POWERPLANT PRODUCTIVITY IMPROVEMENT STUDY

DEMONSTRATION OF THE
DOE/MRI METHODOLOGY

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POWERPLANT PRODUCTIVITY IMPROVEMENT STUDY

Final Report
Project 1, Task 2

Demonstration of the DOE/MRI Methodology

November 17, 1978

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FOREWORD

This is the final report for the Illinois power plant productivity study. It presents the results of Tasks I - V and Quad Cities I Interim Reports.

The work was performed by Trident Engineering Associates, Inc. of Annapolis, Maryland for the Illinois Commerce Commission. The project was overseen by the Department of Energy and the Energy Resources Center. The utilities which participated in the study included Commonwealth Edison Company and Illinois Power Company.

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ABSTRACT

Recently, the Department of Energy has published a methodology* which has been designed to aid in the analysis of power plant performance as it relates to plant productivity and reliability. Basically, the methodology involves analyzing a unit's past outage history in order to develop meantime-to-outage and meantime-to-restore coefficients for each of the power plant's major components. From these reliability coefficients a mathematical performance model is developed which can be used to analyze future productivity behavior of the plant.

This model can be used to assess the impact of an improvement project or corrective action on unit productivity parameters such as heat rate, capacity factor, availability, or equivalent availability. To date, only details for the assessment of improvement projects on a power plant's equivalent availability have been published. The DOE methodology analyzes:

- the effect of component redundancy on unit equivalent availability;
- the effect of component reliability on unit equivalent availability;
- a component's outage trend to project the component's future outage rate;

and presents the results in a documented, organized approach to power plant productivity assessment. While the DOE methodology has additional capabilities, such as identifying root causes and evaluating corrective actions for a unit's lost productivity, it was the purpose of this study to consider only the impact of improvement projects on a unit's equivalent availability.

* U. S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Vols. I - IV, February 1978

The methodology being tested was developed under contract for DOE. This methodology has been distributed by DOE as a potential tool for the utility industry to assess and evaluate productivity and reliability problems of existing and future units.

The purpose of this study is twofold. The first purpose is to illustrate for the utilities how to apply the methodology. Thus, this report contains the analysis performed by applying the methodology at three units of Illinois power plants. The units evaluated were Wood River 5, Quad Cities 1, and Quad Cities 2. A total of eight improvement projects were evaluated at these units. Thus, all outage data and equations used have been included in the report in order to facilitate utility reproduction of the given results.

The following table shows the maximum change in equivalent availability (ΔEA) predicted for various improvement projects evaluated at Wood River 5 and Quad Cities 1 and 2. As can be seen, some of the improvements have a significant effect on the unit equivalent availability. For example, installing cooling towers at Quad Cities 2 could increase the equivalent availability up to .0317. The cost of the improvements were not evaluated as part of the study. Evaluation of the cost of these projects will be accomplished in a separate phase of the Illinois Power Plant Productivity Improvement Study.

The second purpose of the report is to evaluate the methodology as a useful tool for utilities. Trident found the Department of Energy methodology is valid in that it appropriately applies statistical techniques to power plant performance data to calculate a detailed assessment of a unit's future productivity performance. Trident recommends a number of modifications which should be developed and implemented in order to facilitate the application of the methodology by individual utilities and increase the usefulness of the results.

MAXIMUM CHANGE IN EQUIVALENT AVAILABILITY
FOR IMPROVEMENT PROJECTS EVALUATED

Unit	Improvement Project	Δ EA (Maximum)
Wood River 5	Install sixth pulverizer	.0234
	Continuous pulverizer maintenance	.0194
	Addition of new tube bundles	.00106
Quad Cities 1	Moisture drain tank modification	.00131
	Electromatic relief valves modification	.0108
Quad Cities 2	Install drag valve	.0155
	Install Amertap system	.00374
	Install cooling tower	.0317

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1.0 DETAILED PROJECT SUMMARY

1.1 BACKGROUND

In recent years, the subject of public utility power plant productivity and reliability has received significant attention from both Federal and State agencies and from within the utilities. In April 1974, the then Federal Energy Office established the InterAgency Task Group on Power Plant Reliability. The objective of this task group was to develop recommendations for improving the productivity of large fossil-fueled and nuclear electric power plants by identifying the key problems leading to reduced plant availability and possible corrective actions to improve reliability.

Among the recommendations resulting from the task group deliberations were:

- "• The utilities should soon establish industrywide definitive goals and coordinated action plans for improvements in the productivity of its nuclear and large coal-fired units.
- The utilities should improve their reliability data base, especially for large coal-fired units.
- The utilities and architect/engineers should maximize replication of existing unit designs and limit custom designing to essential differences in requirements.
- The FEA, or other appropriate agency, should undertake a detailed analysis and comparison study of successful and below average performance units."

Some of these requirements have already been addressed by the FEA, other government agencies, or by utility connected activities. The FEA sponsored a study, conducted simultaneously by three independent contractors (of whom Trident was one), to characterize and quantify the major reasons for low productivity in large, base-loaded nuclear and fossil-fueled power plants. Twelve plants participated in this study.

In the course of conducting this study, Trident was required to make an assessment of the operation, maintenance, management, and manning of two large fossil-fueled electrical generating units and two large

nuclear-fueled units. The two units to be examined in each category were to consist of one unit with a recent history of above average reliability and one unit with a history of lesser reliability, as measured by available industry statistics. The objective of the study was to determine, insofar as possible, the underlying causes of high and low reliability in comparable plants; and through a knowledge of these "root" causes, to make recommendations having the potential to produce a meaningful increase in the productivity of lower performing generating units. For study purposes, productivity was measured by consideration of plant availability, capacity factor, and forced outage rate, concentrating on those factors causing outages and failures which result in increased fuel use by replacement units. The scope of the study was not limited to outages and failures, but also considered additional factors such as fuel quality, maintenance management, personnel training, design objectives, policy matters, and other similar factors which have a bearing on overall productivity. The findings of this Trident study were categorized into generic root causes.

The FEA, as a follow-on to this root cause assessment study, sponsored one study which has as its focus, providing an assessment of the potential benefits to utilities and consumers of improved power plant availability. A second study initiated at the same time by FEA had as its purpose, the development of improved techniques for assessing cause of power plant unavailability, and the development of quantitative techniques for predicting changes in power availability resulting from corrective actions.

Details of this latter study have recently been published in a Department of Energy report*. In this study, the equivalent availability was used as the performance factor to assess changes in power plant productivity resulting from corrective actions. To demonstrate the technique, it was applied to two power plants; Marshall 4 and Turkey Point 4.

The methodologies developed and documented in these two follow-on studies are being given infield demonstrations through cooperative projects undertaken by DOE with the Ohio Public Utilities Commission and with the Illinois Commerce Commission.

* U. S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Vols. I-IV, February 1978.

The DOE/ICC cooperative project has the following objectives:

- to demonstrate DOE approaches to assess costs and benefits of performance improvements;
- to document Illinois utilities' approaches to improve performance;
- to assess historical performance of coal and nuclear plants in Illinois;
- to assess potential regulatory and incentives policies.

The ICC contracted with Trident and the Energy Resources Center, University of Illinois, for accomplishing the first of these objectives. The scope of Trident's work was to select candidate improvement projects and make estimates of the resulting improvement in plant productivity. The Energy Resources Center is developing the estimated costs and benefits of the candidate improvements.

In the Illinois study, which was administered by the Illinois Commerce Commission, the methodology was applied to three units by Trident Engineering Associates. At each unit, two or three improvement projects were to be evaluated in order to estimate the change in unit equivalent availability if these projects were implemented. This report contains the analysis performed by Trident in the Illinois Power Plant Productivity Study. While the DOE methodology has additional capabilities, such as identifying root causes and evaluating corrective actions for a unit's lost productivity, these aspects of the DOE methodology were not considered in this study.

1.2 OBJECTIVES OF STUDY

The objectives of the study were:

- Application of Department of Energy methodology to Illinois power plants in order to evaluate the change in unit equivalent availability for three different improvement projects at each unit;

- Simplify the method where possible;
- Development and validation of reliability models for two units using the DOE methodology as outlined in the DOE Powerplant Productivity Improvement Study, Volume II, Volume III, and Summary Report,
 - recommendation and substantiation of specific units to be modeled for Commission approval;
 - estimation of plant-specific parameters (generic data to be used whenever plant-specific data is unavailable or unsuitable);
- Estimation of changes in equivalent availability as outlined in the DOE Powerplant Productivity Improvement Study, Volume II, Volume III, and Summary Report;
 - select and propose a minimum of three performance projects per unit for study (selection to be based on technical and economic feasibility, significance of the project, and data availability). Contractor to substantiate improvement projects selected in the proposal to the Commission staff,
 - estimate future equivalent availability by implementation of specific performance improvement projects,
 - estimate future baseline performance without improvement projects to determine change in equivalent availability that would be attainable through project implementation;
- Demonstration of validity of the model by comparing historical equivalent availability data for a unit with values produced by the model over the same period;
- Critique of the DOE methodology as applied above,
 - discussion of problems encountered in methodology application,
 - suggestion of possible improvements to the methodology;

Figure 1.1 - Diagram showing interrelationship of key tasks

- Conduct workshops for the utility, Commission staff, and Energy Resources Center technical staff,
 - discussion of technical progress and problems encountered in applying the DOE methodology,
 - description and critique of the DOE methodology.

1.3 METHOD OF APPROACH

Trident identified five key tasks in order to meet the requirements of the Illinois Commerce Commission's statement of work. The objective of each task and the approach to each task is outlined in sections 1.3.1 through 1.3.5 below. These key tasks and their interrelationship are shown in Figure 1.1. The type, scope, and extent of various documentation which were gathered and reviewed are detailed in the individual tasks.

1.3.1 Task I

Initially in the study, Trident was to select two Illinois power plants in order to evaluate the Department of Energy methodology. The details of this selection process are given in chapter 2. The result of this analysis led to Wood River 5 and Quad Cities 2 being chosen for study. The scope of work was later expanded to include a third unit -- Quad Cities 1.

1.3.2 Task II

To apply the Department of Energy methodology, certain technical, operational, and maintenance information, as well as data on the unit's full and partial outages, were required. The objective of this task was to

collect this information. The unit's technical, operational, and maintenance information was used in Task III to perform a functional analysis.

Trident collected the needed information in two phases. For Phase A, Trident performed a previsit unit analysis. Phase B involved data collection on-site at each unit.

Phase A was accomplished by obtaining the following information from the utilities:

- Unit One-Line Schematics

This information was needed to understand the plant layout, the types of equipment used, and the level of redundancy of the equipment.

L

- Effect of Equipment on Unit Output

This information was needed to establish the unit capacity loss in megawatts when a piece of equipment is not in operation.

- Listing of All Full and Partial Outages between January 1, 1973 and December 31, 1977

This information was needed because the Department of Energy methodology uses unit outage data as an input to project a component or system's equivalent meantime-to-restore and equivalent meantime-to-outage. Since the unavailability factors to be found in Task IV were limited to the five most recent years of unit operation, Trident requested the outage data only for the years 1973 through 1977. The information required for each outage was

- Outage date;
- Outage duration, hours;
- Unit capacity loss, megawatts;
- Outage cause.

- Unit Modifications between January 1, 1973 and December 31, 1977

This information was required because, following a unit modification, the meantime-to-outage or meantime-to-restore for a component or system may significantly change; therefore, the system future failure rates could change. In this situation, the DOE methodology* recommends the use of the component's meantime-to-outage or meantime-to-restore after the modification for projecting the component's or system's future failure and repair rates.

- Unit Practices with Regard to Failed Equipment Repair

The information was needed to determine whether equipment failures can be repaired with the unit on-line. For example, the reactor recirculating pumps at a BWR unit cannot be repaired with the unit operational since these pumps are located inside the containment and are not accessible during reactor operation. Such information is needed because the choice of equations used to calculate a system's meantime-to-outage or meantime-to-restore are dependent on such unit repair practices.

- Failure of Equipment not Resulting in a Unit Outage

This information was needed because the accuracy of the DOE methodology is improved by computing meantime-to-outage for a parallel redundant system based on component outage data rather than system outage data. Since equipment failure in parallel redundant systems often results in no unit power reduction, all noncurtailing outages were requested.

- Annual Unit Operating Reports

These reports were useful in gaining more information on unit outages or system modifications.

* U. S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Vol. III, pp. 61-62, February 1978.

- Unit Heat Balance

This was requested in order to evaluate the effect an improvement project might have on the unit heat rate.

- Unit Organizational Chart

This information was helpful in selecting cognizant personnel for on-site interviews.

- Description of Major Components in Units

This information was needed to understand unit operation and maintenance practices.

In response to the above data requests, Trident received the following information from Illinois Power:

- Detailed information regarding piping, instrumentation, design details, and an electric one-line diagram;
- Summary of Wood River 5 capacity reduction due to equipment outages;
- List of all full and partial outages from 1973 to 1977 including outage data, outage duration, and EEI outage cause. However, the capacity loss was not given in the years 1973-1975 for partial outages;
- Major modifications to Wood River 5 between 1973 and 1977;
- Information regarding repair practices;
- Listing of all noncurtailing outages from 1973-1977;
- Narrative description of events that occurred at Wood River 5 from 1964 to 1977;

- Unit heat balance at 50% load, 75% load, guaranteed turbine rating valves wide open flow -- all heaters in service and valves wide open -- top heater out of service with a 5% overpressure condition;
- Unit organizational chart;
- Report prepared by the unit architect-engineer describing unit equipment.

