existing trends is appropriate. Further, these trends are being perceived and influenced by experts within the network of institutions that comprise the nuclear power community, i.e., nuclear utility operations and engineering, reactor manufacturers, architect-engineers, regulators, national laboratories, the process control industry, and universities and research institutions. Therefore, experts from these institutions were identified who could perceive and predict trends and categories of change over the short term (3-10 years). A modification of the Delphi method[a] was adopted to develop a technological forecast of control room change based upon the opinion of these experts. (Delphi may be characterized as a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem.)

All communications between the moderators at the INEL and the Delphi panel of experts were by telephone and mail. The panel members concurred with the need for the nuclear community to identify, categorize, and ultimately evaluate control room changes and volunteered their efforts in support of the technological forecast. A need for anonymity for individuals and organizations was recognized since the expert's opinion, not the company's official position, was being solicited. This anonymity was preserved.

Two rounds of conferences were conducted with the Delphi panel. Tables S-1 and S-2 show the profile of the Delphi panel. The agenda for Round 1 conference with 38 experts was directed at identifying new control room concepts within the complete spectrum of the man-machine system, e.g., displays, controls, procedures, training.

The moderators of the Delphi process at INEL formatted the results of Round 1 into a four-level hierarchy. The top level is the control room man-machine system; the second level consists of the eight categories, e.g., displays; the third level consists of modifiers to the second level, e.g., display method; and the bottom, or fourth, level consists of the detailed concepts, e.g., CRT display of procedural information.

The agenda for the second round of the Delphi conference requested the experts to provide a pairwise comparison of the relative likelihood of related concepts at Levels 2, 3, and 4. Likelihood refers to the probability of implementing the concept in backfits or future generation control rooms. The pairwise comparison is a time-consuming process, but was necessary to provide reliable data as explained below.

The results of Round 2 provided likelihood ratios from each of 23 experts for each concept or category in the hierarchy of control room concepts. The data were designed for reduction by the Analytic Hierarchy Process[b], which provided a consensus likelihood ratio for each concept or category, i.e., the relative likelihood was established from the most likely to the least likely concept. Tables S-3 and S-4 display the 25 most likely and the 25 least

a. The Delphi Method: Techniques and Applications, Harold A. Linstone and Murray Turoff, Addison-Wesley, 1975.

b. The Analytical Hierarchy Process, Thomas L. Saaty, McGraw-Hill, 1980.

Table S-1. Profile of the Delphi panel (Round 1)

Type of Experience	Number of Experts	Years Experience
Commercial Reactors		
Pressurized water reactor	18	—
Boiling water reactor	4	—
Both	11	—
Other	10	—
Operations	9	39
Technical support	17	115
Design	14	114
Transient analysis	13	63
Safety analysis	3	54
Training	7	46
Construction	3	4
Military Reactors		
Operations	7	21
Technical support	4	11
Design	3	9
Transient analysis	1	2
Training	7	20
Construction	2	4
Reactor Research, Development, and Design		
Core physics characteristics	10	63
Reactor and reactor coolant systems	6	50
Chemical and volume control systems	4	42
Engineered safety features and systems	10	70
Steam and power conversion systems	2	20
Cooling water systems	1	30
Radioactive waste disposal systems	1	1
Refueling systems	1	8
Process instrumentation systems (I&C)	19	188
Plant chemistry	1	8
Plant operations	5	45

Table S-2. Profile of the analytic panel (Round 2)

Type of Experience	Number of Experts	Years Experience
Commercial Reactors		
Pressurized water reactor	6	—
Boiling water reactor	2	—
Both	8	—
Other	7	—
Operations	4	23
Technical support	10	90
Design	11	69
Transient analysis	7	40
Safety analysis	7	35
Training	5	32
Construction	1	2
Military Reactors		
Operations	6	25
Technical support	4	12
Design	4	16
Transient analysis	1	2
Training	6	15
Construction	2	4
Reactor Research, Development, and Design		
Core physics characteristics	4	21
Reactor and reactor coolant systems	2	32
Chemical and volume control systems	2	31
Engineered safety features and systems	7	57
Cooling water systems	1	30
Process instrumentation systems (I&C)	7	80
Plant operations	3	36

Table S-3. Level 4: the 25 most likely concepts relative to the advanced control room forecast which is Level 1

Concept	Relative Likelihood	Relative Rank
1. Current and trend values of process parameters (Item 641)	0.0359	1.00
2. Derived information from computer analysis of process parameters (Item 642)	0.0291	0.81
3. Data validation (Item 713)	0.0219	0.61
4. Computer guidance for selection of procedure (Item 332)	0.0153	0.43
5. Predictive and anticipatory information from computer analysis of current state and model of the process (Item 643)	0.0147	0.41
6. Integrated sets of two or more formats (Item 628)	0.0146	0.41
7. Cathode-ray tubes or plasmascopes (Item 432)	0.0135	0.38
8. Integrated outputs which use combinations of the above for prioritizing or selectivity (Item 435)	0.0130	0.36
9. Improved sensors (accuracy, reliability, response) (Item 712)	0.0128	0.36
10. Integrated sets of two or more methods (Item 656)	0.0125	0.35
11. Intelligent sensors (Item 711)	0.0124	0.35
12. Diagnostics (Item 724)	0.0123	0.34
13. Automation of dynamic systems (Item 142)	0.0123	0.34
14. Automation of core cooling and other protective systems (Item 143)	0.0123	0.34
15. System state estimation (fault detection and identification) (Item 722)	0.0119	0.33
16. Qualification and refresher training will continue to increase in time allotted, innovation, and realism (Item 219)	0.0115	0.32
17. Performance on the job as determined by critical reviews (Item 853)	0.0110	0.31
18. Computer retrieval, CRT display (Item 343)	0.0108	0.30
19. Matrix of function-oriented and event-oriented procedures (Item 312)	0.0107	0.30
20. Interactive I/O between the operator and the computer (Item 634)	0.0105	0.29
21. Use of new emergency operating procedures which are function oriented or event independent (Item 824)	0.0105	0.29

Table S-3. (continued)

Concept	Relative Likelihood	Relative Rank
22. Technical qualification levels of the shift supervisor, the senior reactor operator, and reactor operator will be raised (Item 214)	0.0105	0.29
23. Technical specifications compliance (Item 723)	0.0104	0.29
24. Integrated sets of two or more display methods (Item 618)	0.0102	0.28
25. Performance during training programs (Item 851)	0.0101	0.28

Table S-4. Level 4: the 25 least likely concepts relative to the advanced control room forecast which is Level 1

Concept	Relative Likelihood	Relative Rank
1. Local authorities access to control room communications (Item 519)	0.0003	0.19
2. Headquarters office personnel access to control room communications (Item 516)	0.0005	0.31
3. Security guards access to control room communications (Item 518)	0.0005	0.31
4. NRC resident inspector access to control room communications (Item 517)	0.0006	0.38
5. Operator voice input to alarm or annunciator (Item 453)	0.0008	0.50
6. Closed circuit video message medium for communications (Item 543)	0.0008	0.50
7. Portable, hand-held I/O units for control room communications (Item 546)	0.0009	0.56
8. Plant management office personnel remote access to control room communications (Item 515)	0.0010	0.63
9. Three-dimensional display projection method (Item 615)	0.0011	0.69
10. More functional and reliable actuators as controls or control system components (Item 112)	0.0011	0.69
11. Quality assurance personnel information access (Item 747)	0.0011	0.69
12. Electronic mail (computer handled) communications (Item 545)	0.0011	0.69
13. Remote, hand-held, operator input to alarm or annunciator systems (Item 456)	0.0012	0.75

Table S-4. (continued)

Concept	Relative Likelihood	Relative Rank
14. Health physics technician remote access to control room communications (Item 514)	0.0012	0.75
15. Plant operations review (licensing) information access and I/O (Item 740)	0.0013	0.81
16. Health physics training personnel to receive more training (Item 814)	0.0013	0.81
17. Radiation field information on messages in control room communications (Item 523)	0.0014	0.88
18. Computer-synthesized voice display method (Item 617)	0.0014	0.88
19. Voice recognition in connection with operator display control (Item 655)	0.0014	0.88
20. Voice procedure format (Item 326)	0.0014	0.88
21. Fuel management procedure improvement (Item 355)	0.0015	0.94
22. Maintenance personnel remote access to control room communications (Item 511)	0.0015	0.94
23. Speaker/microphone audio message medium in communications (Item 542)	0.0015	0.94
24. Maintenance technician information access and I/O (Item 745)	0.0015	0.94
25. Engineering support personnel to receive more training (Item 815)	0.0016	1.00

likely concepts, respectively. The Analytic Hierarchy Process algorithms also provided an assessment of the degree of consistency of the panel, i.e., if the panel rates A<B<C, it would be inconsistent for the panel to also rate A>C.

Reliability and consistency statistics were good to excellent. These statistics, together with the broad based, extensive knowledge and experience of the control room experts who participated in this task, support the validity of this forecast.

For the 569 comparisons made by the expert panel of the 217 possible changes, a majority consensus was achieved for 537; an absence of consensus was found for 21; and, for 11 of the comparisons, a definitive instance of controversy was revealed. Those instances of controversy were not associated with any identifiable set of subgroupings of the panel, e.g., utility vs regulators; however, nine of them were concerned with the degree to which the control room should be computerized. One of these was concerned with the role the Technical Support Center would have relative to the control room. The remaining two were due to an inadequate definition of the concept of information management. These bimodal responses are:

1.	Information management (Category 7)	*vs*	Controls (Category 1)
2.	Information management (Category 7)	*vs*	Procedures (Category 3)
3.	Procedures; computer stored, manual retrieval (Item 331)	*vs*	Automatic display of situation-specific procedures (Item 333)
4.	Procedures; computer guidance for selection of procedures (Item 332)	*vs*	Computer-synthesized-situation-specific procedures (Item 334)
5.	Procedures; hard copy in indexed binders (Item 341)	*vs*	Computer retrieval and large screen display (Item 344)
6.	Procedures; hard copy in indexed binders (Item 341)	*vs*	Voice output in conjunction with one of the above (Item 346)
7.	Procedures; control room operations, normal (Item 351)	*vs*	Technical Support Center operations (Item 353)
8.	Alarm logic input; fixed, single-purpose buttons, e.g., present acknowledge buttons (Item 451)	*vs*	Touch panel or screens (Item 454)
9.	Communication message medium; speaker/microphone audio (Item 542)	*vs*	Interactive computer terminal (Item 544)
10.	Display method; analog meters (Item 611)	*vs*	Large screen, projected displays (Item 616)
11.	Display graphics format; bar and column (Item 623)	*vs*	Complete process mimic with pan and zoom (Item 622)

We have reached four conclusions drawn from this forecast of control room changes. First, an inspection of the hierarchy of control room changes reveals that the combination of (a) the perceived needs for control room improvements, and (b) the options that modern man-machine technology provides is leading towards a myriad of control room design possibilities.

Second, an examination of the 25 most likely concepts for control room change listed in Table S-3 shows that these concepts may be classified as belonging to one of the following five groups of related changes:

1. The type of information to be displayed to the operators
2. How displays, alarms, and procedures are presented to, and controlled by, the operators
3. Improvements to plant data processing
4. Automation of supervisory control systems
5. Higher qualifications and more extensive training for personnel.

Third, we conclude that the range of these possibilities extends far beyond hardware choices into areas such as the extent of computerization of operator aids, the degree of automation, and even the levels of functional responsibility within the man-machine systems.

Fourth, an examination of the 25 least likely concepts listed in Table S-4 indicates that the communications between operators, and between operators and the balance of the plant personnel, will not change.

It is our opinion that the use of the computer in control rooms will provide higher levels of information and guidance to the operators, e.g., procedure selection or predictive information, and result in elevating the levels of control and supervision in nuclear plant control rooms.

FOREWORD

The objective of the Advanced Control Room Concepts Project, which was assigned by the Nuclear Regulatory Commission to EG&G Idaho, Inc., at the Idaho National Engineering Laboratory, is to establish the criteria and guidelines needed for regulatory assessment of advanced control room concepts. Control room advancements stem from both the perceived need to improve the performance of the control room man-machine system and from the expanded capabilities of current control systems technology to provide new and alternate design resolution options for those needs. The results of this project are disclosed in this report; i.e., identifying the major changes and categories of changes that are likely to appear in the next generation of control rooms or in backfits to existing control rooms. This identification of changes and the assessment of the likelihood of these changes occurring resulted from a modified Delphi conference among control room experts within the nuclear utilities, the nuclear industries, the process control industry, universities and research institutions, national laboratories, and the Nuclear Regulatory Commission's professional staff.

ACKNOWLEDGMENTS

We would like to thank and acknowledge Scott Mathews, Raymond K. Fink, and Alvin J. Nelson for developing the computer routines used in the Analytic Hierarchy Process evaluation; Carol McKinney and Elaine Beardall for their help in manipulating and tabulating data and results; Dr. Thomas B. Sheridan, MIT, for encouragement and expert advice on forecasting and categorizing control room concepts; Dr. Erik Hollnagel, Halden Project, for contributions toward defining the process control man-machine system; Dr. Michael M. Danchak, Hartford Graduate Center/Rensselaer Polytechnical Institute for contributions in defining the operator's image of computer-based, control room concepts; and to Dr. James P. Jenkins, NRC Research, for providing the definitions and guidelines for the Advanced Control Room Concepts Project.

Special acknowledgments are due to the 38 members of the Delphi panel from the nuclear community whose expert opinion was the means of identifying advanced control room concepts and of assessing their relative likelihoods. The time taken from busy schedules to supply this information is deeply appreciated.

CONTENTS

FIGURES

TABLES

IDENTIFICATION AND ASSESSMENT OF ANTICIPATED MAJOR CHANGES IN CONTROL ROOMS

INTRODUCTION

The Advanced Control Room Concepts Project was initiated at the INEL for the Office of Nuclear Regulatory Research to establish the criteria and guidelines needed for regulatory assessment of advanced control room concepts. The concepts to be assessed encompass the range from near-term modifications of control room designs to presently unidentified high technology characteristics of the control room designs of the 1990s.

The assessment of changes was to encompass the complete control room man-machine system of displays, controls, training, procedures, and communications. The assessment was to include all types of commercial nuclear power plants coming under the jurisdiction of the NRC, including Operating Licensed Plants and Near-Term Operating Licensed Plants. This research program is the subject of this report.

The objective of this project was to categorize control room changes and estimate the degree of change so that a continuum of these changes from present designs to future generation designs can be identified.[1]

The first step was identifying possible technological changes in categorizing nuclear power plants control room designs. These changes were to be applicable to backfitting existing control room designs and to the next generation of control room designs.

The second step was categorizing these possible changes and determining the relative likelihood of the changes being implemented in either the current generation of control room designs or in the next generation of control room designs.

METHODS OF DATA COLLECTION AND ANALYSIS

In Round 1, a modified Delphi Technique was used for conferring with control room experts to identify the possible control room concepts, and to identify the category into which these concepts belong. The second round of the Delphi conference pairwise compared groups of related concepts as to the likelihood of their being used in a backfit or future generation control room.

Identification of Concepts and Categories (Round 1)

Identifying changes now in progress, and those to occur within the next 3-10 years, is a forecasting activity. Since the objective of the task is to identify the continuum of changes, as stated above, a forecasting method based upon extrapolation of existing trends is appropriate.[2]

The method adopted to identify possible technological changes in nuclear power plant control room designs was a modified Delphi Technique. The Delphi Technique may be characterized as a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem.[3]

The use of the Delphi Technique allowed for the gathering of expert opinion from a broad spectrum of individuals from all segments of the commercial nuclear power community. The need for committee activity was eliminated by using a written questionnaire. This also avoided the problems inherent in face-to-face confrontation, in addition to providing anonymity for those panel members who desired it.

The Delphi process was modified by initially accepting all concepts submitted by the panel for evaluation rather than going through the usual feedback iterations to refine the opinions expressed. This approach did not cause any concepts to be

omitted and is supported by the fact that the last few questionnaires returned did not contain any concepts that had not been previously expressed in earlier returned questionnaires.

The concepts gathered from the panel in this first round were then analyzed and placed into groups of like concepts. These groups of like concepts were then structured to form a hierarchy that categorizes the possible control room design changes. These categories are the traditional categories of the man-machine system, controls, displays, procedures, alarms, staffing, training, and communications.

Determination of Relative Likelihoods (Round 2)

In order to obtain the relative likelihood of the identified changes being implemented in either the current generation of control room designs or in the next generation of control room designs, the Analytic Hierarchy Process developed by Thomas L. Saaty was selected, and is described below.[4,5]

With the concepts categorized and structured in the form of a hierarchy, where each group of concepts at a lower level has a meaningful relationship to the element in the next higher level, the relative likelihood of each concept being implemented can be determined. This is accomplished by constructing another questionnaire in which each concept in a related group for each level of the hierarchy is pairwise compared with each of the other concepts in that group. The results obtained from each panel member are then combined by calculating the geometric mean for each group of judgments. [The geometric mean is the only way to combine group judgments and preserve the reciprocal property necessary for the Analytic Hierarchy Process (Reference 5).] These means are then used to produce a qualitative judgment for the relative relationship of each concept in that group which is then used to develop an estimate for an underlying ratio scale that represents the consensus opinion of the Delphi panel. This group opinion is then input into the Analytic Hierarchy Process which in turn results in the relative likelihood of each concept being implemented in a future control room design.

In addition to the statistics associated with Analytic Hierarchy Process, certain descriptive and inferential statistics were calculated to aid in uncovering pertinent trends and information in the data. The reliability of the instrument (coefficient alphas) and distribution of the responses (histograms, means, and standard deviations) were examined as well as checks for differences among the survey groups' perceptions. These analyses are presented and discussed in related sections of this report.

EXPERT PANELS

There were two expert panels used in identifying, categorizing, and estimating the relative likelihood of possible changes to nuclear power plant control rooms. Each panel consisted of members of the commercial nuclear power community and each served without compensation from the INEL. Each panel member was assigned to one of three institutional categories. These categories were developers of new control room technology, appliers of control room technology, and regulators or evaluators. The developers were the reactor manufacturers, universities, and the research and service organizations. The appliers were the utilities and the architect/engineering firms. The regulators and evaluators were government regulatory agencies, the national laboratories, and some service organizations.

