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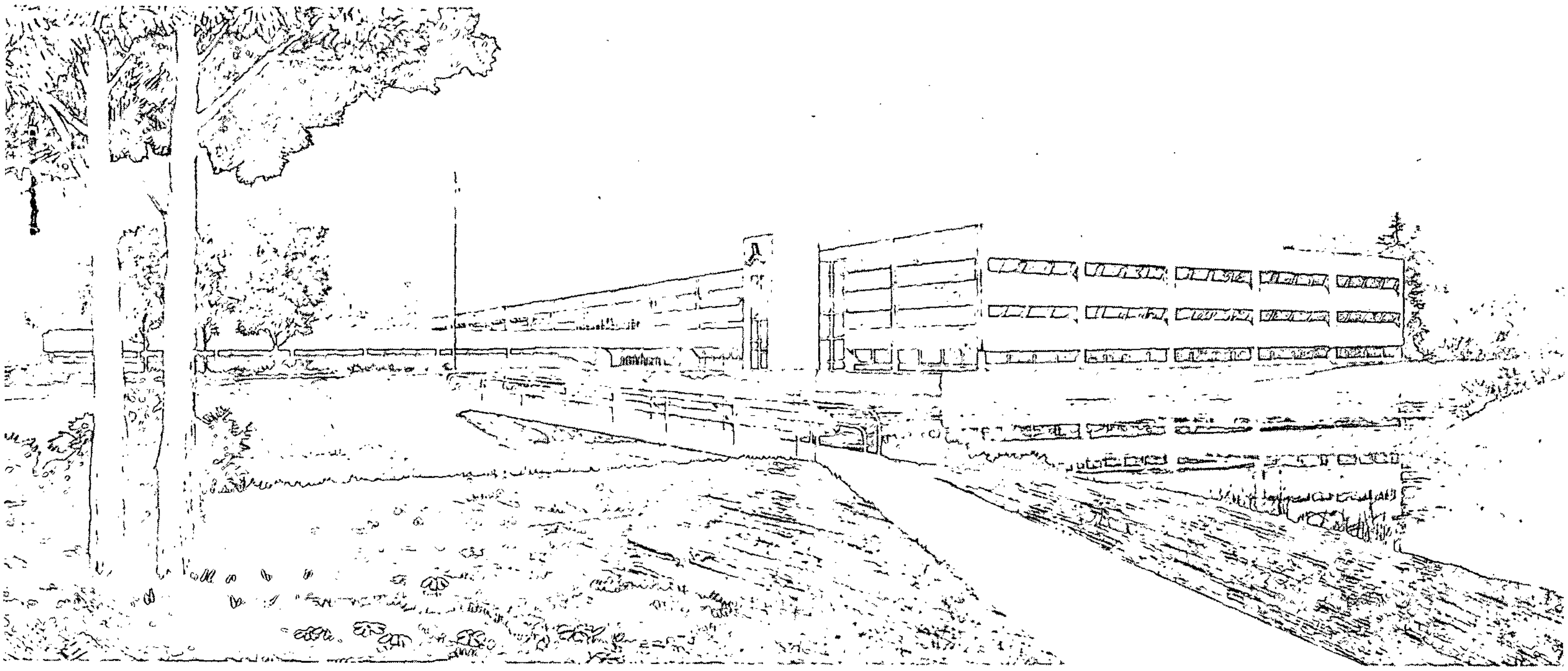

U.S. Department of Energy
Idaho Operations Office • Idaho National Engineering Laboratory

Light Water Reactor Engineered Safety Features Status Monitoring Final Report

Robert G. Brown
James vonHerrmann

August 1981

Prepared for the
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555
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-2278
EGG-2122
Distribution Category: RX

LIGHT WATER REACTOR ENGINEERED SAFETY FEATURES STATUS MONITORING FINAL REPORT

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Published August 1981

Science Applications, Inc.
Palo Alto, California 94304

Prepared for EG&G Idaho, Inc.
Under Subcontract No. K-5151
and the U.S. Nuclear Regulatory Commission
Under DOE Contract No. DE-AC07-76IDO1570
FIN No. A6294

ABSTRACT

A technical basis for making decisions relative to assessing and improving the status monitoring systems for engineered safety features (ESF) has been developed. The fundamental assumption guiding this investigation is that the effectiveness of how a particular component or system's status is monitored should be commensurate with its safety significance. A methodology is proposed whereby the relative importance of safety systems and components is determined using probabilistic risk assessment techniques. This approach was applied to determine the importance of ESF systems and components for the plants evaluated by the Reactor Safety Study. A comparison of these results to the actual status monitoring techniques used in the specific plants was performed to evaluate the usefulness and practical limitations of the technical approach. Although the intent was not to evaluate the adequacy of existing ESF status monitoring schemes, some observations resulting from the plant specific assessments are provided to illustrate the type of conclusions and information which the risk based approach can produce.

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APPENDICES

ACKNOWLEDGEMENTS

The acquisition of plant data and photographs of control room displays were an essential part of this project. In this regard the authors would like to thank the organizations and individuals who provided invaluable assistance in obtaining this information. First and foremost we would like to thank the plant management and reactor operators of the Peach Bottom Atomic Power Station of the Philadelphia Electric Company and the Surry Nuclear Power Station of Virginia Electric and Power Company. In particular, the cooperation and assistance of the following people is most appreciated: station supperintendent Ted Ullrich, and shift supervisors Charles Anderson and Steve Roberts at Peach Bottom; and plant manager Jack Wilson and Doug Rickard of the engineering staff at Surry. US NRC resident inspector Don Burke at Surry was also extremely helpful and cooperative in acquiring the information for this study. We would also like to thank Dave Verrelli and Don Neighbors of the U.S. Nuclear Regulatory Commission's Division of Operating Reactors who arranged for the plant visits.

Additionally we would like to acknowledge the efforts of Harold Scott of the US NRC and Bill Banks of EG&G, Idaho who assisted in the acquisition of information on the plant trips. Finally, we express our sincere appreciation to Arlene Buscemi who assisted in the correlation and presentation of the data in this report.

LIST OF ABBREVIATIONS/ACRONYMS

BIT	Boron Injection Tank (PWR)
BWR	Boiling Water Reactor
CR	Control Room
CSD	Cold Shutdown (Figure 4.11)
CST	Condensate Storage Tank
CVCS	Chemical and Volume Control System (PWR)
DG	Diesel Generator (Figure 4.19)
ECCS	Emergency Core Cooling System
EEG	Emergency Electrical Generator (Diesels, Figure 4.10)
ESF	Engineered Safety Feature
HCV	Hydraulic Control Valve
HSD	Hot Shutdown (Figure 4.11)
HX	Heat Exchanger
LC	Locked-Closed
LCO	Limiting Conditions for Operation
LHSI	Low Head Safety Injection
LO	Locked-Open
LOCA	Loss of Coolant Accident
MOV	Motor Operated Valve
NC	Normally Closed
NO	Normally Open
OC	Outside Containment (See Table 4.3)
OSRS	Outside Spray Recirculation System (Containment Spray Recirculation System trains with pumps outside containment, PWR)
PTL	Pull to Lock

LIST OF ABBREVIATIONS/ACRONYMS (Continued)

PWR	Pressurized Water Reactor
RHR	Residual Heat Removal (System)
RWST	Refueling Water Storage Tank (PWR)
SI	Safety Injection
SOV	Solenoid Operated Valve
TMI	Three Mile Island

NOTE: Abbreviations for the ESF Systems are given in Tables 4.2 (page 17) and 4.6 (page 53) for the PWR and BWR, respectively.

1.0 BACKGROUND

Recent events have reemphasized the importance of those aspects of design and operation which affect the operator's ability to efficiently prevent, diagnose, and respond to off-normal events. One such aspect is the manner in which the status of the systems and/or components specifically designed to respond to potential accident conditions is monitored. The primary ingredients of this facet of design and operation entail the selection of the specific components or subsystems which should be monitored and the specific monitoring mechanism by which their status is made known to the operator. Some examples of status monitoring techniques currently employed are equipment tags, oral and written communications, position indicator lights, and alarms in the control room. The integration of these ingredients define what is referred to in this investigation as a monitoring "scheme".

The incident at Three Mile Island (TMI) was certainly the most publicized confirmation of the safety significance of components which are bypassed or deliberately rendered inoperable. The fact that multiple valves in the Auxiliary Feedwater System were left in the closed position for an extended period following maintenance actions contributed to the progression of the TMI accident. WASH-1400[1] and subsequent risk assessments have pointed out the significance to public safety of "valved-out" components or systems and the importance of alerting the operator to these conditions.

The current regulatory approach to assessing the acceptability of the manner in which the status of bypassed, or inoperable, safety systems or components is monitored is embodied in Regulatory Guide 1.47.[2] This guide sets forth relatively broad criteria by which the safety significance of a bypass or inoperable condition should be assessed. The guide then calls for automatic indication of those bypasses or inoperable conditions which meet these criteria. For example, the guide calls for automatic indication of a bypass or inoperable condition "that is important to the safety of the public" and that can "reasonably be expected to occur more frequently than once per year."

In recent years, increased interest has arisen in alternative regulatory procedures to ascertain the acceptability of various elements of nuclear plant design and operation. This has resulted (at least, in part) from the perception that present procedures do not adequately focus on what is truly important in reactor design and operation. This could result in an inefficient use of safety resources where unwarranted attention is paid to insignificant problems while major problems are not addressed.

As a result of the extensive post-TMI investigations, the NRC has concluded that a probabilistic risk approach "can provide great insight into the relative safety significance of reactor plant systems and design features".(3) Accordingly, the Action Plan which resulted from these investigations calls for the application of these techniques to safety system status monitoring (Task I.D. 5 of NUREG-0660). Such a study would supplement activities by the regulatory staff to develop and implement positions related to status monitoring.

The development of a more thorough, systematic technical basis for decisions relative to improved status monitoring of safety systems than presently exists could provide a significant contribution to the enhancement of public safety. It is the primary purpose of this analysis to ascertain whether a probabilistic risk based approach can supply this technical basis by providing valuable insights into the relative importance of individual components. A more detailed discussion of the objectives of this analysis follows.

2.0 OBJECTIVES

The general objective of the work reported here was to develop a technical basis for decisions relative to improvements in the monitoring of safety systems and components which could ultimately lead to an enhanced level of safety over that which can be (and has been) achieved by previous approaches.

One of the fundamental assumptions of this analysis is that the technical basis referred to above should explicitly address the relative importance of individual systems, subsystems, and components. It is impractical, unnecessary, and often counterproductive to demand an equal level of monitoring for every component. Regulatory Guide 1.47 recognizes this point and proceeds to define a basis for a "practical indicating system covering a wide range of commonly expected conditions." The guidelines call for automatic indication of the status of components which are "important to the safety of the public" and can "reasonably be expected [to be in an inoperable condition] more frequently than once per year." It was the objective of this analysis to develop a technical basis which would involve a more systematic and detailed evaluation of component or subsystem importance than the relatively broad criteria cited in Regulatory Guide 1.47.

In this regard, probabilistic risk assessment has been proposed as a valuable technique to model the relationship of individual components to overall plant safety and thereby provide a logical method for assessing and comparing the relative importance of any one element of the plant. In fact, the Lewis Committee, in their review of WASH-1400, stated: "The information provided by probabilistic risk assessment about the relative importance of different accident sequences should be, to a much greater extent than is currently the case, incorporated into the determination of regulatory and enforcement priorities... the methodology is the best guide we have to what is important to reactor safety."[4] Therefore, the second objective of this analysis was to ascertain whether the use of probabilistic risk analysis could, by allowing a systematic assessment of component importance, provide a useful input to the development of effective monitoring schemes.

As in most analyses which attempt to define an appropriate methodology to solve a specific problem, it is necessary to test the method in an actual operating situation to assess both its theoretical and practical value. Accordingly, the third objective of this analysis was to compare the probabilistic risk based importance ranking of safety system components to the actual monitoring techniques employed in an operating plant. In this way, it is possible to ascertain whether the effectiveness of the monitoring technique which has resulted from the application of existing design practices and regulatory procedures is commensurate with the safety significance of the monitored components. It is then possible both to assess the practical value of a risk based approach and to identify areas where the existing monitoring scheme could be improved. Thus, the general objective of developing a sound basis for improvements in the monitoring of safety systems and components encompasses the more specific objective of defining a useful measure of component importance and ascertaining the value of probabilistic risk assessment as an effective tool in this process.

3.0 TECHNICAL APPROACH

The series of steps that were performed to accomplish the specific objectives (and thereby the general objective) stated in the previous section can be logically summarized as a two step investigative process in which a hypothesis is stated and an experiment is designed and carried out to test that hypothesis.

3.1 Definition of Effective Monitoring Scheme

The primary function of an effective monitoring scheme (in which the individual components to be monitored and a specific monitoring mechanism for each are identified) is to ensure that the reactor operating crew has the optimum amount of information available concerning the status of the safety systems when it is needed. Since this optimum is not achieved by providing an equally effective indication of all possible inoperable or bypassed conditions, the ability to match the appropriate monitoring technique to the individual component importance becomes the fundamental requirement. Thus, in judging the effectiveness of a specific monitoring scheme, or in judging the effectiveness of a particular method of developing such a monitoring scheme, the true test is the relative validity of the following hypothesis:

> The ability of the operating crew to efficiently determine the status of a safety related system or component is commensurate with the safety significance of that system or component.

3.2 Evaluation of Existing Monitoring Schemes

In order to achieve the objectives stated in Section 2.0, an experiment was designed and carried out to test the above hypothesis utilizing the existing monitoring schemes of two operating plants (one BWR and one PWR) and a measure of safety significance based on probabilistic risk evaluations of these plants.

By comparing the relative risk significance of the individual components to the effectiveness of the specific mechanism by which their status is made known to the operator (e.g., equipment tags, alarms, oral or written communication, etc.) it is possible to determine whether a correspondence exists between the safety significance of the components and the manner in which their status is made known to the operator (i.e., the hypothesis can be tested). In addition, for those instances where this correspondence does not exist, it can be determined whether there are legitimate considerations concerning actual plant operation which justify a monitoring scheme different from that which is suggested by a probabilistic risk ranking. This provides a basis to judge the ability of a probabilistic risk assessment to effectively incorporate the important and diverse aspects of actual plant operation, and thus provide a useful input to design and/or operational decisions concerning status monitoring.

Thus, the experiment is designed to meet both the specific objectives of identifying potential improvements in existing plant monitoring schemes and assessing the value of a probabilistic risk approach to accomplish this. By achieving these specific objectives, the more general objective of improving the technical basis for decisions related to safety system monitoring can be accomplished. In the following subsections, the details of this experiment and the manner in which it was carried out are presented.

3.2.1 Risk Ranking

The first step in the experiment was to develop a relative ranking of the safety significance of the individual components comprising the systems designed to respond to potential accident conditions. There are numerous ways in which the "importance" of an individual component can be judged. Pertinent questions which relate to this assessment include:

- How often is the component called upon?
- How reliable is the system with this component out of service?

- Are there additional systems which can act as backup?
- What is the reliabililty of these backup systems?
- What are consequences of system failure?

All of these questions suggest that a probabilistic risk model (in which accident sequences are delineated and the overall risk is expressed as a function of the individual component availabilities) would provide a logical basis for assessing component importance.

Qualitatively, the importance of a component can be expressed as the degree to which the likelihood of a serious consequence is increased should that component not be available to perform its designed function. This qualitative definition appears reasonable since the fundamental purpose of the safety systems is to minimize the likelihood of serious consequences. Quantitatively, the probabilistic risk model can be utilized to define importance as the incremental change in risk given that the component is unavailable.

The WASH-1400 risk assessments were selected as the base line models for each plant considered in these evaluations. These models were chosen because: (1) they represent the best available risk analyses of the plants, (2) while certain deficiencies in these models have been identified, the nature of these deficiencies does not seriously inhibit a relevant ranking of risk contributors, (3) the available resources could be more directly focused on achieving the objectives of the analysis if available models were utilized, and (4) the results of the analysis could be presented in a framework familiar to the industry to enhance peer review.

The initial step in utilizing the WASH-1400 models was the selection of the appropriate measure of risk. While many such measures exist, many of them are plant or site specific and entail considerations unrelated to the function of the safety systems (e.g., population distributions and meteorlogical conditions). The primary design objective of the safety systems is to prevent or at least significantly reduce the probability of events which could release radioactivity from the core. In addition, the operator's primary goal in response to an upset condition is to prevent core damage. Accordingly, one appropriate measure of risk can be taken to be the frequency of core melt. This measure allows the calculation of the importance of each component to be based upon the primary goal of both plant design and operator response and therefore provides a measure consistent with the objectives of this analysis. As discussed in the Section 5, Summary and Conclusions, the choice of the particular measure of risk does have some impact on the ranking of component importance. While core melt probability represents the best choice of all measures for the purposes of this analysis for the reasons stated above, this choice does have the effect of reducing the importance of systems primarily designed to mitigate the effects of core melt rather than prevent core melt (e.g. containment ESF's).

For each plant, the overall risk model was represented by a list of the accident sequences along with the fault trees associated with events in these sequences. Of course, not every possible sequence for every event tree in WASH-1400 was included in the baseline model. However, every sequence which contributed at least 1% to total core melt frequency was included. In addition, careful checks were made to ensure that no sequence was excluded which could contribute significantly to a revised core melt probability if one of the subsystems involved were rendered inoperable. Thus, it could be demonstrated that utilizing a less than "complete" list of sequences would not result in overlooking key pieces of equipment whose outage would significantly increase the probability of core melt. The resultant sequences are listed in Tables 4.1 and 4.5. Note that sequences involving each of the basic initiating events identified in WASH-1400 are included in the table.

Given the list of sequences, the process of calculating the component importance was relatively straightforward and involved the following major steps:

1. The baseline core melt frequency, F(Base), was calculated using WASH-1400 point estimate unavailabilities for the various systems and components. These calculations did not assume the unavailability of any individual components.

2. For each component in the engineered safety systems the core melt frequency conditional upon the unavailability of that component [F(COMP)] was calculated subject to the following constraints:

   o The contribution to unavailability in the risk model from maintenance outages which are prohibited by limiting conditions for operation (LCO) were not included.

   o The common mode failure contributions to system unavailability which involve the component taken out of service or any disabled train resulting from the component outage were not included.

   These two constraints can be illustrated by the following example which postulates a two component system: Pump A and Pump B, either of which can provide adequate flow from System C. The limiting conditions for operation (LCO) require that one of these two trains be available at all time during full power operation.

Pump A	Pump B
Hardware Test and Maintenance Common Mode	Hardware Test and Maintenance Common Mode

The baseline model would include contributions to each component's unavailability from hardware faults, test and maintenance outages, and common cause failure events (which fail both pumps). In calculating the probability of system failure given that Pump A is taken out for maintenance, the test and maintenance and common cause contributions to Pump B unavailability should not be included. The condition system failure probability is then simply equal to the probability that hardware faults will cause Pump B to fail to start and run. It should be noted that only those maintenance acts precluded by LCO are deleted from the calculations For example, maintenance on a BWR HPCI pump would preclude any allowable outages in the LPCIS. However, outages of the ESWS would still be permitted, and the test and maintenance contributions for the ESWS would be included in the importance calculations for the HPCI pump.

In a similar manner, the effect of common mode contributions were altered to correctly model their importance when certain components or trains are taken out of service. If there had been a third pump in the above example, the common mode failure of Pump B and the additional pump would have been included (although the probability of this event would presumably be different than the common cause failure of all 3 pumps in the baseline model).

These two constraints are designed to ensure that the risk model accurately reflects the plant condition when components are taken out of service. The actual probability of maintenance outages is significantly decreased when these maintenance outages are prohibited by LCO. While an accurate value for the probability of LCO violation is difficult to calculate, it was considered to be much lower than the baseline risk model probability of maintenance outage (which does not reflect the impact of LCO on equipment outage). Therefore, the baseline risk model probability of maintenance outage in these situations was not included in the unavailability calculations. The significance of most LCO violations can still be assessed by looking at the system (rather than component) importance.

3. For each component, the ratio of F(COMP) to F(BASE) was determined. For example, if taking component A out of service exposes the plant to a risk level twice as high as when component A is not rendered inoperable, the importance of component A will be equal to 2.0.

   The models used to calculate the importance of individual components were also used to calculate the importance of entire systems and individual trains of redundant systems. In fact, the calculation of system or sub-system importance was often an intermediate step in determining individual component importance. Extracting and reporting these calculations of system or sub-system importance was considered to be a valuable step in the analysis because:

   (1) this information can reflect the importance of combinations of components which might be obscured by limiting attention to individual component importance;

   (2) system level importance can be used to assess the safety significance of LCO violations which were explicitly precluded from calculations of the unavailability of individual components.

   (3) the status of systems or sub-systems is often more directly useful to the operator in an emergency situation than information concerning numerous individual components.

In order to illustrate the steps discussed above, an example calculation is presented in Appendix I. This example starts with the baseline risk model and proceeds step-by-step to calculate the importance of the PWR Containment Spray Injection System and one of the pumps in that system.

3.2.2 Evaluation of Monitoring Technique

The next step in the process of testing the hypothesis was to evaluate the relative effectiveness of the existing monitoring technique for each component. In order to accomplish this, visits were made to both of the plants for which the baseline risk assessment had been performed. For each component, the specific mechanism by which the status of that component is made known to the operator was described and discussed with operators and other plant personnel.

The various types of monitoring techniques (e.g., annunciation in control room, equipment tag, indicator light, etc.) were then reviewed with plant operators and with experts on human factors engineering to assess the relative effectiveness of each technique in alerting the operator to the component status. It is important to note that no explicit attempt was made to evaluate the absolute acceptability of any individual monitoring technique (just as no attempt was made to evaluate an acceptable level of risk). The goal was to rank the various techniques by their relative effectiveness so that the comparison with the risk importance ranking could be made.

It should also be noted that a complete detailed human factors evaluation of the control room and plant status monitoring systems was beyond the scope of this analysis and was not considered necessary to achieve the objectives previously stated. More precisely, this analysis was primarily concerned with the effectiveness of the monitoring technique in <u>transmitting</u> information pertaining to component unavailability to the operator. Examining the anticipated task and work load requirements in order to assess the operator's capability to effectively <u>receive</u> such information, while certainly not ignored, was a secondary consideration in the relative ranking of monitoring techniques.

Both the transmission and reception factors are very important in the development of an effective status monitoring scheme. However, as noted in Section 2.0, an underlying assumption of this analysis is that matching a component's importance to the effectiveness of the manner in which its status is transmitted to the operator is a critical first step in ensuring that the operator receives the necessary information to perform his required tasks. Once an effective transmission scheme is developed based on risk importance, a careful work load and task analysis can (and should) be performed to ensure that the operator is capable of receiving and utilizing this transmitted information.

While precise equations were not used to determine the effectiveness of each type of monitoring technique, the following questions illustrate some of the major factors that went into the evaluations:

- How likely is the operator to become aware of and remain aware of the status of the component? (This is the fundamental question).
- What type of display is used in the control room?
- Are there procedures for confirming that the operator received the information?
- Are spurious signals common?
- How often is information updated or checked?
- What are shift change procedures?
- What is the testing procedure for indicators?

In actual practice, many of the components were monitored in a very similar manner to numerous other components. Because of this similarity in technique and the level of inherent uncertainty which would make impractical a differentiation of two techniques which varied only in minor details, a few basic "types" of monitoring were identified and each component was grouped into one of these types. (For example, one "type" of monitoring technique is the use of equipment tags on a console control switch).

The judgments that go into the ranking of the effectiveness of alternative monitoring techniques are necessarily somewhat subjective in nature. However the clear difference in the "types" of techniques coupled with the expertise of the human factor engineers (drawing on human engineering principles which are based on objective quantitative analyses and experiments concerning similar man/machine interface problems) was judged to be sufficient to produce the necessary confidence that the relative ranking was accurate.

3.2.3 Comparison of Risk Ranking and Monitoring Technique Effectiveness

The third major step in the analysis was to compare the results of the first two evaluations described above. That is, a determination was made whether there existed a correspondence between the risk importance of an individual component and the effectiveness of the manner in which it is monitored.