Additionally, Trident received fuel consumption data for Wood River 5 from 1973 - 1977.

Commonwealth Edison responded to the above data requests with the following information:

- Detailed plant schematics;
- Summary of Quad Cities 2 capacity reduction for redundant components;
- List of full and partial outages for the years 1973-1977. This information included outage date, duration, and cause. However, the capacity loss was not available from EEI data but from other company sources;
- Semi-annual reports containing major modifications to the unit;
- Final Safety Analysis Report (FSAR) for the Quad Cities station from which could be inferred the information regarding repair practices and equipment descriptions;
- Semi-annual reports from 1973 through 1977;
- Unit heat balance;
- Unit organizational chart.

In addition, Trident used information on Quad Cities 2 published in Nuclear Regulatory Commission gray books and in the component nonoperating hour report.

From this information, Trident developed simplified one-line diagrams showing the significant components in the power generating cycle. Also, a chronological list of outages was developed illustrating the following information:

- Outage date (day, month, year);
- Component(s) involved in outage;
- Outage description;
- Outage classification
 - Forced or scheduled,
 - Administrative, conditional, loss of function;
- Time of day unit taken off line;
- Time of day unit returned to service.

Phase A of this task was completed as scheduled on June 13, 1978 for Wood River 5 and June 18, 1978 for Quad Cities 2. The fast and efficient response of Illinois Power and Commonwealth Edison to the detailed data requests was a major factor in meeting the above dates.

Phase B of this task consisted of plant visits to determine more detailed information on outages causes. Outage causes were needed in order to correctly assess the outage time among the different unavailability factors in the DOE methodology. In addition, these visits yielded needed information on capacity loss in partial outages and unit repair practices with respect to failed equipment. Also, as described in chapter 4 of this report, the improvement projects were discussed with the utilities on these visits.

The Wood River 5 unit visit was conducted between June 14-16, 1978. Trident sent three investigators for this visit. They were as follows:

- Dr. Martin E. Nelson, Project Manager;
- Dr. Maido Saarlus, Coal Unit Group Leader;
- Dr. Eugene L. Keating, Coal Unit Team Member.

Table 1.1 summarizes the data collection process at Wood River 5. This table shows the utility people interviewed, dates of interviews, information collected, and any utility reports reviewed.

The Quad Cities 2 unit visit was conducted between June 19-21, 1978. Investigators for this unit were as follows:

- Dr. Martin E. Nelson, Project Manager;
- Dr. Clyde C. Richard, Nuclear Unit Group Leader;
- David K. Wehe, Nuclear Unit Team Member.

Table 1.2 summarizes the data collected at Quad Cities 2. Similarly to Table 1.1, the people interviewed, dates of interviews, information collected, and utility reports reviewed are given in this table. Since Quad Cities 1 unit was not involved in the project at the time of this visit, Trident later revisited Quad Cities on August 14, 1978 to collect the needed information on unit 1.

1.3.3 Task III

The purpose of this task was to develop functional diagrams for each unit. Different levels of functional diagrams can be constructed with the DOE methodology. For example, functional diagrams can be constructed at the generic function level, subfunction level, and equipment function level.

A generic function level diagram is the simplest functional diagram that can be constructed for any power plant. It contains only four elements, which show the four basic functions inherent in a conventional power plant. These functions are steam generation, power conversion, steam condensation, and feed. In addition, shared systems are included in this diagram as a fifth system.

TABLE 1.1

DATA COLLECTED AT WOOD RIVER 5 UNIT

Interview Date	Utility Personnel Interviewed	Information Collected	Utility Reports Reviewed
6/14/78 6/15/78	P. Licklider, Illinois Power Performance Supervisor D. Doiron, Wood River Results Supervisor	Review unit schematics and establish capacity loss for equipment failure and repair practices	
6/14/78 6/15/78 6/16/78	D. Hoem, Illinois Power (Assigned to Clinton nuclear unit) R. Hayes, Baldwin Operations Supervisor D. Doiron R. Winch, Wood River Operations Supervisor	Review outages to determine components repaired in outage and component repair time "	Operating Logs Mechanical and electrical time records EEI reports
6/14/78	D. Doiron	Details on work performed during major scheduled annual outages	Wood River 5 annual outage reports
6/15/78	P. Hutchison, Wood River Plant Manager	Improvement projects under consideration at Wood River 5	
6/14/78 6/15/78 6/16/78	L. Yarger, Wood River Assistant Plant Manager H. Heisler, Illinois Power Supervisor of Energy Systems P. Hutchison	Causes of outages at Wood River 5	
6/16/78	D. Doiron	Load history of Wood River 5	Generating Logs
6/15/78	D. Doiron	Performance of high pressure heaters and new H.P. rotor	Internal reports

TABLE 1.2

DATA COLLECTED AT QUAD CITIES 2 UNIT

Interview Date	Utility Personnel Interviewed	Information Collected	Utility Reports Reviewed
6/19/78	R. Petri, Assistant Lead Nuclear Engineer	Load performance and technical specifications at Quad Cities 2	Unit technical specs Unit power performance graphs
6/19/78	J. Schnitzmeyer, Technical Staff Engineer M. Kooi, Technical Staff Engineer	Outage data and capacity loss information on partial outages	Morning reports EEI reports
6/19/78	G. Conschack, Unit 1 Operating Engineer	Quad Cities 2 operation data sources	Cardex Work requests at Quad Cities 2 Master out-of-service card logs
6/20/78	R. Murray, Technical Staff Engineer D. Clark, Technical Staff Engineer	Unit modifications	Modification logs and modification reports
6/21/78	K. Graesser, Administrative Assistant J. Gudac, Assistant Superintendent K. Lonergan, Outage Coordinator	Improvement projects under consideration at Quad Cities 2	
6/21/78	G. Conschack	Review unit schematics and effects of equipment failure on unit output	
6/19/78 6/20/78 6/21/78	K. Lonergan J. Wunderlich, Technical Staff Engineering Assistant	Data sources available at Quad Cities 2	AMPS report (issued by Gen. Elec.)

The subfunction level diagram is the next simplest diagram that can be used to model a power plant. It shows the important systems within each of the generic functions. Generally, several systems are identified for each generic function. A typical subfunction level diagram will have 10 to 15 elements.

On the basis of the subfunction level diagram, the equipment function level diagram is constructed. This diagram shows all the major components as well as the number of such components within a system. Interconnections between systems and components can be modeled in this diagram, but this always is not necessary. The level of complexity of this diagram depends on the types of components selected to be shown. For example, including all valves and piping can significantly increase a diagram's complexity. The important criterion for deciding to include a component is whether it has contributed, or will probably contribute, to unit outages. Generally, several components will be shown for each system in the subfunction diagram. A typical equipment level diagram will contain approximately 30 to 50 elements.

Thus, Trident's objectives in this task were to develop the following functional diagrams:

- Generic function level diagrams;
- Subfunction level diagrams;
- Equipment function level diagrams.

In addition, in order to evaluate the effect on unit capacity loss for a failure of any system or component, Trident has performed a failure mode and effect analysis for each of the components in the equipment functional level diagram. This information was used in Task IV when evaluating a component's equivalent meantime-to-outage and equivalent meantime-to-restore. Trident constructed the functional diagrams using the information collected in Task II. The resulting equipment function level diagrams for all units was then evaluated to determine the following:

- Whether the outage data collected was sufficient to evaluate the reliability coefficients in the DOE methodology for each of the diagram's elements;

- Whether the diagrams were of sufficient detail to predict a change in unit equivalent availability for the improvement projects evaluated by Trident.

If either of the above conditions were not met, then additional outage data would have to be obtained. After constructing these diagrams, Trident found that it did indeed have all the needed information.

1.3.4 Task IV

The major objective of Task IV was to analyze each unit using the DOE methodology. The analysis for each unit:

- Develops applicable equivalent availability equations;
- Evaluates all coefficients $\left(\frac{em}{eM}\right)$ in the equivalent availability equations, as well as the Department of Energy unavailability coefficients (U_P , U_C , U_F);
- Validates the equations used;
- Develops projections on the $\left(\frac{em}{eM}\right)$ coefficients and the unit loss of function unavailability (U_F);
- Performs a statistical and sensitivity analysis on the $\left(\frac{em}{eM}\right)$ coefficients.

The Department of Energy methodology calculates equivalent availability (EA) from the equation:

$$EA = 1 - U_P - U_C - U_F \quad (1.1)$$

where

U_P = Administrative unavailability

U_C = Conditional unavailability

U_F = Loss of function unavailability

Administrative unavailability (U_P) is the unit unavailability due to regularly planned outages. Examples of administrative outages are reactor refueling at a nuclear unit, annual turbine inspection, or a boiler inspection at a coal unit.

Conditional unavailability (U_C) is the unit unavailability due to outages from a cause outside the power generation cycle. Examples of conditional outages are outages caused by a major natural disaster, lightning, failure of safety system, operator error, and operator training.

Loss of function unavailability (U_F) is the unit unavailability due to outages from equipment failure within the power generation cycle. Examples of loss of function outages are outages due to pump failure, tube leaks, etc.

Trident has calculated these unavailability coefficients (U_P , U_C , U_F) for different outage data bases. This was necessary to establish the validity of the equations used and to develop projections on unit equivalent availability. As shown in Table 1.3, nine outage data bases were used by Trident in analyzing data.

Trident did not incorporate the 1972 outage data into the analysis as discussed in the technical proposal because Quad Cities was not in commercial operation until 1973. However, in order to increase the data base to five years, Trident analyzed 1977 data for all units.

Two slightly different calculational procedures to find the unavailability coefficients were used at Quad Cities and Wood River 5 because of differences in the units' outages. At Quad Cities, many outages involved long ramps, which resulted in significant unit power changes during the outage. Thus, the energy lost in partial outages had to be graphically read from the Quad Cities power performance graphs. Thus, only the megawatt hours lost could be tabulated for Quad Cities outages. Conversely, outages at Wood River 5 involved near constant unit capacity loss during the outage. Thus, the capacity loss for an outage was based on Wood River 5 EEI data. Hence, the outage data at Wood River 5 gives the outage duration and capacity loss which can be used to find the energy lost due to an outage.

Table 1.4 gives the equations used to calculate the administrative unavailability. Equation (1.2) was used to find U_P at both Quad Cities units, since it relates megawatt hours lost in each outage to the administrative

TABLE 1.3

OUTAGE DATA BASES
USED IN ANALYSIS

1973

1974

1975

1976

1977

1973-74

1973-75

1973-76

1973-77

TABLE 1.4

EQUATIONS USED TO CALCULATE
ADMINISTRATIVE UNAVAILABILITY (U_p)

QUAD CITIES 1 AND 2

$$U_p = \frac{\sum_{i=1}^{N_p} \text{Megawatt hours lost in administrative outages}}{(T) (MDC)} \quad (1.2)$$

Where

T = Period time, hours

MDC = Unit maximum dependable capacity, MW

N_p = Number of administrative outages

WOOD RIVER 5

$$U_p = \frac{\sum_{i=1}^{N_p} d_i CL_i}{(T) (MDC)} \quad (1.3)$$

Where

d_i = i th administrative outage duration, hours

CL_i = i th administrative outage capacity loss, MW

unavailability. Equation (1.3) was used to find U_P for Wood River 5, since it relates outage duration and capacity loss to U_P . Equations (1.2) and (1.3) are slight modifications to the equations used in the DOE methodology*. These derivations are given in chapter 5.

Table 1.5 gives the equations used to calculate the conditional unavailability. Equation (1.4) was used to find U_C at Quad Cities since it involves the megawatt hours lost in each outage. Equation (1.5) was used to find U_C for Wood River 5, since it relates outage duration and capacity loss to U_C . These equations are slight modifications to the equations used in the DOE methodology**. These derivations are given in chapter 5.

The loss of function unavailability coefficient was found in a more complicated manner. First, the functional diagrams for both units were reviewed in order to write the appropriate equivalent availability equations. These functional diagrams are given in Figures 3.1 - 3.3 for Wood River 5 and Figures 4.1 - 4.3 for Quad Cities. The same functional diagrams were used for Quad Cities units 1 and 2. Each functional diagram contains a number of elements, each of which represents some power plant function. When the elements in these diagrams are in series, then the loss of function availability (U_F) can be calculated as:

$$U_F = \left[\sum_{j=1}^n \left(\frac{em}{eM} \right)_j \right] \frac{T_o}{T} = \left(\frac{em}{eM} \right) \frac{T_o}{T} \quad (1.6)$$

where

U_F = Loss of function availability

n = Number of elements in function diagram

j = j^{th} element in functional diagram

* U. S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Vol. II, p. 20, February 1978.

** Ibid, p. 22.

TABLE 1.5

EQUATIONS USED TO
CALCULATE CONDITIONAL UNAVAILABILITY (U_C)

QUAD CITIES 1 AND 2

$$U_C = \frac{\sum_{i=1}^{N_c} \text{Megawatt hours lost in conditional outages}}{(T) (MDC)} \quad (1.4)$$

Where

 T = Period time, hours MDC = Unit maximum dependable capacity, MW N_c = Number of conditional outages

WOOD RIVER 5

$$U_C = \frac{\sum_{i=1}^{N_c} d_i CL_i}{(T) (MDC)} \quad (1.5)$$

Where

 d_i = i^{th} conditional outage duration, hours CL_i = i^{th} conditional outage capacity loss, MW

- em_j = Equivalent meantime-to-restore of j^{th} element, hours
- eM_j = Equivalent meantime-to-outage of j^{th} element, hours
- T_o = Unit operational time, hours
- T = Period time, hours

Equation (1.6) is developed in chapter 5 of this report from the DOE methodology*. Thus, to determine U_F , the $\left(\frac{em}{eM}\right)$ ratio must be determined for each element in the function diagram.