The first panel was used to identify the possible categories and the changes that could occur in these categories (Round 1). The second panel participated in the pairwise comparisons of the concepts to determine the relative likelihood for each concept (Round 2).

Profile of the Delphi Panel (Round 1)

The Round 1 Delphi panel contained 38 experts. Of these 38 experts, 17 have obtained their Ph.D. degree, 6 have obtained a M.S. degree, and 13 have a B.S. degree. Also, 35 have commercial reactor experience, 13 have military reactor experience, and 23 have reactor research, development, and design experience. Table 1 shows a summary of the areas and the cumulative years experience for these areas of the Round 1 panel.

Table 1. Profile of the Delphi panel (Round 1)

Type of Experience	Number of Experts	Years Experience
Commercial Reactors		
Pressurized water reactor	18	—
Boiling water reactor	4	—
Both	11	—
Other	10	—
Operations	9	39
Technical support	17	115
Design	14	114
Transient analysis	13	53
Safety analysis	3	54
Training	7	46
Construction	3	4
Military Reactors		
Operations	7	21
Technical support	4	11
Design	3	9
Transient analysis	1	2
Training	7	20
Construction	2	4
Reactor Research, Development, and Design		
Core physics characteristics	10	63
Reactor and reactor coolant systems	6	50
Chemical and volume control systems	4	42
Engineered safety features and systems	10	70
Steam and power conversion systems	2	20
Cooling water systems	1	30
Radioactive waste disposal systems	1	1
Refueling systems	1	8
Process instrumentation systems (I&C)	19	188
Plant chemistry	1	8
Plant operations	5	45

Profile of the Analytic Panel (Round 2)

The Round 2 Delphi panel contained 23 experts, 20 of whom served on the Round 1 panel. Of these 23 experts, 12 have obtained their Ph.D. degree, 1 has obtained a M.S. degree, and 8 have a B.S. degree. Also, of these 23 experts, 21 have commercial reactor experience, 8 have military reactor experience, and 13 have reactor research, development, and design experience. Table 2 contains the summary of the areas and cumulative years experience in these areas of the Round 2 panel. Table 3 discloses the institutional profile of each panel.

Table 2. Profile of the analytic panel (Round 2)

Type of Experience	Number of Experts	Years Experience
Commercial Reactors		
Pressurized water reactor	6	—
Boiling water reactor	2	—
Both	8	—
Other	7	—
Operations	4	23
Technical support	10	90
Design	11	69
Transient analysis	7	40
Safety analysis	7	35
Training	5	32
Construction	1	2
Military Reactors		
Operations	6	25
Technical support	4	12
Design	4	16
Transient analysis	1	2
Training	6	15
Construction	2	4
Reactor Research, Development, and Design		
Core physics characteristics	4	21
Reactor and reactor coolant systems	2	32
Chemical and volume control systems	2	31
Engineered safety features and systems	7	57
Cooling water systems	1	30
Process instrumentation systems (I&C)	7	80
Plant operations	3	36

Table 3. Institutional profile of the Delphi panels

Institution	Number of Members	
	Round 1	Round 2
Academic	3	3
Architect-engineer	0	2
National laboratory	4	1
Reactor manufacturer	10	7
Regulatory	3	1
Research	5	2
Service and supply industry	7	4
Utility owner-operator	6	3
Total	38	23

RESULTS

Categorization of Advanced Control Room Concepts (Round 1)

The first round conference format (shown in Appendix A) was directed toward obtaining a comprehensive list of foreseen, significant, possible changes occurring in control rooms or other nuclear power plant manned stations (such as remote emergency shutdown centers). The term "possible" was used in the sense of "possibly occurring as a consequence of anticipated technological developments." Two time periods were used in forecasting. Three to five years was offered as the "near-term" period, and five to ten years as the "long-term" period.

The first round conference format was open-end structured intentionally. Our interpretation of the control room man-machine system, as shown in Figure 1, was used as a guide in providing likely topic categories. The panel members were encouraged to go beyond the seven suggested categories of training, procedures, alarms, staffing, displays, controls, and communications, if they so desired. The responses from this first round were then hierarchically categorized utilizing expert judgment.

Relative Likelihood of Advanced Control Room Concepts (Round 2)

With the understanding that a modified Delphi/Analytic Hierarchical Process would be used to identify the relative likelihood of the concepts, the first round responses were compiled and merged into a hierarchical categorization of concepts, as shown in Figure 2. This was accomplished by sorting the questionnaires into the traditional categories of the man-machine system (controls, displays, alarms, etc.). No significant differences between the near-term and long-term time periods were apparent in the results obtained from the Round 1 Delphi. Therefore, no distinction between the two time frames was made in the second round instrument. The completed Round 2 instrument, as shown in Appendix B, contained eight major categories. These consisted of the seven suggested categories from Round 1 (controls and control systems, staffing, procedures, alarm or annunciator systems, control room person-to-person communications network, displays, and nuclear power plant personnel training), with information management as the eighth major category. This instrument was completed by the Round 2 panel members, their opinions were entered into a data base, and the Analytic Hierarchy Process calculations were performed.

Most Likely Concepts for Next Generation Control Rooms

Tables 4 through 46 identify the concepts and disclose their relative likelihood expressed as a ratio as determined by the Analytic Hierarchy Process. At Level 2 of the hierarchical categorization, the panel expects that changes in the Displays (Category 6) are most likely while changes in Control Room Person-to-Person Communications (Category 5) are the least likely. Table 4 details the categories and their relative likelihoods, in relation to the focus of the hierarchy (Level 1), the Advanced Control Forecast. The intermediate, Level 3, hierarchical categorization indicates that the Type of Information to be Displayed (Subcategory 64), Staffing Changes (Subcategory 21), and Supervisory Information (Subcategory 72) are the most likely. The 33 concepts of Level 3 are summarized in Table 46. At Level 4 of the hierarchical categorization, there are 184 items or concepts. Figure 3 provides a graphical representation of the eight major categories (Level 2) and the relative likelihoods of the individual items (Level 4) for those categories as they were chosen by the panel members. The 25 most likely concepts and the 25 least likely concepts of Level 4 are discussed in Tables 47 and 48.

Bimodal Responses from the Delphi Panel Forecast of Likelihood

Histograms of the responses from all 23 panel members were plotted for each pairwise comparison and visually inspected for an obvious departure from a normal distribution. Eleven of the pairwise comparisons showed a bimodal response and are discussed in "Bimodal Responses" in the "Assessment of Forecast" section. Figure 4 shows a typical histogram illustrating this bimodality.[a]

a. Bimodality is defined as the apparent division of the panel into two groups with one group forecasting one concept as definitely more likely than the other, and the other group forecasting the other concept as definitely more likely.

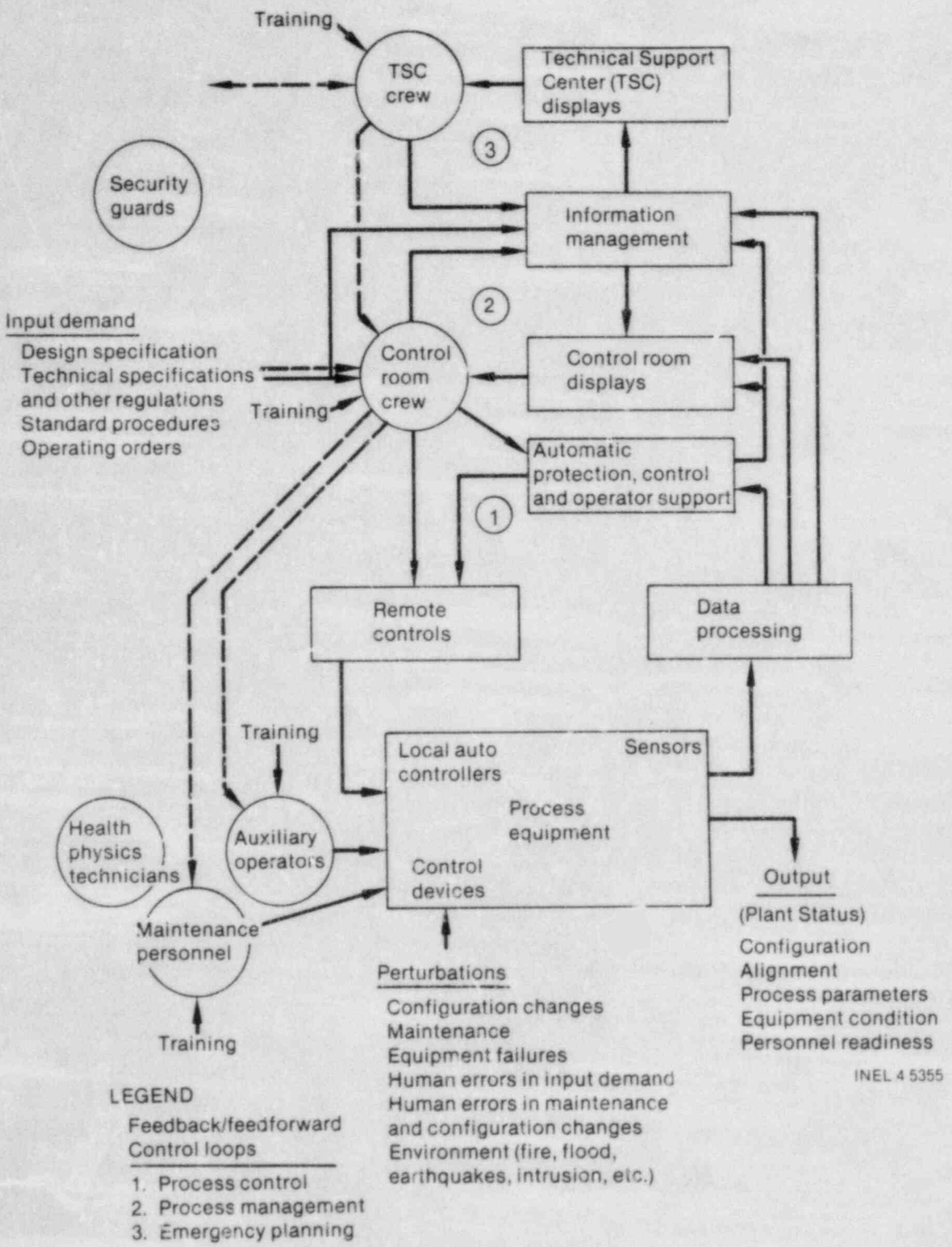
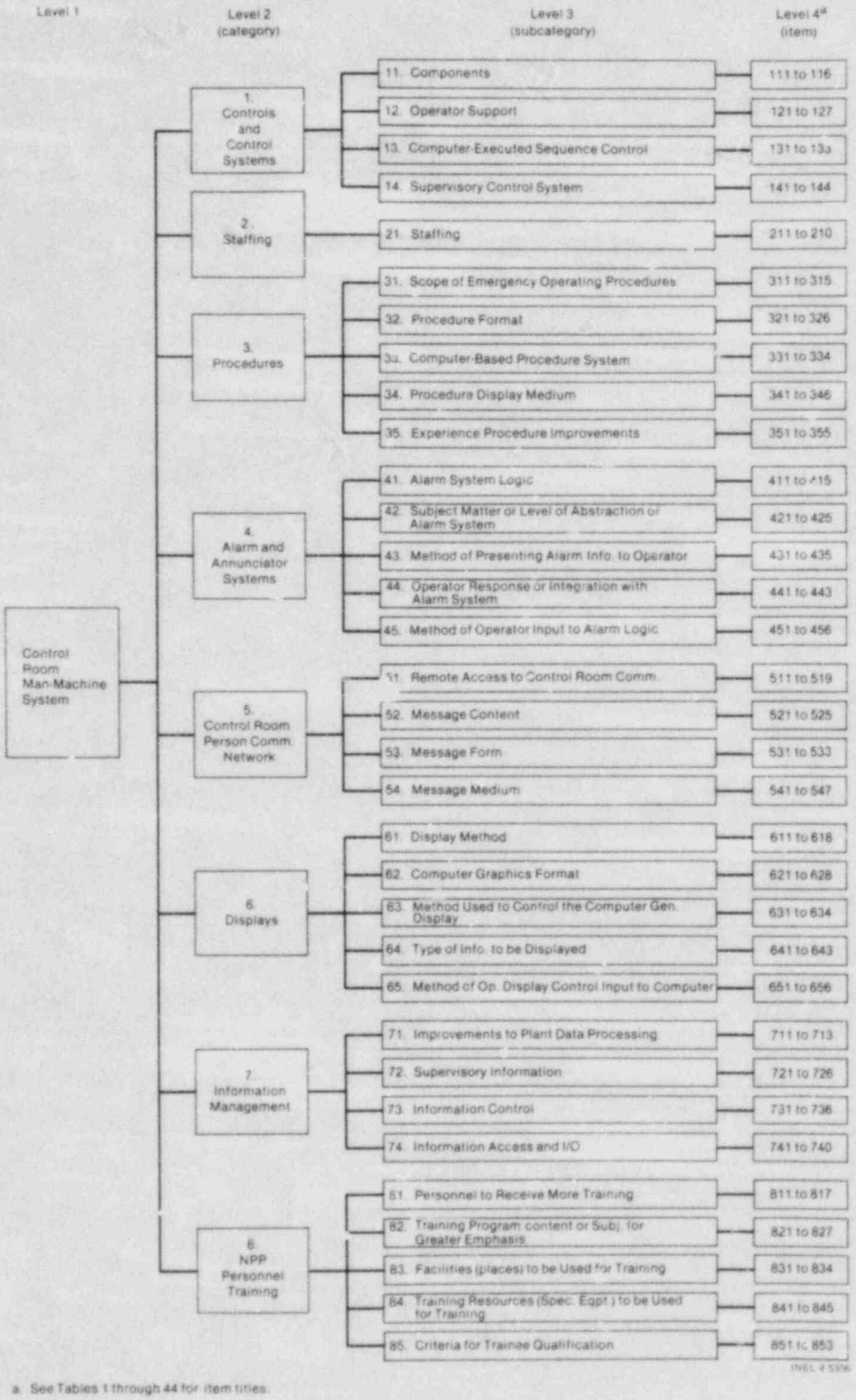


Figure 1. Control room man-machine system.



a. See Tables 1 through 44 for item titles.

Figure 2. Hierarchical categorization of concepts.

Table 4. Level 2: concepts relative to the advanced control forecast which is Level 1[a]

Concept	Relative Likelihood	Relative Rank
Displays (Category 6)	0.21	1.00
Information management (Category 7)	0.15	0.71
Procedures (Category 3)	0.15	0.71
Alarm or annunciator systems (Category 4)	0.14	0.67
Nuclear power plant personnel training (Category 8)	0.13	0.62
Controls and control systems (Category 1)	0.11	0.52
Staffing (Category 2)	0.07	0.33
Control room person-to-person communications network (Category 5)	0.04	0.19

a. Statistics

No. of comparisons:	28
Consistency ratio:	0.007
Alpha:	0.76

Table 5. Level 3: concepts relative to displays[a] (Category 6)

Concept	Relative Likelihood	Relative Rank
Type of information to be displayed (Subcategory 64)	0.39	1.00
Computer graphics format (Subcategory 62)	0.20	0.51
Display method (Subcategory 61)	0.15	0.38
Method of operator display control input to the computer (Subcategory 65)	0.14	0.36
Method used to control the computer-generated display (Subcategory 63)	0.12	0.31

a. Statistics

No. of comparisons:	10
Consistency ratio:	0.006
Alpha:	0.72

Table 6. Level 3: concepts relative to information management[a] (Category 7)

Concept	Relative Likelihood	Relative Rank
Supervisory information (Subcategory 72)	0.34	1.00
Improvements to plant data processing (Subcategory 71)	0.31	0.91
Information access and I/O (Subcategory 74)	0.20	0.59
Information control (Subcategory 73)	0.15	0.44

a. Statistics

No. of comparisons:	6
Consistency ratio:	0.008
Alpha:	0.14

Table 7. Level 3: concepts relative to procedures[a] (Category 3)

Concept	Relative Likelihood	Relative Rank
Scope of emergency operating procedures (Subcategory 31)	0.28	1.00
Computer-based procedure system (Subcategory 33)	0.23	0.82
Procedure display medium (Subcategory 34)	0.21	0.75
Procedure format (Subcategory 32)	0.16	0.57
Procedure improvements for plant operations (Subcategory 35)	0.12	0.43

a. Statistics

No. of comparisons:	10
Consistency ratio:	0.003
Alpha:	0.53

Table 8. Level 3: concepts relative to alarm or annunciator systems[a] (Category 4)

Concept	Relative Likelihood	Relative Rank
Method of presenting the alarm information to the operator (Subcategory 43)	0.30	1.00
Alarm system logic (Subcategory 41)	0.22	0.73
Subject matter, or level of abstraction, of the alarm system (Subcategory 42)	0.20	0.67
Operator response or interaction with alarm systems (Subcategory 44)	0.17	0.57
Method of operator input to alarm logic (Subcategory 45)	0.11	0.37

a. Statistics

No. of comparisons:	10
Consistency ratio:	0.003
Alpha:	0.73

Table 9. Level 3: concepts relative to nuclear power plant personnel training[a] (Category 8)

Concept	Relative Likelihood	Relative Rank
Training program content or subject matter to receive increased emphasis (Subcategory 82)	0.35	1.00
Criteria for trainee qualification (Subcategory 85)	0.21	0.60
Training resources (special equipment) to be used for training (Subcategory 84)	0.19	0.54
Personnel to receive more training (Subcategory 81)	0.15	0.43
Facilities (places) to be used for training (Subcategory 83)	0.10	0.29

a. Statistics

No. of comparisons:	10
Consistency ratio:	0.003
Alpha:	0.80

Table 10. Level 3: concepts relative to controls and control systems[a] (Category 1)

Concept	Relative Likelihood	Relative Rank
Operator support (Subcategory 12)	0.39	1.00
Supervisory control systems (Subcategory 14)	0.29	0.74
Computer-executed sequence control (Subcategory 13)	0.18	0.46
Components (Subcategory 11)	0.14	0.36

a. Statistics

No. of comparisons:	6
Consistency ratio:	0.008
Alpha:	0.61

Table 11. Level 3: concepts relative to staffing (Category 2)

NOTE: Since there is only one subcategory for Category 2, Staffing Changes (Subcategory 21), there are no concepts to be compared. The relative likelihood, is therefore, equal to 1 for computational purposes.