This comparison was undertaken with the recognition that both measures ("risk importance" and "monitoring effectiveness") involve a certain degree of uncertainty. This uncertainty was taken into account with regard to "monitoring effectiveness" by recognizing that it was impossible to differentiate between numerous techniques which differed only on minor details. Therefore, the specific techniques were grouped into a few basic "types" which could then be ranked accordingly to their effectiveness. With regard to risk importance, a realization of the uncertainties inherent to the underlying risk assessment prevented any attempt to differentiate between small differences in calculated importance. This again led to the categorization of importance into a few basic groups which could be designated as "very important", "moderately important", and "not important".

As will be seen the recognition of these uncertainties is and the incorporation of these uncertainties into the comparison process did not prevent the comparison process from producing some valuable results. The uncertainties were not so great to prevent very distinct groupings to be made both in "risk importance" and "monitoring effectiveness". Hence, the determination of whether a "very important" component was also monitored in a "very effective" manner was adequate to achieve the objectives of this analysis.

4.0 RESULTS OF PLANT EVALUATIONS

This section presents the results of the analyses described in Section 3. The PWR evaulations are provided in Section 4.1 and the BWR results are discussed in Section 4.2. For each plant, the risk based importance calculations are presented for the major components of the plant ESF's. The different monitoring techniques employed at the plant are then described as well as other areas such as maintenance and shift turnover procedures, which are an important part of the monitoring scheme. These various mechanisms are then evaluated to assess their relative effectiveness in making the operator aware of the status of a given component. Finally, the evaluations for each plant conclude with a comparison of the importance of a particular component with the effectiveness of its status monitoring technique. Examples where apparent inconsistencies exist between the importance and monitoring effectiveness are discussed and some specific conclusions for each plant are presented.

4.1 PWR ESF Systems Status Monitoring Evaluations

4.1.1 PWR System and Component Importance Results

The accident sequences used to calculate the core melt frequency for the PWR are listed in Table 4.1. These sequences were calculated in WASH-1400[1] to have a nominal core melt frequency ranging from approximately 10^{-5}/yr to 10^{-7}/yr. The important plant systems in these sequences which were evaluated in this study are listed in Table 4.2. The abbreviations used throughout this report are given in parentheses in this listing. Using the methodology described in Section 3.2.1, the importance of each system and its constituent components was calculated. The importance of each system is given in Table 4.2, while the values for the major components in these systems are presented in Table 4.3. As defined previously, the importance is the ratio of the core melt frequency with the indicated component (or system) out of service (i.e. with the component or system unavailability equal to 1.0) to the nominal core melt frequency determined from the WASH-1400 point estimate unavailabilities.

Table 4.1

PWR CORE MELT SEQUENCES

WASH-1400 Accident Sequence Designation	Description
AD	Large LOCA with Failure of Emergency Coolant Injection
AH	Large LOCA with Failure of Emergency Coolant Recirculation
S_1D	Small LOCA with Failure of Emergency Coolant Injection
S_1H	Small LOCA with Failure of Emergency Coolant Recirculation
S_2D	Small-Small LOCA with Failure of Emergency Coolant Injection
S_2H	Small-Small LOCA with Failure of Emergency Coolant Recirculation
S_2C	Small-Small LOCA with Failure of Containment Spray Injection
S_2G	Small-Small LOCA with Failure of Containment Heat Removal
S_2F	Small-Small LOCA with Failure of Containment Spray Recirculation
TML	Transient with Loss of Main Feedwater and Failure of Auxiliary Feedwater.
TKQ	Transient with Failure of Reactor Protection System and Stuck-Open Relief Valve.
TKMQ	Transient with Failure of Reactor Protection System, Loss of Main Feedwater and Stuck-Open Relief Valve.
TMLB'	Loss of Offsite Power in Excess of Three Hours with Failure of Auxiliary Feedwater.

Table 4.2

PWR ESF SYSTEMS IMPORTANCE*

Auxiliary Feedwater System (AFWS)	1800
Low Pressure Recirculation System (LPRS)	33
High Pressure Injection System (HPIS)	30
High Pressure Recirculation System (HPRS)	30
Containment Spray Injection System (CSIS)	24
Containment Spray Recirculation System (CSRS)	24
Containment Heat Removal System (CHRS)	24
Emergency AC Power System (Diesel Generators)	13
Accumulators (ACC)	10
Low Pressure Injection System (LPIS)	3.3
Containment Isolation	1.0**

* Importance is defined as the ratio of the core melt frequency with the indicated system unavailable to the nominal WASH-1400 core melt frequency.

** The selection of core melt frequency as a measure of risk for this study affects this value, as containment integrity has negligable effect on PWR core melt frequency. The use of other measures of risk would show containment isolation to be more important.

Table 4.3

PWR ESF COMPONENT RANKING

Very Important Components

Component (System)	Importance
Condensate Storage Tank (AFWS)	1800
Refueling Water Storage Tank (HPIS,LPIS,CSIS)	32
Manual Valve I-CS-25 (HPIS, LPIS)	32
Boron Injection Tank (HPIS)	30
Manual Valve SI-24 (HPIS)	30
Turbine Driven AFW Pump (AFWS)	16
Manual Valve XV153 (AFWS)	16
Solenoid Operated Valve 102 (AFWS)	16
Accumulators (ACC)	7.2
MOV's 1865A, B, and C (ACC)	7.2
MOV 1890C (LPIS)	3.3
MOV's 1862A and B (LPRS LPIS)	3.1/2.9*
Manual Valves A03 and B03 (LPIS)	2.9
LPIS Pumps (LPIS LPRS)	2.9
MOV's 1890A and B (LPIS)	2.9
MOV's 1860A and B (LPRS)	2.8

Moderately Important Components

Component (System)	Importance
Charging Pump Cooling Water Pumps (HPIS, HPRS)	1.8
Charging Pump Service Water Pumps (HPIS, HPRS)	1.8
Electric Motor Driven AFW Pump (AFWS)	1.7
Manual Valves XV168 and 183 (AFWS)	1.7
MOV's 1867A, B, C, and D (HPIS)	1.7
MOV's 1863A and B (HPRS)	1.6
MOV's 1869A and B (HPRS)	1.6
Boron Injection Tank Heaters (HPIS)	1.6
Diesel Generators (AFWS)	1.5
MOV's 1115B and D (HPIS)	1.5
Boric Acid Piping Trace Heating Circuits (HPIS)	1.4
Manual Valves V4A and B, and V?A and B (CSIS)	1.4
MOV's CS100A and B (CSIS)	1.4
CSIS Pumps (CSIS)	1.4
Spray Header and Nozzle Assemblies (CSIS)	1.4
MOV's 1864A and B (LPIS)	1.2
Manual Valves 1866D, E, and F (HPIS)	1.1
MOV's RS 155A and B (CSRS)	1.1
CSRS Pumps Outside Containment (CSRS)	1.1
MOV's RS 156A and B	1.1
HX's for CSRS Trains O.C.** (CSRS)	1.1
Spray Header and Nozzle Assemblies for CSRS Trains O.C.	1.1
MOV's SW 104 C and D (CHRS)	1.1
MOV's SW 105 C and D (CHRS)	1.1
Manual Valves XV2A20; XV2B20; XV2A21, and XV2B21 (CHRS)	1.1

Unimportant Components (Importance = 1.0)

HPIS
MOV's 1267A, 1269A, 1270A, and 1286A and B, Charging Pumps

HPRS
MOV's 1267B, 1269B, 1270B, 1287A, B, and C, and 1842

CSIS
MOV's CS101A, B, C, and D

CSRS
Motor driven pumps inside containment and HX's and spray assemblies associated with those pump trains.

CHRS
MOV's SW 103A, B, C, and D, SW 104A and B, and SW 105A and B
Manual Valves XV1A20, XV1B20, XV1A21 and XV1B21

AFWS
MOV 102; Manual Valves XV140, 141, 150, 151, 170 and 171
Manual Valves in injection lines leading to main feedwater lines.
Manual Valves in Turbine Drive Steam Supply Lines.

*First value is for LPRS impact, while the second is for LPIS. (See Table 4.4 for explanation).
**O.C. = components associated with CSRS Trains whose pumps are outside containment.

As an example, in Table 4.3 an accumulator has an importance of 7.2. This means that if one of the three accumulators is taken out of service, the frequency of core melt is calculated to increase by a factor of 7.2 during the outage.

Each component in Table 4.3 is listed as it is identified in Appendix II of WASH-1400. In most cases the labels are identical to those used at the plant. Although all components listed on the WASH-1400 system diagrams were considered in the analysis, some have not been listed in the ranking table, to limit the table to a reasonable size. All major components such as motor operated valves (MOV's) and pumps which might have to be taken out of service during operation are included. However, certain components, such as the check valves in HPIS injection lines, are not listed because their importance would be the same as for the manual valves in the same lines (which do appear in the table).

The importance ratios given in Tables 4.2 and 4.3 are expressed in terms of two significant figures for comparison purposes only. They illustrate the type of results and subtle differences which arise using the WASH-1400 data. The use of two significant figures is not intended to imply such a level of precision in the calculations. The uncertainties associated with the WASH-1400 data and analyses are such that for practical purposes a difference in importance, for example between 1.2 and 1.5, can not be convincingly substantiated in most cases.

The components listed in Table 4.3 have been grouped into three broad categories based on the calculated importance ratios. These groups were arbitrarily defined for the sole purpose of demonstrating the methodology. There was no intent to recommend or establish guidelines by quantifying the boundaries of these categories. "Very important" components are those which increase the core melt frequency by more than a factor of two. As can be seen, this category encompasses three orders of magnitude. However, practically the grouping is not nearly this broad as the Condensate Storage Tank is not subject to "outages" in the traditional sense as applied to other components like pumps or valves. "Moderately important" components are those having importance ratios between 1.1 and 2.0. "Insignificant" components are those whose outage has negligible effect on the core melt frequency. Some of the more important components will be discussed briefly to explain the reason for their relative position on the ranking list.

Clearly the most important component in the PWR ESF systems analyzed in this study is the Condensate Storage Tank (CST). This is the only source of water for the AFWS, which, if unavailable, will fail this system. The AFWS is the primary means for heat removal if the power conversion system is unavailable. Hence, it is very important in the transient initiated sequences which comprise a major contribution to the PWR core melt frequency. Because of the relatively high unavailability of the power conversion system in the transient sequences, the unavailability of AFWS, which would result from unavailability of the CST, greatly increases the likelihood for core melt, as shown in Table 4.2. The importance of the CST has of course been recognized, and the plant LCO preclude operation without this source of water.

The HPIS is another very important system, and components whose outage fail this system also rank high on the list in Table 4.3. The Refueling Water Storage Tank (RWST) is the sole source of water for the HPIS, LPIS, and CSIS. Again the LCO require this component be available for operation. However, if the RWST is assumed to be unavailable to supply water to these systems, the LOCA initiated sequences become the dominant contributors to core melt frequency. Manual Valve I-CS-25 is in the single line which supplies water from the RWST to both the HPIS and LPIS. If this valve were closed (as would be the case if the RWST were isolated), no water would be available to these key emergency coolant injection systems. Hence, the importance of this valve is essentially the same as that calculated for the RWST.* Similarly, manual valve SI-24, which is also in the HPIS suction line, but downstream of the LPIS suction line junction, is very important. Closure of this valve disables high pressure injection. Since it does not impact LPIS, its importance is slightly less than that of manual valve I-CS-25. Finally, outage of the Boron Injection Tank (BIT), is assumed to fail the HPIS as water must pass through this component in the normal alignment for coolant injection. LCO preclude isolating this component during operation.

The next grouping of components in the ranking affect the operation of the turbine driven pump of the AFWS. As already noted, the AFWS is the

*The CSIS would still be available as it has separate suction lines from the RWST.

most important of those analyzed in this study. The turbine driven pump is an important part of this system because it provides diversity which permits the AFWS to perform in the event of a loss of electrical power. The pump and its turbine drive, SOV 102 in the turbine steam supply line, and manual valve XV 153 in the pump suction line from the CST are all essential to operation of this leg of the AFWS.

The accumulators and the MOV's in their discharge lines (1865) are also important because response to large and small (S_1) LOCA's require 2 out of 3 accumulators. Since it is assumed that the accumulator injecting into a "broken leg" does not supply water to the core, an outage of an accumulator which feeds an intact loop would result in system failure.

The only other single component in Table 4.3 that can disable a system is MOV 1890C in the LPIS. This valve is in a single line which supplies flow from the LPIS pumps to the cold leg injection header. If this valve is left closed, LPIS is unavailable. Power has been removed from this valve to prevent an inadvertent closure by the operator. However it can still be operated manually. Because of the rather low probability of large LOCA's which require LPIS, MOV 1890 C is not as important as those components discussed previously for the HPIS.

4.1.2 PWR Monitoring Techniques

Several factors contribute to what is defined in Section 1.0 as the status monitoring scheme for a given plant. The integral parts of the scheme are the control room displays for the various systems and components. However, administrative procedures are also very important. Maintenance procedures, if correctly followed, contribute to the information provided to the operator about component availability. Shift change procedures are also an important means of conveying information to the operator. This section describes these and other various facets of the status monitoring system for the PWR analyzed in this study.

4.1.2.1 Control Room Layout

Before describing the individual status monitoring techniques for the ESF systems and components, a brief description of the control room is required to introduce some terminology and provide background to place the different mechanisms in perspective. Both plants considered in this study have two reactors, each operated from the same control room. For the most part, controls and displays pertaining to Unit 1 components are on one side of the room while the second unit is operated on the other side. The controls needed to operate most major components and the ESF systems are located on two consoles both of which face the operator when he is performing routine operations. The inner console immediately in front of the operator is desk shaped. This console contains controls for most all major components which the operator is required to use during routine and emergency conditions. The second, or outer console, is on a vertical wall behind this desk. This wall also contains some controls, principally for valves that are used to isolate components or alter configurations of systems. Also displayed on the outer console are meters which display various measurements (e.g., temperature, pressure, tank water levels, etc.) taken in the plant. At the top of the outer console, just beneath the ceiling, are the annunciator panels. There are 13 panels for each unit, ten panels having 64 windows (8 by 8 array) - not all of which are utilized - and three panels having 40 windows (4 x 10 array). Figure 4.1 shows a typical annunciator panel. The side wall of the control room, perpendicular to the wall which comprises the outer console, contains controls and displays for the boric acid heating systems and the diesel generators.

4.1.2.2 ESF System Level Monitoring

The PWR evaluated in this study has no system level monitoring for the ESF systems listed in Table 4.2. There are no single indicators or annunciators in the control room which explicitly inform the operator of the availability of a given system, or one train of a system (such as "LPIS Train

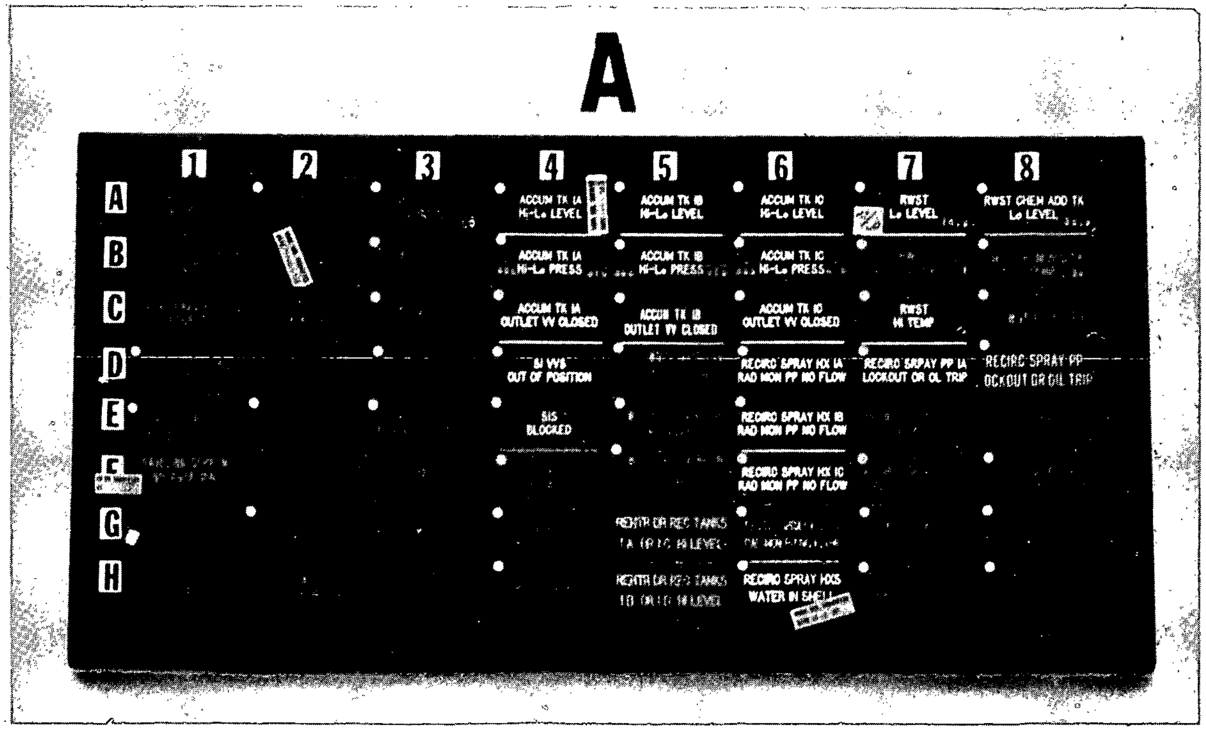

Figure 4.1 PWR Annunciator Panel

A Unavailable"). The operator must infer the system state from the individual component status monitoring displays, as described in Section 4.1.2.3. The systems status is reviewed at shift turnover by completing a checklist (see Section 4.1.2.4), but this only serves to periodically update the operator. This administrative procedure does not inform the operator at the moment the system outage occurs.

4.1.2.3 Component Displays in Control Room

Only a few different techniques are utilized to control and monitor the status of the components listed in Table 4.3. In most cases the method depends on the type of component - for example, a motor operated valve or a pump. Table 4.4 summarizes the different monitoring techniques which were observed and gives examples of ESF system components which are monitored by each method. A comprehensive listing of the monitoring techniques for each component considered in this analysis is provided in Appendix II. A detailed description of the basic methods summarized in this appendix and Table 4.4 is provided in this section. An evaluation of their relative effectiveness is given in Section 4.1.3.

Console Display for MOV Control. The same display technique is used for almost all MOV's in the plant. An example is presented in Figure 4.2.* This display consists of a selector switch which allows the operator to operate the valve remotely from the control room. The small handle can be turned to the left (for close) or to the right (open) from its normal vertical position. A pair of indicator lights are located immediately above each switch. A green light to the upper left of the switch signifies "closed" when illuminated, while the red light on the upper right means "open". Beneath the control switch is a label which identifies the MOV by its alphanumeric identifier, provides an abbreviated description of its function, and identifies the bus which provides power to the motor. This type of control/display is referred to by the phrase "position indicator lights with control switch" in Table 4.4 and Appendix II.

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*Unit 1 of the PWR plant evaluated for this study was not operating when the photographs included in this report were taken. Hence, some of the handle positions and indicator lights illustrated by the figures in this report may not reflect the normal status of that component during operation.

Table 4.4

PWR ESF SYSTEM COMPONENT STATUS MONITORING METHODS

Monitoring Technique *	Example Components
Position Indicator Lights with Control Switch	MOV's 1867 A,B,C,&D: BIT Inlet and Outlet Valves Charging Pump Cooling Water and Service Water Pumps. MOV's 1863 A&B in suction lines for HPRS operation. MOV's 1864 A&B in LPIS Pump Discharge Lines. MOV's CS100 A&B in CSIS Pump Suction Lines. SOV 102 in AFWP Turbine Drive Steam Supply Line.
Position Indicator Lights and Control Switch with Annunciator	Diesel Generators Electrically Driven AFW Pumps CSRS Pumps CSIS Pumps MOV's 1885 A,B,C,&D in LPIS Recirculation Lines MOV's 1865 A,B,&C in Accumulator Discharge Lines Charging Pumps MOV's 1869 A&B in HPRS hot leg injection lines. MOV's 1862 A&B in LPIS Pump Suction Lines. LPIS Pumps
Meter with Annunciator	Accumulators RWST CST
Indicator Lights with Annunciator	Boric Acid Piping Trace Heaters
No Indication in Control Room.	Manual Valves 4A&B in CSIS Pump Suction Lines Manual Valve I-CS-25 in SI Suction Line from RWST Manual Valve SI-24 in HPIS Suction Line from RWST BIT Heaters Turbine Driven AFW Pump

* Detailed descriptions of these techniques with illustrative photographs are given in Section 4.1.2.3.

Figure 4.2 PWR MOV Control Display

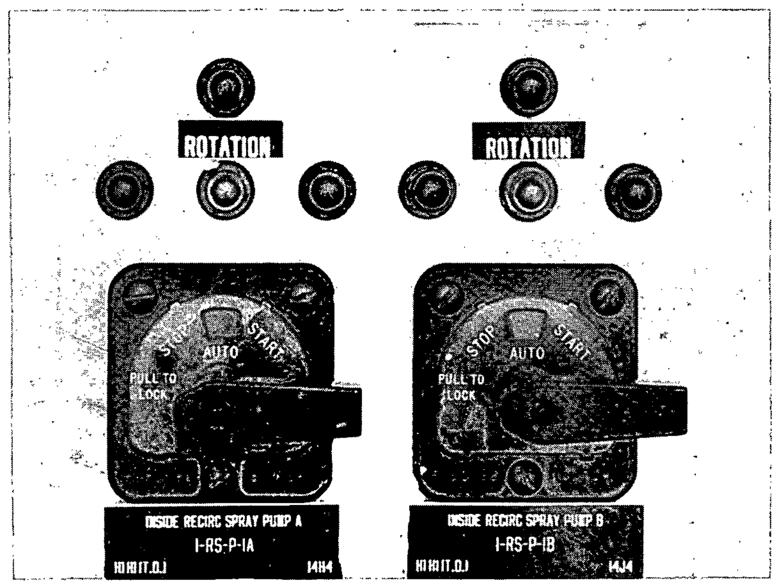


Figure 4.3 PWR Pump Control Display

This basic display was the most frequent for the components of interest in this study. There were a few instances where this MOV control had been altered slightly. One change was the use of a key operated actuation switch, rather than the regular handle. In this setup, the operator must obtain the key from the shift supervisor to change the valve position. In another instance, the basic MOV display design was altered by the operator to prevent accidental operation of MOV's SW 103A, B, C, and D. Brass cylindrical covers have been placed over the switches for each of these four valves. They are not permanently attached and thus can be easily removed if valve operation is required. The indicator lights and label are still visible when these covers are in place.

In the typical MOV display, one of the two indicator lights is always illuminated - depending on the correct valve position required for operation. If both lights are out, either an indicator light bulb has burnt out or the breaker has been racked out thus removing power from the motor for maintenance acitivites.* In this latter case, the control switch may be tagged. In some cases, the power has been permanently removed so that valve operation from the control room is impossible. Hence, the normal appearance of the display is "both lights out." A note affixed to the display reminds the operator that this is the normal condition for that component.

For most valve maintenance activities, it is expected that power would be removed from the motor. Hence, component outage would be reflected by both indicator lights being out and a tag affixed to the display. There are instances where the valve may not be the component under repair, but it is closed to isolate another component for maintenance. In these cases, the display may not always be labeled. However, it is assumed that power would be removed from the MOV to prevent inadvertent opening during maintenance. This would then be reflectd by the absence of indicator lights.

Console Display for Pump Control. Controls for some of the pumps are different than those of the MOV's. Figure 4.3 illustrates the controls for the CSRS pumps inside containment.** Like the MOV display, the typical pump

*Both lights will also be out if an overload on the motor causes power to trip off during operation.
**Table II-1 in Appendix II explains the rotation indicator light.

control has indicator lights, a switch, and label. However, the handle for the selector switch is a large, black 'J-handle'(often referred to as a "pistol-grip" switch). The handle can be manually turned to the left (counterclockwise) to stop pump operation, or to the right to initiate operation. By pulling up on the handle and turning counterclockwise, the pump is locked out and is unavailable for service. In its vertical configuration, the system is in the "auto" or standby condition. A small window, just above the switch handle has a red or green flag which indicates the correct pump operational condition when the switch is in the auto position. The color of this flag should match that of the illuminated indicator light. In addition, the pump display has a third, amber indicator light between the red and green lights. This light indicates an automatic trip of the breaker which provides power to the pump motor. Hence, the amber light only provides information about the breaker during pump operation. It does not provide the operator information about the status of a pump which is in the standby condition.