The function diagrams have been developed at three levels for each unit:

- Generic level;
- Subfunction level;
- Equipment level.

For both Wood River 5 and Quad Cities, all elements at the generic and subfunction level diagrams are in a series configuration. Thus, U_F can be determined easily from these diagrams once the $\left(\frac{em}{eM}\right)$ ratios are determined for each element. However, the equipment level functional diagrams for both units contain a number of parallel configuration elements. Although this configuration can be handled in the DOE methodology, the computation of $\left(\frac{em}{eM}\right)$ is not as simple as in the series case.

To determine the $\left(\frac{em}{eM}\right)$ ratio, both the equivalent meantime-to-restore (em) and the equivalent meantime-to-outage coefficients (eM) must be determined separately. Equations to calculate these quantities are given in Tables 1.6 and 1.7.

Table 1.6 gives the equations used to calculate the equivalent meantime-to-restore coefficients of a component at the equipment level. Equations (1.7) and (1.8) are applicable for single series components, while equation (1.9) is recommended in the DOE methodology for application to parallel identical components. Equations (1.7) and (1.8) are derived in chapter 5 from the DOE methodology**. As discussed in chapter 5, equation (1.9)

* U. S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Vol. II, p. 27, February 1978.

** Ibid, p. 58.

TABLE 1.6

EQUATIONS USED TO CALCULATE
EQUIVALENT MEANTIME-TO-RESTORE

• Single series component

$$em_1 = m_1$$

where

$$m_1 = \left[\sum_{i=1}^N \frac{\text{Megawatt hours lost in loss of function outages}}{(N) \quad (MDC)} \right] \quad (1.7)$$

where

N = Number of full and partial loss of function outages

If all outages have resulted in the same capacity loss (CL), then equation (1.7) can be simplified to:

$$m_1 = \left[\sum_{i=1}^N \frac{d_i}{N} \right] \left[\frac{CL}{MDC} \right] \quad (1.8)$$

where

d_i = i^{th} loss of function outage duration, hours

(continued...)

TABLE 1.6

(Continued)

* n Parallel identical components (reparable with unit on line) *

$$em = \frac{\sum_{j=0}^{r-1} \binom{n}{j} M_1^j m_1^{n-j}}{n \binom{n-1}{r-1} M_1^{r-1} m_1^{n-r}} \quad (1.9)$$

Where

n = Total number of parallel components

r = Number of components required for full operation

M₁ = Found from equation (1.1)a) in Table 1.7

$$\binom{n}{j} = \frac{n!}{j! (n-j)!}$$

* U.S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Volume II, p. 58, February 1978.

can only be applied if the component is repairable with the unit on line. Thus, all parallel systems, which are repairable only with a full outage, were treated by Trident as a single series element.

The equivalent meantime-to-outage coefficients are computed by equations (1.10) and (1.11) given in Table 1.7. Equation (1.10) is applicable for single series components, while equation (1.11) is applicable only to parallel identical components which are repairable with the unit on line.

The loss of function unavailability coefficient U_F computed from equation (1.6) was then compared with the actual U_F which found as follows:

$$U_F \text{ actual} = \frac{\sum_{i=1}^{N_f} \text{Megawatt hours lost by loss of function outages}}{(T) (MDC)} \quad (1.12)$$

where

N_f = Number of loss of function outages

Trident compared loss of function unavailabilities for all nine outage data bases given in Table 1.3. The results showed excellent agreement between the U_F computed in these two manners for all units studied. This agreement established for Trident the correctness of the mathematical expressions and consistency of the data used in the analysis.

Predictions were then made on each unit's equivalent availability and loss of function unavailability for the years 1974-1978. Predictions were made using techniques discussed in both Volumes II and III of the DOE methodology*.

Two tests were then performed on the computed coefficients to estimate the reliability of the outage data. The first test involved a χ^2 test for both the meantime-to-outage and meantime-to-restore coefficients. This test was performed in order to establish a confidence level for the coefficients. Using a 90% confidence limit, a lower limit on the meantime-to-outage coefficient and an upper limit on the meantime-to-restore coefficient was computed for each component at all units. The equations

* U. S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Vol. II, pp. 104-107, 137-140, Vol. III, p. 71, February 1978.

TABLE 1.7

EQUATIONS USED TO CALCULATE
EQUIVALENT MEANTIME-TO-OUTAGE

- Single series component

$$eM = M_1 = \frac{T_o}{N} \quad (1.10)$$

where

T_o = Total operating time, hours

N = Number of full and partial loss of function outages

- n Parallel Identical components (repairable with unit on line) *

$$eM = \frac{\sum_{j=r}^n \binom{n}{j} M_1^j m_1^{n-j}}{n \binom{n-1}{r-1} M_1^{r-1} m_1^{n-r}} \quad (1.11)$$

where

n = Total number of parallel components

r = Number of components required for full operation

$$M_1 = \frac{r T_o}{N} \quad (1.11a)$$

N = Number of outages of all n identical components

m_1 = Found from equation (1.7) or equation (1.8) in Table 1.6

$$\binom{n}{j} = \frac{n!}{j! (n-j)!}$$

* U.S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, February 1978.

(1.13) and (1.14) used in this test are shown in Table 1.8. $\chi^2_{v,\alpha}$ is found from Table 1.9 if $v \leq 30$. If $v > 30$, then $\chi^2_{v,\alpha}$ can be found from equation (1.15) shown in Table 1.10. Equation (1.15) involves a factor which is tabulated as a function of $1-\alpha$ in Table 1.11. The χ^2 test was performed to establish $\left(\frac{em}{eM}\right)$ confidence limits. Details of the χ^2 test are given in the DOE methodology*.

The second test involved performing a sensitivity analysis on the $\left(\frac{em}{eM}\right)$ ratios. This analysis involved removing the largest outage based on megawatt hours lost in a component's history and computing the resulting $\left(\frac{em}{eM}\right)$ ratio. Since the data base is only five years long, a component's $\left(\frac{em}{eM}\right)$ ratio may easily be dominated by a single outage. Thus, this test was performed to determine the percentage differences in $\left(\frac{em}{eM}\right)$ due to the removal of each component's single largest outage.

1.3.5 Task V

The major objectives of Task V was to analyze each unit's improvement projects, using the DOE methodology, to determine the change in unit equivalent availability that would result from implementation of these projects. The selection of improvement projects for each unit is discussed in section 1.5. Trident's method of approach for performing the above analysis is described in this section of the report.

The calculation of $\left(\frac{em}{eM}\right)_{\text{baseline}}$ is found by using the techniques described in the DOE methodology**. Trident performed this calculation in three steps.

First, Trident plotted the cumulative equivalent full power outage time (C) for each component involved in the improvement project. Second, a correlation was performed on the plotted outage data as shown in the DOE methodology***. The following correlation was developed for each improvement project:

* U. S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Vol. II, p. C-30, February 1978.

** Ibid, Vol. III, pp. 55-75.

*** Ibid, Vol. III, pp. 64-65.

TABLE 1.8

 χ^2 TEST EQUATIONS

$$(M)_L = \frac{2M_1 f}{\chi^2_{2f+2, 1-\alpha}} \quad (1.13)$$

$$(m)_U = \frac{2m_1 f}{\chi^2_{2f, \alpha}} \quad (1.14)$$

where

M_L = Lower confidence level of meantime-to-outage

m_U = Upper confidence level of meantime-to-restore

M_1 = Meantime-to-outage

m_1 = Meantime-to-restore

α = Confidence level (taken as .9 in this study)

χ^2 = Determined from Table 1.9

f = Number of outages

TABLE 1.9
X² DISTRIBUTION

[illegible]

* U. S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, p. C-33, Feb. 1978.

TABLE 1.10

DETERMINATION OF $\chi^2_{\nu, \alpha}$ VALUE

Case 1:

$$\nu \leq 30$$

Use Table 1.9

Case 2:

$$\nu > 30$$

Find χ^2 from equation (1.15) below

$$\sqrt{2\chi^2_{\nu, \alpha}} = \sqrt{2\nu - 1} + Z \quad (1.15)$$

Z found from Table 1.11

Example:

$$\text{Let } \alpha = .1 \text{ and } \nu = 50 \quad (1.16)$$

Interpolating from Table 1.11 gives

$$Z = 1.2825 \quad (1.17)$$

Solving for χ^2 gives

$$\sqrt{2\chi^2_{50, .1}} = \sqrt{2(50) - 1} + 1.2825 \quad (1.18)$$

$$\chi^2_{50, .1} \approx 63.08 \quad (1.19)$$

TABLE 1.11*

Z VERSUS $1-\alpha$

[Used with equation (1.15) in Table 1.10]

Z	$1-\alpha$	Z	$1-\alpha$
-3.5	0.00023	+0.0	0.5000
-3.4	0.00034	+0.1	0.5398
-3.3	0.00048	+0.2	0.5793
-3.2	0.00069	+0.3	0.6179
-3.1	0.00097	+0.4	0.6554
-3.0	0.00135	+0.5	0.6915
-2.9	0.0019	+0.6	0.7257
-2.8	0.0026	+0.7	0.7580
-2.7	0.0035	+0.8	0.7881
-2.6	0.0047	+0.9	0.8159
-2.5	0.0062	+1.0	0.8413
-2.4	0.0082	+1.1	0.8643
-2.3	0.0107	+1.2	0.8849
-2.2	0.0139	+1.3	0.9032
-2.1	0.0179	+1.4	0.9192
-2.0	0.0228	+1.5	0.9332
-1.9	0.0287	+1.6	0.9452
-1.8	0.0359	+1.7	0.9554
-1.7	0.0446	+1.8	0.9641
-1.6	0.0548	+1.9	0.9713
-1.5	0.0668	+2.0	0.9773
-1.4	0.0808	+2.1	0.9821
-1.3	0.0968	+2.2	0.9861
-1.2	0.1151	+2.3	0.9893
-1.1	0.1357	+2.4	0.9918
-1.0	0.1587	+2.5	0.9938
-0.9	0.1841	+2.6	0.9953
-0.8	0.2119	+2.7	0.9965
-0.7	0.2420	+2.8	0.9974
-0.6	0.2743	+2.9	0.9981
-0.5	0.3085	+3.0	0.99865
-0.4	0.3446	+3.1	0.99903
-0.3	0.3821	+3.2	0.99931
-0.2	0.4207	+3.3	0.99952
-0.1	0.4602	+3.4	0.99966
-0.0	0.5000	+3.5	0.99977

* Calabro, S. R., Reliability Principles and Practices,
McGraw Hill, p. 350, 1962.

$$C = a_c + b_c T_o \quad (1.28)$$

where

a_c , b_c are correlation coefficients from a least squares best fit to the outage data from equation (1.28)

Third, as shown in the DOE methodology*, when equation (1.28) is used, the following result is obtained:

$$\left(\frac{em}{eM}\right)_{\text{baseline}} = b_c \quad (1.29)$$

The DOE method also provides an option for the use of a geometric projection** but doesn't provide criteria for the choice. Therefore, Trident chose the linear projection for the following reasons:

- Consistency with steady state outage assumption on which DOE method is based;
- No clear geometric trend in any of the components involved with the improvement projects;
- To simplify mathematical analysis.

However, Trident has included, for illustrative purposes, this technique with the Quad Cities analysis.

Equation (1.29) was then used in equation (1.27) to determine $\Delta \left(\frac{em}{eM}\right)$.

The Department of Energy methodology calculates equivalent availability (EA) from the equation:

* U. S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Vol. III, p. 71, February 1978.

** Ibid, p. 73.

$$EA = 1 - U_P - U_C - U_F \quad (1.1)$$

where

U_P = Administrative unavailability

U_C = Conditional unavailability

U_F = Loss of function unavailability

Thus, the change in equivalent availability (ΔEA) from an improvement project is found by the equation:

$$\Delta EA = -\Delta U_P - \Delta U_C - \Delta U_F \quad (1.20)$$

where

ΔU_P = Change in administrative unavailability due to improvement project

ΔU_C = Change in conditional unavailability due to improvement project

ΔU_F = Change in loss of function unavailability due to improvement project

Assuming the improvement projects selected do not affect the administrative or conditional unavailability, then

$$\Delta U_P = \Delta U_C = 0 \quad (1.21)$$

Putting equation (1.21) into equation (1.20) gives the result:

$$\Delta EA = -\Delta U_F \quad (1.22)$$

However, recalling equation (1.6), U_F is calculated as

$$U_F = \left[\sum_{j=1}^n \left(\frac{em}{eM} \right)_j \right] \frac{T_o}{T} \quad (1.6)$$

Putting equation (1.6) into (1.22) gives the following result:

$$\Delta EA = \left[-\sum_{j=1}^n \Delta \left(\frac{em}{eM} \right)_j \right] \frac{T_o}{T} \quad (1.23)$$

Assuming that the improvement project only affects element i in the functional diagram, then

$$\Delta \left(\frac{em}{eM} \right) = 0 \text{ for } j \neq i \quad (1.24)$$

Putting equation (1.24) into equation (1.23) gives

$$\Delta EA = \left[-\Delta \left(\frac{em}{eM} \right)_i \right] \frac{T_o}{T} \quad (1.25)$$

Equation (1.25) gives the change in unit equivalent availability due to a modification of element i in the unit's functional diagram. It is used to evaluate the improvement projects at Wood River 5 and Quad Cities. The subscript i will be dropped for the remainder of this report in order to simplify the writing of the equations. Thus equation (1.25) becomes

$$\Delta EA = - \left[\Delta \left(\frac{em}{eM} \right) \right] \frac{T_o}{T} \quad (1.26)$$

The change in equivalent meantime-to-restore to equivalent meantime-to-outage can be found as follows:

$$\Delta \left(\frac{em}{eM} \right) = \left(\frac{em}{eM} \right) - \left(\frac{em}{eM} \right)_{\text{baseline}} \quad (1.27)$$

where

$\left(\frac{em}{eM} \right)$ is based on improvement project performed on component

$\left(\frac{em}{eM} \right)_{\text{baseline}}$ is based on no improvement project on component

As stated in the DOE methodology*, the improvement program impact assessment generally "must be estimated on an 'ad hoc' basis, each case being unique and requiring considerable amount of judgement on the part of the analyst". Thus, Trident evaluated $\left(\frac{em}{eM}\right)$ by considering the improvement impact on the component's outage history and then made engineering estimates on the equivalent meantime-to-restore and equivalent meantime-to-outage. In addition, Trident performed a parameter study on the meantime-to-outage for cases where no data were available to evaluate the component outage rate used in the improvements.