Table 12. Level 3: concepts relative to control room person-to-person communications network[a] (Category 5)

Concept	Relative Likelihood	Relative Rank
Message medium (Subcategory 54)	0.27	1.00
Message content (Subcategory 52)	0.26	0.96
Remote access to control room communications (Subcategory 51)	0.25	0.93
Message form (Subcategory 53)	0.22	0.81

a. Statistics

No. of comparisons:	6
Consistency ratio:	0.001
Alpha:	0.78

Table 13. Level 4: concepts relative to type of information to be displayed[a] (Subcategory 64)

Concept	Relative Likelihood	Relative Rank
Current and trend values of process parameters (Item 641)	0.45	1.00
Derived information from computer analysis of process parameters (Item 642)	0.37	0.82
Predictive and anticipatory information from computer analysis of current state and model of the process (Item 643)	0.18	0.40

a. Statistics

No. of comparisons:	3
Consistency ratio:	0.004
Alpha:	Insufficient Data

Table 14. Level 4: concepts relative to staffing of advanced control rooms[a] (Subcategory 21)

Concept	Relative Likelihood	Relative Rank
Qualification and refresher training will continue to increase in time allotted, innovation, and realism (Item 219)	0.17	1.00
Technical qualifications levels of the shift supervisor, the senior reactor operator, and reactor operator will be raised (Item 214)	0.15	0.88
Monitoring and control of maintenance activities by the control room crew will increase (Item 218)	0.13	0.76
The shift supervisor's responsibilities will give more priority to process management with an administrative assistant provided to the supervisor (Item 211)	0.11	0.65
The shift technical advisor will be replaced by an increase in the technical qualification level of the shift supervisor and the senior reactor operator (Item 212)	0.11	0.65
Computer technician support will be added or increased (Item 216)	0.09	0.53
Computer usage qualification will be required for the shift supervisor, the senior reactor operator, and the reactor operator (Item 217)	0.09	0.53
The control room operation (communications, procedures, protocol, etc.) will become more formal (Item 213)	0.07	0.41

Table 14. (continued)

Concept	Relative Likelihood	Relative Rank
Engineering degrees will be required for the shift supervisors and the senior reactor operator (Item 215)	0.05	0.29
No significant changes are expected (Item 210)	0.03	0.18

a. Statistics

No. of comparisons:	45
Consistency ratio:	0.007
Alpha:	0.84

Table 15. Level 4: concepts relative to supervisory information[a] (Subcategory 72)

Concept	Relative Likelihood	Relative Rank
Diagnostics (Item 724)	0.24	1.00
System state estimation (fault detection and identification) (Item 722)	0.23	0.96
Technical specification compliance (Item 723)	0.20	0.83
Process state (radiation, fatigue, leakage, etc.) (Item 726)	0.17	0.71
Fuel management (Item 721)	0.08	0.33
Synthesized procedures (Item 725)	0.08	0.33

a. Statistics

No. of comparisons:	15
Consistency ratio:	0.006
Alpha:	0.56

Table 16. Level 4: concepts relative to improvements to plant data processing[a] (Subcategory 71)

Concept	Relative Likelihood	Relative Rank
Data validation (Item 713)	0.47	1.00
Improved sensors (accuracy, reliability, response) (Item 712)	0.27	0.57
Intelligent sensor (Item 711)	0.26	0.55

a. Statistics

No. of comparisons:	3
Consistency ratio:	0.000
Alpha:	Insufficient Data

Table 17. Level 4: concepts relative to training program content or subject matter to receive increased emphasis[a] (Subcategory 82)

Concept	Relative Likelihood	Relative Rank
Use of new emergency operating procedures which are function oriented or event independent (Item 824)	0.22	1.00
Control of the plant during complex transients and severe accidents with actual or threatened release of radiation (Item 822)	0.18	0.82
Use of operator aids, e.g., the SPDS (Item 825)	0.18	0.82
Methods of diagnosing events and developing decisions and plans of action (Item 823)	0.18	0.82
Team training, e.g., training a crew in divisions of responsibilities, lines of authority, communications, etc. (Item 827)	0.11	0.50
Use of interactive computer terminals, e.g., for retrieving plant data, plotting a curve, maintaining a check list, etc. (Item 826)	0.07	0.32
Plant behavior during normal operation, anticipated transients, and expected events and failures (Item 821)	0.07	0.32

a. Statistics

No. of comparisons:	21
Consistency ratio:	0.005
Alpha:	0.76

Table 18. Level 4: concepts relative to operator support[a] (Subcategory 12)

Concept	Relative Likelihood	Relative Rank
Data validation (Item 123)	0.18	1.00
Intelligent information on the process status (Item 122)	0.18	1.00
Diagnostic aids (Item 125)	0.18	1.00
Computerized aids (Item 121)	0.15	0.83
Decision aids (Item 124)	0.15	0.83
Redesign of process for improved man-machine interface (Item 127)	0.08	0.44
Artificial intelligence/expert systems (Item 126)	0.08	0.44

a. Statistics

No. of comparisons:	21
Consistency ratio:	0.008
Alpha:	0.87

Table 19. Level 4: concepts relative to method of presenting the alarm information to the system[a] (Subcategory 43)

Concept	Relative Likelihood	Relative Rank
Cathode-ray tubes or plasmascopes (Item 432)	0.32	1.00
Integrated outputs which use combinations of the above for prioritizing or selectivity (Item 435)	0.31	0.97
Color coding (Item 434)	0.16	0.50
Annunciator windows, or tiles (Item 431)	0.13	0.41
Voice messages from computer or tape (Item 433)	0.08	0.25

a. Statistics

No. of comparisons:	10
Consistency ratio:	0.006
Alpha:	0.82

Table 20. Level 4: concepts relative to computer graphics format[a] (Subcategory 62)

Concept	Relative Likelihood	Relative Rank
Integrated sets of two or more formats (Item 628)	0.35	1.00
Trend displays, i.e., rectilinear curves of parameter values vs time (Item 625)	0.16	0.46
Hierarchical mimic diagram (Item 621)	0.11	0.31
Bar and column displays (Item 623)	0.10	0.29
Complete process mimic diagram with pan and zoom with data display and suppression coordinated with the zoom (Item 622)	0.09	0.26
New formats that are not yet identified (Item 627)	0.07	0.20
Iconic overview displays which provide higher levels of abstracted information, e.g., "safety status" by an integrated pattern of data display (Item 624)	0.06	0.17
Alpha-numeric listings (Item 626)	0.06	0.17

a. Statistics

No. of comparisons:	28
Consistency ratio:	0.016
Alpha:	0.54

Table 21. Level 4: concepts relative to scope of emergency operating procedures[a] (Subcategory 31)

Concept	Relative Likelihood	Relative Rank
Matrix of function-oriented and event-oriented procedures (Item 312)	0.26	1.00
More extensive accident management procedures (Item 314)	0.24	0.92
Function-oriented, event-independent procedures (Item 311)	0.19	0.73
Procedures for beyond-design-basis events (Item 313)	0.16	0.62
Procedures to direct Technical Support Center crew in support of control room crew (Item 315)	0.15	0.58

a. Statistics

No. of comparisons:	10
Consistency ratio:	0.002
Alpha:	0.60

Table 22. Level 4: concepts required relative to computer-based procedures system[a] (Subcategory 33)

Concept	Relative Likelihood	Relative Rank
Computer guidance for selection of procedure (Item 332)	0.45	1.00
Computer stored, manual retrieval (Item 331)	0.24	0.53
Automatic display of situation specific procedure (Item 333)	0.17	0.38
Computer-synthesized-situation-specific procedure (Item 334)	0.14	0.31

a. Statistics

No. of comparisons:	6
Consistency ratio:	0.003
Alpha:	0.85

Table 23. Level 4: concepts relative to supervisory control systems[a] (Subcategory 14)

Concept	Relative Likelihood	Relative Rank
Automation of dynamic systems (Item 142)	0.38	1.00
Automation of core cooling and other protective systems (Item 143)	0.38	1.00
Fully automated plant with knowledge based expert system management (Item 144)	0.15	0.39
Fully automated plant (Item 141)	0.09	0.24

a. Statistics

No. of comparisons:	6
Consistency ratio:	0.001
Alpha:	0.51

Table 24. Level 4: concepts relative to display method[a] (Subcategory 61)

Concept	Relative Likelihood	Relative Rank
Integrated sets of two or more display methods (Item 618)	0.33	1.00
Color cathode-ray tubes (Item 613)	0.26	0.79
Conventional, electromechanical analog meters or indicators (Item 611)	0.10	0.30
Plasmascopes (Item 614)	0.08	0.24
Liquid-crystal displays (Item 612)	0.08	0.24
Large screen, projected displays (Item 616)	0.07	0.21
Computer synthesized voice (Item 617)	0.04	0.12
3-dimensional projection (Item 615)	0.04	0.12

a. Statistics

No. of comparisons:	28
Consistency ratio:	0.016
Alpha:	0.89

Table 25. Level 4: concepts relative to procedure display medium[a] (Subcategory 34)

Concept	Relative Likelihood	Relative Rank
Computer retrieval, CRT display (Item 343)	0.35	1.00
Computer retrieval, large screen display (Item 344)	0.20	0.57
Computer retrieval and printed hard copy (Item 342)	0.15	0.43
Hard copy in indexed binders (Item 341)	0.15	0.43
Film or video tape, large screen display (Item 345)	0.08	0.23
Voice output in conjunction with one of the above (Item 346)	0.07	0.20

a. Statistics

No. of comparisons:	15
Consistency ratio:	0.012
Alpha:	0.92

Table 26. Level 4: concepts relative to alarm system logic[a] (Subcategory 41)

Concept	Relative Likelihood	Relative Rank
Prioritized presentation of alarms based on plant states, number of incoming alarms, etc. (Item 414)	0.27	1.00
Grouping of related alarms (Item 613)	0.24	0.89
Suppression of alarms that are not important in a particular state (Item 413)	0.20	0.74
Deletion of unnecessary alarms (Item 411)	0.18	0.67
Intelligent alarm systems that reason backward to the cause of the event or forward to recommend actions or procedures to the operator (Item 415)	0.11	0.41

a. Statistics

No. of comparisons:	10
Consistency ratio:	0.006
Alpha:	0.70

Table 27. Level 4: concepts relative to information access and I/O[a] (Subcategory 74)

Concept	Relative Likelihood	Relative Rank
Shift supervisor (Item 741)	0.24	1.00
Senior reactor operator (Item 742)	0.21	0.87
Reactor operator (Item 743)	0.12	0.50
Maintenance manager (Item 744)	0.11	0.46
Plant management staff (Item 746)	0.07	0.29
Health physicists (Item 749)	0.06	0.25
System engineer (Item 748)	0.06	0.25
Maintenance technician (Item 745)	0.05	0.21
Plant operations review (licensing) (Item 740)	0.04	0.17
Quality assurance personnel (Item 747)	0.04	0.17

a. Statistics

No. of comparisons:	45
Consistency ratio:	0.008
Alpha:	0.91

Table 28. Level 4: concepts relative to method of operator display control input to the computer[a] (Subcategory 65)

Concept	Relative Likelihood	Relative Rank
Integrated sets of two or more methods (Item 656)	0.43	1.00
Touch panels, screens, or tablets (Item 653)	0.18	0.42
Function keys (Item 652)	0.17	0.40
Tracker ball or mouse or joystick (Item 654)	0.09	0.21
Keyboard general purpose (Item 651)	0.08	0.19
Voice recognition (Item 655)	0.05	0.12

a. Statistics

No. of comparisons:	15
Consistency ratio:	0.028
Alpha:	0.82

Table 29. Level 4: concepts relative to criteria for trainee qualification[a] (Subcategory 85)

Concept	Relative Likelihood	Relative Rank
Performance on the job as determined by critical reviews (Item 853)	0.39	1.00
Performance during training programs (Item 851)	0.35	0.90
Performance on written examinations (Item 852)	0.26	0.67

a. Statistics

No. of comparisons:	3
Consistency ratio:	0.003
Alpha:	Insufficient Data

Table 30. Level 4: concepts relative to subject matter, or level of abstraction, of the alarm system[a] (Subcategory 42)

Concept	Relative Likelihood	Relative Rank
Safety problem, e.g., the safety parameter display system (Item 425)	0.31	1.00
Functional level problems, e.g., upset heat transfer condition or trend in radiation levels (Item 423)	0.24	0.77
System operation problems, e.g., loss of pump (Item 422)	0.21	0.68
Technical specification problem, e.g., insufficient redundancy in standby system (Item 424)	0.14	0.45
Component problems, e.g., hot bearing (Item 421)	0.10	0.32

a. Statistics

No. of comparisons:	10
Consistency ratio:	0.010
Alpha:	0.76

Table 31. Level 4: concepts relative to training resources (special equipment) to be used for training[a] (Subcategory 84)

Concept	Relative Likelihood	Relative Rank
Plant specific simulators (Item 841)	0.36	1.00
Full scope, or engineering simulators which can simulate severe conditions, e.g., two-phase coolant, fuel damage, radiation release (Item 843)	0.19	0.53
Generic plant simulators (not exactly matching the trainee's plant) (Item 842)	0.18	0.50
Interactive computer terminals used for part-task simulators, computer-aided instruction, e.g., the CDC Plato Program (Item 844)	0.15	0.42
Hard copy course material and training aids (Item 845)	0.12	0.33

a. Statistics

No. of comparisons:	10
Consistency ratio:	0.012
Alpha:	0.47

Table 32. Level 4: concepts relative to method used to control the computer-generated display[a] (Subcategory 63)

Concept	Relative Likelihood	Relative Rank
Interactive I/O between the operator and the computer (Item 634)	0.42	1.00
The operator (Item 632)	0.33	0.79
Computer algorithms which analyze the plant status (Item 633)	0.15	0.36
None, the displays will be fixed (Item 631)	0.10	0.24

a. Statistics

No. of comparisons:	6
Consistency ratio:	0.008
Alpha:	0.03

Table 33. Level 4: concepts relative to procedure format[a] (Subcategory 32)

Concept	Relative Likelihood	Relative Rank
Flow chart (Item 323)	0.26	1.00
Event or response tree (Item 324)	0.20	0.77
Pictorial or graphic (Item 325)	0.18	0.69
Double column (Item 322)	0.16	0.62
Present format (single column, indented) (Item 321)	0.14	0.54
Voice over (Item 326)	0.06	0.23

a. Statistics

No. of comparisons:	15
Consistency ratio:	0.003
Alpha:	0.81

Table 34. Level 4: concepts relative to operator response or interaction with alarm systems[a] (Subcategory 44)

Concept	Relative Likelihood	Relative Rank
Provide direction to the alarm logic, e.g., plant state, level of suppression, request for first or last incoming alarm (Item 442)	0.37	1.00
Higher level direction to the alarm logic (Item 443)	0.32	0.86
Acknowledge individual incoming alarms (Item 441)	0.31	0.84

a. Statistics

No. of comparisons:	3
Consistency ratio:	0.005
Alpha:	Insufficient Data

Table 35. Level 4: concepts relative to information control[a] (Subcategory 73)

Concept	Relative Likelihood	Relative Rank
Maintenance (Item 732)	0.29	1.00
Radiation exposure (Item 736)	0.17	0.59
Procedures (Item 733)	0.16	0.55
Shift turnover (Item 731)	0.16	0.55
Access and security (Item 734)	0.12	0.41
Design configuration (Item 735)	0.08	0.28

a. Statistics

No. of comparisons:	15
Consistency ratio:	0.006
Alpha:	0.76

Table 36. Level 4: concepts relative to computer-executed sequence control[a] (Subcategory 13)

Concept	Relative Likelihood	Relative Rank
More intelligence	0.39	1.00
Interactive, shared, cooperative controls (Item 131)	0.37	0.95
Redesign of process for improved man-machine interface (Item 132)	0.24	0.62

a. Statistics

No. of comparisons: 3
Consistency ratio: 0.003
Alpha: Insufficient Data

Table 37. Level 4: concepts relative to personnel to receive more training[a] (Subcategory 81)

Concept	Relative Likelihood	Relative Rank
Control room operators (Item 811)	0.25	1.00
Maintenance personnel (Item 813)	0.21	0.84
Auxiliary operators (Item 812)	0.16	0.64
Technical Support Center staff (Item 817)	0.14	0.56
Engineering support personnel (Item 815)	0.09	0.36
Plant management (above shift supervisor level) (Item 816)	0.08	0.32
Health physics personnel (Item 814)	0.07	0.28

a. Statistics

No. of comparisons: 21
Consistency ratio: 0.005
Alpha: 0.85

Table 38. Level 4: procedure improvements for plant operations[a] (Subcategory 35)

Concept	Relative Likelihood	Relative Rank
Control room operations, emergency (Item 352)	0.39	1.00
Maintenance (Item 354)	0.27	0.69
Technical Support Center operations (Item 353)	0.14	0.36
Control room operations, normal (Item 351)	0.12	0.31
Fuel management (Item 355)	0.08	0.21

a. Statistics

No. of comparisons:	10
Consistency ratio:	0.002
Alpha:	0.59

Table 39. Level 4: concepts relative to components[a] (Subcategory 11)

Concept	Relative Likelihood	Relative Rank
Consoles (human engineering) (Item 116)	0.26	1.00
Computers (more power, redundancy, reliability) (Item 114)	0.23	0.88
Computer I/0 (Item 113)	0.16	0.62
Sensors (more accurate, intelligent, reliable) (Item 111)	0.15	0.58
Local controllers (more intelligent, functions, accuracy reliability) (Item 115)	0.13	0.50
Actuators (more functional and reliable) (Item 112)	0.07	0.27

a. Statistics

No. of comparisons:	15
Consistency ratio:	0.006
Alpha:	0.66

Table 40. Level 4: concepts relative to method of operator input to alarm logic[a] (Subcategory 45)