Pump maintenance outage would be indicated to the operator by the position of the large black handle, the absence of indicator lights (once the breaker is racked out), and a tag on the display. In addition, for all pumps in the ESF systems listed in Table 4.2, an annunciator results when the selector switch is placed in the 'pull to lock' position.

All of the pumps listed in Appendix II had this type of control display except for the charging pump service water pumps and the charging pump cooling water pumps. For these pumps, the display was very similar to the MOV display discussed previously. The selector switch has the same design; however the positions have different meanings. In the vertical position, the pump is off and the green indicator light is lit. Turning the switch to the left (counter clockwise) manually starts the pump (red light). Turning the switch to the right places the control in auto. At this position the green indicator light is illuminated unless an auto start signal is received.

Annunciators. In addition to the displays on the inner and outer consoles, some MOV's and pumps will also generate an alarm if taken out of service. When this component is first taken out of service, an audible as well as visual alert is produced. By acknowledging the annunciator, the audible signal is terminated, but the appropriate window on the annunciator panel remains illuminated until the component is restored to its normal condition for operation. This provides additional notice to the operator of the unavailability of some components. Some annunciators respond to several different conditions in the plant. In this study the most important one is the "SI Valve Out of Position" alarm (in the center of Figure 4.4). This annunciator occurs when the position of any one of 11 MOV's in the HPIS, ACC, or LPIS is altered from its correct standby condition. In order to determine which valve is misaligned, the individual displays on the console must be checked.

Two types of annunciator window designs are used in the plant. The majority of the windows are black with white lettering. However, a few are white with black lettering. These are the "first out" annunciator windows which are actuated with a reactor trip. Beneath each window is a red and a white light bulb. When a trip occurs the first signal received will illuminate the red bulb in the associated window, while the other annunciators (if actuated) will be white. Hence, the operator is aware of which trip setting first occurred during an off-normal transient.

Meters. In addition to the previously discussed status monitoring displays, there are many meters and recorders which provide the measurements of the numerous parameters which are continually monitored throughout the plant. Some of these measurements can also directly or indirectly indicate the status of some systems or components, and thus have been included in Table 4.4 and Appendix II. An example of such a meter is the accumulator water level and pressure meters on the outer console which are shown in Figure 4.5. For the components addressed in this study, meter readings would supplement other mechanisms of status monitoring, and are not the sole source of information.

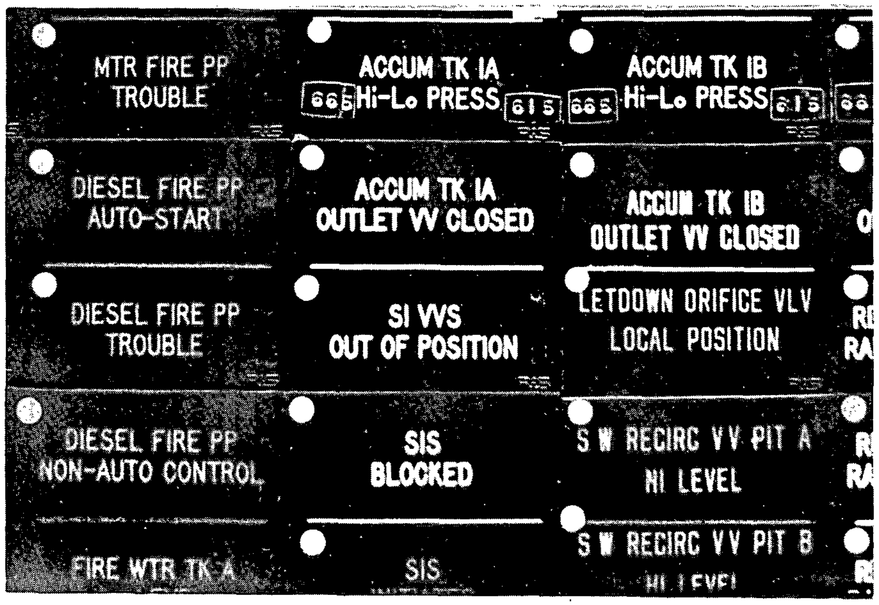


Figure 4.4 PWR Annunciator Window. SI VVS OUT OF POSITION" Window (center) Alerts Operator to Incorrect Position of Certain Valves in the Safety Injection Systems.

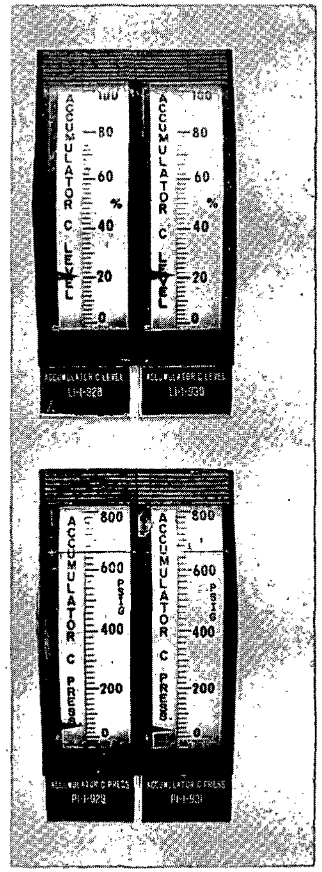


Figure 4.5 PWR Accumulator Level and Pressure Meters

In the case of the accumulator pressure and level, annunciators are provided to alert the operator if these parameters approach potentially unsafe conditions.

Indicator Lights. A totally different status monitoring system is used for the heaters which maintain temperature in the boric acid system containers and piping.* Of primary interest in this study are the heaters for the components supplying boric acid to the HPIS. The status of the various heat tracing circuits is monitored by a panel of red lights (see Figure 4.6) which are illuminated at a very low level under normal conditions. When a fault in the heat tracing occurs, these lights brighten. Each light in the control room display represents several circuits - which are individually monitored in a single cabinet in the auxiliary building. Some cabinets contain circuits which are both safety and non-safety related. Hence, when a fault is indicated in the control room, the operator only knows which cabinet contains the faulty circuit and not the specific heat tracing circuit that has failed. Thus it is not possible to determine if the heat tracing system failure could impact the HPIS from the control room.

A poor design of the boric acid heat tracing system leads to frequent indication of faults in this system. Hence, the operators virtually ignore these indicator lights as usually one or more is always brightly illuminated. Instead of relying on the control room display, a local check of the individual cabinets is performed once each shift. If there are outages in any safety related lines (HPIS), they must be repaired in 24 hours.

4.1.2.4 Maintenance and Administrative Procedures

Maintenance procedures play a very important role in informing the operator of component outages. This awareness originates primarily through the placement of tags and labels on the control room displays when a component is unavailable. However, log books, check lists, and shift turnover

*Because of the unreliability of this monitoring system, a new system was being designed at the time this investigation was performed.

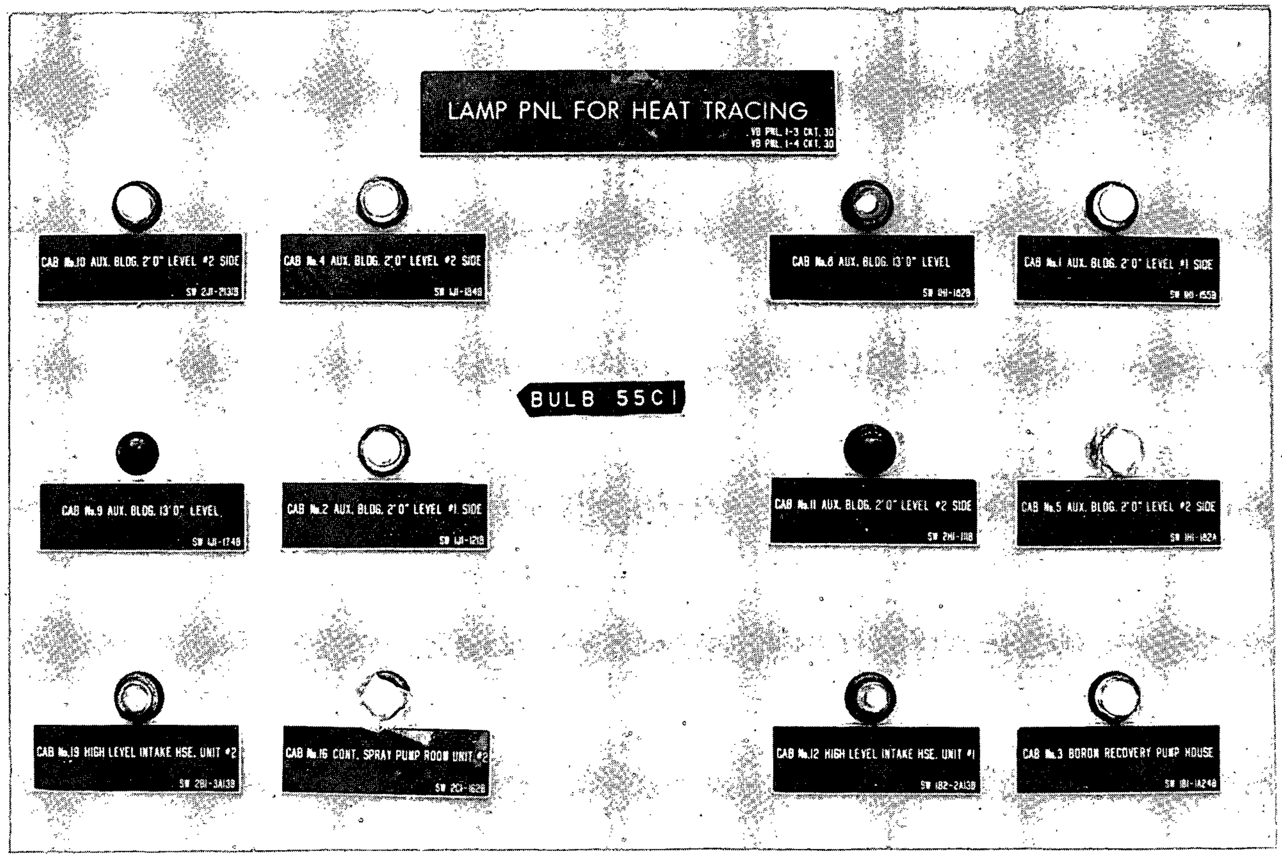


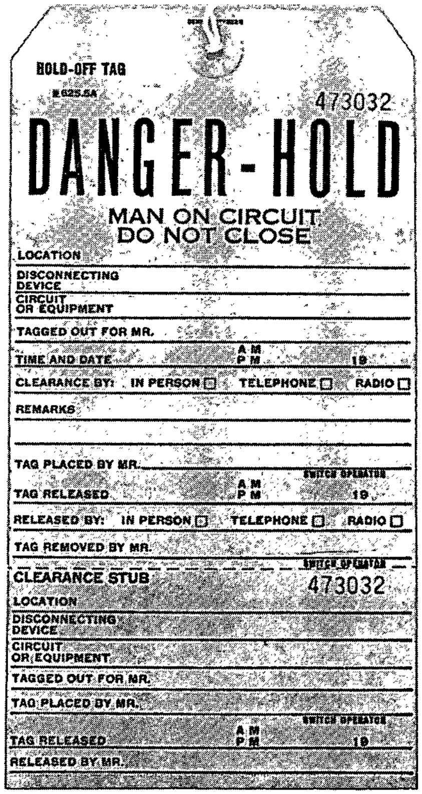
Figure 4.6 PWR Boric Acid Piping Heat Tracing System Monitoring Display

procedures are also important in conveying this information to the plant operators. These subjects will be described in this section for the PWR plant which was evaluated. The effectiveness of these procedures in the overall monitoring scheme is addressed in Section 4.1.3.

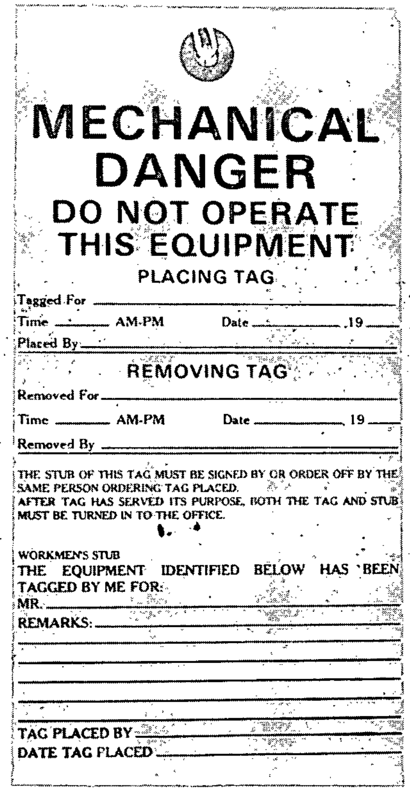
Numerous site procedures have been prepared to direct most plant maintenance activities. These contain more detail than is necessary for assessing the effectiveness of the ESF status monitoring. Hence, only a brief summary of the usual routine is presented highlighting the areas of interest. Prior to performing any work, a work request form is completed which describes the problem and indicates the affected components. The request is routed to the appropriate department to ensure identification of tech. spec. time limitations, other limiting or restrictive conditions, and any special instructions. The specific components are then tagged by a reactor operator. Yellow tags are used for mechanical components, red tags for electrical components, and blue tags for any special instructions. Examples of these tags are shown in Figure 4.7.

Tags are placed on all components impacted by the maintenance activity. For example, if a pump were taken out of service, the manual and motor operated valves in the suction and discharge lines and the vent and drain valves would all be tagged both electrically and mechanically, as well as the breaker(s) which is racked out. When components of ESF systems are involved, a verification of the tag-out operation is independently performed by another person.

In addition to tagging the specific components in the plant, tags or notes may be placed in the control room on the switches which are used to operate the various components. Several types of tags were observed in the control room during the plant visit. Small flags, (pins with red or yellow triangles of paper attached) are inserted into the J-handle control switches to indicate pump maintenance outages. Figure 4.8 illustrates this form of display tagging. Labeling of MOV displays did not appear to be uniform.



a) Red Tag for Electrical Components



b) Yellow Tag for Mechanical Components

Figure 4.7 Sample Tags Used to Identify PWR Component Outage in Plant (Not Used in Control Room)

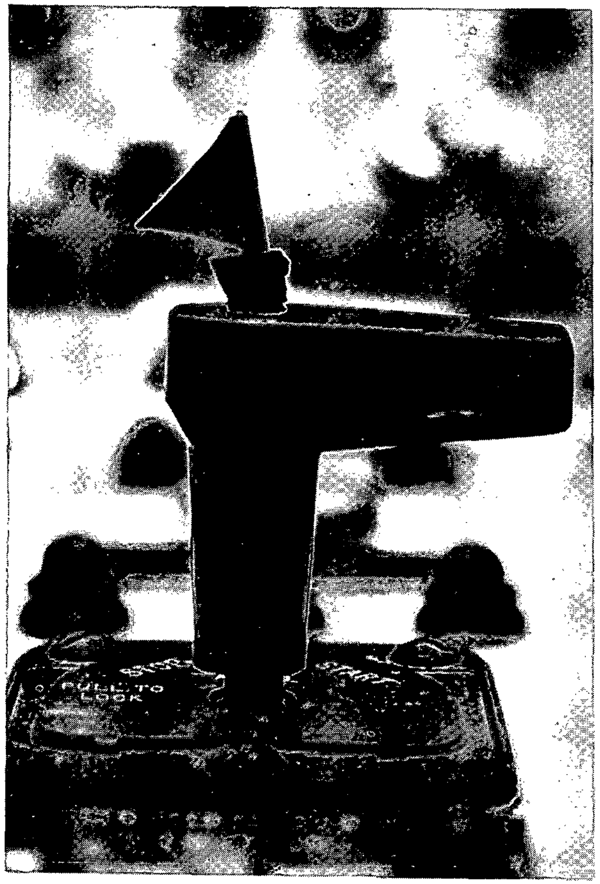


Figure 4.8 Side View of Flag Used to Denote Outage of Certain Pumps in PWR

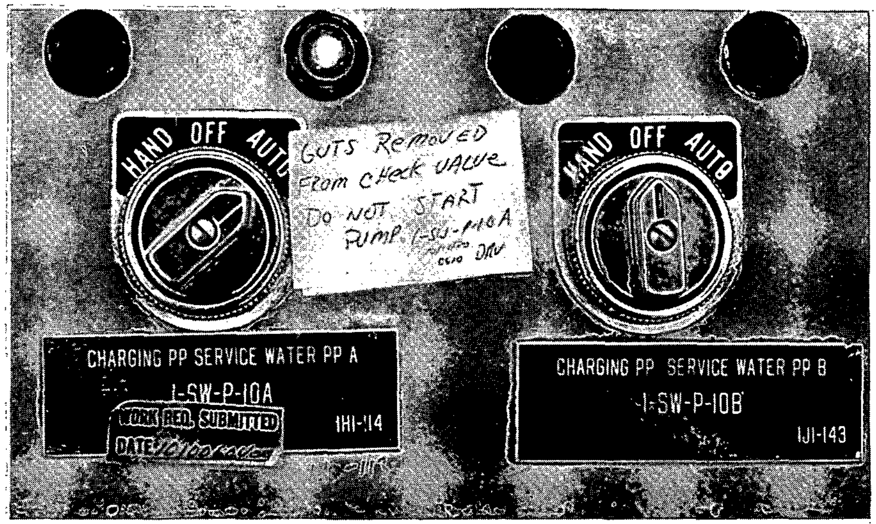


Figure 4.9 Example of Label Used to Alert Operator of Component Outage in PWR

Several different practices were observed, including the use of adhesive stickers and notes written on pieces of paper which were taped to the display. In addition to indicating component outages, such labels were occasionally used to provide other information regarding components or their displays to the operator. A typical example of the labels used on the control displays is shown in Figure 4.9. Several labels are also visible in the photograph of the annunciator panel in Figure 4.1.

Interviews with plant operating personnel indicated that labeling of control room displays was not performed consistently. That is, some displays may or may not be tagged, while others would always be labeled. Those displays for which tagging might not be performed were usually components whose status might be indicated by other, less direct means. For example, a MOV without electrical power would have both lights out.* Another instance where a display might not be tagged is when a MOV is out of service because it is being used to isolate a pump which is under repair. The pump control would be tagged, but the MOV control might not. In this instance, the operator knows that if the pump is out of service, so are all the valves which are used to isolate it. Discussions with plant operators indicated that the operators rely primarily on the indicator lights and not tags or labels on the console to monitor component status. In cases where it was uncertain if a display would be tagged, the phrase "control switch <u>may</u> be tagged" is used in Appendix II. For controls which are always to be tagged, the phrase "<u>should</u> be tagged" was utilized.

Following completion of the maintenance and inspection of the work, the bottom portion of the tag on the component is signed off, and delivered to the shift supervisor. A reactor operator is then directed to remove the tags on all affected components per the applicable procedures. Tags and labels in the control room are removed last and are not removed until all verification testing (if required) has been completed and the system is realigned for normal operation.

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* This can also be interpreted as a burned out bulb.

Shift change procedures also play a very important role in determining the effectiveness of ESF status monitoring. An effective briefing prior to shift turnover can increase the efficiency of operator response in the event of an off-normal situation. Ideally, these procedures should give the operator coming on duty a complete understanding of the state of the plant and its systems. They also provide an opportunity to inform the new operator of recent outages which have occurred since he last worked and update him as to the status of ongoing outages.

Shift change procedures were observed at the PWR evaluated in this study. At the conclusion of each shift, the operator on the departing shift and the on-coming operator review the status of all components displayed on the inner and outer consoles. This walkdown is mostly a routine visual check that the components are in their proper states as defined by the indicator lights. When a component or display has been recently taken out of service, or there is some other problem or information pertaining to a particular component which the operator believes is important, an explanation is given. Otherwise the panel walkdown is a brief visual scan. In addition to the walkdown, a check list is completed at shift turn-over to verify that all switches and controls on safety related systems are in their proper position. This check list appears to be a formality that documents the information transmitted on the walkdown. The check list (see Figure 4.10) contains a list of all the controls related to the ESF systems. It notes their required position and provides a space to record any discrepancies which are observed. At the conclusion of the checklist, space is provided to record components out of position or service, and the reason for this condition.

The shift supervisors also complete a check list at shift turn-over. This list, called the "Minimum Equipment List for Criticality and Power Operation," verifies that the Limiting Conditions for Operation (LCO) are not violated. A sample page of this checklist is shown in Figure 4.11. For components whose outage is not restricted by the LCO, there is no formal mechanism which would preclude outage of a component for an unnecessarily long

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ATTACHMENT 1

3.0 PROCEDURE

	> 200°F	> 350°F	CRITICAL	DISCREPANCY
EEC				
#1 Auto/Exercise	A	A	A	
#2 Auto/Exercise	A	A	A	
#3 Auto/Exercise	A	A	A	
LHSI Pumps				
A Auto/PTL	PTL	A	A	
B Auto/PTL	PTL	A	A	
LHSI RWST Suction				
MOV-( )-862A Open/Closed	O	O	O	
MOV-( )-862B Open/Closed	O	O	O	
LHSI Pump Recirc				
MOV-( )885A Open/Closed	O	O	O	
MOV-( )885B Open/Closed	O	O	O	
MOV-( )885C Open/Closed	O	O	O	
MOV-( )885D Open/Closed	O	O	O	
LHSI Pump Disch.				
MOV-( )864A Open/Closed	O	O	O	
MOV-( )864B Open/Closed	O	O	O	
BIT Recirc				
TV-( )884A Open/Closed	O	O	O	
TV-( )884B Open/Closed	O	O	O	
TV-( )884C Open/Closed	O	O	O	
OSRS Pumps				
A Auto/PTL	PTL	A	A	
B Auto/PTL	PTL	A	A	
OSRS PP, Disch.				
MOV-RS-( )56A Open/Closed	O	O	O	
MOV-RS-( )56B Open/Closed	O	O	O	
OSRS PP. Suction				
MOV-RS-( )55A Open/Closed	O	O	O	
MOV-RS-( )55B Open/Closed	O	O	O	

Figure 4.10. Sample Page of Operator's Shift Turnover Checklist for PWR.

EQUIPMENT	MINIMUM FOR STARTUP	NO. IN SERVICE			MINIMUM FOR POWER OPERATION	TIME ALLOWED BEFORE HSD/CSD	TECH. SPEC REFERENCE
		M	D	S			
Refueling Water Storage Tank (2000 ppm C_B)	385,200 gal. prior to > 350° 450 psig				385,200 Gal.	Attempt to correct while proceeding to < 350°F, 450 psig	3.4A.3 3.3A.1
RWST Chemical Addition Tank (13% NAOH)	Prior to > 350° 450 psig, 3,360 Gal.				3,360 Gal.	Attempt to correct while proceeding to < 350°F, 450 psig	3.4A.4
Containment Spray Subsystem	2 prior to > 350°, 450 psig				1	24 hrs/48 hrs	3.4A.1 3.4B.1
Recirc. Spray Subsystem	4 prior to > 350°, 450 psig				1 outside RS inoperable	24 hrs/48 hrs	3.4A.2 3.4B.2
					1 inside RS inoperable	72 hrs/48 hrs	3.4B.3
RHR Pumps	2				1	14 days/N/A	3.5A.1 3.5B.1
Rod Position Indication	ALL				1/group, 2/bank inoperable	Attempt to correct while proceeding to HSD	3.12E.2
Control Rods	ALL				Not more than 1 inoperable	With 1 inoperable, refer to T.S. with > 1, inoperable to HSD	3.12A.2 3.12C.2
Power Range Instrumentation	3				3	If not met, maintain HSD	3.7A
Intermediate Range Instrumentation	1				No min. while in the pwr. rge	If not met, maintain HSD	3.7A

UNIT NO. 1

MINIMUM EQUIPMENT LIST

PAGE 1 of 6

Figure 4.11 Sample Page of the PWR "Minimum Equipment List for Criticality and Power Operation" period (and thus expose the plant to some increase in risk for this time). For example, it is possible that a valve could be properly tagged and duly noted by the operator, but the maintenance is deferred for a lengthy period, or perhaps forgotten if the work permit were misplaced. Some formal procedure to periodically check the status of maintenance on these type of components might minimize the potential for such occurrences.