Finally, the impact of future changes in administrative or conditional outages on the improvement projects has been estimated in the following manner:

T_o is defined by the equation

$$T_o = T - T_P - T_C - T_F \quad (1.30)$$

where

T_o = Unit operational time, hours

T = Period time, hours

T_P = Full outage time due to administrative outages, hours

T_C = Full outage time due to conditional outages, hours

T_F = Full outage time due to loss of function, hours

Dividing equation (1.30) by T gives

$$\frac{T_o}{T} = 1 - \frac{T_P}{T} - \frac{T_C}{T} - \frac{T_F}{T} \quad (1.31)$$

* U. S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Vol. III, February 1978, p. 77.

where

$$\frac{T_o}{T} = \text{Unit availability}$$

Thus, the future change in unit availability is given by

$$\Delta \frac{T_o}{T} = - \frac{\Delta T_P}{T} - \frac{\Delta T_C}{T} - \frac{\Delta T_F}{T} \quad (1.32)$$

where

$$\Delta \frac{T_o}{T} = \text{Future change in unit availability}$$

$$\frac{\Delta T_P}{T} = \text{Future change in administrative unavailability due to full outages}$$

$$\frac{\Delta T_C}{T} = \text{Future change in conditional unavailability due to full outages}$$

$$\frac{\Delta T_F}{T} = \text{Future change in loss of function unavailability due to full outages}$$

Using equation (1.32), the future availability for the unit can be found as:

$$\left(\frac{T_o}{T}\right)_{\text{future}} = \left(\frac{T_o}{T}\right)_{\text{historical}} + \frac{\Delta T_o}{T} \quad (1.33)$$

where

$$\left(\frac{T_o}{T}\right)_{\text{future}} = \text{Unit availability during its remaining life}$$

$$\left(\frac{T_o}{T}\right)_{\text{historical}} = \text{Unit availability prior to improvement}$$

Equation (1.33) is used in equation (1.25) to evaluate $\frac{T_o}{T}$ for the improvement projects. For this report, $\left(\frac{T_o}{T}\right)_{\text{historical}}$ is based on the 1973-1977 time period. $\Delta \frac{T_o}{T}$ was found for each unit by considering possible future changes in administrative, conditional, or loss of function outages at each unit.

1.4 IMPROVEMENT PROJECT SELECTION

The Department of Energy methodology is used to estimate the change in Wood River 5 and Quad Cities 1 and 2 equivalent availability produced by the implementation of specific performance improvement projects. Three improvement projects were analyzed at Wood River 5 and Quad Cities 2, while two improvement projects were evaluated at Quad Cities 1.

Trident did not choose improvement projects on the basis of a root cause investigation as discussed in the DOE methodology^{*}, since this was beyond the scope of work for the study. Instead, improvement projects were selected simply by listing potential improvement projects at each unit and selecting those which best met the criteria shown in Table 1.12. These criteria were developed jointly by Trident, Energy Resources Center, and the Illinois Commerce Commission. As is shown in Table 1.12, there are four essential and six desirable criteria.

The four essential criteria in Table 1.12 were developed for the following reasons. First, the problem selected needed to be related to a hardware problem since the change in equivalent availability is evaluated from a unit's outage data in the DOE methodology. Thus, an improvement project such as better personnel training could not be easily evaluated. Second, the problem selected needed to be repetitive in order to ensure better confidence in the reliability parameters, which are used to evaluate the project. If the project selected did not have a repetitive history, there would be a large statistical uncertainty in the equivalent meantime-to-outage and equivalent meantime-to-restore parameters. This would produce a high uncertainty in the ΔEA predicted from undertaking the improvement project. Third, the project needed to be suitable to the Department of

* U. S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Vol. 1, February 1978.

TABLE 1.12

IMPROVEMENT PROJECT
SELECTION CRITERIA

Essential Criteria	Desirable Criteria*
1. Hardware problem	1. Significant to plant operation
2. Repetitive problem	2. Undertaken or about to be undertaken by utility
3. Suitable to Department of Energy methodology	3. Outage cause well understood
4. Technically and economically feasible	4. Availability of improvement project
	5. Studied or recommended by utility
	6. Analyzed by a utility improvement project method

* Not necessarily in order of priority.

Energy methodology. Thus, for example, safety systems, which were not modeled in the unit functional diagrams, would not be involved with the improvement projects. Fourth, the problem had to have the appearance of being technically and economically feasible. Of course, the final determination of whether the project is considered economically feasible would be the financial gain derived from the Δ EA produced versus the cost to implement the project.

The improvement projects which passed the essential criteria were then compared to six desirable criteria, shown in Table 1.12, in order to make a final selection. The desirable criteria were developed for the following reasons. First, the problem selected was desired to be significant to plant operation. In other words, the projects selected should have had a large Δ EA impact on the unit. Second, at least one of the projects selected should have been undertaken or about to be undertaken by the utility. Thus the Δ EA experienced at the unit from this project could be actually compared against the predicted Δ EA from the DOE method in the future. Third, the outage cause should have been well understood. This criterion was developed to increase the confidence that the improvement project selected would, in fact, fix the problem. Fourth, there should have been good availability of improvement project cost data. This was desirable since the projects are to be cost evaluated by the Energy Resources Center. Fifth, one of the projects should have been studied or recommended by the utility. If the project has been recommended by the utility, then presumably the utility's rationale for undertaking the project could be contrasted with the analysis from the DOE methodology. It would be preferable if the project had been analyzed by a utility improvement project method since this would provide a comparison between a utility methodology and the DOE methodology for evaluating improvement projects.

1.4.1 Wood River 5 Improvement Projects

Table 1.13 gives a potential improvement list developed for Wood River 5. As can be seen, ten potential improvement projects were considered. Table 1.14 summarizes how these improvement projects meet the essential criteria given in Table 1.12. As can be seen, only four projects meet all the essential criteria. They are:

TABLE 1.13

IMPROVEMENT LIST FOR WOOD RIVER 5

Item	Reason	Comments
Boiler Retubing	Large number of recurrent outages with tube leaks	In 1976, 40% of the furnace division wall tubes were replaced. Although there have been fewer leaks since this improvement, a large number of outages still result from waterwall tube leaks. Some boiler tube leaks are due to the superheater which, because of its configuration, has a heavy bending moment which causes tube ruptures, tear-offs, and leaks. Undertaking this project would be very expensive.
Pulverizers: Add sixth for redundancy	Reduce number of partial outages	Wood River 5 needs all five pulverizers operating to reach its maximum dependable capacity of 398 MW. A failure of one drops the maximum unit output to approximately 340 MW. Although Wood River 5 has been recently limited to producing 360 MW for environmental reasons, a sixth pulverizer would remove an historical source of numerous unit load curtailments. Additionally, adding a sixth pulverizer could significantly increase the unit equivalent availability if and when the environmental constraints on the unit are lifted.
Coal Crusher: Increase capacity	Present equipment has limited capacity	The present coal crusher has a capacity which is 50% of the coal feed requirements at full power. However, Wood River 5 has recently installed a screen to filter out large chunks of coal from the feeder belt. Thus, this improvement is questionable for this study project consideration. Further, there are no outages directly traceable to this component.
High Pressure Heaters Install new tube bundles in all high pressure heaters	Improve flow and unit output	This improvement is about to be undertaken by utility. Plan is to first repair G heaters and then go to F heaters.
-40-		(Continued...)

IMPROVEMENT LIST FOR WOOD RIVER 5

(Continued)

Item	Reason	Comments
Condensate Pump Modify design	Reduce partial outages	When 5C condensate pump is operating, unit maximum output is dropped by 35 MW to 360 MW. This problem could be solved by reworking the outlet condensate piping from the 5C pump and removing a strainer presently in line.
Improve Condensate Install condensate polishing equipment	For reducing tube corrosion, and to reduce silica in condensate after start-up	After outage, full load may not be achieved for a couple of days for danger of silica deposits on tubes. This problem could be reduced by the installation of condensate polishing equipment. At present, Illinois Power is implementing this improvement. However, this problem is hard to model using the Department of Energy methodology.
Glycol Heater: Tube bundle replacement	Tube bundle replacement due to tube leakage	Improvement is about to be undertaken. Utility has ordered new tube bundles to reduce leakage
Ash Handling Pipe Move from present location	Capacity of pond is insufficient	Present ash handling pipe is being rerouted from the old location (under a switchyard and above circulating water pumps), due to need for greater capacity, to a new yard. However, there have been no outages due to this problem and, thus, this project would be difficult to handle using the DOE method.
Convert Boiler to Balanced Draft Boiler	For reduction of fly ash within the plant	Many plants are considering this improvement. However, lack of failure data on the inclusion of an induced draft fan may preclude this improvement from being considered by this model.
	-41-	(Continued...)

IMPROVEMENT LIST FOR WOOD RIVER 5

(Continued)

Item	Reason	Comments
Pulverizer Repairs Use continuous maintenance to repair	Reduce meantime-to-restore for pulverizer outages	Presently, mill outages are repaired by one-shift or two-shift maintenance which extends their duration. Repairs often are not performed on holidays and weekends, further extending pulverizer outages. Improvement project would be to see the Δ EA that could be achieved if all pulverizer outages were immediately repaired. Trident would use the repair times obtained for pulverizer outages in evaluating this project.

TABLE 1.14

EVALUATION OF IMPROVEMENT PROJECTS

AT WOOD RIVER 5

Item	Criteria			
	Hardware	Repetitive	Suitable to DOE	Feasible
Boiler Retubing	Yes	Yes	Uncertain	Uncertain
Add Pulverizers	Yes	Yes	Yes	Yes
Coal Crusher	Yes	No	Yes	Yes
High Pressure Heater	Yes	Yes	Yes	Yes
Condensate Pump	Yes	Yes	Yes	Yes
Improve Condensate	Yes	Yes	No	Yes
Glycol Heater	Yes	No	Yes	Yes
Ash Handling	Yes	Yes	No	Yes
Balanced Draft	Yes	Uncertain	Uncertain	Uncertain
Pulverizer (Mill) Repairs	Yes	Yes	Yes	Yes

- Add additional pulverizer;
- Add tube bundles to all high pressure heaters;
- Modify condensate pump;
- Use continuous maintenance on pulverizer repairs.

Of these projects, the condensate pump was not chosen because of its small significance on unit output.

Two other projects possibly could be analyzed. They are:

- Retubing boiler;
- Convert boiler to balanced draft.

While these last two projects are potentially very significant to unit operation, Trident felt they should not be evaluated because of some uncertainty in the application of the DOE methodology in their analysis.

All three improvement projects chosen, as shown in Table 1.15, appear to be significant to unit operation, their outage causes are well understood, and cost data should be available. In addition, inclusion of the feedwater heater improvement project gives an improvement which has been studied and recommended by the utility, as well as about to be undertaken by the utility. Thus, the improvement projects selected at Wood River 5 were consistent with the criteria established for their selection.

1.4.2 Quad Cities 2 Improvement Projects

Table 1.16 lists six potential improvement projects for Quad Cities 2. Table 1.17 shows how each specific project meets the essential criteria in Table 1.12. As shown, only three projects possibly meet the essential criteria. These are:

- Correct the feedwater regulating valve problem by change to a drag valve;

TABLE 1.15

IMPROVEMENT PROJECTS
FOR WOOD RIVER 5

1. Add sixth pulverizer coal system.
2. Install new tube bundles in all high pressure heaters.
3. Use three-shift maintenance to repair pulverizer outages.

TABLE 1.16

IMPROVEMENT LIST FOR QUAD CITIES 2

Item	Reason	Comments
Install Drag Feedwater Regulating Valves	Large number of lost megawatts to feedwater regulating valve caused outages	Boiling water reactors need good feedwater control to maintain reactor vessel water levels within narrow limits. Use of a drag valve could solve problem because it gives better flow control and less turbulence. Plant personnel also presently considering use of a hydraulic coupling flow control system on feed pumps for better flow regulation.
Install 100% Turbine Bypass System	Would reduce scrams from load rejections	Several plants of this design have 100% bypass capability. Quad Cities 2 has only 40% bypass. System appears to have adequate bypass lines. New valves, condenser modification, and change of orifice plates might upgrade system to 100% with minimal expense. Project not feasible because of technical licensing and analysis considerations.
Circulating Water System Modification	Significant partial load operation caused by cooling water limitation	Spray canal provided for closed cooling is unable to provide adequate heat removal to give acceptable low condenser temperatures over much of the year. Cooling towers and/or direct river water cooling would eliminate this restriction.
Feedwater Heater Drain Piping Modification	Uncertainty in operation at full load	History of instability in controlling drain flow from high pressure heaters at high load has resulted in lack of confidence in system. Repiping of system could possibly eliminate problem.
Torus Vacuum Relief Check Valves Modification	Common failure with potential for plant outage	9 of 12 needed for plant operation. To date, redundancy has been adequate to keep plant on-line. Repiping valves to outside torus as in Dresden plant would allow service with plant on line, giving greater reliability.
Condenser: Install Amertap cleaning system	Fouling of condenser	Fouling of condenser source of lost megawatts. Installation of Amertap system could reduce fouling.