Concept	Relative Likelihood	Relative Rank
Touch panel or screens (Item 454)	0.30	1.00
Function keys (Item 455)	0.23	0.77
Fixed, single-purpose buttons, e.g, present acknowledge buttons (Item 451)	0.20	0.67
Keyboard (Item 452)	0.13	0.43
Remote, hand-held control, with multiple keys (Item 456)	0.08	0.27
Voice (Item 453)	0.06	0.20

a. Statistics

No. of comparisons:	15
Consistency ratio:	0.012
Alpha:	0.83

Table 41. Level 4: concepts relative to facilities (places) to be used for training[a] (Subcategory 83)

Concept	Relative Likelihood	Relative Rank
On-site training centers (Item 832)	0.47	1.00
Technical Support Centers (Item 833)	0.22	0.47
Control room and local control stations and work locations (Item 834)	0.17	0.36
Off-site training centers (Item 831)	0.14	0.30

a. Statistics

No. of comparisons:	6
Consistency ratio:	0.004
Alpha:	0.67

Table 42. Level 4: concepts relative to message medium[a] (Subcategory 54)

Concept	Relative Likelihood	Relative Rank
Integrated systems with selective applications of each of the above (Item 547)	0.27	1.00
Telephones (Item 541)	0.21	0.78
Interactive computer terminal (Item 544)	0.14	0.52
Speaker/microphone audio (Item 542)	0.13	0.48
Electronic mail (handled by computer with CRT or hard copy output) (Item 545)	0.10	0.37
Portable, hand-held I/O units (Item 546)	0.08	0.30
Closed circuit video (Item 543)	0.07	0.26

a. Statistics

No. of comparisons:	21
Consistency ratio:	0.007
Alpha:	0.86

Table 43. Level 4: concepts relative to message content[a] (Subcategory 52)

Concept	Relative Likelihood	Relative Rank
Plant status data, e.g., process parameters, valve positions (Item 521)	0.28	1.00
Response to unplanned event, internal or external (Item 525)	0.26	0.93
Maintenance data, e.g., surveillance due, surveillance test in progress, test results (Item 522)	0.17	0.61
Request for assistance, e.g., to maintenance, engineering, management (Item 524)	0.16	0.57
Radiation fields (Item 523)	0.13	0.46

a. Statistics

No. of comparisons:	10
Consistency ratio:	0.012
Alpha:	0.75

Table 44. Level 4: concepts relative to remote access to control room communications[a] (Subcategory 51)

Concept	Relative Likelihood	Relative Rank
Technical Support Center personnel (Item 512)	0.26	1.00
Auxiliary operators (Item 513)	0.23	0.88
Maintenance personnel (Item 514)	0.14	0.54
Health physics technicians (Item 514)	0.11	0.42
Plant management office personnel (Item 515)	0.10	0.38
NRC resident inspector (Item 517)	0.05	0.19
Security guards (Item 518)	0.05	0.19
Headquarters office personnel (Item 516)	0.04	0.15
Local authorities (Item 519)	0.02	0.08

a. Statistics

No. of comparisons:	36
Consistency ratio:	0.015
Alpha:	0.87

Table 45. Level 4: concepts relative to message content[a] (Subcategory 52)

Concept	Relative Likelihood	Relative Rank
Audio, plain language (Item 531)	0.56	1.00
Graphic information, e.g., drawings, mimics, trend curves (Item 533)	0.24	0.43
Alpha-numeric data (Item 532)	0.20	0.36

a. Statistics

No. of comparisons:	3
Consistency ratio:	0.000
Alpha:	Insufficient Data

Table 46. Level 3: concepts relative to the advanced control room forecast which is Level 1

Concept	Relative Likelihood	Relative Rank
Type of information to be displayed (Subcategory 64)	0.0797	1.00
Staffing changes (Subcategory 21)	0.0695	0.87
Supervisory information (Subcategory 72)	0.0521	0.65
Improvements to plant data processing(Subcategory 71)	0.0471	0.59
Training program content or subject matter to receive increased emphasis (Subcategory 82)	0.0467	0.59
Operator support (Subcategory 12)	0.0444	0.56
Method of presenting the alarm information to the operator (Subcategory 43)	0.0417	0.52
Computer graphics format (Subcategory 62)	0.0412	0.52
Scope of emergency operating procedures (Subcategory 31)	0.0407	0.51
Computer-based procedure system (Subcategory 33)	0.0343	0.43
Supervisory control systems (Subcategory 14)	0.0325	0.41
Display method (Subcategory 61)	0.0311	0.39
Procedure display medium (Subcategory 34)	0.0304	0.38
Alarm system logic (Subcategory 41)	0.0297	0.37
Information access and I/O (Subcategory 74)	0.0297	0.37
Method of operator display control input to the computer (Subcategory 65)	0.0292	0.37
Criteria for trainee qualification (Subcategory 85)	0.0286	0.36
Subject matter, or level of abstraction, of the alarm system (Subcategory 42)	0.0267	0.34
Training resources (special equipment) to be used for training (Subcategory 84)	0.0256	0.32
Method used to control the computer-generated display (Subcategory 63)	0.0249	0.31
Procedure format (Subcategory 32)	0.0240	0.30
Operator response or interaction with alarm systems (Subcategory 44)	0.0236	0.30
Information control (Subcategory 73)	0.0226	0.28
Computer-executed sequence control (Subcategory 13)	0.0206	0.26
Personnel to receive more training (Subcategory 81)	0.0194	0.24
Procedure improvements for plant operations (Subcategory 35)	0.0177	0.22
Components (Subcategory 11)	0.0153	0.19
Method of operator input to alarm logic (Subcategory 45)	0.0146	0.18
Facilities (places) to be used for training (Subcategory 83)	0.0139	0.17
Message medium (Subcategory 54)	0.0114	0.14
Message content (Subcategory 52)	0.0113	0.14
Remote access to control room and communications (Subcategory 51)	0.0107	0.13
Message form (Subcategory 53)	0.0093	0.12

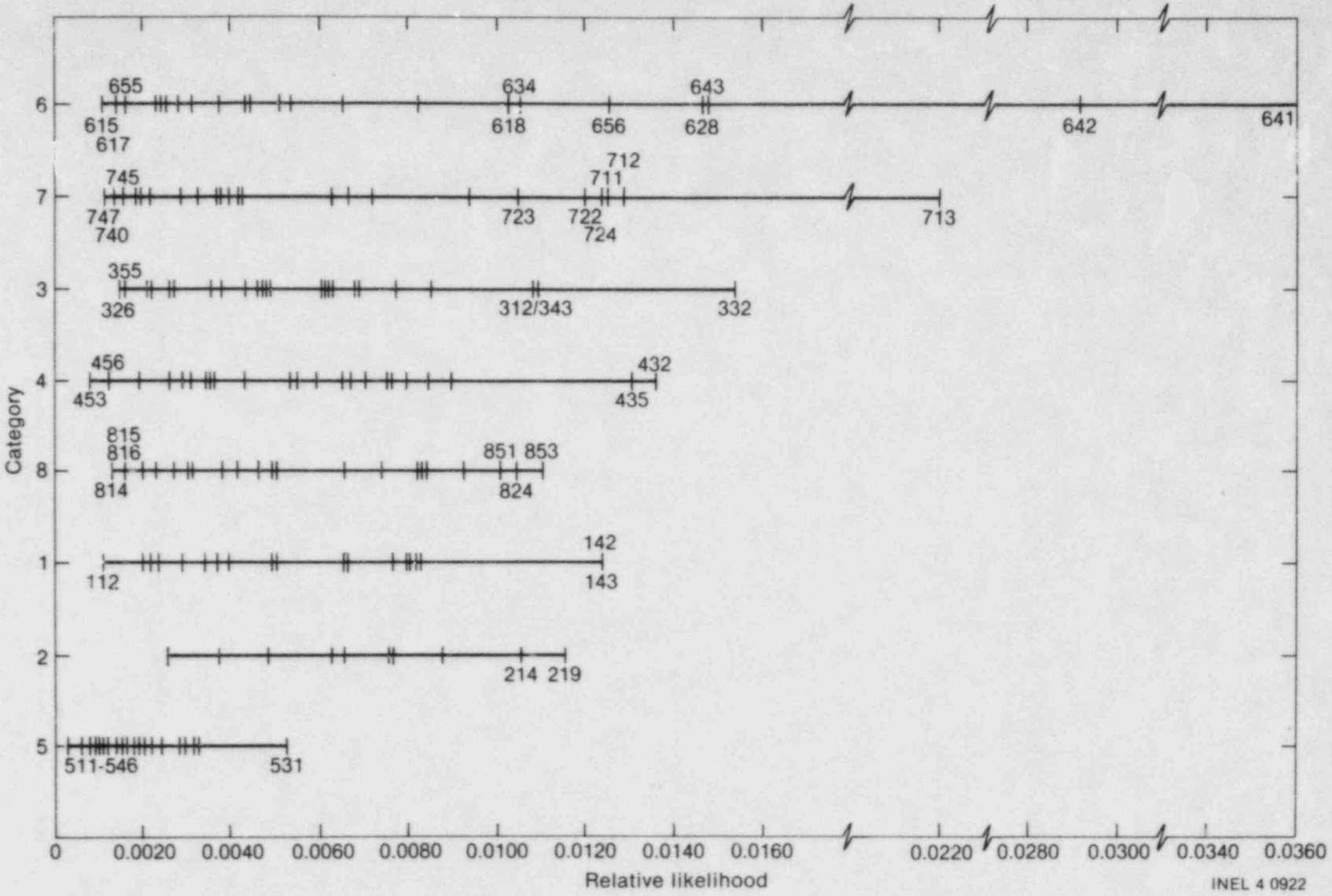


Figure 3. Level 4 most likely and least likely concepts (items).

Table 47. Level 4: the 25 most likely concepts relative to the advanced control room forecast which is Level 1

Concept	Relative Likelihood	Relative Rank
1. Current and trend values of process parameters (Item 641)	0.0359	1.00
2. Derived information from computer analysis of process parameters (Item 642)	0.0291	0.81
3. Data validation (Item 713)	0.0219	0.61
4. Computer guidance for selection of procedure (Item 332)	0.0153	0.43
5. Predictive and anticipatory information from computer analysis of current state and model of the process (Item 643)	0.0147	0.41
6. Integrated sets of two or more formats (Item 628)	0.0146	0.41
7. Cathode-ray tubes or plasmascopes (Item 432)	0.0135	0.38
8. Integrated outputs which use combinations of the above for prioritizing or selectivity (Item 435)	0.0130	0.36
9. Improved sensors (accuracy, reliability, response) (Item 712)	0.0128	0.36
10. Integrated sets of two or more methods (Item 656)	0.0125	0.35
11. Intelligent sensors (Item 711)	0.0124	0.35
12. Diagnostics (Item 724)	0.0123	0.34
13. Automation of dynamic systems (Item 142)	0.0123	0.34
14. Automation of core cooling and other protective systems (Item 143)	0.0123	0.34
15. System state estimation (fault detection and identification) (Item 722)	0.0119	0.33
16. Qualification and refresher training will continue to increase in time allotted, innovation, and realism (Item 219)	0.0115	0.32
17. Performance on the job as determined by critical reviews (Item 853)	0.0110	0.31
18. Computer retrieval, CRT display (Item 343)	0.0108	0.30
19. Matrix of function-oriented and event-oriented procedures (Item 312)	0.0107	0.30
20. Interactive I/O between the operator and the computer (Item 634)	0.0105	0.29
21. Use of new emergency operating procedures which are function oriented or event independent (Item 824)	0.0105	0.29
22. Technical qualification levels of the shift supervisor, the senior reactor operator, and reactor operator will be raised (Item 214)	0.0105	0.29
23. Technical specifications compliance (Item 723)	0.0104	0.29
24. Integrated sets of two or more display methods (Item 618)	0.0102	0.28
25. Performance during training programs (Item 851)	0.0101	0.28

Table 48. Level 4: the 25 least likely concepts relative to the advanced control room forecast which is Level 1

Concept	Relative Likelihood	Relative Rank
1. Local authorities access to control room communications (Item 519)	0.0003	0.19
2. Headquarters office personnel access to control room communications (Item 516)	0.0005	0.31
3. Security guards access to control room communications (Item 518)	0.0005	0.31
4. NRC resident inspector access to control room communications (Item 517)	0.0006	0.38
5. Operator voice input to alarm or annunciator (Item 453)	0.0008	0.50
6. Closed circuit video message medium for communications (Item 543)	0.0008	0.50
7. Portable, hand-held I/O units for control room communications (Item 546)	0.0009	0.56
8. Plant management office personnel remote access to control room communications (Item 515)	0.0010	0.63
9. Three-dimensional display projection method (Item 615)	0.0011	0.69
10. More functional and reliable actuators as controls or control system components (Item 112)	0.0011	0.69
11. Quality assurance personnel information access (Item 747)	0.0011	0.69
12. Electronic mail (computer handled) communications (Item 545)	0.0011	0.69
13. Remote, hand-held, operator input to alarm or annunciator systems (Item 456)	0.0012	0.75
14. Health physics technician remote access to control room communications (Item 514)	0.0012	0.75
15. Plant operations review (licensing) information access and I/O (Item 740)	0.0013	0.81
16. Health physics training personnel to receive more training (Item 814)	0.0013	0.81
17. Radiation field information on messages in control room communications (Item 523)	0.0014	0.88
18. Computer-synthesized voice display method (Item 617)	0.0014	0.88
19. Voice recognition in connection with operator display control (Item 655)	0.0014	0.88
20. Voice procedure format (Item 326)	0.0014	0.88
21. Fuel management procedure improvement (Item 355)	0.0015	0.94
22. Maintenance personnel remote access to control room communications (Item 511)	0.0015	0.94
23. Speaker/microphone audio message medium in communications (Item 542)	0.0015	0.94
24. Maintenance technician information access and I/O (Item 745)	0.0015	0.94
25. Engineering support personnel to receive more training (Item 815)	0.0016	1.00

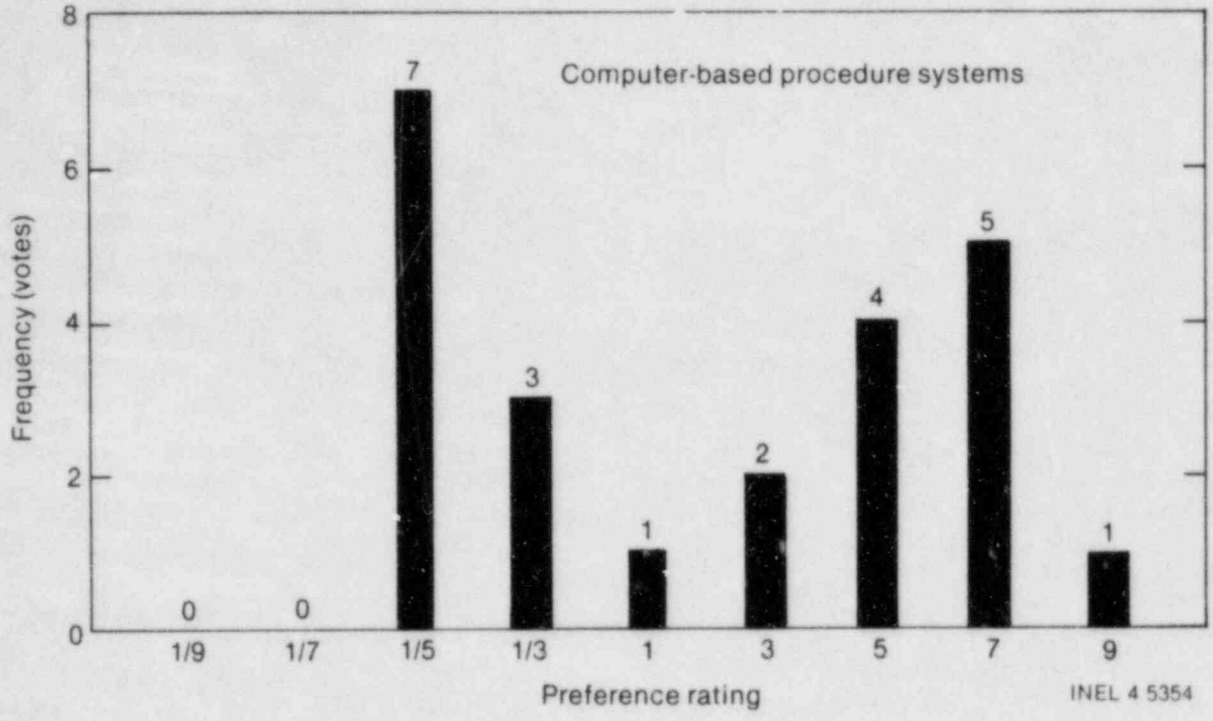


Figure 4. Computer stored: manual retrieval (Item 331), left, *vs* auto display of situation-specific procedures (Item 333), right.

ASSESSMENT OF FORECAST

Analytic Hierarchy Process Consistency Ratios

The maximum consistency ratio (for any group of concepts at any level) was 0.022 or 2.2% for the concepts relative to the Method of Operator Display Control Input to the Computer (Subcategory 65) from Level 4. Table 28 lists these concepts. The consistency ratio for Level 2 category comparison was 0.007 or 0.7%. The maximum ratio for the Level 3 comparisons was 0.018 or 1.8% for the concepts relative to Alarm or Annunciator System (Category 4). The Level 4 consistency ratios range from 0.016 to 0.000 (rounded off to the nearest whole number).

The consistency ratios calculated by the Analytic Hierarchy Process represent the amount of inconsistency that exists in the selections made in the previous comparisons expressed as a percentage of a completely random set of pairwise comparisons of the same size. Ratios less than 0.100 (the minimum value that indicates further panel response is needed) are deemed acceptable by Dr. Saaty (Reference 4). Consistency ratios this low are an indication that the concepts were reasonably grouped into related categories. Eighty percent of the consistency ratios were less than 0.011. Twenty percent were greater than 0.010, with a maximum ratio of 0.022. All of the consistency ratios are given in Appendix D as well as in each of the relative likelihood tables (Tables 4 through 45).