An additional local check of certain manual valves is performed weekly to verify their correct position. Hence, some valves whose status is not monitored in the control room are periodically monitored. Although this does not directly inform the operator about the status of these valves, it does give some assurance that a valve will not be left in an incorrect position for an extended period. Finally, as noted in Section 4.1.2.3, a local check of the boron heat tracing circuits is completed every shift.

4.1.3 Human Factors Evaluation of Status Monitoring Approach

During the plant visit to acquire information on how each component was monitored, a review of the relative effectiveness of each monitoring technique discussed in Sections 4.1.2.2 and 4.1.2.3 was performed. This evaluation was performed only to compare the different monitoring techniques and not make judgments on the overall acceptability of the system. These assessments were based primarily on the observations of a human factors specialist who was part of the team which visited the plants. It should be emphasized that a detailed human factors investigation of the control room design is beyond the scope of this work, and is not considered necessary to provide the qualitative observations required for this investigation.

As noted in Section 4.1.2.2, there is no system level status monitoring in the plant control room. The operator must determine system status from the individual component displays. For experienced operators who possess a good understanding of the plant design, this assessment would be simple and straightforward in most cases. However, this approach may not give correct information in all cases as there are some components which are not monitored in the control room whose outage, or incorrect configuration could disable a system. Thus the control displays could indicate that the system was available, while in fact it would be disabled or degraded. Hence, this method is much less effective than a single indication of system availability which is given high priority in the hierarchy of control room status monitoring techniques. In the remainder of this section, each of the monitoring techniques observed for the ESF system components is evaluated separately in order of decreasing relative effectiveness. Following these assessments are some general observations pertaining to various aspects of the status monitoring system.

Tagged Console Display with Annunciator. This technique is used for several MOV's and pumps in the systems examined. A description of the specific displays used for pumps and MOV's is given in Section 4.1.2.3. This monitoring technique is typified by the following indication of component outage:

- Illuminated annunciator window which may have an adhesive label.
- Tag on the control switch on the console display.

In addition, the following would also indicate a component outage in most cases:

- position indicator lights above control switch (would be out if power is removed)
- switch handle position (e.g. "pull-to-lock" position for some pumps).

Some examples of components monitored in this manner are MOV's 1865A, B, and C in the accumulator discharge lines, MOV's 1862A and B in LPIS pump suction lines, and the diesel generators. In addition, all pumps in the ESF systems considered in this evaluation are monitored in this manner, as positioning the control switch in the "pull-to-lock" position will produce an annunciator.

This monitoring and tagging scheme is the most effective in the plant, primarily because of the several different mechanisms which convey information to the operator. Even though the audible alarm when the annunciator is initially actuated is no longer present, the illuminated window should improve operator awareness of a component outage - particularly if the window is also tagged. The use of tags on control switches, or labels on annunciators supplements the position indicator lights and annunciator lights. They are generally more visible and often provide some explanation as to the reason for the outage. In addition, such labels can explain outages which may not be reflected by the indicator lights alone (i.e., a component may be in its correct position and so indicated by the display, but unable to change its position if required for system response). The effectiveness of tags on the control switches might be enhanced if more uniform labels were used in the subject plant. Often the notes are scraps of paper taped to the display and might be confused with other informational messages which are affixed to the console. In this regard, the flags utilized on the J-handle pump controls (Figure 4.8) are much more effective than notes taped to the console. The use of a uniformly shaped and colored label or tag for the control switches should improve operator awareness of component outage.

Annunciator and Meter Reading. This type of monitoring is used only for the RWST and CST, which are never taken out of service,* and the accumulators which are limited to a four hour outage by the LCO. The meters are on the outer console and thus difficult to read from behind the inner console. Presumably these would be labeled if a tank or accumulator was out for maintenance. In the case of the CST or RWST, an annunciator window would be illuminated only if a high or low level trip were reached. Hence, if the tank were drained, it is expected that an annunciator window would be lit. Again, presumably a label would be placed on the annunciator window. Furthermore, prior to startup, the operator must complete a check list which includes verifying CST and RWST level, as well as clear the annunciator panel. Hence, in the unlikely event that these tanks are not refilled, this condition is likely to be discovered during pre-startup checkout.

*In practice, one tank could be taken out of service due to the presence of a backup CST, as well as the capability to use the CST or RWST of the other unit at the plant.

Accumulator outages would likely be annunciated by hi/low pressure and level alarms. In addition, the 1865 MOV's in the discharge lines would probably be closed. This would actuate the "SI Valve Out of Position" (Figure 4.4) annunciator and the MOV display would be tagged. If this occurs, as expected, the accumulator outage monitoring effectiveness is greatly enhanced. Furthermore, the accumulators appear on the "Minimum Equipment List for Criticality and Power Operation " checklist which must be completed at each shift change.

Tagged Console Display. This technique is the same as the first method listed in this section except that there is no annunciator to alert the operator to component unavail-ability. Hence, it is somewhat less effective. This technique is used for many MOV's. Examples of components monitored in this manner are MOV 102 and SOV 102 in the steam lines for the turbine drive of the turbine driven AFW pump; and the BIT inlet valves, MOV's 1867A and B, which admit flow from the charging pumps to the BIT during HPIS operation.

Console Display. As noted in Section 4.1.2.4, some control displays may not be tagged when the component is out for maintenance. There are other instances where valves may be used to isolate another component (e.g. pump) which is being serviced and the valve control display is not labeled. In these cases, the only display of component status immediately available to the operator are the position indicator lights. If these indicate an abnormal position or are out (power removed), then the operator may be aware that the valve is out of service.

Because of the absence of a visible tag on the console display, this monitoring technique is considered less effective than a tagged display. This is because indicator lights may blend in with the panel noise and could be overlooked. Furthermore there is always the potential for misinterpretation when the indicator bulbs burn out. Finally, the displays which fall into this category are all located on the outer console (wall behind the bench board or inner console) and therefore are less easily and less frequently observed from the operator's normal work station behind the inner console.

In the case noted above, where a valve is used to isolate another component, presumably that component would be tagged, and an experienced operator would recognize that the isolation valve would also be unavailable even though they are not tagged. However, the absence of a tag on the control room display could increase the likelihood that this valve is not returned to its proper condition for operation after maintenance has been completed.* Based on the usual procedures for returning a component to service (See Section 4.1.2.4), the presence of a label on the control room display would serve as an additional reminder, if the valve were inadvertently left in the wrong position.

<u>Boron Heat Tracing Monitoring System</u>. As discussed is Section 4.1.2.3, this system is very ineffective. Because of the frequent heat tracing faults, this system is virtually ignored by the operators. Furthermore, a human factors evaluation of this technique indicates that it is much less effective than the others used in the plant. As noted in Section 4.1.2.1, the display shown in Figure 4.6 is located on a separate panel on the side of the control room. This location is relatively ineffective for purposes of status monitoring. It is not within the operator's view when performing routine duties. Furthermore its distance from the normal work station is such that the indication of a fault is difficult to recognize, even when looking directly at the panel. This is due to the nature of the monitoring technique in which a small red light brightens when a fault occurs. This increased intensity over the normal illumination of the bulb can be difficult to discern from a distance - particularly since the bulb intensity levels for the unfaulted condition are not consistent.

<u>No Control Room Indication</u>. There are some components in the ESF systems that have no status indication in the control room. These are generally manual valves or other passive components. Presumably the status of these components is not displayed because the operator has no remote control capability. Hence, they were not considered necessary in the design of the reactor control

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* In cases where maintenance involves ESF components which must be tested before returning to service, such errors would be detected during the verification testing. However, it is also possible that testing the system with a valve in the incorrect position could damage the system and thus extend the outage. Thus a tag on the control room display would reduce the likelihood of this occurrence.

room. As would be expected this is the least effective means of status monitoring. For these components, the only information on component status or valve positions would be from entries in the log book or in some cases a note might be affixed to the console to alert the operator of the condition. A group of manual valves are checked locally on a weekly basis. Hence the operator has reasonable assurance that these valves are in their correct positions and will not be inadvertently left in an incorrect position for an extended period. However, whether or not this check list is routinely reviewed by the operator is uncertain.

General Observations. The following are some general observations pertaining to control room disign which are relative to the effectiveness of the existing status monitoring system.

Most of the annunciator windows are black with white lettering. Only the few "first out" windows are white with black lettering. The black background makes the illuminated windows difficult to locate and read from the operator's normal work station behind the inner consol. A design with black lettering on a white background would be much more effective. Another factor which can detract from the effectiveness of the illuminated annuciator window for status monitoirng is the background 'noise' from other windows which are continually illuminated. As an example, recent more stringent operating procedures require the RWST to be filled above the high level annunciator set point. Hence, this window is always lit. Situations such as this contribute to a significant amount of background noise on the annunciator panel. This interference decreases the effectiveness of those annunciators which display important information to the operator.

Another aspect of the annunciator panel design which detracts from the effectiveness of this status monitoring technique is the lack of specificity for certain annunciators. In some instances, one annunciator is used to represent several off normal conditions. One such example is the "SI VVS OUT OF POSITION" annunciator illustrated in Figure 4.4. When this alarm occurs, the operator must check the individual console displays to determine which of 11 MOV's is misaligned.

As noted earlier, one control room is used for both units at the plant. While the control room design is segregated, the same audible sound is used for the annunciators for each unit. From some locations in the control room it is difficult to determine wheter an alarm originates from the Unit 1 or Unit 2 annunciator boards.

There is not indication on the panel as to the correct valve position when the valve is in its standby condition. Since some valves are open and others must be colsed, there is a mixture of red and green lights which are illuminated. The operator must know the correct valve positions (as would be expected for an experienced operator), or else consult the shift change check list or operating procedures to verify correct valve position. This type of display is less effective than the use of a uniform color ("green board" approach) to represent proper system alignment.* As noted previously, the operators rely on the display indicator lights to give component status information. Generally when

* Although the uniform color approach may be more effective for status monitoring, it could cause some difficulties when performing tests and other routine operations. Indicator light colors no longer correspond to a specific component state. Hence, a green light may mean valve open in some cases and closed in others. This inconsistency could be a source of confusion for operators when performing routine operations.

a component is out of service, both indicator lights will be out. Hence unavailability is indicated by the absence of signal. A more effective method to enhance operator awareness would be the use of tags to "highlight" the condition. The use of tags was found to be inconsistent. The current method of reliance on indicator lights is also a potential cause of confusion as burned out bulbs could be misleading. A "press to test" capability would be an effective way to identify failed bulbs. Currently the operator could mistake a failed bulb for a racked out breaker (unless the display is tagged).

In addition to the combination of display design and tagging, the relative location of the individual displays on the consoles can influence the monitoring effectiveness. Thus even though the monitoring technique for two components may be the same, the placement on the control panel can make a difference in the effectiveness of transmitting information to the operator. Priorities can be established by location as well as display design. For the components evaluated in this study, the only distinct differentiation in this regard is the placement of certain, less frequently operated valve controls on the outer console rather than directly in front of the operator on the inner console.

The controls and displays for the different ESF systems are generally grouped together on the console, but the boundaries are not defined. For example, there are no demarcation lines separating the controls for two systems which are adjacent on the console. For the HPIS, the charging pump controls are located with the volume control system component displays, rather than the HPIS component displays. This may not be the most effective for HPIS operation and status monitoring display, but it is definitely more efficient for normal operation which requires charging pump operation for volume control.

4.1.4 Comparison of Monitoring Effectiveness and Importance

The final step in the ESF status monitoring system evaluation was a comparison of the effectiveness of the monitoring technique utilized for each component with its importance as presented in Table 4.2 and 4.3. It can then be determined if there is a correspondence between the risk significance of the component and the effectiveness of the manner in which it is monitored, relative to other components. It is important to reemphasize that only the relative effectiveness of the monitoring techniques has been determined in Section 4.1.3. No judgments have been made as to the acceptability of any one approach. Even though one technique is relatively less effective than another method, does not imply that it is ineffective for status monitoring. The following discussion presents the results of this comparison. Particular attention is given to those systems and components where there is an apparent inconsistency between the monitoring approach and its importance.

One aspect of the status monitoring system design which leads to the greatest inconsistencies is the lack of system level monitoring in the control room. Currently, the operator must determine the system status from the individual component information. As noted in Section 4.1.3, this is a much less efficient and less expedient method than using a single, effective indication of system status. Although knowledge of the availabililty of the components comprising a given system is often very important information, the most important information required by the operator is whether or not the system will perform its intended function if its use is required.

An examination of the "very important" components in Table 4.3 shows that many are not monitored in the most effective manner. In fact all of the manual valves and MOV's 1890A, B, and C in the LPIS are not monitored at all in the control room. The operator has no knowledge of their current position, and, unless an entry has been made in the log book or the shift turnover checklist, there is no indication of outage for maintenance.

In the case of the manual valves, their primary purpose is to isolate other components (generally pumps) in their respective systems.* They should always be open at other times and are not required to change position should system operation be initiated. Hence, from the viewpoint of the

*In some cases, the LCO preclude closure of these valves during operation, and thus they are only closed for maintenance purposes at plant shutdown.

control room designer, there is no need for remote control capability, and thus no reason for adding an additional display to an already crowded control room. These valves must be open during operation (when not isolating a component), and given that there is a periodic check of the valve position, it is considered that the operator inherently knows the status of these valves. While this approach is understandable, it does not provide a continuous indication to the operator of a valve that is inadvertently left in the closed position after maintenance* or is mistakenly closed during operation. These situations are likely to be recognized at the local inspection, but there is some period of time during which the operator has no knowledge of this condition and there is no means to bring it to his attention.

The 1890 MOV's in the LPIS have displays on the inner console, similar to the other MOV's as described in Section 4.1.2.3 (1890 A and B are key activated). However, power has been removed from these valves, hence the indicator lights are out. The operator has no way of knowing the current position of these valves. These valves do not appear in the checklist, for valves which are inspected locally so it is uncertain how frequent their position is verified. Valve 1890C is tested quarterly as part of the in-service insrection program. It is also located near similar valves in the plant, although it is tagged to minimize the possibility of accidental closure. Since closure of 1890C disables the LPIS, it is assumed that no activities which require extended period of valve closure are permitted during operation. Valves 1890A and B are utilized for LPIS hot leg injection. However, they are normally closed (as cold leg injection is required for initial period after a large break), and can only be opened after power is restored. In order to open these from the control room (after restoration of power) the operator must obtain a key from the shift supervisor to operate the selector switch. It is uncertain if any maintenance activity would leave these valves in the open position and thus contribute to the risk by increasing the LPIS unavailability. However, there is the possibility that they might be left open following testing.

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*In many instances, testing of a system is performed immediately after maintenance, and thus valve closure would be detected.

As noted in Section 4.1.3, the LCO preclude operation without the CST and the RWST. Thus, although they are the most important components in the plant, they would certainly not be taken out-of-service intentionally during operation. If they were out-of-service during shutdown, the operator would be alerted to this condition by the annunciator board (which must be cleared before start-up), and by the completion of the "Minimum Equipment List for Criticality and Power Operation" (if this list is completed carefully as required by procedures). A more likely cause of unavailability for these water sources is the closure of the manual valves in the ESF pump suction lines.* In these instances, the tanks may be indicated as ready by the level measurements (and hence no annunciator lights on), but the flow can not reach the respective systems due to valve closure. As noted previously, none of these manual valves are monitored in the control room.

The accumulators are analagous to the CST and RWST in that annunciators and meters are used to monitor availability. However, unlike these components, the valves in the discharge lines are well monitored, (1865 A, B, and C) would presumably be closed during accumulator outage. Closure of these valves would also trigger another annunciator as well as the indication from the MOV console display. Thus for most accumulator outages, the component status monitoring is the most effective in the plant.

The Boron Injection Tank (BIT) is another component required for operation. It also appears on the pre-startup check list. Although the status of this tank is not directly monitored, if it were out-of-service the inlet and outlet MOV's (1867A, B, C, and D) would almost certainly be closed and their displays tagged. Furthermore, annunciators which monitor tank temperature would likely be illuminated. This combination is determined to be the most effective type of monitoring technique in the plant.

Another component which is determined to be very risk significant is the turbine driven auxiliary feedwater pump. There are no displays in the control room which give the status of this component. Should the turbine

*All of these manual valves appear in the "very important" category of Table 4.3, except the two valves in the motor driven AFW pump suction lines (valves XV168 and XV183). These valves have an importance of 1.8, and thus just beneath the cut-off selected for this category.

drive or the pump be out for maintenance, the shift turnover checklist would remind the operator of this condition. On the control panels, the only indication would be an indirect one. If the turbine driven auxiliary feedwater pump were out for maintenance, both MOV 102 and SOV 102 (which admit steam to the turbine) would be closed and electric power removed from these valves. Thus, the indicator lights for these valves would both be out. From this, the operator can deduce that the turbine driven pump is unavailable. It is unlikely that the valve displays would be labeled to indicate the specific reason for the valve closures. Thus the status of a very important component is monitored ineffectively compared to most other components in the plant.

Having addressed most of the components in the "very important" category, it is also instructive to examine the other extreme. Of particular interest are those components whose outage has essentially no impact on risk, but yet are monitored very effectively relative to other components. There are several instances of this condition in the control room. One example is MOV 102 in the steam supply line to the turbine driven auxiliary feedwater pump. Valve outage would be indicated by the position of the control switch on the inner console, indicator lights (both out), and a tag on the control switch handle. However, the risk based importance calculations show that the unavailability of this valve has no significant effect on the core melt frequency. Here again, it is important to note that the current monitoring scheme was based on other considerations in addition to safety. The control room designer was obviously striving for simplicity and uniformity using identical MOV control displays. Thus, the status of many MOV's is monitored in an identical manner, irrespective of their importance.

4.2 BWR ESF Systems Status Monitoring Evaluations

4.2.1 BWR System and Component Importance Results

The accident sequences used to calculate the core melt frequency for the BWR are listed in Table 4.5. These sequences were calculated in WASH-

Table 4.5

BWR CORE MELT SEQUENCES

WASH-1400 Accident Sequence Designation	Description
AE	Large LOCA with Failure of Emergency Coolant Injection
AJ	Large LOCA with Failure of High Pressure Service Water
AI	Large LOCA with Failure of Low Pressure Coolant Recirculation
AHI	Large LOCA with Failure of Core Spray Recirculation System and subsequently Low Pressure Coolant Recirculation.
S_1E	Small LOCA with Failure of Emergency Coolant Injection
S_1J	Small LOCA with Failure of High Pressure Service Water
S_1I	Small LOCA with Failure of Low Pressure Coolant Recirculation
S_1HI	Small LOCA with Failure of Core Spray Recirculation System and subsequently Low Pressure Coolant Recirculation.
S_2E	Small-Small LOCA with Failure of Emergency Coolant Injection
S_2J	Small-Small LOCA with Failure of High Pressure Service Water
S_2I	Small-Small LOCA with Failure of Low Pressure Coolant Recirculation
S_2HI	Small-Small LOCA with Failure of Core Spray Recirculation System and subsequently Low Pressure Coolant Recirculation.
TW	Transient with Failure of Power Conversion System and Residual Heat Removal System.
TC	Transient with Failure of Reactor Protection System
TQUV	Transient with Loss of Feedwater and Failure of High Pressure Coolant Injection, Reactor Core Isolation Cooling, and Low Pressure ECCS.

1400[1] to have a nominal core melt frequency between approximately 10^{-5} and 10^{-8} per year. It is important to note that the BWR core melt frequency is dominated by the TC and TW accident sequences. All other sequences have a probability of occurrence at least two orders of magnitude less per year. As will be discussed later, these values from the base line risk assessment have a very dominant influence on the results of the component and system risk ranking presented in this section.

The important plant systems in these sequences which were evaulated in this study are given in Table 4.6. The acronyms used to refer to these BWR systems are given in parentheses in this listing. Using the methodology described in Section 3, the importance of each system and the major components in these systems was calculated. The importance of each system is given in Table 4.6, while the results for the major components are presented in Table 4.7. Each component in Table 4.7 is listed as it is identified in Appendix II of WASH-1400. In most cases, the component numbers are the same as those used at the plant. Although all components listed on the WASH-1400 system diagrams were considered in this analysis, some have not been listed in the ranking table to limit the table to a reasonable size. All major components in the BWR ESF systems, such as MOV's and pumps, which might have to be taken out of service are included in Table 4.7.

The components listed in Table 4.7 have been grouped into three categories based on the calculated importance ratios. These groupings were arbitrarily defined for the sole purpose of demonstrating the methodology. There was no intent to recommend or establish guidelines by quantifying the limits of these categories. Similar to the grouping used for the PWR, "very important" components are those which increase the core melt frequency by more than a factor of two. "Moderately important" components are those with importance greater than 1.1 but less than 2.0. Risk insignificant components comprise the third category. As discussed in Section 4.1.1, the expression of the importance ratios in two significant figures is not intended to imply such a level of precision; but rather to point out subtle differences which arise using the WASH-1400 data.

Table 4.6

BWR ESF SYSTEMS IMPORTANCE

Emergency Service Water System (ESWS)	2700
High Pressure Service Water System (HPSWS)	2700
Low Pressure Coolant Recirculation System (LPCRS)	
- including Residual Heat Removal Mode of Operation	2700
- excluding Residual Heat Removal Mode of Operation	54
Low Pressure Coolant Injection System (LPCIS)	9.7
Core Spray Injection System (CSIS)	
- both trains	5.0
- one train	1.0
Automatic Depressurization System (ADS)	1.3
Reactor Core Isolation Cooling System (RCIC)	1.1
High Pressure Coolant Injection System (HPCIS)	1.1
Core Spray Recirculation System (CSRS)	1.0
Vapor Suppression System (VS)	1.0
Primary Containment System (PC)	1.0**
Secondary Containment System (SC)	1.0**

* Importance is defined as the ratio of the core melt frequency with the indicated system unavailable to the nominal WASH-1400 core melt frequency.

** The selection of core melt frequency as a measure of risk for this study affects these values as containment integrity has negligible effect on BWR core melt frequency. The use of other measures of risk would show isolation to be more important.

Table 4.7

BWR ESF COMPONENT RANKING

Very Important Components

Component (System)	Importance
Manual Valve 506 (ESWS)	2700
MOV 2486 (HPSWS)	34
MOV's 15A and B (LPCIS)	9.7
MOV's 25A and B (LPCIS)	9.7
Manual Valves 81A and B (LPCIS)	9.7
Control Valves 46A and B (LPCIS)	9.7
MOV's 39A and B (LPCIS)	9.7
MOV 33 (LPCIS)	9.7
Condensate Storage Tank (RCICS, HPCIS)	7.0
MOV's 10-89A, B, C, and D (HPSWS)	3.9
Manual Valves V11A and B (HPSWS)	3.9

Moderately Important

Component (System)	Importance
HPSW Pumps (HPSWS)	1.1
MOV 2803 (HPSWS)	1.1
MOV's 15,16,18,20,21,27,30 and 131 (RCIC)	1.1
Turbine Driven Pump (RCIC)	1.1
Turbine Stop and Control Valves (RCIC)	1.1
Manual Valves in RCIC pump suction and Turbine Discharge Line (RCIC)	1.1
Oil Pump for Turbine Control Valve (RCIC)	1.1
MOV's 14,15,16,17,19,20,21,29, and 31 (HPCI)	1.1
Turbine Driven Pump (HPCI)	1.1
Turbine Stop and Control Valves (HPCI)	1.1
Manual Valves in Pump Suction and Turbine Discharge Lines (HPCI)	1.1
Oil Pump for Turbine Control Valve (HPCI)	1.1

Unimportant Components

(Importance = 1.0)

Component (System)
MOV's 7A, B, C, and D; 11A and B, 12A and B, and 26A and B (CSIS)
Pumps 37A, B, C, and D (CSIS)
Manual Valves 14A and B, and 63A, B, C, and D (CSIS)
Manual Valves V16A and B, and V8A, B, C, and D (CSIS)
ADS Valves (ADS)
MOV's 13A, B, C, and D (LPCIS)
Pumps 35A, B, C, and D (LPCIS)
MOV 20 (LPCIS)
Manual Valves 28A, B, C, and D (LPCIS)

The effect of a few very dominant sequences is illustrated by the results in Tables 4.6 and 4.7. Because of the relatively high contribution of the TW sequence to core melt frequency, several components associated with decay heat removal system operation are calculated to be amount the most important. In fact, with the exception of the CST, all components in the "very important" category contribute to increased risk due to outage through the TW sequence. The most important component is manual valve 506 in the ESWS. This valve is in the single line which transports water from the discharge of the LPCRS and CSRS pump compartment coolers to the discharge pond. If this normally locked-open valve were left closed, cooling for these rooms would be lost in the event that use of the ESWS is required. This failure is assumed to lead to overheating and failure of the LPCRS and CSRS pumps. The loss of these pumps leaves only the power conversion system for long term heat removal. Hence, unavailability of LPCRS and CSRS greatly increases the probability of the TW sequence, as evidenced by the importance ratio of 2700.