TABLE 1.17

EVALUATION OF IMPROVEMENT PROJECTS
AT QUAD CITIES 2

Item	Criteria			
	Hardware	Repetitive	Suitable to DOE	Feasible
1. Feedwater Regulating Valves	Yes	Yes	Yes	Yes
2. 100% Turbine Bypass System	Yes	Yes	Yes	No
3. Circulating Water System Modification	Yes	Yes	Yes	Yes
4. Feedwater Heater Drain Piping	Yes	Yes	No	Yes
5. Torus Vacuum Relief Check Valves	Yes	Yes	No	Yes
6. Install Amertap System	Yes	Yes	Yes	Yes

- ◊ Install Amertap system to reduce condenser tube fouling;
- ◊ Modify the circulating water system by adding cooling towers.

There appears to be suitable outage data and plant derate data to evaluate all three of the projects. Additionally, three other problem areas were investigated. The 100% turbine bypass was eliminated because of technical licensing and analysis considerations. The bypass, if used, could result in reactor scrams. Modification of feedwater heater drain piping or torus vacuum relief check valves could not be modeled by the DOE methodology and thus was rejected for study. No specific outages have been detected for either of these two systems, making the development of meantime-to-outage and meantime-to-restore impossible from the data as presently analyzed. Thus, the improvement projects listed in Table 1.18 were analyzed.

1.4.3 Quad Cities 1 Improvement Projects

Table 1.19 lists five potential improvement projects for Quad Cities 1. This list was developed subject to the condition that improvement projects on unit 1 were not to be identical to those evaluated for unit 2. Table 1.20 shows that each project given in Table 1.19 meets the essential criteria in Table 1.12. Thus, the project selection was more difficult at unit 1 than unit 2.

The projects selected were:

- ◊ The moisture separator drain tank because it is significant and the outage cause well understood;
- ◊ The electromatic relief valves because the improvement had been studied by the utility and its implementation is being considered by the utility.

These projects are shown in Table 1.21.

The reactor feed pump recirculation line modification and scram reactivity fix were not chosen because of their relatively small impact on unit operation.

TABLE 1.18

IMPROVEMENT PROJECTS
FOR QUAD CITIES 2

1. Alterations to feedwater regulating valves.
2. Install Amertap system for condenser tube cleaning.
3. Modify circulating water system (ultimate heat sink) to remove operating restrictions.

TABLE 1.19
IMPROVEMENT LIST FOR QUAD CITIES 1

Item	Reason	Comments
Change Fuel Assemblies	Large number of loss megawatts due to long ramps after outages	Present fuel assemblies are of the 7x7 design which, consequently, limit the reactor to ramps as low as 3 MW/hr. when returning to power after an outage. Switching to 8x8 fuel could increase the ramp rate Quad Cities 1 would be allowed by the fuel warranty.
Moisture Drain Tank Modification	Source of numerous turbine trips	Present design of moisture drain tank results in high vibration level during start-up. This has caused instrumentation to fail, causing level to rise in the drain tank and to backup into the moisture separator, which results in a turbine trip. Movement of transmitters off drain tanks and installation of new faster acting valves should eliminate problem.
Electromatic Relief Valve Modification	Source of unit outages due to valve leaks and unit pumping power losses	Present valve design has two problems. First, locking arm has broken off or vibrated off some valves. Second, disc retainer threads are fretting which causes valve not to operate. In addition, technical specifications require unit shut down after 7 days with valves not operable. Several fixes available; however, none are certain to correct problem.
Reactor Feed Pump Recirculation Line	Source of two unit outages	Valves leaking badly. This results in large quantities of water being dumped to condenser. Therefore, a fourth condenser pump must be run to accommodate leakage through valves. This increases pumping power; also, loss of MW if have to go to 3 out of 4.
Scram Reactivity Fix	Causes deratings at end of core life	At end of core life, it takes longer to scram reactor. The unit has to be derated due to NRC regulations because of additional time it takes to insert control rods. Installing larger valves could reduce scram time and, thus, increase reactor power at end of fuel cycle.

TABLE 1.20 EVALUATION OF IMPROVEMENT PROJECTS AT QUAD CITIES 1				
Item	Essential Criteria			
	Hardware	Repetitive	Suitable to DOE	Feasible
1. 8x8 Fuel Assemblies	Yes	Yes	Yes	Yes
2. Moisture Separator Drain Tank	Yes	Yes	Yes	Yes
3. Electromatic Relief Valves	Yes	Yes	Yes	Uncertain
4. Reactor Feed Pump Recirculation Line Valves	Yes	Yes	Yes	Yes
5. Scram Reactivity	Yes	Yes	Yes	Yes

TABLE 1.21

IMPROVEMENT PROJECTS
FOR QUAD CITIES 1

1. Moisture Separator Drain Tank Modification
2. Electromatic Relief Valve Modification

Finally, the 8 x 8 fuel assembly switch was not chosen for two reasons:

- ° It does not involve loss of function; therefore, ΔEA would have to be computed by the change in the conditional unavailability. This was not considered sufficiently instructive for the utilities.
- Project implementation decision has already been made by Commonwealth Edison and evaluating the ΔEA versus cost for the project would have no practical significance for the utility.

2.0 UNIT SELECTIONS

This chapter discusses Trident's selection process of Wood River 5 and Quad Cities 2 as the units to be studied. Section 2.1 reviews Trident's criteria for unit selection. Based on these criteria, Trident developed a candidate list of five nuclear and three coal units. Outage data from these units is presented in section 2.2, which is used in section 2.3. Section 2.3 gives the analysis which supported Trident's recommendation to evaluate Wood River 5 and Quad Cities 2 with the DOE methodology.

2.1 CRITERIA FOR UNIT SELECTION

Only Illinois units which met the following criteria were considered:

- Coal or nuclear fueled;
- 400 MW or larger;
- Commercial operation since January 1, 1974.

In addition, there was the additional restriction that the unit must be operated by either Commonwealth Edison Company or Illinois Power Company. All Illinois units which met these criteria are shown in Table 2.1 for coal and Table 2.2 for nuclear. As can be seen, there are nine coal and five nuclear units in these tables. Wood River 5 has been included since its net summer dependable capacity is only 2 MW below the 400 MW capacity criterion.

Trident next considered two conditions desired by the Illinois Commerce Commission, which were as follows:

- One unit to be coal, while the other to be nuclear;
- One unit to belong to Commonwealth Edison and the other to Illinois Power.

As can be seen in Table 2.2, all the nuclear units are operated by Commonwealth Edison. Thus, the nuclear plant must be a Commonwealth

TABLE 2.1
POTENTIAL COAL UNITS

Unit	Utility	MDC (MW)	Commercial Operation
Baldwin 1	Illinois Power	605 ¹	July 13, 1970
Baldwin 2	Illinois Power	605 ¹	May 21, 1973
Wood River 5	Illinois Power	398 ¹	1964
Joliet 7	Commonwealth	660 ²	1965
Joliet 8	Commonwealth	660 ²	1966
Will County 4	Commonwealth	598 ²	April 17, 1963
Kincaid 1	Commonwealth	660 ²	June 7, 1967
Kincaid 2	Commonwealth	660 ²	June 10, 1968
Powerton 5	Commonwealth	893 ²	July 1972

¹ Net summer dependable capacity as given by Energy Resources Center, Report No. UICC-ERC-78-200, March 1978.

² Nameplate capacity as given by Energy Resources Center, Report No. UICC-ERC-78-200, March 1978.

TABLE 2.2

POTENTIAL NUCLEAR UNITS

Unit	Utility	MDC* (MW)	Commercial Operation
Dresden 2	Commonwealth	809	June 9, 1972
Dresden 3	Commonwealth	809	November 11, 1971
Zion 1	Commonwealth	1050	December 31, 1973
Quad Cities 1	Commonwealth	809	February 18, 1973
Quad Cities 2	Commonwealth	809	March 10, 1973

* MDC = Unit MW - net based on NRC Gray Books

unit and the coal plant must be an Illinois Power unit. As shown in Table 2.1, there are three potential Illinois Power coal units; Baldwin 1, Baldwin 2, and Wood River 5.

Trident then considered the productivity performance of each of the units. The availability, capacity factor, and forced outage rate is shown in Table 2.3 for the coal units and Table 2.4 for the nuclear units. These tables show that all units have productivity parameters typical of large generating units.

Trident then considered how each of these unit's performance from 1973 - 1977 fit the assumptions and limitations of the Department of Energy (DOE) methodology. For example, the DOE method assumes the units are in a steady state with respect to the occurrences of outages and the duration of these outages. In other words, it assumes that the units' meantime-to-outage and meantime-to-restore are independent of time. Also, the methodology predicts the units' meantime-to-restore and meantime-to-outage primarily on the basis of the units' outage history. The validity of this approach increases as the number of outages increases. However, a component's meantime-to-restore parameter computed in this manner can be distorted by a single long duration outage. Additionally, Trident has found that such long duration outages tend not to be repetitive and, therefore, less predictable than shorter outages. Thus, the validity of the DOE method increases when fewer such outages occur. Also, the more systems or components with failures, the more detailed the DOE methodology is in predicting unit performance.

In addition to these considerations, Trident also considered the specific improvement projects. Since the basic predictive nature of the DOE methodology lies in the estimation of future unit loss of function unavailability, the units with high unavailability loss of function would have more significant improvement projects.

From these considerations, Trident developed seven factors which reflected a unit's performance in relation to the assumptions of the DOE method and the specific improvement projects. These factors are as follows:

- * Number of loss of function outages from year-to-year at a unit.

A unit in steady state should have the same number of outages from year to year. Trident believes this is best measured by the ratio $\left(\frac{\sigma_o}{\bar{x}_o}\right)$ of each unit

TABLE 2.3

PRODUCTIVITY PARAMETERS FOR COAL UNITS*
(1973 - 1977)

Unit	Parameter	Year					Cumulative 1973 - 1977
		1973	1974	1975	1976	1977	
Wood River 5	Availability	68.1	70.5	74.8	75.8	81.4	74.1
	Capacity Factor	50.0	43.6	46.8	45.6	44.3	46.1
	Forced Outage Rate	23.9	29.1	13.5	8.9	10.0	17.1
Baldwin 1	Availability	81.7	85.4	76.6	71.8	69.2	76.9
	Capacity Factor	70.3	70.0	60.8	59.2	51.7	62.4
	Forced Outage Rate	5.2	4.7	10.2	5.7	16.2	8.4
Baldwin 2	Availability	63.2	87.8	71.5	85.7	75.8	76.8
	Capacity Factor	67.2	76.0	60.5	74.1	59.8	67.5
	Forced Outage Rate	3.1	12.2	5.5	7.3	7.6	7.1

* Source: Illinois Power

TABLE 2.4
PRODUCTIVITY PARAMETERS FOR NUCLEAR UNITS*
(1973-1977)

Unit	Parameter	Year					Cumulative 1973 - 1977
		1973	1974	1975	1976	1977	
Zion 1	Availability	-	57.2	70.0	62.1	74.2	65.8
	Capacity Factor	-	45.1	65.9	53.5	56.9	51.3
	Forced Outage Rate	-	14.9	16.9	18.4	3.0	12.9
Quad Cities 1	Availability	84.9	61.9	85.1	64.9	80.2	74.7
	Capacity Factor	70.0	50.8	216.7	50.2	52.3	56.8
	Forced Outage Rate	7.1	9.8	12.5	6.3	6.0	9.2
Quad Cities 2	Availability	84.5	82.6	51.7	81.3	87.9	74.6
	Capacity Factor	74.3	63.8	125.6	63.7	64.9	59.1
	Forced Outage Rate	7.4	12.3	11.0	4.1	3.5	12.2
Dresden 2	Availability	87.6	64.1	55.1	75.9	71.9	68.5
	Capacity Factor	71.6	48.2	42.3	64.5	52.2	50.8
	Forced Outage Rate	10.3	21.8	7.7	4.1	8.7	16.0
Dresden 3	Availability	65.0	51.5	82.4	92.2	72.7	67.4
	Capacity Factor	45.7	31.3	59.4	76.6	55.7	52.7
	Forced Outage Rate	14.8	13.5	4.1	7.8	14.3	9.2

* Source: NRC Gray Books

where

σ_o = standard deviation of the number of loss of function outages at a unit from year to year

σ_o is calculated from the equation

$$\sigma_o = \sqrt{\frac{\sum_{i=1}^N (x_{oi} - \bar{x}_o)^2}{N - 1}} \quad (2.1)$$

N = Number of years outage data reviewed

x_{oi} = Number of loss of function outages in year i at unit

$\bar{x}_o$ = Average number of loss of function outages per year at a unit.

- Duration in hours of loss of function outages from year-to-year at a unit.