Reliability Coefficients

To ensure that the instrument and respondents gave homogeneous responses within the groups of concepts at the various levels of the hierarchy, reliability coefficients were calculated. Coefficient alphas were selected for use in this phase because they (a) provide a well-accepted measure of the instruments internal consistency, and (b) characterize the domain being sampled by the comparison and the homogeneity of the respondents' answers. Coefficient alphas were calculated to measure the degree of consensus of the responses for each group of concepts. This degree of consensus is derived from the formulation that total variation in an

instrument is composed of true intra-individual differences, intra-individual differences, and error intra-individual differences. This concept is represented by

$$\sigma_x^2 = \sigma_t^2 + \sigma_i^2 + \sigma_e^2 \quad (1)$$

where

σ_x^2 = variance of observed scores

σ_t^2 = variance of true scores

σ_i^2 = item variance

σ_e^2 = variance of errors.

Fifty-four percent of the coefficients were greater than 0.76; 40% were between 0.50 and 0.75; and 6% were less than 0.50.

Reliability is estimated by taking the variance associated with the observed score, less the variance associated with the errors, divided by the variance associated with the observed scores. A reliability coefficient of 0.75 indicates that 75% of the variance in the score depends on true variance in the domain being measured, while 25% depends on error variance. Thus, the coefficient gives a measure of accuracy, or whether a group of comparisons would produce approximately the same rank order of items. The alphas for each group of concepts are given on the relative likelihood tables (Tables 4 through 45).

Differences Among Three Panel Subgroups

Three subgroups of individuals were surveyed. These subgroups are developers, users, and regulators of advanced control room concepts. A question of interest was whether or not these subgroups' perceptions differed significantly from one another. In an attempt to ascertain these differences, comparisons were made among the three subgroups for each group of concepts of the hierarchy. One-way analyses of variance were conducted for the 42 groups of concepts of the hierarchy. Only one of these tests showed statistical significance. Message Content (Subcategory 52) produced a significant effect ($F = 5.78$, $p < 0.01$). These analyses add overwhelming support to the concept that the groups did not differ significantly in their perceptions of current and future changes in the control room.

Bimodal Responses

The results of 11 of the pairwise comparisons disclosed a bimodal response from the panel. These bimodal responses are:

1.	Information management (Category 7)	*vs*	Controls (Category 1)
2.	Information management (Category 7)	*vs*	Procedures (Category 3)
3.	Procedures; computer stored, manual retrieval (Item 331)	*vs*	Automatic display of situation-specific procedures (Item 333)
4.	Procedures; computer guidance for selection of procedures (Item 332)	*vs*	Computer-synthesized-situation-specific procedures (Item 334)
5.	Procedures; hard copy in indexed binders (Item 341)	*vs*	Computer retrieval and large screen display (Item 344)
6.	Procedures; hard copy in indexed binders (Item 341)	*vs*	Voice output in conjunction with one of the above (Item 346)
7.	Procedures; control room operations, normal (Item 351)	*vs*	Technical Support Center operations (Item 353)
8.	Alarm logic input; fixed, single-purpose buttons, e.g., present acknowledge buttons (Item 451)	*vs*	Touch panel or screens (Item 454)

9. Communication message medium; speaker/microphone audio (Item 542)	*vs*	Interactive computer terminal (Item 544)
10. Display method; analog meters (Item 611)	*vs*	Large screen, projected displays (Item 616)
11. Display graphics format; bar and column (Item 623)	*vs*	Complete process mimic with pan and zoom (Item 622).

See Figures 5 through 15 for histograms of the panel response for each of the 11 comparisons.

An inspection of the 11 comparisons discloses an apparent cause for, or interpretation of, the polarizations of the panel on each comparison. This permits segregating the 11 bimodal responses into 5 sets:

First, Comparisons 1 and 2 involve the categorical concept of "information management." The agenda for the pairwise comparison contained a minimum of definitive statements on the concept of information management which is subject to various interpretations. Additional conferences among the Delphi panel with the ambiguity in the definitive statements eliminated, would be necessary to provide a consensus on the definition for the concept of information management. This was not done due to time constraints.

Second, Comparisons 3 through 6 involve the impact of computerization on the retrieval and display of procedures in the control room. The bimodal responses can be associated with two distinctly different opinions of this impact which could be termed "innovative" and "conservative." The innovative opinion favors the introduction of computerization, whereas the conservative opinion favors current methods of using procedures and a minimum of computerization.

Third, Comparison 7 also concerns procedures; but, instead of computerization, the comparison involves the role of the Technical Support Center and its interface with, and support of, the control room. The bimodal response of the panel discloses a difference of opinion as to the relative importance of the Technical Support Center to the control room operations.

Fourth, Comparisons 8, 9, and 10 again relate to the innovative vs the conservative opinions of the computerization of the control room. In these three comparisons, computerization of alarms, communications, and data display were compared to current concepts.

Fifth, Comparison 11 relates to the innovative vs conservative opinions on the forms of computer graphics. Bar and column formats for computer graphic displays are in widespread use and probably exist at most nuclear power plants in many of the Safety Parameter Display Systems in the control rooms. Pan and zoom display of a computer process mimic diagram is, by contrast, a laboratory-stage concept.

To summarize, two of the bimodal responses probably involve a lack of consensus on the definition of "information management." One response reflects a difference of opinions on the importance of Technical Center Support of control room operations. The remaining eight responses disclose "innovative" and "conservative" views of the computerization of the control room.

As previously disclosed, a statistical test was performed to determine if the two distinctly different judgments on these 11 comparisons could be associated with institutional sectors, or subgroups, within the complete panel. No statistically significant difference was found among the three subgroups chosen. See the section of this report entitled, "Differences Among Three Panel Subgroups."

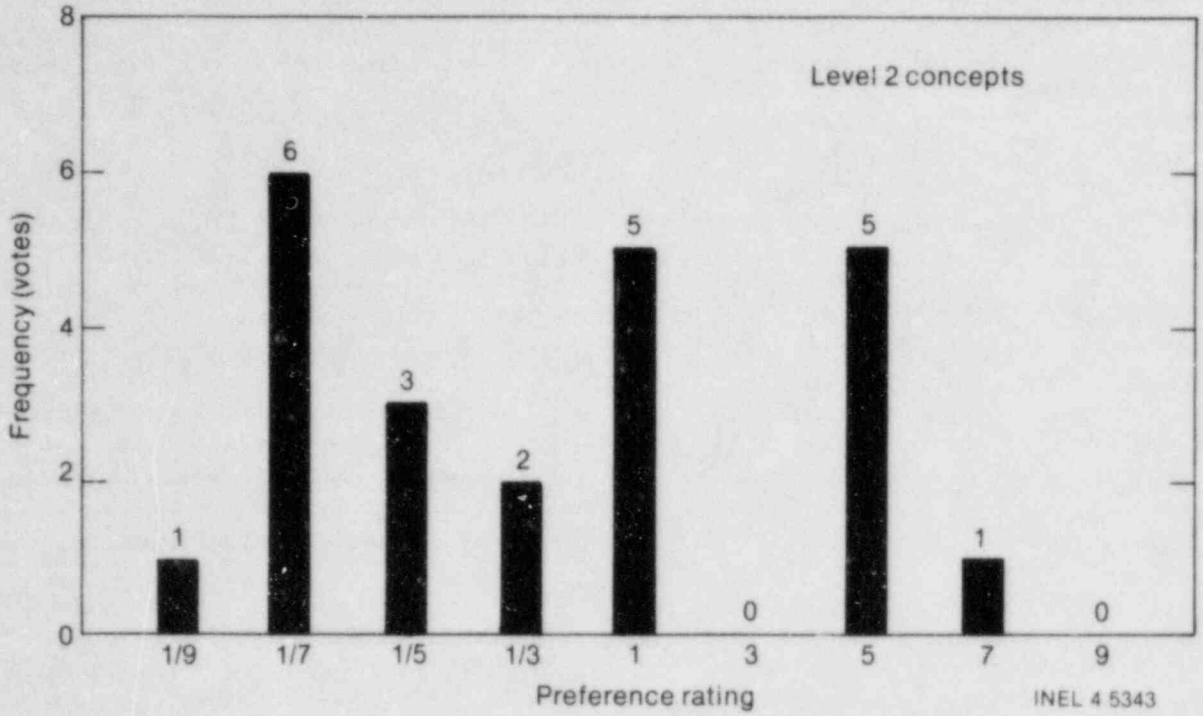


Figure 5. Controls and control systems (Category 1), left, *vs* information management (Category 7), right.

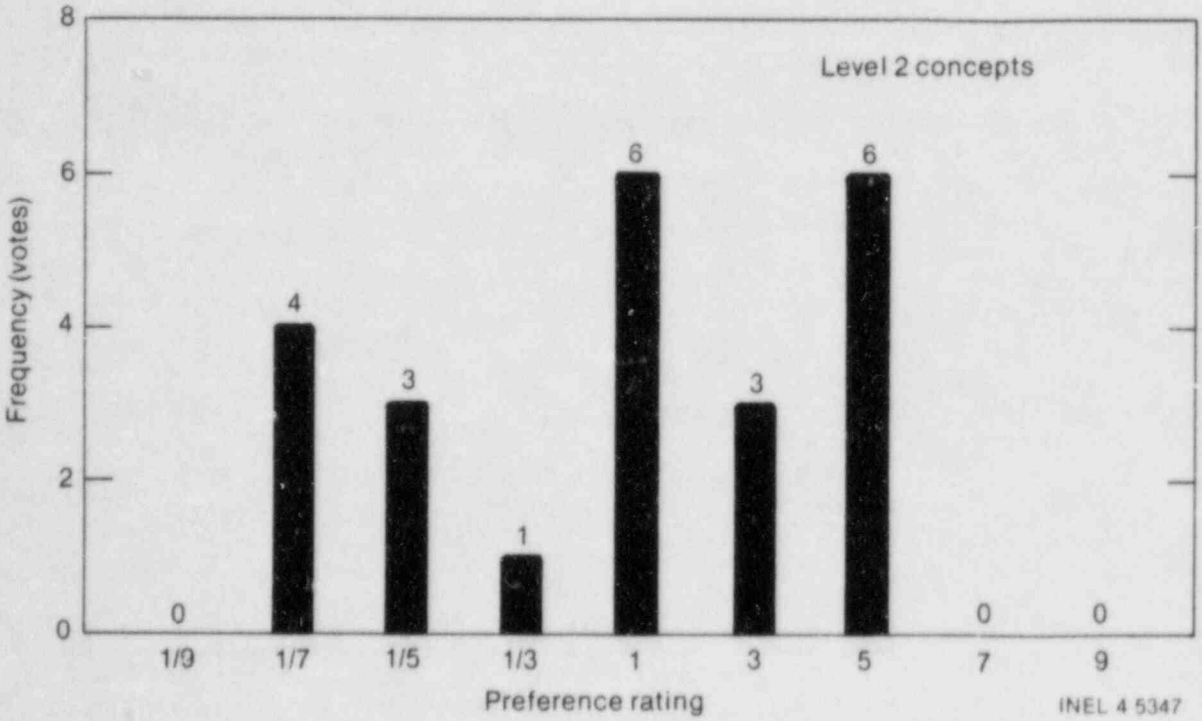


Figure 6. Procedures (Category 3), left, *vs* information management (Category 7), right.

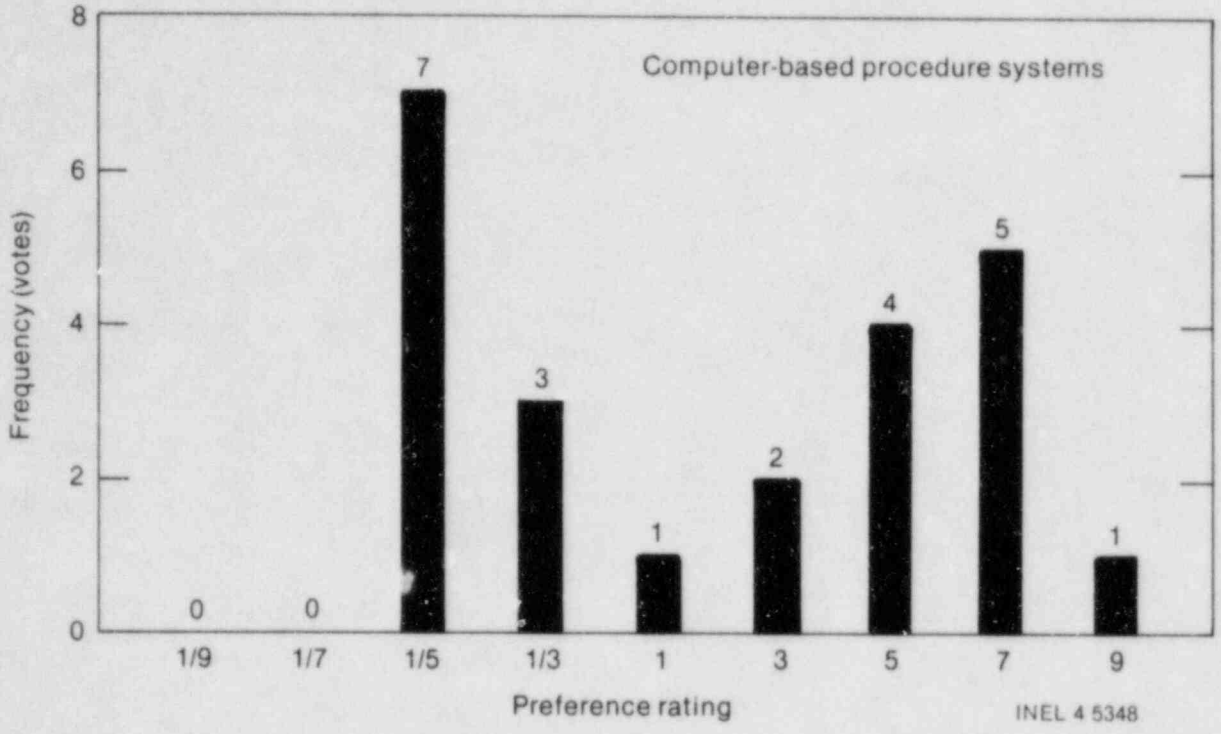


Figure 7. Computer stored: manual retrieval (Item 331), left, *vs* auto display of situation-specific procedures (Item 333), right.

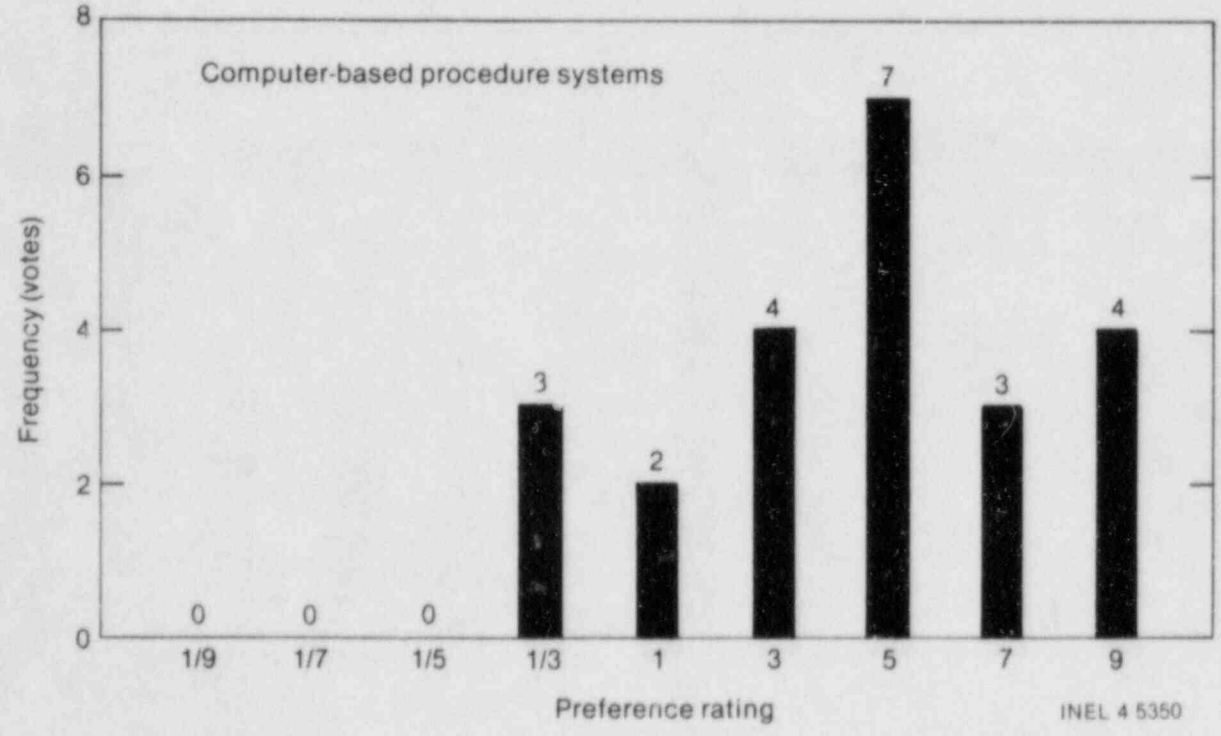


Figure 8. Procedures: computer guidance for selection of procedures (Item 332), left, *vs* computer-synthesized-situation-specific procedures (Item 334), right.