MOV 2486 of the HPSWS is located in the pipe which discharges cooling water from the LPCRS heat exchangers into the discharge basin. It is normally open. If this valve should be left closed MOV 2803 must open to redirect this water to the emergency cooling towers. If this valve fails to open heat removal from the torus is lost and the RHR system fails. The other HPSWS valves (10-89 abd V11 valves) in the "very important" category of Table 4.7 would eliminate half of the HPSWS if taken out of service. Hence, only two heat exchangers would be available for heat removal from the torus. Outage of any of these valves increases the core melt frequency by a factor of ~ 4.

The LPCIS valves in the"very important" category of Table 4.7 each have the capability to disable one train of the LPCIS if they are in an incorrect position. While this has a significant impact on the probabilities for the large LOCA sequences, the dominant effect is again through the TW sequence as one RHR train is lost.

The only component of the most important group that does not appear in the systems associated with the TW sequence is the CST. This tank supplies water to both the RCIC and HPCI systems. Here again, it is not the LOCA sequences, but rather the transient sequence TQUV which is the major contributor to increased risk from CST outage. For this sequence, unavailability of the CST disables all form of makeup at high pressure, thus requiring the use of the ADS and low pressure ECI systems.

4.2.2 BWR Monitoring Techniques

This section describes the status monitoring scheme used in the BWR considered in this study. The discussion is organized similar to the PWR discussion, addressing the control room design, the specific component displays, and administrative procedures.

4.2.2.1 Control Room Layout

Like the PWR, the BWR plant has two units (designated 2 and 3), each operated from the same control room. The control room is segregated with each unit controlled from a different half of the room. A diesel control panel is located in the center of the room as both units share the four diesel generators. Each unit has a reactor operator, while operation of the entire control room is overseen by the control or chief operator whose work station is behind the diesel panel at the center of the room. Again, similar to the PWR, the main controls are located on a benchboard or inner console, directly in front of the reactor operator. The wall behind this contains meters, recorders, and controls and displays for other components utilized less frequently by the operator. In contrast to the PWR, the controls and displays for most of the ESF systems are located on separate panels which are on the wall behind the main consoles. Hence, they are not within the operators' view during routine plant control operations. There is a separate panel for each system and separate annunciator panels above the ECCS panels which respond to off-normal conditions in those systems. Annunciator boards for the remainder of the plant are on the opposite wall above the outer console.

4.2.2.2 ESF System Level Monitoring

The BWR evaluated in this study has no system level monitoring for the ESF systems listed in Table 4.6. There are no single indicators or annunciators in the control room which explicitly alert the operator to system unavailability as a result of component outages. The operator must infer the system state from the individual component status monitoring displays, which are described in the following section. This task is expedited by an operational aid (discussed in Section 4.2.2.3). However, the operator must still review the component displays on each ESF system panel.

The shift turnover check lists also require the operator to verify system status (see Section 4.2.2.4) at each shift change. However, this only serves to periodically update the operator and does not inform the operator at the moment the outage occurs.

4.2.2.3 Component Displays in Control Room

Four different types of displays are used to control or monitor the status of the components in the BWR ESF systems. Table 4.8 summarizes these techniques and gives examples of ESF system components that are monitored by each method. A comprehensive listing of the displays utilized for the major components evaluated by this investigation is given in Appendix II. A detailed description of these methods is provided in this section. The relative effectiveness of these displays in conjunction with the use of tags and labels is presented in Section 4.2.3.

<u>Position Indicator Lights</u>. This display consists of a pair of lights (green for closed, red for open) with a label which identifies the component. This type of display was used for certain air operated valves and some check valves. An example of this monitoring technique is presented in Figure 4.12. The plant operators have developed an operational aid to assist the operator in quickly assessing the status of a given component. A green or red circular

Table 4.8

BWR ESF SYSTEM COMPONENT STATUS MONITORING METHODS

Monitoring Technique *	Example Components
Position Indicator Lights	RCIC Turbine Control Valve Manual Valves 81 A&B in LPCI Injection Lines Manual Valves 14 A&B in CSIS Injection Lines Control Valves 46 A&B in LPCI Injection Lines
Position Indicator Lights and Control Switch	MOV's 15 & 16 in HPCI Turbine Steam Supply Line MOV 17 in HPCI Pump Suction Line MOV's 7 A,B,C,&D in CSIS Pump Suction Lines MOV's 2486 & 2803 in HPSW Discharge Lines.
Position Indicator Lights and Control Switch with Annunciator	ADS Valves LPCI Pumps** MOV 20 in Cross-tie Line between LPCI Trains CSIS Pumps**
Meter with Annunciator	Condensate Storage Tank
No Indication in Control Room	HPCI Pump and Booster Pump Manual Valves 63 A,B,C, & D in CSIS Pump Discharge Lines Manual Valve 506 in ESWS

* Detailed descriptions of these techniques with illustrative photographs are given in Section 4.2.2.3.

** Some (but not all) outages produce an alarm.

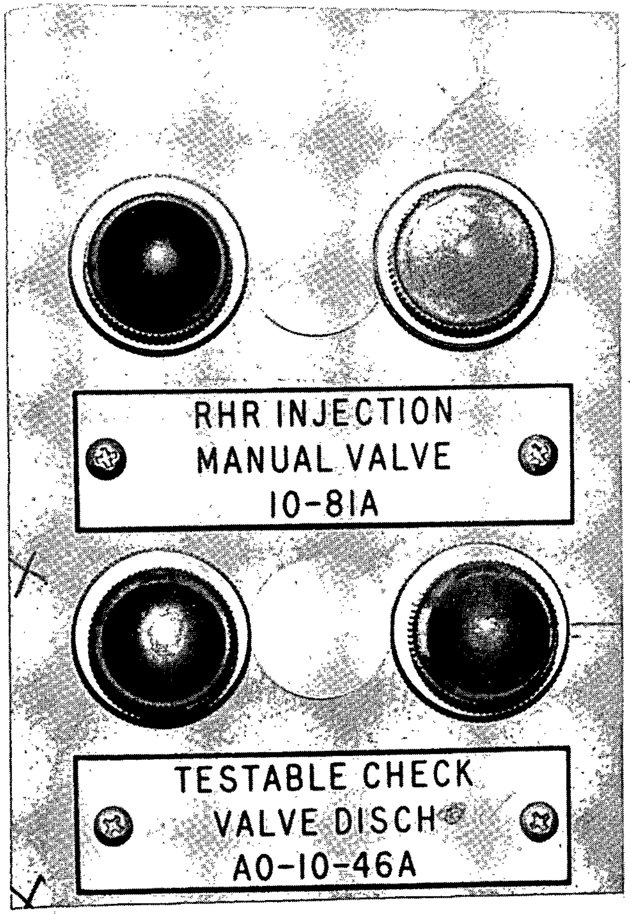


Figure 4.12 BWR Position Indicator Light Displays

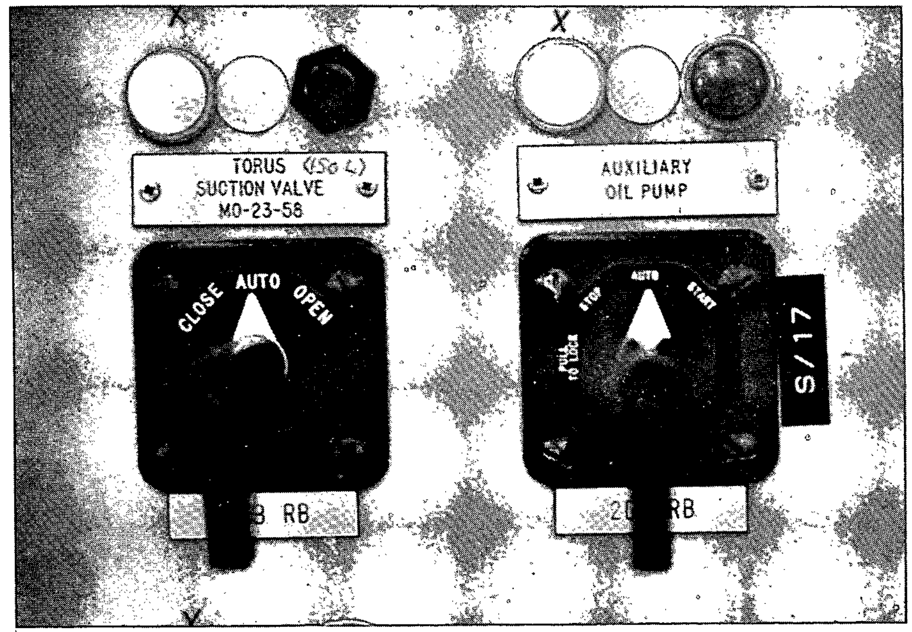


Figure 4.13 BWR MOV and Pump Control Switch Displays

sticker is placed between the two indicator lights on each display. The color of this dot should agree with the color of the illuminated light when the component is in its correct standby position. The operator can rapidly check the status of each ESF system by ensuring that the colors of the illuminated indicator lights match those of the associated stickers for each component on a given panel.

Position Indicator Lights with Control Switch. This display consists of the position indicator lights just described as well as a selector switch to operate a pump or valve. The aforementioned operational aid will tell the operator if the component is in its correct position.* The majority of the components in Table 4.7 were monitored in this manner. Figure 4.13 shows an example of this type of display.

Annunciators. Annunciators are also used to alert the operator to the outage of some components. These supplement the control display noted above. When the component is initially taken out of service, an audible and visual alarm occurs. By acknowledging the annunciator, the audible signal is terminated, but the appropriate window on the annunciator board remains illuminated. This provides additional notice to the operator of the unavailability of some components. Some typical annunciator windows are shown in Figure 4.14.

Meters. In addition to the above status monitoring methods, there are meters and recorders which provide measurements of the many parameters which are monitored throughout the plant. These meters provide important information which can reflect the status of components or systems. One such example is the CST water level meter shown in Figure 4.15. For the components considered in this study, meter readings are not the only means by which this information is available to the operator. For example, the CST also has an annunciator to alert the operator to a low water level condition.

*Even if incorrectly positioned, some valves are automatically realigned when the particular ESF system is activated. Hence, the indicator lights do not necessarily provide information on component availability. This is accomplished by the tagging procedure discussed in Section 4.2.2.4.

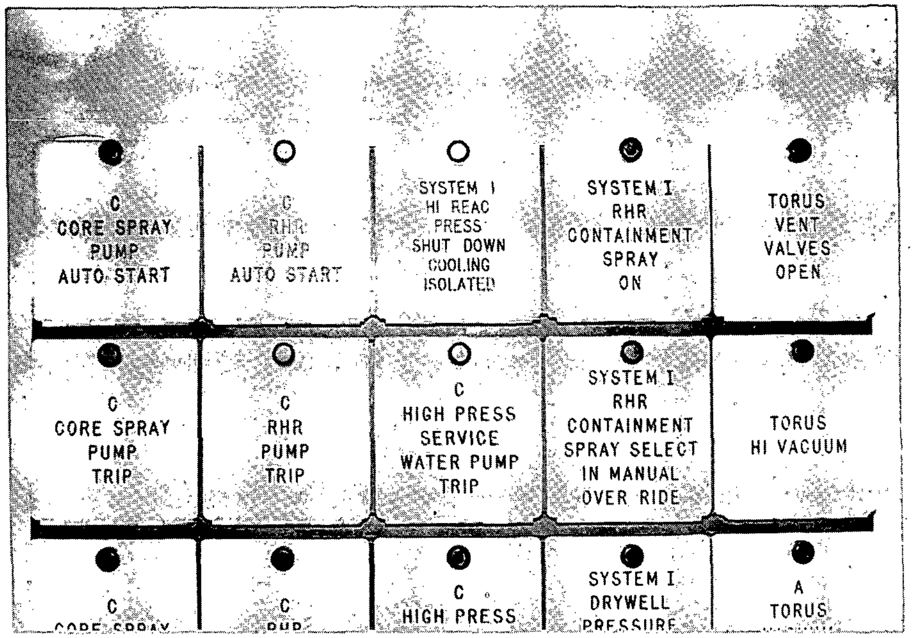


Figure 4.14 BWR Annunciator Windows

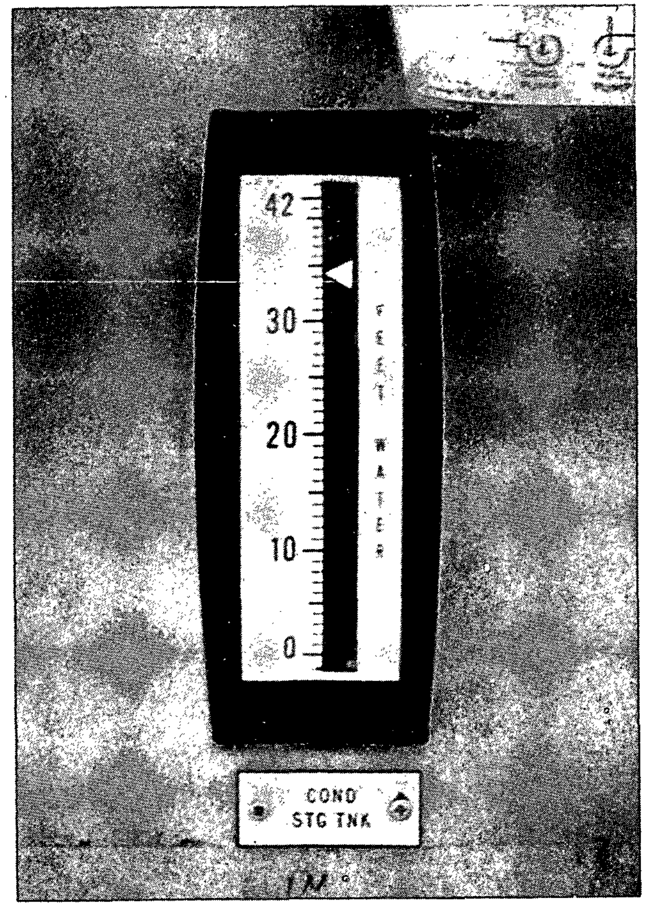


Figure 4.15 BWR CST Level Meter

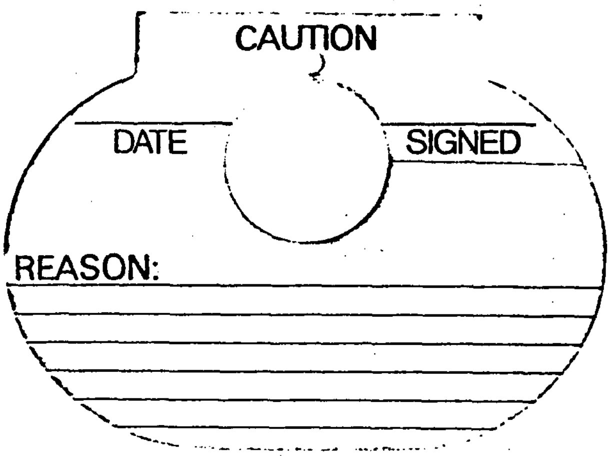
4.2.2.4 Maintenance and Administrative Procedures

Maintenance procedures play a very important role in informing the operator of component outages. This awareness originates primarily through the placement of tags and labels on the control room displays when a component is unavailable. However, log books, checklists, and shift turnover procedures are also important in conveying this information to the plant operators. These subjects will be described in this section for the BWR plant which was evaluated. The effectiveness of these procedures in the overall monitoring scheme is addressed in Section 4.2.3.

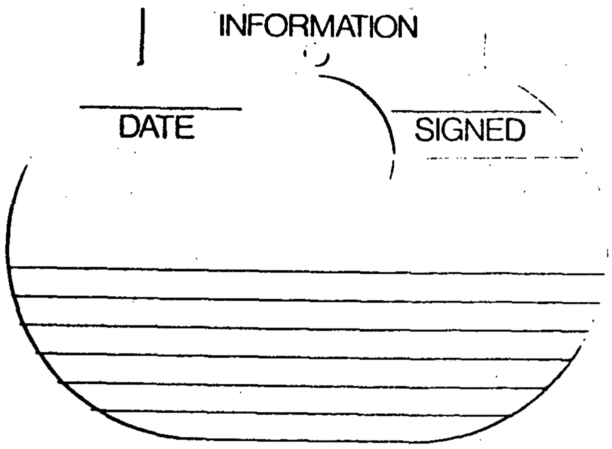
Numerous procedures have been prepared to direct most plant maintenance activities. In addition, the operating utility has a standard "blocking procedure" which is used at all plants for taking components out of service. Even these general procedures contain more detail than is necessary for understanding the role of these procedures in the BWR plant status monitoring scheme. Hence only a brief summary of the usual routine is presented in this section.

A request for maintenance, whether routine or to correct a problem, can be initiated by anyone in the plant. For example, if a problem such as a leaky valve is spotted, the component is tagged locally with a white tag and a maintenance request form completed. The form and bottom half of the tag are transmitted to the shift supervisor, who reviews the request and takes the action to initiate repair. The engineering staff reviews the request noting any special restrictions or test requirements, and the work group supervisor provides the specific procedures to be followed. The request is then delivered to the control room. The control room operator makes the decision when to take the component out of service and writes a local work permit. This permit is given to the "floor operator" who blocks and tags the valves necessary to perform the work.* Tags are also placed in the control room on the displays of all valves and components involved in the maintenance outage. Specific tags are used for different purposes. Figure 4.16 shows the

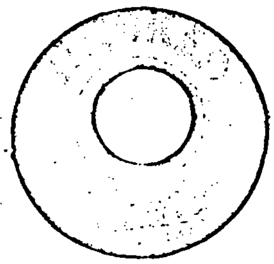
*Blocking may also be done remotely from the control room.



a) Caution Tag (yellow) - provides information to operator about off normal condition and warns of special considerations or consequences if the component is to be used.



b) Information Tag (white) - provides information to operator about an off normal condition.



c) Blocking Tag (red) - informs operator that component is out of service and is not to be operated.

DEFICIENCY REPORTED

MRF. No. ....

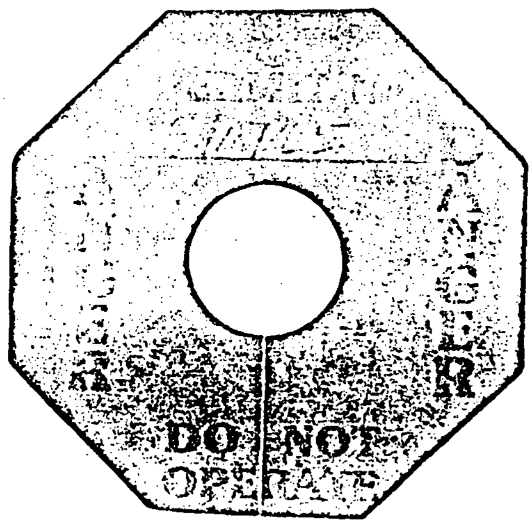
By ....

Device No. ....

Problem: ....

....

d) Deficiency Sticker (yellow) - used when a deficiency has been identified, but equipment has not been taken out of service (blocked).



e) Blocking Tag (red) - informs operator that component is out of service and is not to be operated.

Figure 4.16. Tags Used in BWR Control Room.

different tags used in the control room. The red octagonal tag tells the operator not to operate the tagged component, and is placed on the control switch handles in most maintenance situations. Figure 4.17 shows the placement of one of these tags on a pump control display. Adhesive labels are affixed to annunciator windows or meters to alert the operator when a safety related component deficiency is present, but the component has yet to be blocked (and thus tagged) and the deficiency is not obvious by other means of component status monitoring. These deficiency stickers (shown in Figure 4.16) are often used for unreliable or inaccurate indicator readings. Deficiency stickers are not recorded on the maintenance request form and there are not specific procedures to ensure their removal. They are generally removed during testing after the condition has been repaired.

Following completion of the work, the maintenance request form is signed off by the mechanic and returned to the control room. The control room operator then directs removal of the block and tags. This direct involvement of the operator in isolating components and returning them to operation enhances operator awareness of component outages.

The shift turnover procedures observed at the BWR are very similar to those discussed in Section 4.1.2.4 for the PWR. Checklists are completed and a visual review of each ESF panel is performed. The panel walkdown at shift change should identify most cases of incorrect component status. The effectiveness of this review is enhanced by the color coded stickers used to indicated the correct component position or status (See Section 4.2.2.3). The checklist appears to be a formality that documents the panel status as reviewed during the walkdown. It is not completed during the actual walkdown but afterward. The control room reactor operator (for each unit), the chief operator, and the shift supervisor each have separate checklists. These lists are presented in Figures 4.18, 4.19, and 4.20 respectively. As these lists illustrate, key component outages are reviewed at three different levels during each shift change.

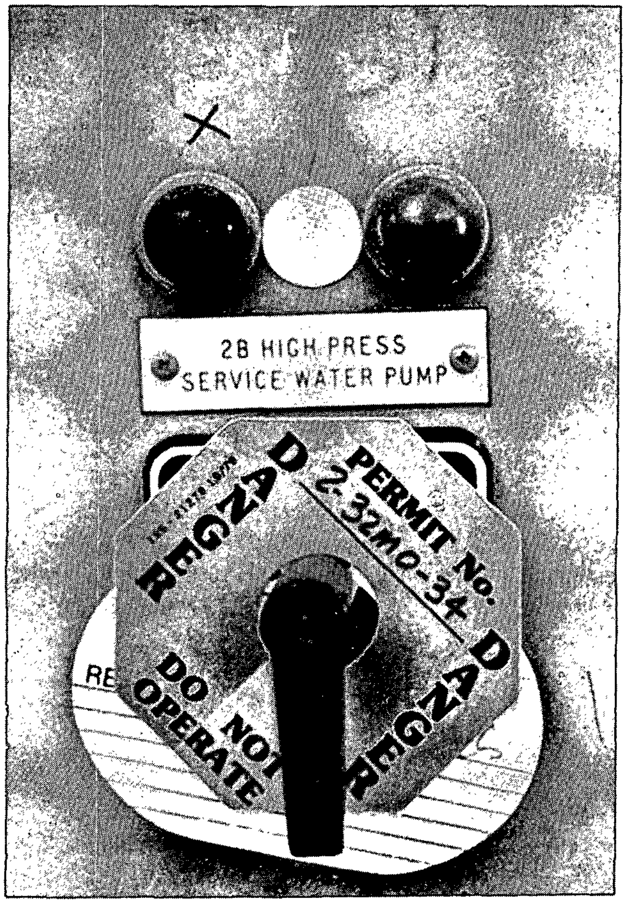


Figure 4.17 Placement of a Blocking Tag in BWR Control Room (Caution Tag is Visible beneath Blocking Tag)

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CONTROL ROOM REACTOR OPERATOR

SHIFT TURNOVER

CHECKLIST

UNIT ____________

COMPLETED BY ______________________ (OPER) DATE ______________ SHIFT __________

ACKNOWLEDGED BY ______________________ (OPER-INCOMING) SHIFT __________

REVIEWED BY ______________________ (S.S. OR S.S.V.-INCOMING) SHIFT __________

SHUTDOWN __________ REFUEL __________ STARTUP __________ RUN __________

CORE THERMAL POWER (RUN MODE ONLY) (LIMIT 3293 MW_T) __________ MW_T

STEADY __________ INCREASING __________ DECREASING __________

CIRCLED VALUES ON ST9.1 (OUT OF SPEC.) EXPLANATION

__________ __________

__________ __________

__________ __________

INSTRUMENTATION BYPASSED OR O.O.S. (STARTUP & RUN MODE) EXPLANATION

NUCLEAR INST __________ __________

" " __________ __________

RAD. MONITORS __________ __________

" " __________ __________

SAFETY RELATED __________ __________

" " __________ __________

" " __________ __________

PANEL CHECK	HPCI	RCIC	C.S.I	RHRI	PRI CONT	C.S.II	RHRII	PCIS
Alarm Test	___	___	___	___	___	___	___	___
System Lineup (Red & Green Dots)	___	___	___	___	___	___	___	___
Panel Lights	___	___	___	___	___	___	___	___

PANEL CHECK	CAD	COND	F.W.	TURB	REACTOR	RECIRC	RWCU	PL.SERV
Alarm Test	___	___	___	___	___	___	___	___
System Lineup	___	___	___	___	___	___	___	___
Panel Lights	___	___	___	___	___	___	___	___

PANEL CHECK	PROC. RAD
ALARM TEST	___
SYSTEM LINEUP	___
PANEL LIGHTS	___

Page 2 of 2

CONTROL ROOM REACTOR OPERATOR

SHIFT TURNOVER

CHECKLIST

SYSTEM OR COMPONENT WHICH IS INOP. AS PERMITTED BY TECH SPEC'S

ITEM	DATE INOP	DEADLINE DATE
___	___	___
___	___	___
___	___	___
___	___	___

OTHER COMMENTS OR INFO. (HP & C, ETC.)