Again, a unit in steady state should have the same outage duration hours from year to year. Trident feels this is best represented by the ratio of $(\sigma_H / \bar{x}_H)$ at a unit,

where

σ_H = standard deviation of the number of loss of function outage hours at a unit from year to year.

σ_H is calculated by the equation

$$\sigma_H = \sqrt{\frac{\sum_{i=1}^N (x_{Hi} - \bar{x}_H)^2}{N - 1}} \quad (2.2)$$

$\bar{x}_H$ = Average number of loss of function outage hours per year at a unit

N = Number of years used

x_{H_i} = Number of loss of function outage hours in year i at unit.

- Number of systems or components at a unit with outages.

The more systems or components with failures, the more effective the DOE method.

- Average number of outages per system.

The larger the number of outages per system, the more valid are the meantime-to-restore and meantime-to-outage parameters.

- Distribution of average number of outages per system.

Ideally, all the systems at a unit should have a large number of outages. Trident believes a figure of merit for the distribution of outages from system to system is the standard deviation of the average number of outages per system. This is represented at each unit by $(\sigma_s / \bar{x}_s)$,

where

σ_s = standard deviation of the average number of outages per system.

σ_s is found by the equation

$$\sigma_s = \sqrt{\frac{\sum_{i=1}^N (x_{s_i} - \bar{x}_s)^2}{N - 1}} \quad (2.3)$$

$\bar{x}_s$ = Average number of outages per system, cumulative over N years

N = Number of years outage data reviewed

x_{si} = Number of outages in system i, cumulative over N years.

- * Number of outages involving loss of function greater than two weeks (336 hours).

This parameter is calculated to note if any long duration outages have occurred, which could perturb the analysis. Trident felt single outages shorter than two weeks wouldn't significantly perturb the DOE method.

- * Percent unit unavailability due to loss of function (U_F / U).

More meaningful improvement projects should be available at a unit for selection the larger this parameter.

In section 2.2, unit outage data is given to determine these seven factors for each unit. These factors are then used to rank the units. Trident's method for this ranking and their conclusions are presented in section 2.3.

2.2 DATA FOR UNIT SELECTION

The outage histories of the units shown in Table 2.5 have been reviewed from 1973-1977 for selecting one coal and one nuclear unit. The outage history of the nuclear units is based on the NRC gray books for 1974 through 1977 and the AEC* for 1973. The outage history of the coal units is based on yearly summary EEI coded data obtained from Illinois Power.

Tables 2.6, 2.7, and 2.8 show the outage data for three coal units, while Tables 2.9 through 2.13 show the outage data for the five nuclear units.

* AEC Report, Nuclear Power Plant Operating Experience in 1973, #DOE-ES-004, December 1974.

TABLE 2.5	
POTENTIAL UNITS FOR APPLICATION OF DOE METHODOLOGY	
Nuclear	Coal
Zion 1	Baldwin 1
Quad Cities 1	Baldwin 2
Quad Cities 2	Wood River 5
Dresden 2	
Dresden 3	

Source: Illinois Power

[illegible]

Source: Illinois Power

Outage Type	1973		1974		1975		1976		1977		1973-1977	
	No. of Outages	Hours	No. of Outages	Hours	No. of Outages	Hours	No. of Outages	Hours	No. of Outages	Hours	No. of Outages	Hours
Administrative	2	1108.9	2	888.6	2	1317.9	2	2043.2	2	1527.5	10	6886.1
Conditional	1	44.0					1	8.2	1	2.5	3	54.7
Loss of Function	10	349.8	9	409.7	-15	757.5	18	418.2	14	1167.2	66	3102.4
System/Component												
1. Boiler			5	226.4	1	5.9	9	102.7	2	11.5	17	346.9
2. Turbine							2	12.3	2	60.9	4	73.2
3. Generator												
4. Feed Pumps	1	47.9			2	10.0			1	2.2	4	60.1
5. Tube Leaks	6	271.9	3	143.5	9	615.7	4	191.6	7	489.5	29	1712.2
6. Valves, Piping												
7. Feedwater Heater					1	113.7	1	78.2			2	191.9
8. Reheater												
9. Condenser												
10. Coal System												
11. Ash												
12. Electrical	1	.4	1	39.8	1	6.6			2	603.1	5	649.9
13. Other	1	6.3		.	1	5.6	2	33.4			4	45.3
14. Forced Draft Fans	1	23.3		" "		"					1	23.3

Source: Illinois Power

[illegible]

TABLE 2.9
FULL OUTAGES AT ZION 1
(1974-1977)

Source: NRC Gray Books

Outage Type	1974		1975		1976		1977		1974-1977	
	No. of Outages	Duration (Hours)	No. of Outages	Duration (Hours)	No. of Outages	Duration (Hours)	No. of Outages	Duration (Hours)	No. of Outages	Duration (Hours)
Administrative	3	29.1	5	867.0	1	2626.4	3	2077.2	12	5599.7
Conditional	11	162.3	15	1173.3	4	177.3	8	141.2	38	1654.1
Loss of Function	13	3391.4	9	639.4	9	1169.1	6	44.5	37	5244.4
Primary										
Pressurizer	1	300.6	0	0	0	0	0	0	1	300.6
Valves	0	0	0	0	1	29.2	0	0	1	29.2
Instrumentation and Control	0	0	1	6.8	2	8.8	1	12.7	4	28.3
Secondary										
Condenser	2	152.6	4	534.6	0	0	0	0	6	687.2
Valves										
MSIV	3	286.3	0	0	1	460.4	0	0	4	746.7
PRV	0	0	1	41.0	1	9.8	1	6.8	3	57.6
Generator	3	2487.9	0	0	0	0	1	8.0	4	2495.9
Feedwater Pumps	3	71.6	1	17.6	1	11.4	1	7.7	6	108.3
Turbine	0	0	1	.5	0	0	2	9.3	3	9.8
Ancillary Equipment	1	92.4	1	38.9	1	637.0	0	0	3	768.3
Instrumentation and Control	0	0	0	0	2	12.5	0	0	2	12.5

TABLE 2.10
FULL OUTAGES AT QUAD CITIES 1
(1973-1977)

Source: NRC Gray Books

Outage Type	1973		1974		1975		1976		1977		1973-1977	
	No. of Outages	Duration (Hours)	No. of Outages	Duration (Hours)	No. of Outages	Duration (Hours)	No. of Outages	Duration (Hours)	No. of Outages	Duration (Hours)	No. of Outages	Duration (Hours)
Administrative	4	703.0	4	2801.2	0	0	4	2023.3	5	2095.2	17	7627.7
Conditional	7	235.0	1	21.8	3	122.6	2	14.1	5	61.5	18	455.0
Loss of Function	11	355.0	10	409.0	6	1090.6	13	1133.5	14	414.0	54	3402.1
Primary Side												
MG Sets	0	0	0	0	0	0	0	0	1	102.9	1	102.9
Recirculating Pumps and Lines	1	44.0	0	0	1	939.0	0	0	1	63.1	3	1046.1
Control Rods	0	0	0	0	0	0	0	0	1	7.8	1	7.8
Valves												
FRV	1	10.0	0	0	1	8.7	0	0	0	0	2	18.7
MSIV	0	0	0	0	0	0	0	0	0	0	0	0
All Others	3	157.0	3	58.3	1	44.9	5	413.8	1	22.7	13	696.7
Feedwater Pumps	0	0	0	0	1	26.2	0	0	1	28.0	2	54.2
Feedwater Piping and General System	0	0	0	0	0	0	1	112.3	0	0	1	112.3
Instrumentation and Control	3	39.0	1	5.2	1	6.9	0	0	3	17.0	8	68.1
Condenser	1	78.0	1	168.0	1	64.9	0	0	0	0	3	310.9
Generator	0	0	0	0	0	0	2	542.4	1	52.2	3	594.6
Turbine	0	0	0	0	0	0	3	42.9	3	55.7	6	98.6
Ancillary Equipment	0	0	1	23.8	0	0	0	0	0	0	1	23.8
MSR	0	0	2	135.2	0	0	1	9.1	1	5.3	4	149.6
SJAE	0	0	0	0	0	0	0	0	0	0	0	0
EHC	1	8.0	2	18.5	0	0	0	0	0	0	3	26.5
Drywell	0	0	0	0	0	0	1	13.0	1	59.3	2	72.3
Circulating Water Side (Gener.)	1	19.0	0	0	0	0	0	0	0	0		19.0

Source: NRC Gray Books

[illegible]

TABLE 2.12

FULL OUTAGES AT DRESDEN 2
(1973-1977)

Source: NRC Gray Books

Outage Type	1973		1974		1975		1976		1977		1973-1977	
	No. of Outages	Duration (Hours)	No. of Outages	Duration (Hours)	No. of Outages	Duration (Hours)	No. of Outages	Duration (Hours)	No. of Outages	Duration (Hours)	No. of Outages	Duration (Hours)
Administrative	2	95.0	4	1637.9	1	1897.5	1	1610.4	3	2288.4	11	7529.2
Conditional	6	354.0	1	37.0	3	190.0	3	221.2	2	38.4	15	840.6
Loss of Function	11	639.0	10	1494.7	11	274.4	9	238.1	5	134.3	46	2780.5
Primary Side												
MG Sets	1	77.0	0	0	0	0	0	0	0	0	1	77.0
Recirculating Pumps and Lines	1	55.0	3	836.4	0	0	1	6.9	2	80.5	7	978.8
Control Rods	0	0	1	112.0	0	0	0	0	0	0	1	112.0
Valves												
FRV	2	46.0	0	0	0	0	2	14.2	0	0	4	60.2
MSIV	0	0	0	0	1	23.6	0	0	0	0	1	23.6
All Others	1	41.0	3	331.0	5	158.8	2	85.7	1	13.7	12	630.2
Feedwater Pumps	0	0	0	0	0	0	0	0	0	0	0	0
Feedwater Piping and General System	2	130.0	0	0	0	0	0	0	0	0	2	130.0
Instrumentation and Control	1	14.0	2	10.3	2	14.6	0	0	2	40.1	7	79.0
Condenser	0	0	0	0	0	0	0	0	0	0	0	0
Generator	2	97.0	0	0	0	0	0	0	0	0	2	97.0
Turbine	0	0	1	158.0	1	40.4	0	0	0	0	2	198.4
Ancillary Equipment	1	179.0	1	35.0	0	0	0	0	0	0	2	214.0
MSR	0	0	1	12.0	0	0	1	44.5	0	0	2	56.5
SJAE	0	0	0	0	0	0	1	45.1	0	0	1	45.1
EHC	0	0	0	0	2	37.0	2	41.7	0	0	4	78.7
Drywell	0	0	0	0	0	0	0	0	0	0	0	0
Circulat. Water Side (Gen.,)	0	0	0	0	0	0	0	0	0	0	0	0

Source: NRC Gray Books

[illegible]

These tables show the number of outages and the duration of outages for each of the three DOE unavailability factors (administrative, conditional, and loss of function for the years 1973-1977). Trident's analysis of this data is presented in the next section.

The loss of function outages have been further divided into 14 systems for the coal units and 18 systems for the nuclear units, with the exception of Zion 1. Zion 1 is a pressurized water reactor (PWR), while the other four nuclear units are boiling water reactors (BWR). Thus for Zion 1, Trident identified 11 systems with outages.

2.3 DATA ANALYSIS AND UNIT SELECTION

The data shown in Tables 2.6 through 2.13 were used as the basis of Trident's recommendation for unit selection. The data was analyzed using the seven criteria described in section 2.1. The results of this analysis are given in Table 2.14 for the coal units and Table 2.15 for the nuclear units.

Each table has seven categories corresponding to the seven criteria. Categories 1 and 2 show the $\left(\frac{C_O}{X_O}\right)$ and $\left(\frac{C_H}{X_H}\right)$ parameters, which are a measure of how near the units are to steady state. Since the DOE method assumes steady state, it is preferred to have this ratio as small as possible. Category 3 is the number of systems with outages. The larger this number, the better the DOE method should predict unit performance. Thus, it is desirable to have the parameter as large as possible. Category 4 gives the average number of outages per system. The larger this value, the more statistically valid are the meantime-to-restore and meantime-to-outage parameters of a unit, and thus the more valid the DOE method becomes. Consequently, it is better to have this parameter as large as possible. Category 5 is a measure of the distribution of the average number of outages per system at a unit. Thus, this parameter measures whether the outages are all occurring in one system or are spread out over many systems at a unit. It is desirable to have this parameter as small as possible. Category 6 gives the number of outages involving loss of function that exceeded 336 hours (two weeks). Long outages have the potential to perturb the DOE method results and, thus, it is desirable to have this parameter as small as possible. Category 7 reflects

TABLE 2.14

ANALYSIS OF COAL UNITS

Category Number	Factor	Wood River 5	Baldwin 1	Baldwin 2
1	$\frac{\sigma_o}{\bar{x}_o}$	.320	.280	.248
2	$\frac{\sigma_H}{\bar{x}_H}$	.460	.555	.584
3	Number of systems with outages	10	8	11
4	Average number of outages per system	6.79	4.71	3.28
5	$\frac{\sigma_s}{\bar{x}_s}$	2.86	1.63	.993
6	Number of outages involving loss of function >336 h	3	1	3
7	$\frac{U_F}{U}$	.675	.309	.367

TABLE 2.15

ANALYSIS OF NUCLEAR UNITS

Category Number	Factor	Zion 1	Quad Cities 1	Quad Cities 2	Dresden 2	Dresden 3
1	$\frac{\sigma_o}{\bar{x}_o}$	.31	.29	.22	.29	.39
2	$\frac{\sigma_H}{\bar{x}_H}$	1.11	.58	.44	1.00	.40
3	Number of systems with outages	11	16	16	14	16
4	Average number of outages per system	3.36	3.00	2.78	2.67	2.39
5	$\frac{\sigma_s}{\bar{x}_s}$	.50	1.07	1.12	1.19	.58
6	Number of outages involving loss of function >336 h	4	2	1	1	0
7	$\frac{U_F}{U}$	.42	.30	.31	.25	.22

the percentage of a unit's unavailability which is due to the loss of function. As discussed in section 2.2, the higher this percentage, the more potentially significant improvement projects should be identified at each of the units studied.