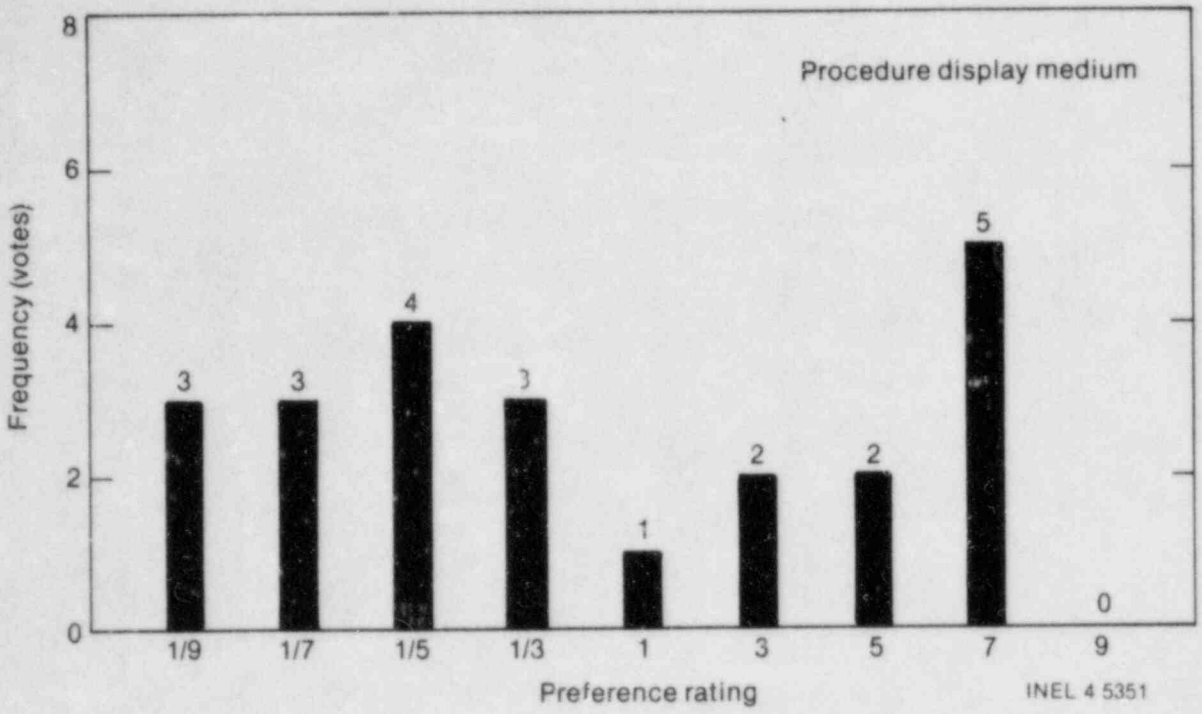


Figure 9. Procedures: hard copy in indexed binders (Item 341), left, *vs* computer retrieval and large screen display (Item 344), right.

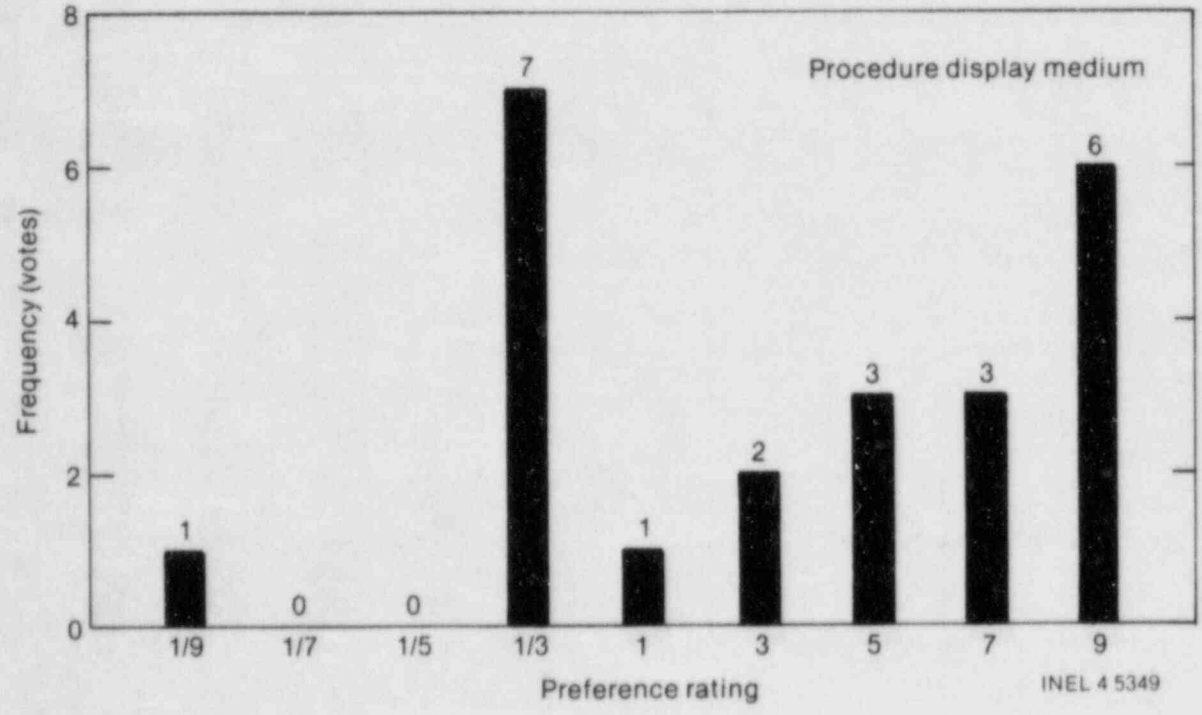


Figure 10. Procedures: hard copy in indexed binders (Item 341), left, *vs* voice output in conjunction with one of the above (Item 346), right.

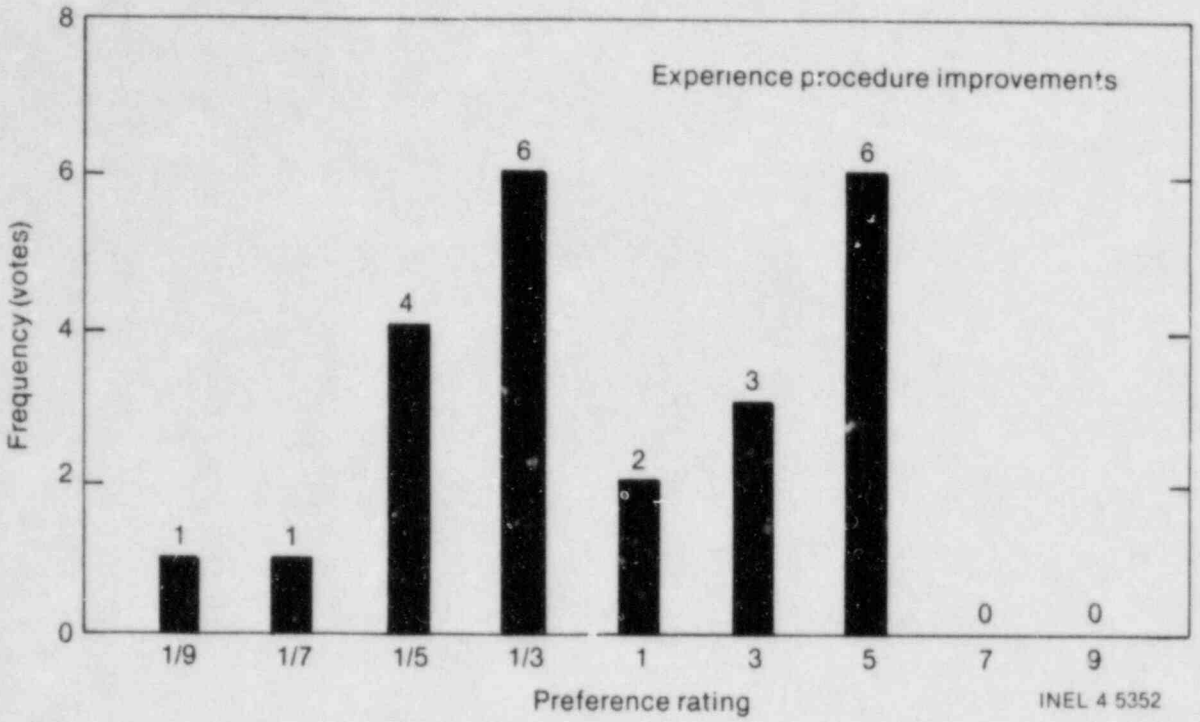


Figure 11. Procedures: control room operations, normal (Item 351), left, *vs* Technical Support Center operations (Item 353), right.

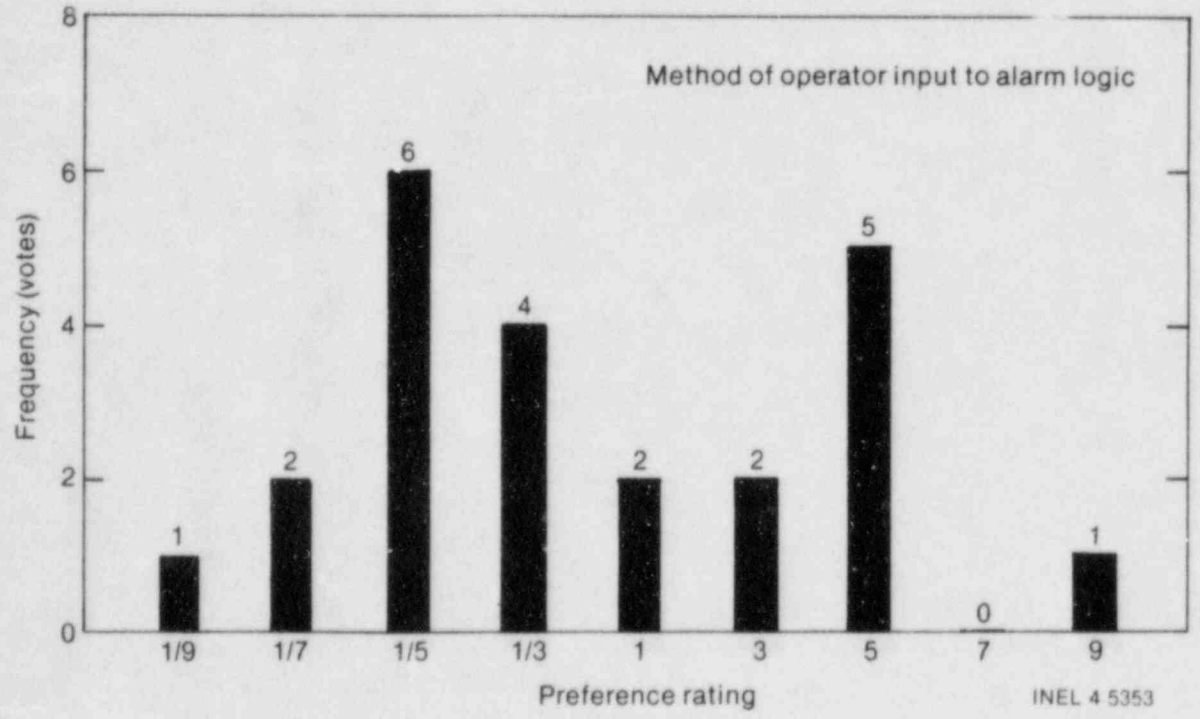


Figure 12 Alarm logic input fixed, single-purpose buttons (e.g., present acknowledge buttons) (Item 451), left, *vs* touch panel or screens (Item 454), right.

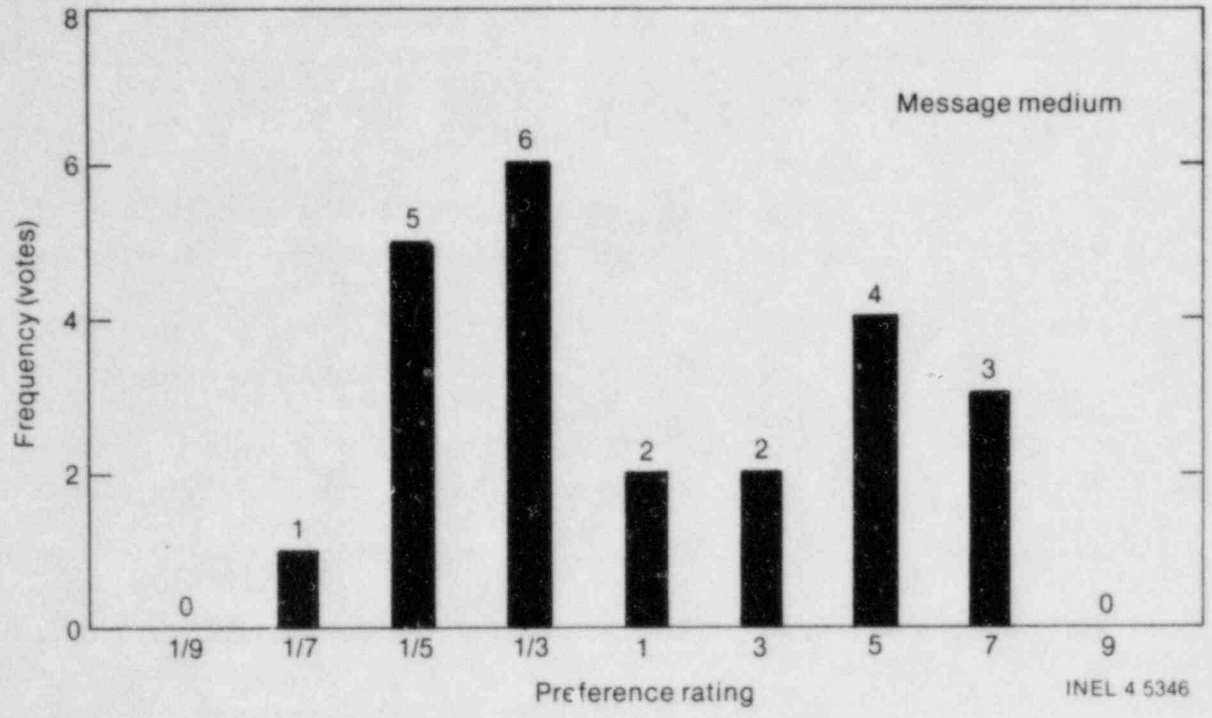


Figure 13. Communication message medium: speaker/microphone audio (Item 542), left, *vs* interactive computer terminal (Item 544), right.

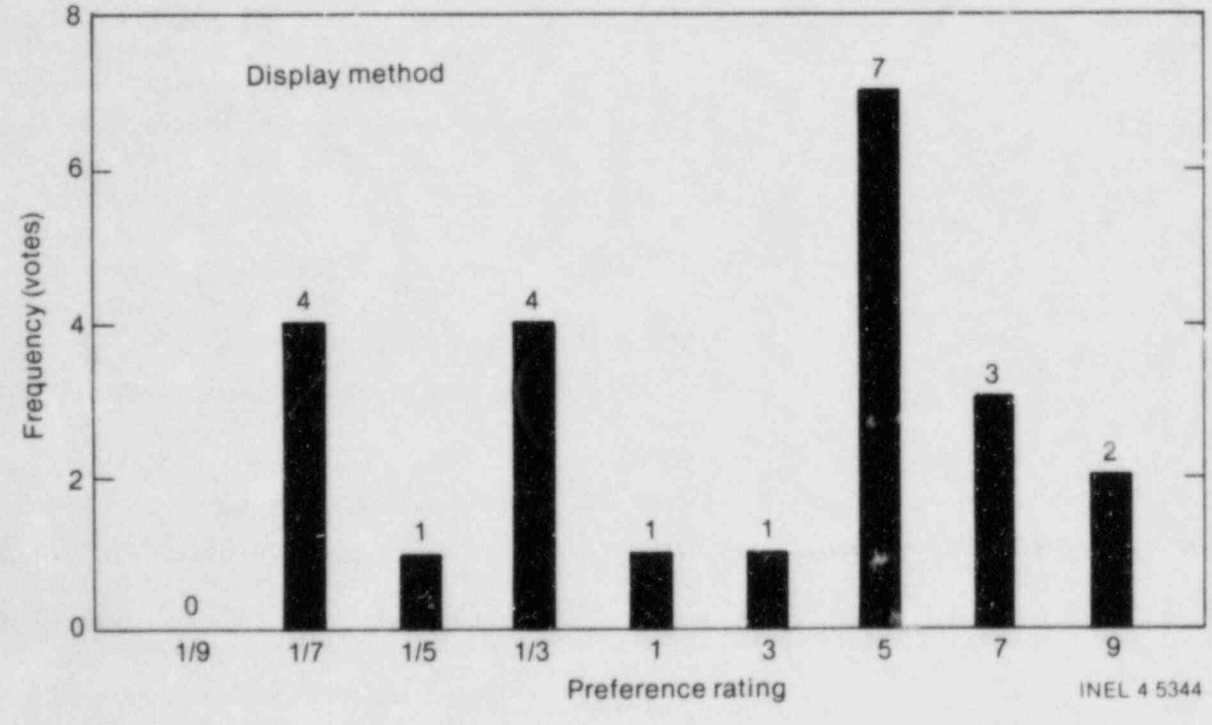


Figure 14. Display method: analog meters (Item 611), left, *vs* large screen, projected displays (Item 616), right.

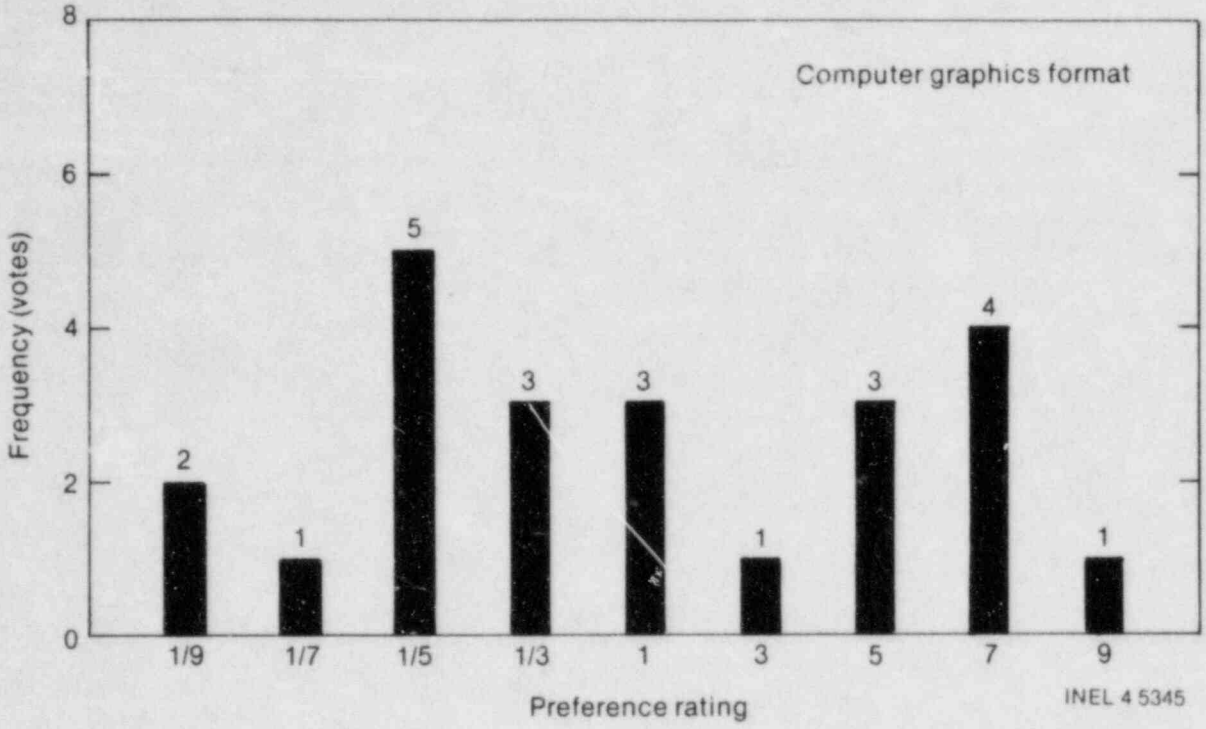


Figure 15. Complete process mimic with pan and zoom (Item 622), left, *vs* display method, analog meters (Item 611), right.