____

____

____

____

____

____

____

Figure 4.18 BWR Reactor Operator Shift Turnover Checklist

CONTROL OPERATOR
SHIFT TURNOVER
CHECKLIST

COMPLETED BY________________________(OPER) DATE________________ SHIFT__________

ACKNOWLEDGED BY________________________(OPER-INCOMING) SHIFT__________

REVIEWED BY____________________(S.S. OR S.S.V.-INCOMING) SHIFT__________

SYSTEM LINEUP	NORM	ABNORMAL / REASON
B-1 DG.	______	____________________
B-2 DG.	______	____________________
B-3 DG.	______	____________________
B-4 DG.	______	____________________
12/13 Bus	______	____________________
22/23 Bus	______	____________________
32/33 Bus	______	____________________
42/43 Bus	______	____________________
2 SU	______	____________________
3 SU	______	____________________
Substation (North)	______	____________________
" (South)	______	____________________

INSTRUMENTATION BYPASSED OR O.O.S.		EXPLANATION
2 Vent Stack Rad. Mon	______________	______________
Cont. Rm. Rad Mon.	______________	______________
Off Gas Rad Mon.	______________	______________
Stack Gas Rad. Mon.	______________	______________
3 Vent Stack Rad Mon.	______________	______________
Area Rad. Mon. (Unit 2)	______________	______________
Area Rad. Mon. (Common)	______________	______________
Area Rad. Mon. (Unit 3)	______________	______________

CONTROL OPERATOR
SHIFT TURNOVER
CHECKLIST

	Normal	Abnormal / Reason
Unit 2 Recomb & Annunc.	______	______________
Unit 3 Recomb & Annunc.	______	______________
Recomb. Rad. Mon.	______	______________

Panel Check	B-1 DG & Aux	B-2 DG & Aux	B-3 DG & Aux	B-4 DG & Aux
Alarm Test	______	______	______	______
System Lineup	______	______	______	______
Panel Lights	______	______	______	______

Panel Check	Gen & Aux Unit 2	Gen & Aux Unit 3	S.U & Clg. twr.
Alarm Test	______	______	______
System Lineup	______	______	______
Panel Lights	______	______	______

SYSTEM OR COMPONENT WHICH IS INOP. AS PERMITTED BY TECH SPEC'S

ITEM	DATE INOP	DEADLINE DATE
______________	________	____________
______________	________	____________
______________	________	____________
______________	________	____________

OTHER COMMENTS OR INFO. (HP & C, etc.)

____
____
____
____
____
____

Figure 4.19 BWR Control Operator Shift Turnover Checklist

SHIFT SUPERVISION SHIFT TURNOVER

CHECKLIST

COMPLETED BY ______________________ (S.S.V.) DATE ______________________ SHIFT ____________

1. Completed Review of C.O. Turnover Checklist ____________ S.S.V. ____________ S.S.
2. " " " Unit 2 A.C.O. Turnover Checklist ____________ S.S.V. ____________ S.S.
3. " " " Unit 3 A.C.O. " " ____________ S.S.V. ____________ S.S.

4. Surveillance Tests in Progress or Approved

A.	LAB	YES	NO
B.	HP & C	YES	NO
C.	T.E'S	YES	NO
D.	SHIFT	YES	NO

5. New Operating Instructions Issued (Review Shift Mtg. Report or POG) ____________ S.S.

____________ S.S.V.

6. New Letters to Shift Reviewed (if any) ____________ S.S.

____________ S.S.V.

7. Held Shift Mtg. YES NO

Reason if no mtg. held ______________________________________

____

____

8. System or Component which is Inop as permitted by Tech Specs.

ITEM	DATE INOP.	DEADLINE DATE	RESOLVED DATE

9. Other Comments or Info. (HP & C, ETC.)

10. Reviewed by ______________________ (oncoming S.S.V.)

" " ______________________ (" S.S.)

Figure 4.20 BWR Shift Supervisor Shift Turnover Checklist

One aspect of the shift change procedures unique to the BWR was a brief meeting of the entire operating crew prior to shift turnover. The chief operator briefly summarizes the status of both units, noting any problems or areas of special concern. This occurs prior to the ESF panel review.

Unlike the PWR, there is no periodic, local check of manual valves in the ESF systems that are not monitored in the control room, (e.g., RCIC suction valve and ESWS manual valve 506). These valve positions are checked prior to start-up, but not routinely during operation. Hence, if a manual valve were inadvertantly left in an incorrect position the operator would have no knowledge of such a condition for a considerable period of time. Furthermore, there is no independent verification of correct valve positions after maintenance. In many cases, these types of errors would likely be discovered during testing, which is required after maintenance on an ESF system. However, performing a test with a valve in the wrong position could cause damage to the system, thus extending the outage.

4.2.3 Human Factors Evaluation of Status Monitoring Approach

During the plant visit to acquire information on how each component was monitored, a review of the relative effectiveness of each monitoring technique discussed in Section 4.2.2.2 and 4.2.2.3 was performed. This evaluation was performed only to compare the different monitoring techniques and not make judgments on the overall acceptability of the system. These assessments were based primarily on the observations of a human factors specialist who was part of the team which visited the plants. It should be emphasized that a detailed human factors investigation of the control room design is beyond the scope of this work, and is not considered necessary to provide the qualitative observations required for this investigation.

As noted in Section 4.2.2.2, there is no system level status monitoring in the BWR control room. The operator must determine the status of the ESF systems by checking the status of the individual components. Hence, each display for the components comprising a given system must be checked to see if it is available. This process is enhanced by the use of the colored dots between the indicator lights which indicate the correct state of the component (see Section 4.2.2.3). However, this approach may not give correct information in all cases as there are some components which are not monitored in the control room whose outage, or incorrect configuration could disable a system. The control displays could indicate that a system was available, while in fact it was degraded or disabled. Hence, this method is much less effective than a single indication of system availability which is given a high priority in the hierarchy of control room status monitoring techniques. In the remainder of this section, each of the monitoring techniques observed in the plant for the ESF system components is evaluated separately in order of decreasing relative effectiveness. Following these assessments, some general observations pertaining to various aspects fo the status monitoring system are presented.

Tagged Console Display with Annunciator. This technique is used for several components in the ESF systems. It is typified by the following indications of component outage

- illuminated annunciator window which may have an adhesive deficiency sticker
- tag on the control switch on the console display..

For most maintenance activities power would be removed from the components being repaired and the MOVs which isolate them. Hence, the indicator lights would both be out. In other instances, the indicator lights, by comparison with the colored dot, and control switch handle position may also indicate an incorrect position, or outage of the component. However, the operator relies principally on the tag as an indication of component status.

This monitoring and tagging scheme is the most effective in the plant, primarily because of the two different displays which convey information to the operator. Even though the audible alarm when the annunciator is initially actuated is no longer present, the illuminated window should improve operator awareness of a component outage - particularly if the window is also tagged with a deficiency sticker. The use of tags on control switches, or labels on annunciators supplements the position indicator lights and annunciator lights. They are much more visible than the lights, and often provide some explanation as to the reason for the outage. In addition, such labels can explain outages which may not be reflected by the indicator lights alone (i.e., a component may be in its correct position and so indicated by the display, but unable to change its position if required for system response). The use of uniformly shaped and colored tags for different component status conditions adds to the effectiveness of these control switch tags. For example, the red octagonal tag tells the operator that the component is inoperable, while the yellow caution tag may be used if the component is available, but there is some special information of which the operator should be aware of if he utilizes that component.

Annunciator and Meter Reading. Of the components assessed, this approach applies only to the CST. This is never intentionally taken out of service during operation, unless the HPCI and RCIC systems are aligned to take suction from the Unit 3 CST. The tank status is indirectly monitored by water level measurement. Low level would be indicated on a meter (see Figure 4.15) and a recorder as well as the annunciator panel. Should the tank be out for service, the annunciator window and perhaps the CST level meter would be labeled. In those instances where the CST is drained during shutdown, the pre-startup checklist which requires verification of adequate CST level would also alert the operator in the unlikely event that the tank is not refilled.

Tagged Console Display. This technique is the same as the previous one except that there is no annunciator to alert the operator to component unavailability. Hence, it is somewhat less effective. This technique is used for many MOV's. Specific examples include the displays for MOV's in the steam supply lines for the RCIC and HPCI turbines and MOV 2486 which admits HPSW to the discharge basin.

Tagged Console Display Without Control Switch. As noted in Section 4.2.2.3, some valves have only position indicator lights on the console and no selector switch. For these displays, the larger more prominent tags cannot be used. Instead, the smaller deficiency stickers are used to indicate component outage. This monitoring technique is judged to be somewhat less effective than the displays with the selector switches due to the smaller labels which must be used. Examples of components monitored in this fashion are control valves 46A and B in the LPCI injection lines, and the HPCI turbine control valve.

It is worth noting that as long as the blocking procedures are followed, any component which has a control switch on the ESF panel would be tagged or labeled if it is taken out of service or rendered unavailable by isolating another component. For those components monitored only by a pair of indicator lights, the procedures are less rigorous. Although no specific examples could be identified, interviews with the operators indicated that these displays may not always be labeled, if they are disabled during maintenance. In the absence of a label, component unavailability would be indicated by valve position (illuminated indicator light does not match color of the sticker), or absence of indicator lights (power removed). The latter of these two conditions is much less effective as discussed in Section 4.1.3.

No Control Room Indication. There are some components in the ESF systems that have no status indication in the control room. These are generally manual valves or other passive components. Presumably the status of these components is not displayed because of the operator has no remote control capability. Hence, they were not considered necessary in the design of the reactor control room. As would be expected, this is the least effective means of status monitoring. For these components, the only information on component status or valve positions would be from entries in the log book, or in some cases, a note might be affixed to the console to alert the operator of the condition. A group of manual valves are checked locally prior to reactor startup, but there are no further checks of manual valve positions during operation. A very important example of a manual valve that is not monitored in the control room is ESWS valve 506 which is in the discharge line leading from the heat exchangers in the reactor building to the discharge pond.

General Observations. In addition to the specific displays discussed previously, some general observations pertaining to control room design which are relative to the effectiveness of the existing status monitoring system were made during the plant visit. These are discussed briefly in the remainder of this section.

As noted in Section 4.2.2.1, the ESF panels are located behind the operator and thus not within his field of vision when performing routine plant operations. Furthermore, the individual displays on the ECCS panels are difficult to distinguish from the operator's normal work station. The ECCS annunciator windows are also difficult to read from this position. To check these panels, the operator must walk to the back wall of the control room. However, when examining these displays or utilizing the ESF controls, his back is to the remainder of the plant controls and instrumentation displays. The panels themselves are well-organized functionally. A separate panel is provided for each system. There appears to be no differentiation of component importance by the location of the different control displays on each ESF panel.

The use of a mixture of red and green illuminated indicator lights to indicate correct system alignment is not as effective as the use of a single color or a blank board approach.* However, the use of colored stickers to indicate the correct component status or valve position is a good operational aid, and assists the operator in rapidly assessing the status of a system. Because of the location of the ESF panels, this visual check cannot be easily performed from the operator's normal work station.

Indicator light failure is also a potential cause for some confusion. As discussed for the PWR (Section 4.1.3), a press-to-test capability would assist the operator in those instances. However, if the blocking procedure is followed, all cases where both indicator lights are out as a result of maintenance action would be tagged.

---

* Although the uniform color approach may be more effective for status monitoring, it could cause some difficulties when performing tests and other routine operations. Indicator light color no longer corresponds to a specific component state. Hence, a green light may mean valve open in some cases and closed in others. This inconsistency could be a source of confusion for operators when performing routine operations.

4.2.4 Comparison of Monitoring Effectiveness and Component Importance

The final step in the ESF status monitoring system evaluation was a comparison of the effectiveness of the monitoring technique utilized for each component with its importance as presented in Table 4.7. It can then be determined if there is a correspondence between the risk significance of the component and the effectiveness of the manner in which it is monitored, relative to other components. It is important to reemphasize that only the relative effectiveness of the monitoring techniques has been determined in Section 4.2.3. No judgments have been made as to the acceptability of any one approach. Even though one technique is relatively less effective than another method, this does not imply that it is ineffective for status monitoring. The following discussion presents the results of this comparison. Particular attention is given to those systems and components where there is an apparent inconsistency between the monitoring approach and its importance.

One aspect of the status monitoring system design which leads to the greatest inconsistencies is the lack of system level monitoring in the control room. Currently the operator must determine the system status from the individual component information. As noted in Section 4.2.3, this is a much less efficient and less expedient method than using a single, effective indication of system status. Although knowledge of the availability of the components comprising a given system is often very important information, the most important information required by the operator is whether or not the system will perform its intended function if its use is required.

The status monitoring approach used for the BWR ESF system components is very consistent and depends almost entirely on the type of component. All pumps and MOV's in these systems have similar displays* and are all tagged in the same manner with identical tags. The only significant differentiation which can be attributed to safety is the use of annunciators in addition to the console display, for alerting the operator of an incorrect position or outage of some pumps and MOV's. The use of these annunciators does not correspond well with the results of the importance calculations.

The greatest inconsistency is observed for ESWS manual valve 506, clearly the most important component in this study. There is no display in the control room to indicate the valve's position, nor is there any other

*Some slight differences in selector switch design, which do not significantly affect status monitoring are the only differences.

information available ot the operator except in perhaps the maintenance log book which would indicate valve outage or closure for maintenance activities. Because this valve cannot be operated remotely, it is likely that no need for a control room display was forseen, particularly since the component is not in one of the ECCS's. Manual valve 506 is located near other, similar valves in the plant. Although it is locked open and the shift supervisor controls the key, the operator still has no assurance that is could be inadvertently left closed, particularly since there is no periodic check of manual valve positions in the plant. It should also be noted tht the accident sequence through which outage of this valve contributes to increased risk (TW) is a slowly developing one. It requires many hours before core damage occurs for a loss of decay heat removal sequence. Hence, if the valve was inadvertently left closed, there is substantial time available to discover this mistake. The same absence of control room display was observed for manual valves V11A and B in the HPSWS which also appear in the very important category of Table 4.7.

Manual valves 81A and B in the LPCIS discharge lines are monitored in the control room by position indicator lights. Although the absence of a control switch limits the effectiveness of this display (by requiring a smaller tag if taken out of service), there is still some indication to the operator of component status. Position indicator lights are also the only type of display used for LPIS control valves 46A and B.

The MOV's noted in the very important category are all monitored by either of the two most effective means described in Section 4.2.3. Hence, there is reasonable agreement between their importance and the monitoring effectiveness. However, since nearly all MOV's in the ESF systems are monitored in this manner, these components are not monitored more effectively than many other lesser important MOV's.

As discussed in Section 4.2.1, the dominance of the TW and TC sequences in the baseline risk assessment results in a large number of components whose outage does not significantly affect the core melt frequency. Among these components are many which are monitored in the most effective manner possible. One set of examples are the CSIS pumps, which are calculated to be of insignificant risk importance. Outage of these pumps is indicated by a tagged control switch handle, and indicator lights above the switch, and in almost all cases an illuminated annunciator window. As discussed in Section 4.2.3, this is the most effective monitoring method utilized in the plant. Yet the risk based importance for these pumps is calculated to be 1.0.

5.0 SUMMARY AND CONCLUSIONS

As discussed in Section 2, the main objectives of this analysis were to develop and apply a logical basis by which an effective monitoring scheme - one in which the effectiveness of the monitoring technique is commensurate with the safety importance of the component monitored - could be constructed or an existing monitoring scheme could be judged. More specifically, these objectives translated into ascertaining whether a probabilistic risk approach could or should form the foundation of this approach to status monitoring decisions by assessing the existing monitoring schemes at two operating plants using a risk based measure of component importance. The two main products of this investigation which are relevant to the objectives stated above are: (1) the delineation of the relative strengths and weaknesses inherent to a probabilistic risk based importance ranking of components; and (2) an identification of those aspects of the existing monitoring schemes where there are inconsistencies between component importance and monitoring effectiveness, and thus could be improved. These two areas are presented and discussed in the subsections below.

5.1 Value of Probabilistic Risk Based Approach

As discussed in Sections 2 and 3, the task of developing a truly effective monitoring scheme entails two major considerations: (1) theoretically, the operator should be aware of the status of any component that can affect the ability of the plant to respond to accident conditions; but (2) practically, there are limitations and constraints involved which relate to the operators ability to absorb and retain a vast amount of information concerning the status of components given the already high information load associated with the operator's normal duties and accident response procedures. These two considerations imply that the optimum monitoring scheme would be one in which the relative effectiveness of the monitoring technique (and thus increase in operator information load) is commensurate with the safety significance of the monitored component. This in turn implies the need for a logical systematic way of measuring a component's "importance". It is the general conclusion of this analysis, with a few reservations noted below, that probabilistic risk assessment provides a valuable tool for determining the relative importance of individual components within a large complex system and can thereby form the basis for effective decisions related to the status monitoring of safety related components. The probabilistic risk model is able to provide insights into the relative importance of various components which are not apparent from (and are sometimes obscured by) the application of currently accepted regulatory procedures such as the use of a single failure criterion to assess design adequacy.

An illustrative example of such insights which resulted from this analysis involves the turbine driven pump in the Auxiliary Feedwater System of the PWR. On the steam supply line to the turbine there are two valves in parallel: MOV 102, a normally closed motor-operated valve which "fails as is" upon loss of electric power, and SOV 102, a normally closed solenoid-operated valve, which "fails open" upon loss of electric power to the solenoid. A cursory look at the system configuration would probably lead to the conclusion that the two valves are of equal importance and no existing regulatory procedure or guideline would differentiate between the importance of these valves. However, the risk based approach calculates that SOV 102 is about 15 times more important than MOV 102. That is, if SOV 102 were rendered inoperable, the plant would be exposed to a level of risk 15 times higher than if MOV 102 were rendered inoperable.

The main reason for this difference in importance is because the probabilistic model looks upon the turbine driven pump subsystem in the context of the overall plant design and analyzes the ability of the subsystem to perform its function under the conditions with are likely to exist when the subsystem is called upon. One of the most important conditions under which the turbine driven pump is required is produced by a loss of offsite power (leading to loss of main feedwater and the need for auxiliary feedwater) combined with a failure of the diesel generators (which precludes use of the two motor driven auxiliary feed pumps). In fact, the primary design rationale for a turbine driven feed pump is to provide a diversity with respect to power sources and protect against just such a blackout condition. Under these conditions, MOV 102 could not be opened anyway. However, under these conditions, the unavailability of SOV 102 would lead to the unavailability of the auxiliary feedwater system and to core melt. Looked upon in a different way, if MOV 102 is taken out of service, the loss of offsite power and failure of the diesels would still have to be accompanied by failure of SOV 102 (or other faults leading to the unavailability of the turbine pump); however, if SOV 102 is taken out of service, the loss of offsite power and failure of the diesels will lead to core melt without the need for any additional failures. Thus, SOV 102, provides an additional barrier to core melt over MOV 102.

This example illustrates that each component or subsystem must be examined in the context of the possible conditions which might exist (and the relative likelihood of those conditions) when the component is called upon. Those components which can still operate and must operate under such conditions should not be intentionally rendered inoperable and this last remaining barrier sacrificed without ensuring that the operator is aware of the situation. The probabilistic risk model provides a very logical systematic manner for identifying these important components.

The reservations mentioned above with regard to the use of probabilistic risk models are primarily concerned with the amount of uncertainty inherent to any risk assessment of a large complex system. There are, of course, uncertainties associated with any proposed approach and the fact that it is the relative importance of the components which is of concern does certainly lessen the impact of many of these probabilistic uncertainties. However, great care must be taken in applying the results of any risk assessment to the tasks described in this report. In all likelihood, the underlying risk assessment was not performed with the goal of developing status monitoring schemes. Many conservatisms and questionable assumptions might be present which, although not affecting the goals of the original risk assessors, could seriously inhibit an accurate ranking of component importance.

The most important concern relevant to the importance ranking task involves the case where one or two sequences dominate the risk assessment. Since an individual component's importance is obviously very sensitive to the relative importance of the accident sequence with which it is logically associated, overly conservative assumptions associated with dominant sequences can artificially raise the importance of many components. Alternatively, and perhaps more importantly, they can mask the importance of components not associated with these dominant but conservative sequences.

An example of this situation arose in addressing the BWR sequence TW (transient followed by loss of decay heat removal). This sequence was calculated in WASH-1400 to contribute more than half of the total core melt probability for BWRs and almost all other sequences (except TC - the BWR ATWS sequence) had frequencies of one or two orders of magnitude less. This obviously made many components in the decay heat removal systems very important. Subsequent to publication of WASH-1400, however, questions arose concerning the validity of the dominance of this sequence (see, for example, Reference 5). While not explicitly endorsing any specific recalculation of this sequence frequency, the uncertainty in the quantification could not be ignored. Therefore, for this analysis, the importance factors which were calculated for the BWR were looked at very closely to ensure that the importance of components not associated with decay heat removal were not obscured by the dominance of TW or that the importance of decay heat removal components was not falsely magnified.

There will, of course, always be uncertainties and assumptions associated with any risk assessment. It is also not necessary to determine what is an appropriate level of conservatism - that will obviously be driven by the goals of the underlying risk assessment. However, in order to effectively utilize these risk models for the purposes described here, the analyst must assess whether a consistent level of conservatism exists throughout the model. If some dominant sequences involve what are considered to be overly conservative assumptions (relative to other sequences) the calculated importance factors must be carefully interpreted in the light of this judgment.

The fundamental conclusion which can be derived from these observations concerning the inherent uncertainties in the underlying risk assessment is that specific decisions should not and need not be based on a precise quantification of importance. The value of the risk based importance is not to produce directions such as "use monitoring technique A if the importance is greater than X", but is to allow identification of inconsistencies in monitoring techniques where the effectiveness of the technique is clearly not commensurate with the importance of the component. It must be recognized that the uncertainties in the underlying risk assessment and the subjective nature of evaluating the effectiveness of diverse monitoring techniques preclude precise quantification of either variable. However, this inherent coarseness does not imply that valuable conclusions concerning effective status monitoring schemes cannot be reached. The uncertainties associated with the underlying risk models utilized in this analysis were not so great to prevent very distinct groupings to be made in both "risk significance" and monitoring effectiveness." Hence, it was possible to effectively test the hypothesis stated in Section 3.1 given these inherent levels of uncertainty. The use of groupings does not significantly diminish the value of the approach or the results; it is merely a recognition of real world uncertainties and attempts should not be made to "over-quantify" and imply a level of precision where it is not possible or necessary to do so.