In order to select a unit, Trident ranked the units in each of the seven categories. For the three coal units, the unit which had the best parameter is given three points; next best - two points; and the worst in each category is given one point. For the five nuclear units, the unit which had the best parameter is given five points; next best - four points; and so on with the worst unit given one point in each category. These rankings were then summed over all seven categories. Thus, the unit with the highest total points should have had a performance that most closely approximates the assumptions and limitations of the DOE method.

Table 2.16 shows the rankings for each of the seven categories for the coal units. As can be seen, Wood River 5 has 14.5 points, Baldwin 1 has 14 points, while Baldwin 2 has 13.5 points. Thus, each of the units' point totals is very close. However, Wood River 5 outage characteristics appear to be slightly more suited to the DOE method than Baldwin 1 or Baldwin 2.

Table 2.17 shows the rankings for each of the seven categories for the nuclear units. As can be seen, Quad Cities 2 has the highest point total with 25.5 points. The next best nuclear unit was Quad Cities 1 with 22.5 points.

Thus, Trident recommended Wood River 5 for the coal unit selection and Quad Cities 2 for the nuclear unit selection. However, Trident felt the DOE method could be applied to any of the units. The main significance of the recommendation was that Trident felt Wood River 5 and Quad Cities 2 were best suited of the reviewed units for the application of the DOE methodology. Trident realized there were numerous additional criteria that could have been added to those used. However, Trident believed the categories chosen were representative of the inherent assumptions and limitations in the DOE method. Subsequent utility permission was granted for study of these two units.

Later in the study, it was felt additional insight could be gained into the DOE methodology by analyzing a unit identical to one being studied. Since Quad Cities 1 is nearly identical to Quad Cities 2, while Wood River 5 had no closely identical unit within Illinois Power, Quad Cities 1 was chosen to be evaluated with the DOE methodology. However, due to time and

TABLE 2.16 RANKING OF COAL UNITS			
Category	Wood River 5	Baldwin 1	Baldwin 2
1	1	2	3
2	3	2	1
3	2	1	3
4	3	2	1
5	1	2	3
6	1.5	3	1.5
7	3	2	1
Total	14.5	14	13.5
NET RANKING	1	2	3

TABLE 2.17					
RANKING OF NUCLEAR UNITS					
Category	Zion 1	Quad Cities 1	Quad Cities 2	Dresden 2	Dresden 3
1	2	3.5	5	3.5	1
2	1	3	4	2	5
3	1	4	4	2	4
4	5	4	3	2	1
5	5	3	2	1	4
6	1	2	3.5	3.5	5
7	5	3	4	2	1
Total	20	22.5	25.5	16	21
NET RANKING	4	2	1	5	3

manpower restraints, only two improvement projects were evaluated at Quad Cities 1. Thus the three units studied were:

- Wood River 5;
- Quad Cities 1;
- Quad Cities 2.

3.0 WOOD RIVER 5

This chapter contains the analysis for Wood River 5 using the Department of Energy methodology. A brief description of Wood River 5 is given in 3.1, while the functional analysis is presented in 3.2. Section 3.3 gives the outage data collected along with the analysis to determine the meantime-to-outage and meantime-to-restore coefficients. The equivalent availability model for Wood River 5 is developed in 3.4. This model is then applied in 3.5 to evaluate the change in equivalent availability for three improvement projects.

3.1 UNIT DESCRIPTION

Wood River 5 was built in 1964 with a guaranteed gross rating of 331 MW with 3.5" Hg condenser pressure and a name plate rating of 356 MW at 1.5" Hg condenser pressure. Presently Wood River 5 has a maximum dependable capacity of 398 MW. With the top feedwater heaters out of service, the main steam at 5% overpressure, and a maximum throttle flow through the turbine, the unit delivers approximately 409 MW at 1.5" Hg condenser pressure. The turbine and boiler are capable of maintaining loadings for periods of at least four hours at the 409 MW load. All auxiliaries are sized so that they do not limit the output of the turbine-generator when operating under the above conditions.

The turbine is a cross-compound, double flow design with a 3600 rpm high pressure turbine and a 1800 rpm low pressure turbine.

The seven heater, regenerative type, feedwater heating cycle is comprised of four closed low pressure heaters, a direct contact deaerating heater, and two closed high pressure heaters that operate in a split string.

The drains from the high pressure heaters are normally cascaded to the deaerating heater. The drains from low pressure heaters "A" and "B" are cascaded back to the condenser. The combined drains from heaters "C" and "D" are pumped back onto the condensate line at a point between these two heaters.

The single bottom exhaust of the low pressure turbine discharges into a two-pass surface condenser. The single shell condenser has a two section water box. Each water box is equipped with division walls and motor-operated internal butterfly valves to facilitate backwashing each tube section. Three half-size, vertically stacked, centrifugal, diffuser-type condensate pumps are installed. The pumps take their suction from suitable hot wells located beneath the condenser. Two half capacity vertical circulating pumps supply cooling water from an intake tunnel.

The boiler is a pressurized fired, divided furnace type. Boiler auxiliaries include two vertical, regenerative type, air heaters, five-combination coal pulverizers and exhausters, oil ignitors, and superheat and reheat temperature control. Three forced circulation pumps are also provided. Two forced draft blowers are provided to supply combustion air to the pressurized fired boiler.

The ash handling system includes an ash storage hopper equipped with a water trough seal. Ash is pumped intermittently from the hopper to the ash storage ponds.

Two half-size, noncondensing steam turbine-driven boiler feed pumps are provided. A motor driven boiler feed pump is also provided to serve a dual purpose -- first, to serve as a boiler start-up pump and second, for parallel operation with one of the turbine-driven pumps when the other is out of service. Since the motor-driven pump has a slightly smaller size than either turbine driven boiler feed pump, the unit losses about 55 MW when the motor driven pump is in operation.

The combustion air preheating system is an indirect cycle with a closed, forced circulation loop between the air preheating coils and a steam-to-ethylene glycol solution heat exchanger. The steam supply for heating the glycol solution is normally taken from the exhaust of the turbine driven boiler feed pumps.

Table 3.1 shows the major equipment items at Wood River 5. The equipment items are broken down by the four generic functions in the Department of Energy methodology. The components given in this table correspond to the components used in the functional analysis given in Section 3.2. Table 3.1 shows the number installed at Wood River 5, number required for full power operation, capacity loss for component failure, whether the component is repairable on line, and whether major modifications have

TABLE 3.1
MAJOR EQUIPMENT AT WOOD RIVER 5

COMPONENT IN GENERIC FUNCTION	NUMBER IN UNIT	NUMBER REQUIRED FOR FULL POWER OPERATION	UNIT CAPACITY LOSS FOR COMPONENT FAILURE (MW) (Number of Failed Components MW Lost)	REPAIRABLE WITH UNIT ON LINE	MAJOR MODIFICATION SINCE 1973
<u>STEAM GENERATION</u>					
Pressurized Fired Boiler					
Water Side System					
Economizer	1	1	Full	No	No
Waterwall Tubes	N/A	N/A	Full	No	Yes
Circulating Pumps	3	3	1 - 145 to 175 MW 2 - Full	Yes	No
Superheater	1	1	Full	No	Yes
Reheater	1	1	Full	No	No
Water Drum	1	1	Full	No	No
Steam Drum	1	1	Full	No	No
Coal/Air Sytem					
Air Heater	2	2	1 - 205 MW 2 - Full	Yes	No
Air Preheater	1	1	1 - 205	Yes	No
Forced Draft Fan	2	2	1 - 145 MW 2 - Full	Yes	Yes
Burners	40	40	Unknown	No	No
Pulverizer Coal System					
Transporter	1	1	Full	Yes	No
Feeder	5	5	See Table 3.2	Yes	No
Mills	5	5	See Table 3.2	Yes	Yes
Exhauster	5	5	See Table 3.2	Yes	No
Waste Disposal Ash Handling System					
Sluice Pump	2	1	2 - Full	No	No
Ash Hopper	1	1	Full	No	Yes
Steam Soot Blowers	N/A	N/A	0	No	No
<u>POWER CONVERSION</u>					
High Pressure and Intermediate Pressure Turbine	1	1	Full Outage	No	Yes
Low Pressure Turbine	1	1	Full Outage	No	No
Piping	N/A	N/A	Full	No	No
Exciters	3	2	2 - Full	No	No
Generator Current Transformers	1	1	Full	No	No
Main Transformer	1	1	Full	No	No

MAJOR EQUIPMENT AT WOOD RIVER 5
(Continued)

COMPONENT IN GENERIC FUNCTION	NUMBER IN UNIT	NUMBER REQUIRED FOR FULL POWER OPERATION	UNIT CAPACITY LOSS FOR COMPONENT FAILURE (MW) (Number of Failed Components - MW Lost)	REPAIRABLE WITH UNIT ON LINE	MAJOR MODIFICATION SINCE 1973
POWER CONVERSION (Continued)					
Auxiliary Transformer	3	2	Variable	Yes	No
Substation	1	1	Full	No	No
STEAM CONDENSATION					
Condenser Water Box	2	2 (Summer) 1 (Winter)	1 - 100 MW (Summer) 1 - 0 MW (Winter) 2 - Full	Yes	No
Condensate Pump	3	See Table 3.2	See Table 3.2	Yes	No
Condenser Circulating Water Pumps	2	2 (Summer) 1 (Winter)	1 - 30 MW (Summer) 1 - 0 MW (Winter) 2 - Full	Yes	Yes
Gland Steam Condenser	2	0	2 - Full	Yes	No
Condenser Vacuum Pumps	2	2	Variable	Yes	No
FEED					
Low Pressure Regenerative Feedwater Heater	4	4	1 - 0 MW 2 - 40 MW 3 - 80 MW 4 - 120 MW	Yes	No
Deaerating Feed Tank	1	1	Full	No	No
Boiler Feed Pump	3	See Table 3.2	See Table 3.2	Yes	No
Boiler Feed Pump Turbines and Motor	3	See Table 3.2	See Table 3.2	Yes	No
High Pressure Feedwater Heater Strings	2	2	1 - 55 MW 2 - Full	Yes	No
Heater Drain Pumps	2	0	1 - 0 MW 2 - 0 MW	Yes	No
SHARED SYSTEMS					
Piping	N/A	N/A	Full	No	No

been performed on the component since 1973. For example, Wood River 5 has two air heaters, both of which are needed for full operation. Table 3.1 shows that the loss of one heater results in a 205 MW capacity loss, while the loss of two heaters results in a full outage. Further, Table 3.1 shows that the air heaters can be repaired with the unit on-line and that there has been no major modification to this component since 1973.

The coal pulverizer system, condensate pumps, and boiler feed pumps listed in Table 3.1 have the effect of their failure on unit output given in Table 3.2.

3.2 FUNCTIONAL ANALYSIS

This section contains the functional diagrams and failure mode and effect analysis for Wood River 5.

Figure 3.1 shows the functional diagram at the generic level for Wood River 5. The four basic power plant functions shown in this figure are (1) power conversion, (2) steam condensation, (3) feed and (4) steam generation. The numbering system assigned to these four functions shown in this figure is the same as that used in the Department of Energy methodology. In addition, shared systems or components have been assigned to a fifth separate function as recommended in the Department of Energy methodology as a fifth system.

The functional diagram at the subfunction level is shown in Figure 3.2 for Wood River 5. This figure shows the major systems used for power generation. As can be seen, the power conversion function has been divided into the electrical conversion system (1A) and the energy conversion system (1B). The steam condensation function has been divided into five subfunctions. They are the condensate system (2A), discharge system (2B), cooling water system (2C), condensate feed system (2D), and the gland steam condensation system (2E). The three subfunctions which compose the feed function are the low pressure heater system (3A), feedwater feed system (3B), and high pressure heater system (3C). The steam generation function is represented by five subfunctions, which are the energy exchange system (4A), air discharge system (4B), coal disposal system (4C), coal supply system (4D), and air supply system (4E).

TABLE 3.2
EFFECT OF COMPONENT FAILURE ON
WOOD RIVER 5 OUTPUT

System	Component	Unit Capacity Loss MW
Pulverizer Coal System	1 Feeder, mill, or exhaustor	60
	2 Feeders, mills, or exhausters	160
	3 Feeders, mills, or exhausters	260
Condensate Pumps (3 in unit)	5A	35
	5B	35
	5C	0
	2 Pumps	140 Additional
Boiler Feed Pumps or Boiler Feed Pump Turbine (3 in unit)	5A	55
	5B	55
	5C	0
	2 Pumps	240 Additional

FUNCTIONAL DIAGRAM - GENERIC LEVEL

WOOD RIVER 5

Figure 3.1

Figure 3.3, which represents the functional diagram at the equipment level for Wood River 5, models over 35 different types of major components used in the unit as well as showing the number of components in a system. Figure 3.3 shows only the significant components and interconnections at Wood River 5. Minor equipment is not shown, such as valves, drain pumps, etc. However, all equipment which did result in outages has been shown. Obviously, the physical volume or location of the equipment within the unit is not reflected in Figure 3.3.