SUMMARY OF FORECAST

The analysis of the Round 1 response produced a four-level hierarchy based on eight general categories of changes and contained 42 related groups of changes that are likely to appear in future control rooms. This hierarchy forms a continuum of possible changes from present control room designs to some set of future generation designs.

The use of this continuum as a model for the Round 2 data collection and analysis resulted in a forecast that yields the relative likelihood for each change, i.e., its relative probability of being implemented as part of some future control room designs. This forecast is based on an extrapolation of current trends in control design. As such, it does not contain any information as to long-term changes which may result from one or more technological breakthroughs.

The validity of this forecast is supported by the broad based and extensive knowledge and experience of control room experts drawn from the nuclear power community who participated in this task. The forecast is further supported by descriptive and inferential statistics that yielded results which showed that the panel gave responses with good to excellent reliability and consistency. All but 3 of the 42 reliability coefficient alphas fall in the acceptable range of 0.50 to 0.99.[6] The range for the consistency ratios are from 0.016 to 0.000, where values that are less than 0.100 are acceptable.

For the 569 comparisons made by the expert panel of the 217 possible changes, a majority consensus was achieved for 537; an absence of consensus was found for 21; and for 11 of the comparisons, a definite instance of controversy was revealed. Those instances of controversy were not associated with any identifiable set of subgroupings of the panel, e.g., utility vs regulators; however, nine of them were concerned with the degree to which the control room should be computerized. One of these was concerned with the role the Technical Support Center would have relative to the control room. The remaining two were due to a lack of adequate definition of the concepts being compared.

CONCLUSIONS

Our first conclusion drawn from this forecast resulted from an inspection of the hierarchy of control room changes shown in Figure 2. That conclusion is, the combination of (a) the perceived needs for control room improvements, and (b) the options that modern man-machine technology provides is leading towards a myriad of control room design possibilities.

An examination of the 25 most likely concepts listed in Table 47 led to our second conclusion that these control room design concepts may be classified as belonging to one of the following five groups of related changes:

1. The type of information to be displayed to the operators
2. How displays, alarms, and procedures are presented to, and controlled by, the operators
3. Improvements to plant data processing
4. Automation of supervisory control systems
5. Higher qualifications and more extensive training for personnel.

These groups of related concepts, along with their rank order, are listed below. The first group encompasses the general categories of displays, information management, and procedures. The second group includes similar, general categories, as well as alarms. The third group deals with information management. The control and control systems category are covered in the fourth group. The fifth and final group covers the staffing and training categories.

Group 1: Current and trend values of process parameters (1)

Derived information from computer analysis of process parameters (2)

Computer guidelines for the selection of procedures (4)

Predictive and anticipatory information from computer analysis of current state and models of the process (5)

Diagnostics (12)

System state estimation (fault detection and identification) (15)

A matrix of function-oriented and event-oriented EOPs (19)

Technical specifications compliance (23)

Group 2: Integrated sets of two or more formats of computer-generated graphics (6)

CRTs or plasmascopes to present alarm information (7)

Integrated outputs which use combinations of annunciators, CRTs, voice messages, or color coding to prioritize or select alarms (8)

Integrated inputs which use combinations of keyboards, touch panels or tablets, tracking ball or joystick; or voice recognition for operator-control displays (10)

Computer-retrieval, CRT displays (18)

Interactive I/O used by operators to control computer-generated displays (20)

Integrated outputs which are combinations of conventional analog meters, liquid crystal displays, CRTs, plasmascopes, 3-D projection, large screen projection, or computer-synthesized voice to display information (24)

Group 3: Data validation (3)

Improved sensors as to accuracy, reliability, and response (9)

Installation of intelligent sensors (11)

Group 4: Automation of dynamic systems (13)

Automation of core cooling and other protective systems (14)

Group 5: Qualification and refresher training will continue to increase in time allotted, innovation, and realism (16)

On-the-job performance as determined by critical reviews (17)

Training in the use of new EOPs which are function oriented or event independent (21)

Technical qualification levels of the shift supervisor, the senior reactor operator, and the reactor operator will be elevated (12)

Trainee qualification to be determined by performance during training programs (25)

Third, we conclude that the range of these possibilities extends far beyond hardware choices into areas such as the extent of computerization of operator aids, the degree of automation, and even the levels of functional responsibility within the man-machine system.

An examination of the 25 least likely concepts listed in Table 48 led to our fourth conclusion that the communications between operators, and between operators and the balance of the plant personnel, will not change.

We have avoided assessing or implying significance to the forecast results. However, there is an observation we wish to state. That is, the significance of this forecast of control room changes is that the proliferation of designs, together with the lack of national, systematic guidelines for the next generation of control rooms in the United States, is out of balance with the economic, radiological, and societal risks incurred in each separate control room design.

REFERENCES

1. NUREG-0985, *U.S. Nuclear Regulatory Commission Human-Factors; Program Plan Vol. 1*, 1983.

2. Harold A. Linstone and Devendre Sahal, *Technological Substitution, Forecasting Techniques and Applications*, Elsevier, 1976.

3. Harold A. Linstone and Murray Turoff, *The Delphi Method: Techniques and Applications*, Addison-Wesley, 1975.

4. Thomas L. Saaty, *The Analytical Hierarchy Process*, McGraw-Hill, 1980.

5. Thomas L. Saaty, "Priority Setting in Complex Problems," *IEEE Transactions on Engineering Management, Vol. EM-30, N.3*, August 1983.

6. G. Helmstadter, *Principles of Psychological Measurement*, New York, Appleton-Century-Crofts, 1964.

APPENDIX A
ADVANCED CONTROL ROOM CONCEPTS (A6390)
IDENTIFY MAJOR CHANGES IN CONTROL ROOMS

APPENDIX A
ADVANCED CONTROL ROOM CONCEPTS (A6390)
IDENTIFY MAJOR CHANGES IN CONTROL ROOMS

EG&G Idaho, Inc., solicits your participation in a panel to develop a forecast of concepts for future reactor control rooms.

EG&G Idaho, Inc., under contract to the NRC, is attempting to forecast significant changes which may occur over the next decade in nuclear power plant control rooms and other manned stations. We would like to include you in a panel of experts to assist in this forecasting task. The purpose of this forecast is to identify where criteria and guidelines can provide a rational, objective basis for the regulatory assessment of the introduction of advanced control room concepts.

There are two phases of the project in which we need your contributions. The first is in the determination of possible control room changes. The second phase involves your assessment of the relative likelihood of the foreseen changes. In this phase, all panel members will be asked to make likelihood assessments on a selected list of possible changes. It is anticipated that a computerized response mechanism will be established for this second phase; those without access to computer communications devices will be able to participate by mail.

All participants will, of course, receive a copy of the final forecast which will be developed through analysis of the panel's results.

Description of First Phase. Initially, we need your participation to obtain an extensive, comprehensive list of the significant possible changes you foresee occurring in control rooms or other manned stations (such as remote emergency shutdown centers). The term "possible" is used in the sense of "possible with anticipated technological developments."

Two time periods will be used in forecasting, with 3-5 years being defined as the "near-term" period, and 5-10 years as the "long-term" period.

In this first phase, we are trying not to limit or direct your responses. Except for presenting likely topic categories the format has been intentionally kept unstructured. For each category, please list the significant changes you foresee in the upcoming 3-5- and 5-10-year time periods. A space is allotted for you to add categories that you might feel should be included.

Thank you for your participation.

NOTE: The following page is a sample of the survey sheets that were sent out for seven preliminary categories.

FORECAST TOPIC CATEGORIES

DISPLAY

3-5 Years

5-10 Years

CONTROL

3-5 Years

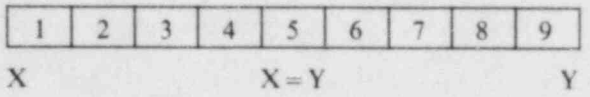
5-10 Years

APPENDIX B
INSTRUMENTS TO OBTAIN PAIRWISE COMPARISON OF CONCEPTS

APPENDIX B
INSTRUMENTS TO OBTAIN PAIRWISE COMPARISON OF CONCEPTS

Rating Instrument Example

To indicate how strongly you believe that an idea or concept will be applied in future control rooms over the one it is being compared to, you are to place an X in the appropriate division of the rating scale shown below.



Each of the divisions on this scale represent a relative value whose meaning is given below.

Box	Description
1	X is absolutely more likely than Y.
2	X is demonstrably more likely than Y.
3	X is essentially or strongly more likely to occur than Y.
4	X is weakly more likely to occur than Y.
5	X and Y are equally likely to occur.
6	Y is weakly more likely to occur than X.
7	Y is essentially or strongly more likely to occur than X.
8	Y is demonstrably more likely than X.
9	Y is absolutely more likely than X.

An example of the use of this rating scale and of the pairwise comparisons follows. This example is for PART IV: ALARM OR ANNUNCIATOR SYSTEMS, Section 4: Operator response or interaction with alarm systems

PART IV, SECTION 4

The concepts for operator interaction with alarm or annunciator systems are:

A. Acknowledge individual incoming alarms

B. Provide direction to the alarm logic, e.g., plant state, level of suppression, request for first or last incoming alarm

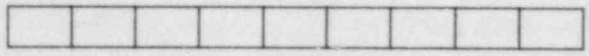
C. Higher level direction to the alarm logic

FOR THESE OPERATOR INTERACTIONS, WHICH OPERATOR RESPONSE OR INTERACTION WITH ALARM SYSTEMS WILL BE MORE LIKELY?

To indicate how strongly you believe that an idea or concept will be applied in future control rooms over the one it is being compared to, place an X in the appropriate decision of the rating scale shown with each of the pairwise comparisons given below.

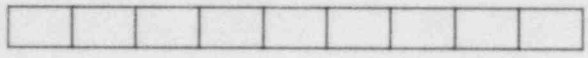
A. Acknowledge individual incoming alarms

B. Provide direction to the alarm logic, e.g., plant state, level of suppression, request for first or last incoming alarm



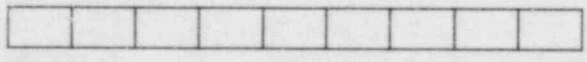
A. Acknowledge individual incoming alarms

C. Higher level direction to the alarm logic



B. Provide direction to the alarm logic, e.g., plant state, level of suppression, request for first or last incoming alarm

C. Higher level direction to the alarm logic



In order to keep this Appendix as brief as possible, the rating scales have been deleted from each group of concepts in the rating instrument.

Rating Instrument

Categories. The categories in the Advanced Control Room Concepts forecast are:

Category 1. Controls and Control Systems

Category 2. Staffing

Category 3. Procedures

Category 4. Alarm or Annunciator Systems

Category 5. Control Room Person-to-Person Communications Network

Category 6. Displays

Category 7. Information Management

Category 8. Nuclear Power Plant Personnel Training

For these categories, which of the following will be the most likely to be pursued in developing an advanced control room?

Category 1: Controls and Control Systems. The concepts (subcategories) for the Control and Control Systems category are:

Subcategory 11. Components
Subcategory 12. Operator Support
Subcategory 13. Computer-Executed Sequence Control
Subcategory 14. Supervisory Control Systems

For these concepts, which area of Controls and Control Systems will be more likely to be developed for an advanced control room?

Category 2: Staffing. Since there is only a Subcategory 21 for Category 2, there are no concepts to be compared.

Category 3: Procedures. The concepts for the Procedures category are:

Subcategory 31. Scope of Emergency Operating Procedures
Subcategory 32. Procedure Format
Subcategory 33. Computer-Based Procedure System
Subcategory 34. Procedure Display Medium
Subcategory 35. Procedure Improvements for Plant Operations

For these Procedure concepts, which will be the more likely to be pursued in developing an advanced control room?

Category 4: Alarm or Annunciator Systems. The concepts for Alarm or Annunciator Systems category are:

Subcategory 41. Alarm System Logic
Subcategory 42. Subject Matter, or Level of Abstraction, of the Alarm System
Subcategory 43. Method of Presenting the Alarm Information to the Operator
Subcategory 44. Operator Response or Interaction with Alarm Systems
Subcategory 45. Method of Operator Input to Alarm Logic

For these categories, which of the following concepts for Alarm or Annunciator Systems will be the more likely to be the focus in developing an advanced control room?

Category 5: Control Room Person-to-Person Communications Network. The concepts for the Control Room Person-to-Person Communications Network category are:

Subcategory 51. Remote Access to Control Room Communications
Subcategory 52. Message Content
Subcategory 53. Message Form
Subcategory 54. Message Medium

For these Control Room Person-to-Person Communications Network concepts, which is the more likely to be pursued in developing an advanced control room?

Category 6: Displays. The concepts for the Displays category are:

Subcategory 61. Display Method
Subcategory 62. Computer Graphics Format
Subcategory 63. Method Used to Control the Computer-Generated Display
Subcategory 64. Type of Information to be Displayed
Subcategory 65. Method of Operator Display Control Input to the Computer

For these Display concepts, which will be the more likely to be pursued in developing an advanced control room?

Category 7: Information Management. The concepts for the Information Management category are:

Subcategory 71. Improvements to Plant Data Processing
Subcategory 72. Supervisory Information
Subcategory 73. Information Control
Subcategory 74. Information Access and I/O

For these Information Management concepts, which is the more likely to be pursued in developing an advanced control room?

Category 8: Nuclear Power Plant Personnel Training. The concepts for Nuclear Power Plant Personnel Training category are:

Subcategory 81. Personnel to Receive More Training
Subcategory 82. Training Program Content or Subject Matter to Receive Increased Emphasis
Subcategory 83. Facilities (Places) to be Used for Training
Subcategory 84. Training Resources (Special EquipMent) to be Used for Training
Subcategory 85. Criteria for Trainee Qualification

For these concepts, which is the more likely to be pursued in developing an advanced control room?

Category 1, Subcategory 11: Components. The concepts for controls or control systems Components are:

Item 111. Sensors (more accurate, intelligent, reliable)

Item 112. Actuators (more functional and reliable)
Item 113. Computer I/O
Item 114. Computers (more power, redundancy, reliability)
Item 115. Local controllers (more intelligent, functions, accuracy, reliability)
Item 116. Consoles (human engineered)

For these concepts, which controls or control system Components will be more likely to be improved or added to the control room?

Category 1, Subcategory 12: Operator Support. The Operator Support concepts for controls and control systems are:

Item 121. Computerized aids
Item 122. Intelligent information on the process status
Item 123. Data validation
Item 124. Decision aids
Item 125. Diagnostic aids
Item 126. Artificial intelligence/Expert systems
Item 127. Redesign of process for improved man-machine interface

For these concepts, which improvements to controls and control systems will be more likely to be developed for Operator Support.

Category 1, Subcategory 13: Computer-Executed Sequence Control. The concepts for the type of Sequence Control of the controls and control systems category are:

Item 131. Interactive, shared, cooperative control
Item 132. Redesign of process for improved man-machine interface
Item 133. More intelligence

For these concepts, which type of Sequence Control will be more likely to be implemented?

Category 1, Subcategory 14: Supervisory Control Systems. The concepts for the level of automation for Supervisory Control Systems of the controls and control systems category are:

Item 141. Fully automated plant
Item 142. Automation of dynamic systems
Item 143. Automation of core cooling and other protection systems
Item 144. Fully automated plant with knowledge based expert system management

For the Supervisory Control Systems, which level of automation will be more likely to be implemented?

Category 2, Subcategory 21: Staffing of Advanced Control Rooms. The concepts for the Staffing category are:

Item 211. The shift supervisors responsibilities will give more priority to process management with an administrative assistant provided to the supervisor.
Item 212. The shift technical advisor will be replaced by an increase in the technical qualification level of the shift supervisor and the senior reactor operator.
Item 213. The control room operation (communications, procedures, protocol, etc.) will become more formal.
Item 214. Technical qualifications levels of the shift supervisor, the senior reactor operator, and reactor operator will be raised.
Item 215. Engineering degrees will be required for the shift supervisor and the senior reactor operator.
Item 216. Computer technician support will be added or increased.
Item 217. Computer usage qualification will be required for the shift supervisor, senior reactor operator, and the reactor operator.
Item 218. Monitoring and control of maintenance activities by the control room crew will increase.
Item 219. Qualification and refresher training will continue to increase in time allotted, innovation, and realism.
Item 210. No significant changes are expected.

For these concepts, which is the more likely to be pursued in Staffing an advanced control room?

Category 3, Subcategory 31: Scope of Emergency Operating Procedures. The concepts for the Scope of Emergency Operating Procedures of the procedures category are:

Item 311. Function-oriented, event-independent procedures
Item 312. Matrix of function-oriented and event-oriented procedures
Item 313. Procedures for beyond-design-basis events

Item 314. More extensive accident management procedures
Item 315. Procedures to direct Technical Support Center crew in support of control room crew

For these concepts, what will be the more likely Scope of Emergency Operating Procedures?

Category 3, Subcategory 32: Procedure Format. The concepts for Procedure Format of the procedures category are:

Item 321. Present format (single column, indented)
Item 322. Double column
Item 323. Flow chart
Item 324. Event or response tree
Item 325. Pictorial or graphic
Item 326. Voice over

For these concepts, which Procedure Format will be more likely?

Category 3, Subcategory 33: Computer-Based Procedure System. The concepts for Computer-Based Procedures of the procedures category are:

Item 331. Computer stored, manual retrieval
Item 332. Computer guidance for selection of procedure
Item 333. Automatic display of situation-specific procedure
Item 334. Computer-synthesized-situation-specific procedure

For these concepts, which Computer-Based Procedure System will be more likely?