In addition to the problems associated with the inherent uncertainties in the underlying risk assessment noted above, there are two other points which should be mentioned concerning the use of a probabilistic risk approach in developing status monitoring schemes. The first point is that the selected measure of risk can significantly affect the results of the component importance ranking. In this analysis, the frequency of core melt was the selected measure of risk. This obviously resulted in high importance ratios for those systems which are designed to prevent core damage. However, if acute fatalities in the surrounding poputation had been chosen, this would have elevated the importance of systems which are designed to mitigate the consequences of a core melt (e.g. containment ESF's).

Secondly, the true value to the operator of knowing a component's status might depend greatly upon the operator's required or possible tasks following the initiation of an accident sequence. If the operator is not required or cannot perform any useful function under some accident condition, the value of knowing the status of a pump which is required to start under this condition is certainly diminished to some extent. Conversely, if the operator has a long time to try to discover and repair a problem, the value of effective status monitoring could be altered. One example is manual valve 506 in the BWR ESWS (Section 4.2.1). An importance of 2700 was calculated for this component. However, outage or misposition of this valve contributes to increased core melt frequency through the TW sequence. Since there are many hours before core damage would occur for this sequence, there is plenty of time available for discovery and repair of the problem (particularly since this valve is readily accessable). Of course, an effective status monitoring system can be very valuable in rapidly locating these unknown outages, thus providing more time to correct the situation before core damage occurs or the system experiences an undesirable thermal transient.

Another situation not reflected in the original risk models are those cases where operator error in responding to an event degrades system performance. It can be argued that the value of the status information is enhanced if it involves situations where the operator could inadvertently degrade a system's response to an accident condition if he were unaware of the status of a component or system which he is required or might be expected to operate. These considerations could, of course, be incorporated into the risk model. However, most available risk models would be expected to require substantial revisions before these aspects of operational actions are adequately reflected in the model.

The specific results presented in Section 4 and summarized in the following subsection concerning the monitoring techniques of the two operating plants demonstrate the possibility of reaching useful conclusions given these uncertainties and considerations. Inconsistencies can be efficiently identified by utilizing the approach described in this analysis which would not be apparent by employing current design practices or regulatory procedures. Thus, the probabilistic risk based approach is a valuable tool (if used with caution) to enhance the effectiveness of status monitoring schemes and thereby improve the level of safety of nuclear plants.

5.2 Conclusions from Specific Plant Evaluations

A comparison of the risk based component ranking to the actual status monitoring schemes incorporated in specific plants was performed to evaluate the usefulness and limitations of this methodology. It should be emphasized that this assessment was not performed to judge the adequacy of ESF status monitoring at each plant, nor was it intended to establish numerical standards for developing and evaluating status monitoring systems. Nevertheless some observations which resulted from these plant assessments are worthy of mention as they illustrate the types of conclusions and information which this approach can produce. Furthermore, some of the suggestions for improving status monitoring are applicable to many operating plants, and thus are worthy of further consideration.

The comparison of the risk based component importance with the effectiveness of the different monitoring techniques revealed several inconsistencies for both plants evaluated in this study. The major inconsistency is an absence of system level status monitoring in the control room. The operator must determine the system status by assimilating the information from the individual console displays for the components which comprise the system. For experienced operators, this process is straightforward and simple in most cases. However, certain, less frequently encountered conditions could occur where the operator may not be fully aware of the ramifications of component outages. In addition, there are some components which can degrade or disable a safety system, whose status are not monitored in the control room (e.g. several manual valves). Thus, the current approach is much less effective than a single indication of system status that is given a priority in the hierarchy of control room status monitoring techniques that is commensurate with its importance.

Inconsistencies between monitoring effectiveness and importance for the various individual components were also identified in this evaluation. These discrepancies can be attributed primarily to two general characteristics of the control room design. First, with only a few exceptions, the status monitoring techniques employed at both plants considered in this study are entirely dependent upon the type of components. For example, all pumps in the

ESF Systems have similar control room displays; and the same administrative and tagging procedures are used when they are taken out of service. Hence, the effectiveness of status monitoring for all ESF system pumps is virtually identical at each plant. The reason for this similarity is that the control room design is based on other considerations in addition to safety. Simplicity of operation, for instance, is a major and very important factor which contributed to the uniformity of the present design of the control room displays.

With this uniform approach, some inconsistencies between the effectiveness of the status monitoring technique and the importance of various components are expected and were discovered in the analysis for each plant. One example is the use of an annunciator, "SI Valve Out of Position" in the PWR, in addition to the console displays to alert the operator to the incorrect position of certain valves in the safety injection sysems. While the monitoring technique is identical for these valves, the results of the risk-based importance calculations indicate that there are significant differences in the importance of these valves. Furthermore, although they are monitored by the most effective technique utilized in the plant, they are not the most risk significant. There are other MOV's in the plant whose outage would have a greater impact on core melt frequency, which are not monitored by an annunciator.

The other major aspect of component status monitoring common to both plants is the absence of any control room indication for the position of manual valves. This appears to result from the philosophy that since the capability for remote operation of these components is not required, there is no need to display their status in the control room and thus contribute to an already crowded control room. Since there is no display in the control room, the only means by which their status is checked is a periodic local inspection of valve position. This monitoring technique is the most ineffective of those observed at the plants. However, the importance calculations demonstrate that both plants have several manual valves which are very important if inadvertently left in the wrong position. The most prominent example of this descrepancy is valve 506 in the BWR ESWS. The risk model calculates an increase in core melt frequency in excess of three orders of magnitude if this valve is inadvertently left closed.

Additional manual valves and other components where there is a discrepancy between monitoring effectiveness and importance are discussed in Section 4.1.4 for the PWR and 4.2.4 for the BWR. It is recommended that some consideration be given to improving the monitoring techniques for these components. This is especially important in the case of the key manual valves identified for each plant. The addition of some display of their status to the operator, coupled with a consistent control room display tagging procedure for outages of these valves would significantly improve the ESF monitoring scheme at both plants. It is recognized, however, that the addition of individual control room displays for numerous manual valves could actually adversely affect overall operator effectiveness by overloading him with information. For this reason, system level indications which incorporate the information concerning the status of numerous individual valves could provide the most effective means of supplying this important status information to the operator.

REFERENCES

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APPENDIX I

EXAMPLE SYSTEM AND COMPONENT IMPORTANCE CALCULATIONS

This appendix provides a sample calculation of system and component importance to illustrate the methodology discussed in Section 3.2.1. The system selected for this example is the PWR Containment Spray Injection System (CSIS). To illustrate a specific component importance calculation, a pump in this system was selected.

The CSIS pumps take suction from the RWST and deliver water to spray headers in the containment. The dispersal of cold water throughout the containment atmosphere is intended to reduce containment pressure following a LOCA and assist in fission product removal. The CSIS consists of two, nearly identical, independent subsystems. A simplified flow diagram is given in Figure A.1. As treated in WASH-1400, failure of the CSIS is considered to be failure to deliver water from the RWST to the containment atmosphere at a rate at least equivalent to the full delivery of one of the two spray pumps. The following example shows how an outage of one of these pumps impacts core melt frequency.

As outlined in Section 3.2.1, the initial step in the assessment is to determine the base line core melt frequency. This provides the necessary standard of comparison for evaluation of the impact of component outages. The first step is the establishment of an overall risk model for the PWR. This was accomplished by selecting from the WASH-1400 event trees all accident sequences which contributed at least 1% to the nominal core melt frequency. Additional sequences were selected to ensure that all initiating events and all ESF systems were respresented. The inclusion of these additional sequences was necessary to ensure that the effects of major changes in ESF unavailability would not be neglected because the affected base-line sequences were not originally major contributions to risk. The resulting risk model for the PWR is comprised of 13 accident sequences.

Using the list of sequences in Table 4.1, a base-line core melt frequency, F(Base), was determined by summing the individual contributions from each sequence.

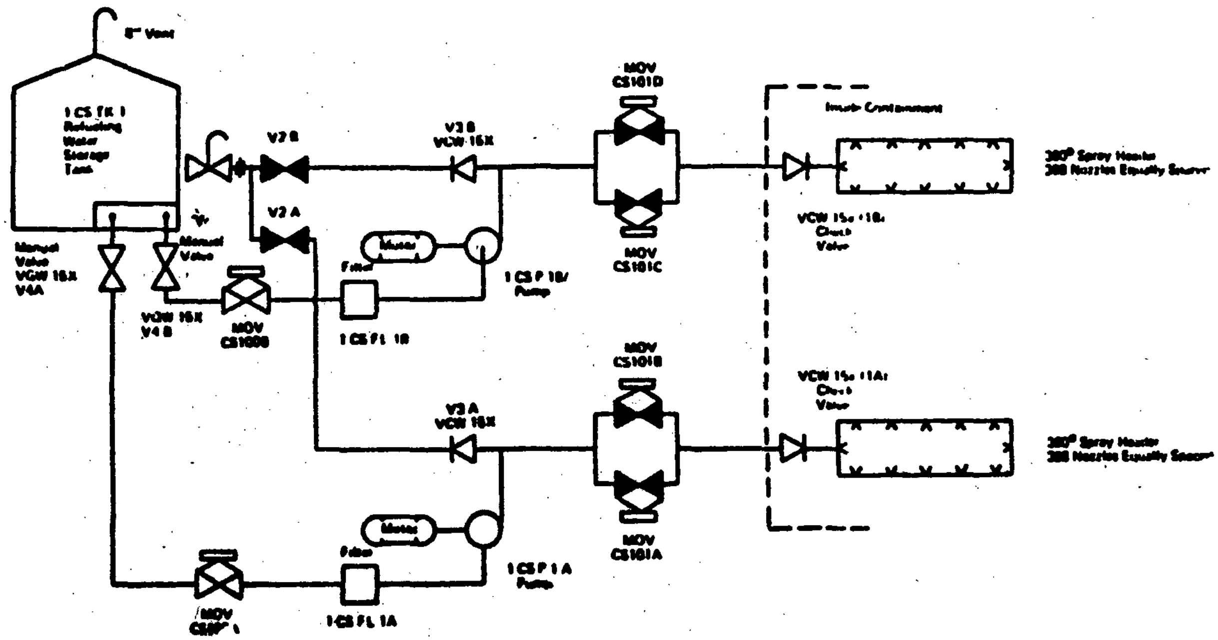

Figure A.1 CSIS Flow Diagram
(Reference 1)

$$F(Base) = F(Sequence\ 1) + F(Sequence\ 2) + \ldots + F(Sequence\ 13) \quad (1)$$

The contribution from each sequence was calculated by multiplying the initiating event frequency by the point estimate unavailabilities for the system failures associated with that sequence. For example, the contribution from the S_2C sequence is determined by multiplying the frequency of the small-small LOCA initiator f_{S_2} by the unavailability of the CSIS, Q_{CSIS}.

$$F(S_2C) = f_{S_2} \cdot Q_{CSIS} \quad . \quad (2)$$

Using the WASH-1400 data,

$$f_{S_2} = 10^{-3}\ year^{-1}$$

$$Q_{CSIS} = 2.4 \times 10^{-3}$$

Therefore

$$F(S_2C) = 2.4 \times 10^{-6}\ year^{-1}$$

In a similar manner, the core melt frequencies for each sequence in Table 4.1 were calculated. Their resulting sum is:

$$F(Base) = 4.3 \times 10^{-5}\ year^{-1}$$

This nominal value is then used as a basis for comparison when calculating the effects of component outage.

The second task identified in Section 3.2.1 was to calculate the core melt frequency assuming a given system or component were unavailable (F(SYS) or F(COMP)). This translates into solving the equation for core melt frequency with the specific system or component unavailability equal to 1.0. In determining F(SYS) for the example CSIS, $Q_{CSIS} = 1.0$ is substituted into equation (2). Of the sequences comprising the risk model, the CSIS only appears in the S_2C sequence. The core melt frequency for the S_2C sequence, assuming unavailability of the CSIS, simply becomes the initiator probability

$$F'(S_2C) = (10^{-3}\ \text{year}^{-1}) \cdot (1.0)$$

Substituting this value in equation (1)

$$F(CSIS) = 1.02 \times 10^{-3}\ \text{year}^{-1}$$

The importance of the CSIS is then given by the ratio of F(CSIS) to F(Base).

$$I(CSIS) = 24$$

This ratio means that, if both trains of the CSIS are disabled the likelihood of core melt is increased by a factor of 24. Since LCO preclude outage of both CSIS trains during power operation, this value is a measure of the additional risk should this LCO inadvertently be violated.

To calculate the importance of individual components, the unavailabilities comprising the risk model (equation 1) must be examined in more detail. In general, each system unavailability is comprised of contributions from hardware failures (Q_H), test and maintenance (Q_{TM}), and common mode failures (Q_{CM}). Hardware failures can be grouped according to the number of individual component failures required to fail the system. Generally, only contributions from single failures (Q_S) and double failures (Q_D) are significant contributors to the system unavailability.

For the CSIS, the nominal values for those contributors are

$$\left.\begin{array}{l} Q_S = 4.4 \times 10^{-7} \\ Q_D = 3.2 \times 10^{-4} \end{array}\right\} Q_H$$

$$Q_{TM} = 1.5 \times 10^{-4}$$

$$Q_{CM} = 1.9 \times 10^{-3}$$

In calculating the importance of a single CSIS pump, the CSIS reduced fault tree* was evaluated using a failure probability of 1.0 for one pump. Since the outage of a single pump effectively disables one train of the CSIS, there are many single failures in the redundant train which can fail the system. Thus the hardware contribution increases to

$$Q_H' = 1.8 \times 10^{-2}$$

As discussed in Section 3.2.1, it was assumed that LCO are not violated when calculating the importance of component outages. Hence, if the pump is assumed to be out of service, there is no other maintenance contribution.

$$Q_{TM}' = \varepsilon$$

Likewise, the common mode contribution must be examined to see if it is still applicable under the assumed condition of pump outage. The common mode contribution to CSIS unavailability is comprised of a calibration error of the Consequence Limiting Control System (CLCS) sensors which provide the initiation signal for the CSIS; and a failure to close the recirculation valves in both trains after the monthly test. Both of these events are included in the reduced fault tree as contributors to the individual failure probabilities for each train. Hence, they contribute through the revised hardware unavailability, Q_H'. Since the redundant train is out of service the

* Appendix II of WASH-1400, page II-273.

common mode contribution which accounts for coupling of these events is no longer applicable. Hence, the CSIS unavailability given that one pump is unavailable, is

$$Q_{CSIS}' = Q_H'$$

$$Q_{CSIS}' = 1.8 \times 10^{-2}$$

This value is then substituted into equation (1) and a revised core melt frequency is determined.

$$F(\text{CSIS pump}) = 5.9 \times 10^{-5}$$

The importance is then determined by

$$I(\text{CSIS pump}) = \frac{F(\text{CSIS pump})}{F(\text{Base})}$$

$$I(\text{CSIS pump}) = 1.4$$

This means that the core melt frequency is increased by a factor of 1.4 when a single CSIS pump (or one CSIS train) is taken out of service.

APPENDIX II

ESF COMPONENT STATUS MONITORING DATA

This appendix provides a comprehensive listing of the monitoring techniques for the ESF components considered in this investigation. This information is compiled in two large tables: Table II-1 for the PWR and Table II-2 for the BWR. The first column of each table lists the component using the same numbering scheme as WASH-1400. A brief description of the component location or function is provided to assist in identification of each entry in the table. The importance of each component as calculated by the methodology described in Section 3 and illustrated in Appendix I, is given in the second column of the tables. The remaining two columns summarize the information obtained during the plant visits. The specific monitoring technique used for each component is summarized in the third column, and clarifying comments or additional information is presented in the last entry. More detailed discussions of the different monitoring techniques, as well as illustrative photographs, are included in Section 4.

Table II-1

PWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE*	MONITORING TECHNIQUES	COMMENTS
Accumulators (ACC)			
Accumulators (3) Store water for injection into core.	7.2	• Annunciator on hi/low ACC pressure. • Annunciator on hi/low ACC level. • ACC level and pressure meters on outer console. • Illuminated annunciator light may also be tagged if ACC is unavailable.	• LCO pevent outage of more than 1 ACC at any given time. • If an ACC were taken out of service, MOV 1865 (A,B, or C) might also be closed. This would also be annunciated, and presumably the MOV switch on the console tagged.
MOV's 1865A, B, and C N.O., upstream of two check valves in ACC discharge line	7.2	• Indicator light with control switch on inner console. Control switch should be tagged if valve out for maintenance. • Annunciator if valve is closed. ("SI Valve Out of Position" annunciator also used for other key valves).	• Electric power removed from this valve.
MOV's 1720 A, B, and C N.C., permit ACC discharge into RHR line.	7.2	• Indicator light with control switch on inner console. Control switch should be tagged if valve out for maintenance.	• If this valve were left open and RHR line depressurized, accumulator discharge would initiate alarm.
HCV's 1851A, B, and C N.C., admit coolant to ACC.	7.2	• Indicator light with control switch on outer console. Control switch should be tagged if valve out for maintenance. • Annunciator on hi/low ACC level. • ACC level meter on outer console.	• Valve outage only impacts ACC availability if outage affects pressure or inventory in ACC.

*Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-1 (Continued)

PWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE*	MONITORING TECHNIQUES	COMMENTS
ACC - continued HCV's 1853A, B, and C N.C., admit N_2 to ACC to maintain pressure.	7.2	• Indicator light with control switch on outer console. Control switch should be tagged if valve out for maintenance. • Annunciator on hi/low ACC pressure. • ACC pressure meter on outer console.	• Valve 'outage' only impacts ACC availability if outage affects pressure or inventory in ACC.
HCV's 1852A, B, and C N.C., ACC drain valves	7.2	• Indicator light with control switch on outer console. Control switch should be tagged if valve out for maintenance. • Annunciator on hi/low ACC level. • ACC level meter on outer console.	• Valve 'outage' only impacts ACC availability if outage affects pressure or inventory in ACC.
ACC Vent Valves (3) N.C., release N_2 from ACC	7.2	• Indicator light with control switch on outer console. Control switch should be tagged if valve out for maintenance. • Annunciator on hi/low ACC pressure. • ACC pressure meter on outer console.	• Valve 'outage' only impacts ACC availability if outage affects pressure or inventory in ACC.
High Pressure Injection System (HPIS)			
Refueling Water Storage Tank (RWST) Source of water for HPIS, LPIS, and CSIS	32	• Annunciator on lo and lo-lo RWST level. • Level displayed on meters on outer console.	• RWST from Unit 2 capable of supplying HPIS of Unit 1. Risk analysis does not reflect this recent design change. • RWST importance calculation incorporates impact of outage on LPIS and CSIS as well as HPIS.

*Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-1(Continued)

PWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE *	MONITORING TECHNIQUE	COMMENTS
HPIS - continued Manual Valve I-CS-25 N.O., in single line from RWST. Upstream of LPIS junction.	32	• No indication in CR. • HPIS flow measurements would indirectly indicate valve position. • Local check of valve alignment performed weekly.	• Valve is key locked open. Shift supervisor controls key. • Valve position is checked periodically. • Valve closure would also affect LPIS. Importance calculations incorporate this contribution.
Manual Valve SI-24 N.O., in single line from RWST, downstream of LPIS junction.	30	• No indication in CR. • HPIS flow measurements would indirectly indicate valve position. • Local check of valve alignment performed weekly.	• Valve is key locked open. Shift supervisor controls key. • Valve position is checked periodically.
MOV's 1115 B and D N.C., in parallel lines leading to charging pump suction header.	1.5	• Indicator lights with control switch on inner console. Control switch should be tagged if out for maintenance.	
MOV's 1267A, 1269A, and 1270A N.O., admit water from charging pump suction header A to individual pumps.	1.0	• Indicator lights with control switch on outer console. Control switch may be tagged if valve is closed during pump maintenance.	• Valve only closed when performing maintenance on charging pump. In this instance charging pump controls would be tagged.

*Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-1(Continued)

PWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE *	MONITORING TECHNIQUE	COMMENTS
HPIS - continued			
Charging Pumps 1-CH-P-1A, B and C Deliver water to core during HPIS and HPRS operation.	1.0	• Indicator lights with control switch on inner console. Pump control switch tagged if out for maintenance. • Annunciator if pump is unavailable.	• MOV's isolating pump would closed during maintenance. This would be evident by indicator lights and perhaps tags on MOV control. • Importance calculation reflects contribution to HPRS.
MOV's 1286A, B, and C N.O., between pump discharge and header leading to BIT.	1.0	• Indicator lights with control switch on outer console. Control switch should be tagged if out for maintenance.*	• Valves only closed during pump maintenance as flow paths are used in normal CVCS operation.
MOV 1867 A and B (BIT inlet valves) N.C., in parallel lines between pump discharge header and BIT. Open on SICS signal to divert flow from charging line to BIT.	1.7	• Indicator lights with control switch on inner console. Control switch should be tagged if out for maintenance.	• Successful operation of BIT inlet valves would also be indicated by increasing BIT pressure which is displayed on a meter on the outer console.
Boron Injection Tank (BIT) Store boric acid for HPIS	30	• No direct indication; however, depending on nature of outage, several annunciators for BIT or boric acid system may be actuated. Also BIT inlet and outlet MOV's would be de-energized and tagged during maintenance.	• LCO preclude taking BIT out of service when reactor is at power. • Risk calculation assumes isolation of BIT will fail HPIS.

* Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-1(Continued)

PWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE *	MONITORING TECHNIQUE	COMMENTS
<u>HPIS - continued</u>			
BIT Heaters (2) Maintain temperature in BIT.	1.6	• No direct indication in CR. • Annunciator on lo BIT temperature.	
Boric Acid Piping Trace Heating Circuits (2) Maintain temperature in boric acid lines which provide inventory to BIT.	1.4	• Operability indicated by several red lights on a side panel. Light intensity increases when there is a failure in heat tracing circuit. • Heat tracing operability checked locally every 8 hours. • Annunciator on heat tracing circuit trouble.	• Unreliability of existing monitoring system has caused the 8 hour local check. • Indicator lights on panel display monitor other non-safety related lines as well. Hence, operator cannot determine if fault is in HPIS line. • Monitoring system and heat tracing circuit being redesigned & modified at time of study
MOV's 1867 D and C (BIT Outlet Valves) N.C. in parallel paths between BIT and cold leg injection header.	1.7	• Indicator lights with control switch on inner console. Control switch should be tagged if valve out for maintenance.	• Failure of BIT outlet valves to open on demand would be annunciated by hi BIT pressure
Manual Valves 1866 D, E, and F N.O., in cold leg discharge lines.	1.1	• No indication in CR.	• MOV is tack-welded in position. Welds are checked once a year. • Special procedures are followed for any valve maintenance.

* Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-1 (Continued)

PWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE*	MONITORING TECHNIQUE	COMMENTS
HPIS - continued			
Charging Pump Cooling Water Pumps (2) provide coolant to pump seals.	1.8	• Indicator lights with control switch on inner console. May not tag switch if pump out for maintenance. • Annunciator on low discharge pressure when pump is operating, but no annunciation when standby pump is taken out of service.	• One pump must be operating (control switch in "hand" position) and the other in "auto" at all times. If one pump is down for maintenance, the control switch is turned to "off". LCO limit the allow able time for maintenance. • Importance calculation reflec contribution to HPRS.
Charging Pump Service Water Pumps (2) provide coolant to remove heat from intermediate seal HX's and lube oil coolers.	1.8	• Same as for Charging Pump Cooling Water Pumps.	• Same as for Charging Pump Cooling Water Pumps.
High Pressure Recirculation System (HPRS)			• Some components previously addressed as part of HPIS evaluation.
MOV's 1863 A and B N.C., admit water from LPRS pump discharge to charging pump suction headers.	1.6	• Indicator lights with control switch on inner console. Switch should be tagged if valve is out for maintenance.	
MOV's 1869 A and B N.C., admit water from charging pump discharge headers to hot leg injection lines.	1.6	• Indicator lights with key operated control switch on inner console. Key controlled by shift supervisor. • Annunciator if valves are open ("SI Valve out of position annunciator" also used for other key valves).	• Breaker open, hence no power available to open valves fro CP. Yellow sign attached by magnet indicates this to ope ator (sign is very easily displaced).

*Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-1(Continued)

PWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE *	MONITORING TECHNIQUE	COMMENTS
HPRS - continued			
MOV's 1267 B, 1269B, and 1270B N.O., admit flow from LPIS Train A to charging pump suction.	1.0	• Indicator lights with control switch in outer console. Control switch may be tagged if out for maintenance, or if charging pumps are out for maintenance.	• Valves only closed when charging pumps are out for maintenance. In this instance charging pump controls would also be tagged.
MOV's 1287 A, B, and C N.O., between charging pump discharge and one of hot leg injection headers.	1.0	• Indicator lights with control switch on outer console. Control switch should be tagged if valve out for maintenance.	• Valves only closed during pump maintenance. In this instance charging pump controls would also be tagged.
MOV 1842 N.C., admits water from charging pump discharge header to cold leg injection (used to bypass BIT)	1.0	• Indicator lights with control switch on inner console. Control switch should be tagged if valve out for maintenance.	
Low Pressure Injection System (LPIS)			• Some components already addressed as part of HPIS.
MOV 1862 A and B N.O., in parallel lines which deliver water from RWST to LPIS pumps.	2.9	• Indicator lights with control switch on inner console. Control switch should be tagged if valve out for maintenance. • Annunciator if valve is closed ("SI Valve Out of Position" annunciator also used for other key valves).	• At the time of the WASH-1400 analysis there was only one valve in a single line which fed both LPIS pumps. The design has now been changed to two parallel flow paths each having a MOV. The importance calculations are for the current design.

* Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-1(Continued)

PWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE *	MONITORING TECHNIQUE	COMMENTS
LPIS-continued Manual Valves A03 & B03 N.O. in LPIS pump suction lines downstream of MOV's 1862A and B.	2.9	• No indication in CR. • Local check of valve alignment performed weekly.	• Importance calculation reflects contribution to LPRS.
LPIS Pumps Supply water for low pressure injection and recirculation operation.	2.9	• Indicator lights with control switch on inner console. Control switch tagged if pump out for maintenance. • Annunciator if pump is unavailable.	• Importance calculation reflects contribution to LPRS.
MOV's 1864A and B N.O. in LPIS pump discharge lines.	1.2	• Indicator lights with control switch on inner console. Control switch should be tagged if valve out for maintenance.	
MOV 1890C N.O., in single line which provides water to cold leg injection header.	3.3	• Indicator lights with control switch on inner console. Power has been removed from this valve so all lights are out, and therefore no direct indication of valve position in CR. • Valve is tagged locally.	• LCO prohibit valve closure during operation. • Valve is manually operable and near similar (though not tagged) valves. • Valve tested and position checked quarterly.
MOV's 1890A and B N.C., permit LPIS injection into hot legs.	2.9	• Indicator lights with key locked actuation switch on inner console. Power has been removed from this valve so both lights are out.	

* Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-1(Continued)

PWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE *	MONITORING TECHNIQUE	COMMENTS
Low Pressure Recirculation System (LPRS)			• Some LPRS components previously addressed as part of LPIS evaluations.
MOV's 1860A and B N.C., in parallel lines between sump and LPIS pump suction.	2.8	• Indicator lights with control switch on inner console. Switch should be tagged if valve out for maintenance.	
MOV's 1862 A and B N.O., in parallel lines which deliver water from RWST to LPIS pumps. Must close when transfering to LPRS operation.	3.1	• Indicator lights with control switch on inner console. Control switch should be tagged if valve out for maintenance. • Annunciator if valve is closed ("SI valve Out of Position" annunciator also used for other key valves).	• See note on MOV 1862 design change under LPIS. • Valve position defining unavailable state is different for LPRS than for LPIS; hence a separate calculation is performed.
Containment Spray Injection System (CSIS)			• RWST already evaluated as part of HPIS importance calculations.
Manual Valves V4A and B N.O., in parallel suction lines from RWST.	1.4	• No indication in CR. • Local check of valve alignment performed weekly.	
MOV's CS100A and B N.O., in parallel suction lines from RWST, downstream of manual valves V4A and B.	1.4	• Indicator lights with control switch on inner console. Control switch should be tagged if valve out for maintenance.	

* Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-1(Continued)

PWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE*	MONITORING TECHNIQUE	COMMENTS
CSIS -continued CSIS Pumps 1A and B Deliver water from RWST to spray nozzles in containment.	1.4	• Indicator lights with control switch on inner console. Control switch should be tagged if pump out for maintenance. • Annunciator if pump out of service.	• MOV's isolating pump would presumably be closed during maintenance. This would be evident by indicator lights and perhaps a tag on the MOV control display.
MOV's CS101A, B, C and D N.C., in parallel paths downstream of each pump discharge (A and B are downstream of pump A; C and D are downstream of pump B).	1.0	• Indicator lights with control switch on inner console. Control switch should be tagged if valve out for maintenance.	
Spray Headers and Nozzles (one each train) spray water into containment	1.4	• No indication in CR.	• Presumably MOV's CS101 A and B or C and D would be closed in the affected loop if maintenance were required on these components. This would be evident by the indicator lights and perhaps a tag on the MOV control display.

* Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-1 (Continued)

PWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE*	MONITORING TECHNIQUE	COMMENTS
<u>CSIS - continued</u>			
Manual Valves V2A and B N.C., in test lines returning flow to RWST.	1.4	• No indication in CR. • Dual verification of valve closure after pump test. • Local check of valve alignment performed weekly.	
<u>Containment Spray Recirculation System (CSRS)</u>			
Electric Motor Driven Pumps Inside Containment.	1.0	• Indicator lights with control switch on inner console Only pump control display with a blue light. Should be tagged if pump out for maintenance. • Annunciator if pump out of service.	• Blue indicator light indicates pump shaft rotation during testing. Pump is tested "dry" (no water in spray lines) & run only long enough to verify rotation and amperage.
Heat Exchangers for trains with pumps inside containment.	1.0	• No indication in CR. • Meters on outer console monitor spray temperature, cooling water flow, and service water radiation level when system is operational.	• Heat exchanger kept empty to avoid corrosion problems with service water. Water detector on shell side of HX actuates an annunciator. • Pressure tested at refueling.
Spray Header and Nozzle Assemblies for trains with pumps inside containment.	1.0	• No indication in CR.	• Importance calculation incorporates contribution from CHRS.

* Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-1(Continued)

PWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE*	MONITORING STATUS	COMMENTS
CSRS - continued			
MOV's RS 155A and B N.O., in suction lines for pumps outside containment.	1.1	• Indicator lights with control switch on inner console.Control switch should be tagged if valve out for maintenance.	
Electric Motor Driven Pumps outside containment.	1.1	• Indicator lights with control switch on inner console. Control switch should be tagged if pump out for maintenance. • Annunciator if pump out of service.	• MOV's on suction and discharge line of pump out for maintenance would presumably be closed and thus not in their standby positions. • LCO precludes pump outage in excess of 72 hours.
MOV's RS 156A and B N.O., in discharge lines for pumps outside containment.	1.1	• Indicator lights with control switch on inner console. Control switch should be tagged if valve out for maintenance.	
Heat Exchangers for trains with pumps outside containment.	1.1	• No indication in CR. • Meters on outer console monitor spray temperature and cooling water flow when system is operational.	• Importance calculation incorporates contribution from CHRS.
Spray Header and Nozzle Assemblies for trains with Pumps outside containment.	1.1	• No indication in CR.	

* Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-1 (Continued)

PWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE*	MONITORING TECHNIQUE	COMMENTS
Containment Heat Removal System (CHRS)			• CSRS/CHRS HX's listed under CSRS.
MOV's SW 103A, B, C and D N.C., in parallel lines in each of two lines drawing water from intake canal. (Valves open on CLCS Hi-Hi signal).	1.0	• Indicator lights with control switch on inner console. Control switch may be tagged if valve is out for maintenance.	• Brass covers are placed over control switch to prevent accidental opening of these valves when operator means to operate the condensate valves which have identical controls immediately below the SW103 valve controls.
MOV's SW 104A, B, C and D N.O., admits water to CSRS HX's.	1.0(Valves A and B) 1.1(Valves C and D)	• Indicator lights with control switch on inner console. Control switch may be tagged if valve is out for maintenance.	
MOV's SW 105A, B, C and D N.O., in discharge line from each HX.	1.0(Valves A and B) 1.1(Valves C and D)	• Indicator lights with control switch on inner console. Control switch may be tagged if valve is out for maintenance.	
Manual Valves XV1A20, XV1B20 XV2A20, and XV2B20 N.O., vent air at HX inlet.	1.0(Valves 1A20 and 1B20) 1.1(Valves 2A20 and 2B20)	• No indication in CR.	

* Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-1 (Continued)

PWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE*	MONITORING TECHNIQUE	COMMENTS
<u>CHRS - continued</u> Manual Valves XV1A21, XV1B21 XV2A21, and XV2B21 N.O., vent air at HX outlet.	1.0 (Valves 1A21 and 1B21) 1.1 (Valves 2A21 and 2B21)	• No indication in CR.	
<u>Auxiliary Feedwater System (AFWS)</u>			• Design changes since the completion of WASH-1400 allow the AFWS of Unit 2 to supply Unit 1, and provide two CST's for each unit. AFW pump suction can be taken directly from either a 100,000 gal. tank (preferred) or a 110,000 gal. tank (the one present at the time WASH-1400 was performed). Each of these two tanks can be replenished by a 300,000 gal. tank by opening manual valves. This additional capability has not been included in the importance calculations.
Condensate Storage Tank (CST) source of water for AFWS.	1840	• Annunciator on lo CST level. • Level recorder on outer console.	
Manual Valves XV168 and 183 N.O., in lines from CST to electrically driven AFW pumps.	1.7	• No indication in CR. • Local check of valve alignment performed weekly. Independent verification of position after maintenance.	

* Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-1 (Continued)

PWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE*	MONITORING TECHNIQUE	COMMENTS
AFWS - continued			
Electric AFW Pumps(2)	1.7	• Indicator lights with control switch. Control switch should be tagged if pump out for maintenance. • Annunciator if pump is unavailable.	
Manual Valve XV153 N.O., in line from CST to turbine driven AFW pump.	16	• No indication in CR. • Local check of valve alignment performed weekly. Independent verification of position after maintenance.	
Turbine Drive and Turbine Driven AFW Pump.	16	• No indication in CR.	• If turbine driven pump were unavailable, MOV 102 & COV 102 would be closed with power removed (indicator lights out). The displays would not be tagged.
Manual Valves XV140 and 141 XV150 and 151 XV170 and 171 N.O., in parallel paths from each AFW pump discharge to the two AFW headers.	1.0	• No indication in CR. • Local check of valve alignment performed weekly.	• Valves only closed during pump maintenance, in which case pump outage would be indicated as noted for respective pumps. Independent verification of correct valve position after completion of maintenance. • Single valve closure has negligible effect on risk. Closure of one pair of valves has same effect as outage of the associated pump.

* Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-1(Continued)

PWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE*	MONITORING TECHNIQUE	COMMENTS
AFWS-continued MOV's N.O., in the 6 lines from two injection headers to main feed lines.	1.0	• Indicator lights with control switch on inner console. Control switches should be tagged if valve out for maintenance.	• Valves only used to isolate steam generators. Independent verification of correct valve position after completion of maintenance. • Single valve closure has negligible effect. • Closure of one pair which isolates a steam generator also has negligible impact as adequate heat removal can be achieved through only one steam generator.
Manual Valves (N.O.) in the 6 lines from the two injection headers to the main feed lines.	1.0	• No indication in CR.	• Valves only used to isolate steam generators. Independent verification of correct valve position after completion of maintenance. • Single valve closure has negligible effect. • Closure of one pair which isolate a steam generator aslo has negligible impact as adequate heat removal can be achieved through only one steam generator.

* Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-1 (Continued)

PWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE*	MONITORING TECHNIQUE	COMMENTS
AFWS-continued Manual Valves (N.O.) in Turbine Drive Steam Supply Lines	1.0	• No indication in CR. • Local check of valve alignment performed weekly.	• Valves closed only to perform maintenance on turbine drive and when isolating steam generator. Independent verification of correct valve position after completion of maintenance
MOV 102 N.C., admits steam to turbine drive; in parallel path with SOV 102	1.0	• Indicator lights and control switch on inner console. Switch should be tagged if out for maintenance.	
SOV 102 N.C., admits steam to turbine drive; in parallel path with MOV 102.	16	• Indicator lights and control switch on inner console. Switch should be tagged if out for maintenance.	
Diesel Generators 2: one dedicated to Unit 1, the other shared between units.	1.5	• "First Out" annunciator when diesel is taken out of service. • "Auto-exercise switch" would be in exercise position and "auto-start disabled" light illuminated. • Energy supply breaker control switch in pull-to-lock position. • Diesel generator panel may be tagged.	• Prior to taking a diesel out of service, the swing diesel is dedicated to the affected unit. Importance calculations assume this has been done. • Diesel generator panel is on the side of the control room, on a wall perpendicular to the wall with the outer console.

* Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-2

BWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE*	MONITORING TECHNIQUE	COMMENTS
Reactor Core Isolation Cooling System (RCIC)			
Condensate Storage Tank (CST) Source of water for RCIC and HPCI	7.0	• Annunciator on lo CST level. • Meter on RCIC panel. • Chart recorder on inner console also records CST level.	• Water can also be drawn from suppression pool, but operator action is required to realign valves. • Importance calculations include impact on HPCI operation. • CST from Unit 3 can be used to supply Unit 2.
MOV's 15, 16, and 131 (15 and 16 N.O.; 131 N.C.) in steam supply line for turbine.	1.1	• Indicator lights with control switch on RCIC panel. Control switch would be tagged if valves are out for maintenance.	
Turbine Driven Pump	1.1	• Indicator lights with control switch on RCIC panel. Control switch would be tagged if pump is out for maintenance. • Some maintenance outages may trip an annunciation (e.g., removing power from a logic bus).	• Control switches for MOV's isolating pump would also be tagged in the event of pump maintenance.
Turbine Stop Valve and Control Valve	1.1	• Indicator lights on RCIC panel. Display would be tagged if valves are out for maintenance.	
Locked-Open Valve in pump suction line.	1.1	• No indication in CR.	

*Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-2(Continued)

BWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE*	MONITORING TECHNIQUE	COMMENTS
RCIC (continued)			
MOV 18 in pump suction line	1.1	• Indicator lights with control switch on RCIC panel. Control switch would be tagged if valve is out for maintenance.	
MOV 20 N.O., downstream of flow meter in pump discharge line.	1.1	• Indicator lights with control switch on RCIC panel. Control switch would be tagged if valve out for maintenance.	
MOV 21 N.C. in pump discharge line, downstream of test line.	1.1	• Indicator lights with control switch on RCIC panel. Control switch would be tagged if valve out for maintenance.	
MOV 30 and MOV(HPCI) N.C., in test line returning fluid to CST.	1.1 (See comment)	• Indicator lights with control switch on RCIC panel. Control switch would be tagged if valve out for maintenance.	• WASH-1400 assumed that coolant lost through test line would fail RCIC. Plant operators disagree with this assumption.
MOV 27 N.C. in min. flow bypass; returns water to suppression pool.	1.1 (See comment)	• Indicator lights with control switch on RCIC panel. Control switch would be tagged if valve out for maintenance.	• WASH-1400 assumed that coolant lost through the minimum recirculation line would fail the RCIC. Plant operators disagree with this assumption.
Locked-Open Valve in Turbine Steam Discharge Line.	1.1	• Indicator lights with control switch on RCIC panel. Control switch would be tagged if valve out for maintenance.	

* Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-2 (Continued)

BWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE*	MONITORING TECHNIQUE	COMMENTS
RCIC (continued)			
Oil Pump Supplying Oil to Turbine Control Valve	1.1	• No indication in CR.	
High Pressure Coolant Injection System (HPCI)			•CST listed under RCIC evaluations.
MOV's 15 and 16 N.O., in steam supply line to turbine.	1.1	• Indicator lights with control switch on HPCI panel. Control switch would be tagged during valve maintenance.	
MOV 14 N.C., admits steam to turbine.	1.1	• Indicator lights with control switch on HPCI panel. Control switch would be tagged during valve maintenance.	
Turbine Driven Booster Pump and High Pressure Pump.	1.1	• No indication in CR. • Some maintenance outages may trop an annunciator (e.g., removing power from a logic bus).	•Control switches for MOV's isolating pump would be tagged if pump is out for maintenance.
Turbine Stop Valve and Control Valve	1.1	• Indicator lights on HPCI panel. Display would be tagged during valve maintenance.	
Locked-Open Valve in pump suction line from CST.	1.1	• No indication in CR.	

* Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-2 (Continued)

BWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE*	MONITORING TECHNIQUE	COMMENTS
HPCI (continued)			
MOV 17 N.O., in pump suction line from CST.	1.1	• Indicator lights with control switch on HPCI panel. Control switch would be tagged during valve maintenance.	
MOV 20 N.O. downstream of flowmeter in pump discharge.	1.1	• Indicator lights with control switch on HPCI panel. Control switch would be tagged during valve maintenance.	
MOV 19 N.C. downstream of test line junction in pump discharge.	1.1	• Indicator lights with control switch on HPCI panel. Control switch would be tagged during valve maintenance.	
MOV 21, 29, and 31 N.C., in test lines. Return water to CST or suppression pool.	1.1 (See comment)	• Indicator lights with control switch on HPCI panel. Control switch would be tagged during valve maintenance.	• WASH-1400 assumed that coolant lost through test line would fail HPCI. Plant operators disagree with this assumption.
Valve in Minimum Flow Bypass Line. N.C.	1.1 (See comment)	• Indicator lights with control switch on HPCI panel. Control switch would be tagged during valve maintenance.	• WASH-1400 assumed that coolant lost through minimum flow bypass line would fail HPCI. Plant operators disagree with this assumption.
Locked-Open Valve downstream of drain pot in turbine discharge.	1.1	• No indication in CR.	

* Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency

Table II-2(Continued)

BWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE*	MONITORING TECHNIQUE	COMMENTS
HPCI (continued)			
Oil Pump Supplying Oil to Turbine Control Valves.	1.1	• Indicator lights with control switch on HPCI panel. Control switch would be tagged if pump were out for maintenance.	• HPCI will not operate when this pump is unavailable.
Automatic Depressurization System (ADS)			
ADS Valves (5)	1.0	• Indicator lights with control switch on main steam isolation panel. Control switch would be tagged if valve were unavailable for some reason. • Annunciator if valve in open position.	• No maintenance performed during plant operation. • The 5 ADS valve displays are part of overall safety valve display. The ADS valves are labeled by colored tape to distinguish them from the other safety valves.
Low Pressure Coolant Injection System (LPCI)			
MOV's 13A, C, B, D N.O., in pump suction lines.	1.0	• Indicator lights with control switch on RHR panel. Control switches would be tagged during valve maintenance. • Annunciator if power is removed from valve motors.	
Pumps 35A, C, B, D	1.0	• Indicator lights with control switch on RHR panel. Control switches would be tagged during pump maintenance. • Some maintenance outages may trip an annunciator.	• Control switches for MOV's isolating pump would be tagged during pump maintenance.

* Importance is defines as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-2(Continued)

BWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE*	MONITORING TECHNIQUE	COMMENTS
LPCI - continued Locked-Open Valves 28A, B, C, and D in pump discharge lines downstream of HX's	1.0	• No indication in CR.	
MOV 20 allows flow from all pumps to enter either injection leg.(See comment).	1.0 (See comment)	• Indicator lights with control switch on RHR panel. Indicator lights are both out as power has been removed from this MOV. Control switch would be tagged during valve maintenance. • Annunciator if valve is opened.	• At the time of WASH-1400, plant had a loop selection logic to enable injection from all 4 pumps to the intact recirculation line (in case of a recirculation line break). MOV 20 was key locked open to permit flow to either recirculation line. This logic has now been removed and the valve is key locked closed creating two independent LPCI trains.
MOV's 15A and B N.O. in injection legs.	9.7	• Indicator lights with control switch on RHR panel. Control switch would be tagged during valve maintenance.	
MOV's 25A and B N.C. in injection legs.	9.7	• Indicator lights with control switch and RHR panel. Control switch would be tagged during valve maintenance.	
Valves 81A and B Locked-Open in injection lines inside containment.	9.7	• Indicator lights on RHR panel. Display would be tagged during valve maintenance.	

* Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-2 (Continued)

BWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE*	MONITORING TECHNIQUE	COMMENTS
LPCI (continued)			
Control Valves 46A and B In injection lines inside containment.	9.7	• Indicator lights on RHR panel. Display would be tagged during valve maintenance.	
MOV's 39A and B N.C. in torus test and spray lines.	9.7	• Indicator lights with control switch on RHR panel. Control switch would be tagged during valve maintenance.	
MOV 33 N.C. to pressure vessel head spray	9.7	• Indicator lights with control switch on RHR panel. Control switch would be tagged during valve maintenance.	
Core Spray Injection System (CSIS)			
MOV's 7A and C, B and D N.O. in pump suction lines from suppression pool.	1.0	• Indicator lights with control switch on CSIS panel. Control switch would be tagged if valves out for maintenance.	
Pumps 37A and C, B and D	1.0	• Indicator lights with control switch on CSIS panel. Control switch would be tagged if pump out for maintenance. • Some maintenance outages may trip an annunciator.	
Locked-Open Valves 63A and C, B and D in pump discharge lines.	1.0	• No indication in CR.	• Local inspection of valve position periodically. • Shift supervisor controls key required to operate valve.

* Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-2(Continued)

BWR ESF STATUS MONITORING

COMPONENT	IMPORTANCE*	MONITORING TECHNIQUE	COMMENTS
CSIS - continued			
MOV 11A and B N.O. in separate injection lines	1.0	• Indicator lights with control switch on CSIS panel. Control switch would be tagged if valves out for maintenance.	
MOV 12A and B N.C. in separate injection lines	1.0	• Indicator lights with control switch on CSIS panel. Control switch would be tagged if valves out for maintenance	
Locked-Open Valves V14A and B in separate injection lines inside containment	1.0	• Indicator lights on CSIS panel. Display would be tagged if valves out for maintenance.	
MOV's 26A and B N.C. in test line that injects water into torus	1.0	• Indicator lights with control switch on CSIS panel. Control switch would be tagged if valves out for maintenance.	
Locked-Closed Valves V16A and B, and V8A, B C, and D in lines from CST to pump suction lines.	1.0	• No indication in CR	• If two of these valves (e.g., 16A and 8A or 8C) are left open suppression pool would be drained. Single valve left open has no effect. • Valves are key locked closed. Shift supervisor controls key.
Emergency Service Water System (ESWS)			
Valve 506 Locked-Open in discharge line leading from reactor building cooling water HX's.	2700	• No indication in CR.	• Only component whose outage impacts ESWS availability. Other components have no significant effect on risk.

*Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency.

Table II-2(Continued)

BWR ESF COMPONENT STATUS MONITORING

COMPONENT	IMPORTANCE*	MONITORING TECHNIQUE	COMMENTS
High Pressure Service Water System (HPSW)			Only components whose outage impacts HPSWS availability are listed.
Pumps A,B,C,D	1.1	• Indicator lights with control switch on RHR panel. Control switch would be tagged if pump out for maintenance. • Some maintenance outages may trip an annunciator.	
MOV's 10-89A,B,C,D N.C. in discharge lines of HX's for LPRS	3.9	• Indicator lights with control switch on RHR panel. Control switch would be tagged if valves out for maintenance.	
Valves V11A and B N.O. downstream of header from each pair of HX discharge.	3.9	• No indication in CR.	
MOV 2486 N.O. admits water to discharge basin	34	• Indicator lights with control switch on outer console (across room from ECCS panels). Control switch would be tagged if valve out for maintenance.	
MOV 2803 N.C. admits water to cooling tower if reservoir level is low (HPSW operates in recirc. mode).	1.1	• Indicator lights with control switch on outer console (across room from ECCS panels). Control switch would be tagged if valve out for maintenance.	

*Importance is defined as the ratio of the core melt frequency with the indicated component out of service to the nominal WASH-1400 core melt frequency

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