Category 3, Subcategory 34: Procedure Display Medium. The concepts for Procedure Display Medium of the procedures category are:

Item 341. Hard copy in indexed binders
Item 342. Computer retrieval and printed hard copy
Item 343. Computer retrieval, CRT display
Item 344. Computer retrieval, large screen display
Item 345. Film or video tape, large screen display
Item 346. Voice output in conjunction with one of the above

For these concepts, which Procedure Display Medium will be more likely?

Category 3, Subcategory 35: Procedure Improvements for Plant Operations. The concepts for Procedure Improvements for Plant Operations of the procedures category are:

Item 351. Control room operation, normal
Item 352. Control room operation, emergency
Item 353. Technical Support Center operations
Item 354. Maintenance
Item 355. Fuel management

For these concepts, which plant operations field will more likely experience Procedure Improvements?

Category 4, Subcategory 41: Alarm System Logic. The concepts for Alarm System Logic for alarm or annunciator systems are:

Item 411. Deletion of unnecessary alarms
Item 412. Grouping of related alarms
Item 413. Suppression of alarms that are not important in a particular plant state
Item 414. Prioritizing presentation of alarms based on plant states, number of incoming alarms, etc.
Item 415. Intelligent alarm systems that reason backward to the cause of the event or forward to recommend actions or procedures to the operator

For these concepts, which Alarm System Logic concept will be more likely to be developed?

Category 4, Subcategory 42: Subject Matter, or Level of Abstraction, of the Alarm System. The concepts for alarm or annunciator systems Subject Matter, or Level of Abstraction are:

Item 421. Component problems, e.g., hot bearing
Item 422. System operation problems, e.g., loss of pump
Item 423. Functional level problems, e.g., upset heat transfer condition or trend in radiation levels
Item 424. Technical specification problem, e.g., insufficient redundancy in standby system
Item 425. Safety problem, e.g., the safety parameter display system

For these concepts, which Subject Matter, or Level of Abstraction, of the alarm system will be more likely?

Category 4, Subcategory 43: Method of Presenting the Alarm Information to the System. The concepts for the Method of Presenting Information from alarm or annunciator systems are:

Item 431. Annunciator windows, or tiles
Item 432. Cathode-ray tubes or plasmascopes
Item 433. Voice messages from computer or tape
Item 434. Color coding
Item 435. Integrated outputs which use combinations of the above for prioritizing or selectivity

For these concepts, which Method of Presenting the Alarm Information to the operator will be more likely?

Category 4, Subcategory 44: Operator Response or Interaction with Alarm Systems. The concepts for Operator Response or Interaction with alarm or annunciator systems are:

Item 441. Acknowledge individual incoming alarms
Item 442. Provide direction to the alarm logic, e.g., plant state, level of suppression, request for first or last incoming alarm
Item 443. Higher level direction to the alarm logic

For these operator interactions, which Operator Response or Interaction with Alarm Systems will be more likely?

Category 4, Subcategory 45: Method of Operator Input to Alarm Logic. The concepts for the Method of Operator Input to alarm or annunciator systems are:

Item 451. Fixed, single-purpose buttons, e.g., present acknowledge buttons
Item 452. Keyboard
Item 453. Voice
Item 454. Touch panel or screen
Item 455. Function keys
Item 456. Remote, hand-held control, with multiple keys

For these concepts, which method of Operator Input to Alarm Logic will be more likely?

Category 5, Subcategory 51: Remote Access to Control Room Communications. The concepts for Remote Access to Control Room Communications of the control room person-to-person communications network category are:

Item 511. Maintenance personnel
Item 512. Technical Support Center personnel
Item 513. Auxiliary operators
Item 514. Health physics technicians
Item 515. Plant management office personnel
Item 516. Headquarters office personnel
Item 517. NRC resident inspector
Item 518. Security guards
Item 519. Local authorities

For these concepts, who will more likely need Remote Access to Control Room Communications?

Category 5, Subcategory 52: Message Content. The concepts for Message Content of the control room person-to-person communications network category are:

Item 521. Plant status data, e.g., process parameters, valve positions
Item 522. Maintenance data, e.g., surveillance due, surveillance test in progress, test results
Item 523. Radiation fields
Item 524. Request for assistance, e.g., to maintenance, engineering, management
Item 525. Response to unplanned events, internal or external

For these concepts, which Message Content will be more likely?

Category 5, Subcategory 53: Message Form. The concepts for the Message Form of the control room person-to-person communications network category are:

Item 531. Audio, plain language
Item 532. Alpha-numeric data
Item 533. Graphic information, e.g., drawings, mimics, trend curves

For these concepts, which Message Form will be more likely?

Category 5, Subcategory 54: Message Medium. The concepts for the Message Medium of the control room person-to-person communications network category are:

Item 541. Telephones
Item 542. Speaker/microphone audio
Item 543. Closed circuit video
Item 544. Item interactive computer terminal

Item 545. Electronic mail (handled by computer with CRT or hard copy output)
Item 546. Portable, hand-held I/O units
Item 547. Integrated systems with selective applications of each of the above

For these concepts, which Message Medium will be more likely?

Category 6, Subcategory 61: Display Method. The concepts for the Display Method of the display category are:

Item 611. Conventional, electromechanical analog meters or indicators
Item 612. Liquid crystal displays
Item 613. Color cathode-ray tubes
Item 614. Plasmascopes
Item 615. Three-dimensional projection
Item 616. Large screen, projected displays
Item 617. Computer-synthesized voice
Item 618. Integrated sets of two or more display methods

For these concepts, which Display Method will be more likely to predominate?

Category 6, Subcategory 62: Computer Graphics Format. The concepts for the Computer Graphics Format of the display category are:

Item 621. Hierarchical mimic diagram
Item 622. Complete process mimic diagram with pan and zoom data display and suppression coordinated with the zoom
Item 623. Bar and column displays
Item 624. Iconic overview displays which provide higher levels of abstracted information, e.g., "safety status," by an integrated pattern of data display
Item 625. Trend displays, i.e., rectilinear curves of parameter value vs time
Item 626. Alpha-numeric listings
Item 627. New formats that are not yet identified
Item 628. Integrated sets of two or more formats

For these concepts, which Computer Graphics Format will be more likely?

Category 6, Subcategory 63: Method Used to Control the Computer-Generated Display? The concepts for the Method Used to Control the Computer-Generated Display of the display category are:

Item 631. None, the displays will be fixed
Item 632. The operator
Item 633. Computer algorithms which analyze the plant status
Item 634. Interactive between the operator and the computer

For these concepts, which Method Used to Control the Computer-Generated Display will be more likely?

Category 6, Subcategory 64: Type of Information to be Displayed? The concepts for the Type of Information to be Displayed of the display category are:

Item 641. Current and trend values of process parameters
Item 642. Derived information from computer analysis of process parameters
Item 643. Predictive and anticipatory information from computer analysis of current state and model of the process

For these concepts, which Type of Information will be more likely to be displayed?

Category 6, Subcategory 65: Method of Operator Display Control Input to the Computer. The concepts for Operator Display Control of the display category are:

Item 651. Keyboard general purpose
Item 652. Function keys
Item 653. Touch panels, screens, or tablets
Item 654. Tracker ball or mouse or joystick
Item 655. Voice recognition
Item 656. Integrated sets of two or more methods

For these concepts, what method of Operator Display Control Input to the Computer will be more likely?

Category 7, Subcategory 71: Improvements to Plant Data Processing. The concepts for Improvements to Plant Data Processing for the information management category are:

Item 711. Intelligent sensors
Item 712. Improved sensors (accuracy, reliability, response)
Item 713. Data validation

For these concepts, which Improvements to Plant Data Processing will be more likely to occur?

Category 7, Subcategory 72: Supervisory Information. The concepts for Supervisory Information for the information management category are:

Item 721. Fuel management
Item 722. System state estimation (fault detection and identification)
Item 723. Technical specifications compliance
Item 724. Diagnostics
Item 725. Synthesized procedures
Item 726. Process state (radiation, equipment, fatigue, leakage, etc.)

For these concepts, which operational area or Supervisory Information will be more likely developed?

Category 7, Subcategory 73: Information Control. The concepts for Information Control for the information management category are:

Item 731. Shift turnover
Item 732. Maintenance
Item 733. Procedures
Item 734. Design configuration
Item 735. Access and security
Item 736. Radiation exposure

For these concepts, which will be more likely to require Information Control?

Category 7, Subcategory 74: Information Access and I/O. The concepts for Information Access and I/O for the information management category are:

Item 741. Shift supervisor
Item 742. Senior reactor operator
Item 743. Reactor operator
Item 744. Maintenance manager
Item 745. Maintenance technician
Item 746. Plant management staff
Item 747. Quality assurance personnel
Item 748. System engineer
Item 749. Health physicists
Item 740. Plant operations review (licensing)

For these concepts, who will be more likely to require Information Access and I/O?

Category 8, Subcategory 81: Personnel to Receive More Training. The concepts for the Personnel to Receive More Training for the nuclear power plant personnel training category are:

Item 811. Control room operators
Item 812. Auxiliary operators
Item 813. Maintenance personnel
Item 814. Health physics personnel
Item 815. Engineering support personnel
Item 816. Plant management (above shift supervisor level)
Item 817. Technical Support Center staff

For these concepts, which Personnel category will be more likely to receive more training?

Category 8, Subcategory 82: Training Program Content or Subject Matter to Receive Increased Emphasis. The concepts for the Training Program Content or Subject Matter to Receive Increased Emphasis for the nuclear power plant personnel training category are:

Item 821. Plant behavior during normal operation, anticipated transients, and expected events and failures
Item 822. Control of the plant during complex transients and severe accidents with actual or threatened release of radiation
Item 823. Methods of diagnosing events and developing decisions and plans of action
Item 824. Use of new emergency operating procedures which are function oriented or event independent
Item 825. Use of operator aids, e.g., the SPDS
Item 826. Use of interactive computer terminals, e.g., for retrieving plant data, plotting a curve, maintaining a check list
Item 827. Team training, i.e., training a crew in divisions of responsibilities, lines of authority, communications

For these concepts, which Training Program or Subject Matter will be more likely to receive increased emphasis?

Category 8, Subcategory 83: Facilities (Places) to be Used for Training. The concepts for Facilities (Places) to be Used for Training for the nuclear power plant personnel training category are:

Item 831. Off-site training center
Item 832. On-site training centers
Item 833. Technical Support Centers
Item 834. Control room and local control stations and work locations

For these concepts, which Facilities (Places) will be more likely to be used for training?

Category 8, Subcategory 84: Training Resources (Special Equipment) to be Used for Training. The concepts for Training Resources (Special Equipment) to be Used for Training for the nuclear power plant personnel training category are:

Item 841. Plant specific simulators
Item 842. Generic plant simulators (not exactly matching the trainee's plant
Item 843. Full scope, or engineering simulators which can simulate severe conditions, e.g., two-phase coolant, fuel damage, radiation release
Item 844. Interactive computer terminals used for part-task simulators, computer-aided instruction, e.g., the CDC PLATO program
Item 845. Hard copy course material and training aids

For these concepts, which Training Resources (Special Equipment) will be more likely to be used for training?

Category 8, Subcategory 85: Criteria for Trainee Qualification. The concepts for Criteria for Trainee Qualification for the nuclear power plant personnel training category are:

Item 851. Performance during training programs
Item 852. Performance on written examinations
Item 853. Performance on the job as determined by critical reviews

For these concepts, which criteria will be more likely to be used to judge Trainee Qualifications?

APPENDIX C
DOMINANCE MATRIX

APPENDIX C
DOMINANCE MATRIX

For ease of analyses of the eight major concepts, we found a dominance matrix to be useful (Figure C-1)[C-1]. The matrix presents the *weighted* modal responses of the pairwise comparison responses. The matrix is read in the following manner:

The entries are read along the rows. These entries show whether the concept named at the head of the row dominated the concept listed at the head of each column, and by how much. That is, the dominance is weighted by how far along the scale the majority of responses occurred. For this weighting, the point at which the concepts were felt to be equally likely was designated as "O." The unit distances along the scale were numbered 1 through 4.

In cases where there were two definite opinions, both scale distances are reported (as in the case of Information Management vs Procedures). Thus, those who rated Controls and Control Systems as more likely than Staffing, did so at 3 units from zero; while those who rated Staffing as more likely, did so at 2 units from zero. Where "O" is entered in the matrix, the majority judged the concepts as equally likely. Where "X" is entered, there was no majority opinion—the respondents held every opinion at every level.

The table below the matrix reports the weighted scores for each category of concept by subtracting the column total for that concept from its row total (E row - E column = weighted score). The number of times a concept dominates or the number of times it is subordinated to other concepts is a simple frequency count.

Reference

C-1. G. Helmstadter, *Principles of Psychological Measurement*, New York, Appleton-Century-Crofts, 1964.

Dominant	Subordinate: 1. Control & Control Syst.	2. Staffing	3. Procedures	4. Alarm/Annunc. Syst.	5. Commun. Net	6. Displays	7. info. Mgmt.	8. Training	Row Total
1. Control & Control Syst.		3	X	0	2	0	1	X	6
2. Staffing	2		0	0	1	0	0	0	3
3. Procedures	X	2		X	1	X	1	0	4
4. Alarm/Annunc. Syst.	2	2	X		3	0	1	2	10
5. Commun. Net	0	0	0	0		0	0	0	0
6. Displays	2	2	X	0	3		0	2	9
7. Info. Mgmt.	3	2	0	0	2	0		1	8
8. Training	X	2	0	1	2	0	0		5
	−9	−13	0	−1	−14	0	−3	−5	0

Category	Weighted Score	Number of Times Dominates/Subordinated
1. Control & Control Syst.	−3	3/4
2. Staffing	−10	2/6
3. Procedures	+4	3/0
4. Alarm/Annunc. Syst.	+9	5/1
5. Commun. Net	−14	0/7
6. Displays	+9	4/0
7. Info. Mgmt.	+5	4/3
8. Training	0	3/3

Rank Ordered	
4. Alarm/Annunc. Syst.	
6. Displays	+9
7. Info. Mgmt.	+5
3. Procedures	+4
8. Training	0
1. Control & Control Syst.	−3
2. Staffing	−10
5. Commun. Net	−14

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Figure C-1. Dominance matrix.

APPENDIX D
CONSISTENCY RATIOS

Table D-1. Consistency ratios

Relevant Concept	Hierarchy Level	Table Number	AHP[a] Consistency Index	Random Consistency Index	Consistency Ratio
Advance control room man-machine system	2	3	0.010	1.24	0.007
Controls and control system (Category 1)	3	9	0.007	0.90	0.008
Staffing (Category 2)	3	10		_b	
Procedures (Category 3)	3	6	0.003	1.12	0.003
Alarm or annunciator systems (Category 4)	3	7	0.018	1.12	0.016
Communications network (Category 5)	3	11	0.001	0.90	0.001
Displays (Category 6)	3	4	0.007	1.12	0.006
Information management (Category 7)	3	5	0.007	0.90	0.008
Personnel training (Category 8)	3	8	0.004	1.12	0.003
Components (Subcategory 11)	4	38	0.007	1.24	0.006
Operator support (Subcategory 12)	4	17	0.011	1.32	0.008
Computer-executed sequence control (Subcategory 13)	4	35	0.002	0.58	0.003
Supervisory control systems (Subcategory 14)	4	22	0.001	0.90	0.001
Staffing of advanced control rooms (Subcategory 21)	4	13	0.011	1.49	0.007
Scope of emergency operating procedures (Subcategory 31)	4	20	0.002	1.12	0.002
Procedure format (Subcategory 32)	4	32	0.004	1.24	0.003
Computer-based procedure system (Subcategory 33)	4	21	0.002	0.90	0.003
Procedure display medium (Subcategory 34)	4	24	0.015	1.24	0.012
Procedure improvements for plant operations (Subcategory 35)	4	37	0.002	1.12	0.002
Alarm system logic (Subcategory 41)	4	25	0.007	1.12	0.006
Subject matter, or level of abstraction, of the alarm system (Subcategory 42)	4	25	0.012	1.12	0.010
Method of presenting the alarm information to the system (Subcategory 43)	4	18	0.007	1.12	0.006
Operator response or interaction with alarm systems (Subcategory 44)	4	33	0.003	0.58	0.005
Method of operator input to alarm logic (Subcategory 45)	4	39	0.015	1.24	0.012
Remote access to control room communications (Subcategory 51)	4	43	0.021	1.45	0.015
Message content (Subcategory 52)	4	42	0.014	1.12	0.012
Message form (Subcategory 53)	4	44	0.000	0.58	0.000
Message medium (Subcategory 54)	4	41	0.008	1.32	0.007
Display method (Subcategory 61)	4	23	0.023	1.41	0.016
Computer graphics format (Subcategory 62)	4	19	0.022	1.41	0.016
Method used to control the computer-generated display (Subcategory 63)	4	31	0.008	0.90	0.008

Table D-1. (continued)

Relevant Concept	Hierarchy Level	Table Number	AHP[a] Consistency Index	Random Consistency Index	Consistency Ratio
Type of information to be displayed (Subcategory 64)	4	12	0.002	0.58	0.004
Method of operator display control input to the computer (Subcategory 65)	4	27	0.027	1.24	0.004
Improvements to plant data processing (Subcategory 71)	4	15	0.000	0.58	0.000
Supervisory information (Subcategory 72)	4	14	0.008	1.24	0.006
Information control (Subcategory 73)	4	34	0.007	1.24	0.006
Information access and I/O (Subcategory 74)	4	26	0.012	1.49	0.008
Personnel to receive more training (Subcategory 81)	4	36	0.006	1.32	0.005
Training program content (Subcategory 82)	4	16	0.006	1.32	0.005
Facilities to be used for training (Subcategory 83)	4	40	0.004	0.90	0.004
Training resources (special equipment) to be used for training (Subcategory 84)	4	30	0.013	1.12	0.012
Criteria for trainee qualification (Subcategory 85)	4	28	0.002	0.58	0.003

a. AHP = Analytic Hierarchy Process.

b. Because there is only one subcategory (Subcategory 21), there is no consistency index.

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EG&G Idaho, Inc.
P.O. Box 1625
Idaho Falls, Idaho 83415