Table 3.3 lists all the components shown in Figure 3.3. This table gives the element letter identification used in Figure 3.3, number required for maximum dependable capacity, number in unit, whether components are in series, parallel or shared, and the table where the component outage data has been tabulated.

Finally, Table 3.4 is the failure mode and effects analysis performed for Wood River 5. This table was constructed primarily from the information in Table 3.1. It shows for each component in the equipment level functional diagram the effect of any component's failure on Wood River 5 output. This table is used to determine the unit capacity loss for a given equipment failure. This unit capacity loss is used to evaluate the loss of function outage data in Section 3.3 in determining a component's equivalent meantime-to-outage and equivalent meantime-to-restore.

3.3 OUTAGE DATA

The outage data for Wood River 5 has been divided into three categories: administrative, conditional, and loss of function outages. This was done to simplify computation of the U_P , U_C , U_F unavailability factors in Section 3.4. This data was collected primarily using the following sources:

- EEI reports;
- Mechanical and electrical time records;
- Operating logs;
- Generation logs.

TABLE 3.3
EQUIPMENT FUNCTIONAL DIAGRAM AND OUTAGE DATA COLLECTED
WOOD RIVER 5

COMPONENT IDENTIFIER	SYSTEM/COMPONENT	NUMBER REQUIRED FOR MDC	NUMBER IN UNIT	REMARK	TABLE WHERE OUTAGE DATA TABULATED
1A (a-b)	Generator/Exciter	2/2	2/3	Parallel	3.7.1
1A (c)	Main Transformer/ Auxiliary Transformer	1/2	1/2	Series	3.7.2
1A (d)	Substation	1	1	Series	3.7.3
1B (a)	High Pressure and Intermediate Pressure Turbine	1	1	Series	3.7.4
1B (b)	Low Pressure Turbine	1	1	Series	3.7.5
2A (a)	Condenser	1 (summer) 1/2 (winter)	1	Series	3.7.6
2B	Condenser Discharge System	1	1	Series	No outages
2C (a-b)	Condenser Circulating Water Pumps	2 (summer) 1 (winter)	2	Parallel	No outages
2D (a-c)	Condensate Pumps	2 or 3	3	Parallel	3.7.7
2E (a)	Gland Steam Condenser	0	1	Series	No outages
3A (a-d)	Low Pressure Heaters	4	4	Series	No outages
3A (e)	Deaerating Feed Tank	1	1	Series	No outages
3B (a-b)	Turbine-Driven Boiler Feed Pumps	2	2	Parallel with 3B (c)	3.7.8
3B (c)	Motor-Driven Boiler Feed Pump	0	1	Parallel with 3B (a-b)	3.7.8
3C (a-d)	High Pressure Feedwater Heater	4	4	Parallel/ Series	3.7.9
4A (a)	Reheater	1	1	Series	3.7.10
4A (b)	Superheater	1	1	Series	3.7.11
4A (c)	Steam Drum	1	1	Series	No outages
4A (d)	Waterwall Tubes	All	Many	Parallel	3.7.12
4A (e-g)	Boiler Circulating Pumps	3	3	Parallel	3.7.13
4A (h)	Lower Drums	1	1	Series	No outages
4A (i)	Economizer	1	1	Series	3.7.14
4A (j)	Burners	40	40	Parallel	3.7.15

EQUIPMENT FUNCTIONAL DIAGRAM AND OUTAGE DATA COLLECTED

WOOD RIVER 5

(Continued)

COMPONENT IDENTIFIER	SYSTEM/COMPONENT	NUMBER REQUIRED FOR MDC	NUMBER IN UNIT	REMARK	TABLE WHERE OUTAGE DATA TABULATED
4B (a-b)	Air Heater (Gas side)	2	2	Parallel Shared with 4E (d-e)	No outages
4B (c)	Precipitator	1	1	Series	No outages
4C (a-b)	Sluice Pumps	1	2	Parallel	No outages
4C (c)	Ash Hopper	1	1	Series	3.7.16
4D (a)	Coal	1	1	Series	No outages
4D (b)	Transporter	1	1	Series	No outages
4D (c-g)	Pulverizer Coal System - Feeders	5	5	Parallel	3.7.17
4D (h-l)	Pulverizer Coal System- Mills	5	5	Parallel	3.7.18
4D (m-q)	Pulverizer Coal System- Exhauster	5	5	Parallel	3.7.19
4E (a-b)	Forced Draft Fan	2	2	Parallel	3.7.20
4E (c)	Air Preheaters	1	1	Series	3.7.21
4E (d-e)	Air Heater (Air side)	2	2	Parallel shared with 4B (a-b)	No outages
SA	Piping (Entire plant)	1	1	Series	3.7.22

TABLE 3.4
FAILURE MODE AND EFFECT ANALYSIS
WOOD RIVER 5

Functional Hierarchy Level	Failure Mode	Effect on Unit
1. Power Conversion System A. Electrical Conversion System (a) Generator exciter off high pressure - intermediate pressure turbine. (b) Generator exciter off low pressure turbine Generator current transformer (c) Main transformer Auxiliary transformer (d) Substation B. Energy Conversion System (a) High pressure and intermediate pressure turbine (b) Low pressure turbine	Fails to operate Fails to operate Fails to operate Fails to operate Fails to operate Fails to operate	Full outage Full outage Full outage Full outage Full outage Full outage
2. Steam Condensation System A. Condensate System (a) Condenser B. Condenser Discharge System	Loss of 1 water box Loss of 2 water boxes Water discharge temperature above plant limits	100 MW summer 0 MW winter Full outage Reduction in unit power (variable)
	-91-	(continued...)

FAILURE MODE AND EFFECT ANALYSIS

WOOD RIVER 5

(continued)

Functional Hierarchy Level	Failure Mode	Effect on Unit
C. Cooling Water System (a) 2 Circulating pumps	One pump fails to operate Two pumps fail to operate	30 MW summer 0 MW winter Full outage
D. Condensate System (a) 5A Pump (b) 5B Pump (c) 5C Pump	Fails to operate Fails to operate Fails to operate Two pumps fail to operate Three pumps fail to operate	35 MW 35 MW 0 MW 140 MW additional Full outage
E. Gland Steam Condensation System (a) Gland steam condenser	Fails to operate	0 MW
<hr/>		
3. Feed System		
A. Low Pressure Heater System (a-d) Low pressure heaters (e) Deaerating feed tank (DFT)	Loss of any heater Loss of DFT	0 MW Full outage
B. Feedwater Feed System (a) 5A Turbine-driven feed pump (b) 5B Turbine-driven feed pump (c) 5C Motor-driven feed pump	Fails to operate Fails to operate Fails to operate Two pumps fail to operate Three pumps fail to operate	55 MW 55 MW 0 MW 240 MW additional Full outage
C. High Pressure Heater System (a-b) F ₁ G ₁ String (c-d) F ₂ G ₂ String	Loss of string Loss of string Both strings fail to operate	55 MW 55 MW Full outage
<hr/>		
	- 92 -	(continued. . .)

FAILURE MODE AND EFFECT ANALYSIS

WOOD RIVER 5

(continued)

Functional Hierarchy Level	Failure Mode	Effect on Unit
4. Steam Generation System		
A. Energy Exchange System		
(a) Reheater	Failure of integrity	Full outage
(b) Superheater	Failure of integrity	Full outage
(c) Lower drums	Failure of integrity	Full outage
(d) Waterwall tubes	Failure of integrity	Full outage
(e-g) 3 Boiler circulation pumps	One pump fails to operate	145-175 MW
	Two pumps fail to operate	Full outage
	Three pumps fail	Full outage
(h) Water drum	Failure of integrity	Full outage
(i) Economizer	Failure of integrity	Full outage
(j) Burners	Fails to operate	Full outage
B. Air Discharge System		
(a-b) 2 Air heaters (gas side)	Loss of one heater	205 MW
	Loss of two heaters	Full outage
(c) Precipitator	Fails to operate	Full outage
C. Ash Disposal System		
(a-b) Sluice pumps	Loss of one pump	0 MW
	Loss of two pumps	Full outage
(c) Ash hopper	Loss of hopper	Full outage
D. Coal Supply System		
(a) Coal	Fail to move into unit	Full outage
(b) Transporter	Fails to operate	Full outage
(c-g) 5 Feeders	One fails to operate	60 MW
	Two fail to operate	160 MW
	Three fail to operate	260 MW
	Four fail to operate	360 MW
	Five fail to operate	Full outage
	Same as feeders	Same as feeders.
(h-l) 5 Mills		Mill must be in different string than failed feeder to cause additional MW loss

FAILURE MODE AND EFFECT ANALYSIS

WOOD RIVER 5

(continued)

Functional Hierarchy Level	Failure Mode	Effect on Unit
(m-q) 5 Exhausters	Same as feeder or mill	Same as feeder or mill. Exhauster must be in different string than failed feeder or mill to cause additional MW loss
E. Air Supply System		
(a-b) 2 Forced draft fans	One fails to operate Two fail to operate	145 MW Full outage
(c) Air preheater	Loss of heater	Loss of efficiency Variable capacity reduction
(d-e) 2 Air heaters (air side)	Loss of one heater Loss of two heaters	205 MW Full outage

5. Shared Systems		
A. Piping	Failure of integrity	Full outage

In cases where more than one component was not operating (multiple failures), the component which was limiting the unit output has been assigned the outage time. A discussion of multiple failures is given in Section 5.1.

Table 3.5 is a chronological listing of the administrative outages at Wood River 5, excluding reserve shutdown. Table 3.5 is used in computing the administrative unavailability factor, U_P , for Wood River 5 in Section 3.4.

A chronological listing of the conditional outages is given in Table 3.6. The information in Table 3.6 is used in computing the conditional unavailability factor, U_C , for Wood River 5 in Section 3.4.

Tables 3.7.1 - 3.7.22 give the loss of function outage data and analysis from 1973-1977 for Wood River 5. These tables are composed of three subtables. The first subtable gives the component functional diagram information, which includes the component letter identifier and component configuration. The component configuration tells whether the element is being treated in a series or parallel configuration when computing the equivalent meantime-to-outage and equivalent meantime-to-restore coefficients.

The second subtable gives the full and partial outages attributed to the component.

The third subtable gives the analysis of the outage data. This table shows for nine different time periods:

- the number of component outages;
- the meantime-to-outage (M_1);
- the equivalent meantime-to-outage (eM);
- the total outage duration;
- capacity loss or megawatt hours lost divided by the maximum dependable capacity (MWH lost/MDC)
- the meantime-to-restore (m_1);
- equivalent meantime-to-restore (em);
- $\left(\frac{em}{eM}\right)$ ratio.

TABLE 3.5

WOOD RIVER 5

ADMINISTRATIVE OUTAGES*

Source: EEI

Date	Total Outage Duration (Hours)	Capacity Loss (MW)	Comments
2/23/73	849.9	398	Boiler overhaul
3/30/75	588.1	398	Boiler overhaul
12/6/75	1726.0	398	Replacement of turbine rotor including 1976 boiler overhaul
4/1/77	530.7	398	Boiler overhaul
* Reserve shutdown not included.			

TABLE 3.6

WOOD RIVER 5

CONDITIONAL OUTAGES

Source: EEI

Date	Total Outage Duration (Hours)	Capacity Loss (MW)	Comments
3/18/74	4.3	398	Check overspeed trips
10/10/75	34.0	398	Condenser discharge tunnel inspection
12/25/76	181.3	398	Precipitator inspection
2/21/77	3.8	160	5E Mill inspection
4/25/77	5.2	260	5E Mill inspection

TABLE 3.7.1
WOOD RIVER 5

Generator/Exciter

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 1A (a-b)

Component Configuration: Series

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss (MW)	Comments
8/16/73	1.4	398	#5 H.P. amplidyne unit trip
12/6/74	26.5	398	Inspection for gear noise in exciter
2/16/76	21.0	398	L.P. amplidyne loss of field relay
6/9/76	4.6	398	Loss of field (L.P. amplidyne)

LOSS OF FUNCTION ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	Capacity Loss (MW)	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	1	5,961	5,961	1.4	398	1.4	1.4	.000235
1974	1	6,142	6,142	26.5	398	26.5	26.5	.004314
1975	0							0
1976	2	3,330	3,330	25.6	398	12.8	12.8	.003844
1977	0							0
1973-74	2	6,051	6,051	27.9	398	14.0	14.0	.002314
1973-75	2	9,296	9,296	27.9	398	14.0	14.0	.001506
1973-76	4	6,313	6,313	53.5	398	13.4	13.4	.002123
1973-77	4	8,082	8,082	53.5	398	13.4	13.4	.001658

TABLE 3.7.2

WOOD RIVER 5

Main Transformer /

Auxiliary Transformers

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 1A (c)

Component Configuration: Series

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss (MW)	Comments
8/27/73	887.8	398	Fire - B phase conductor failed
9/25/76	10.3	398	5B - Auxiliary transformer tripped
9/27/76	3.2	398	5B - Auxiliary transformer tripped

LOSS OF FUNCTION ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	Capacity Loss (MW)	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	1	5,961	5,961	887.8	398	887.8	887.8	.148935
1974	0							
1975	0							0
1976	2	3,330	3,330	13.5	398	6.8	6.8	.002042
1977	0							0
1973-74	1	12,103	12,103	887.8	398	887.8	887.8	.073354
1973-75	1	18,591	18,591	887.8	398	887.8	887.8	.047754
1973-76	3	8,417	8,417	901.3	398	300.4	300.4	.035690
1973-77	3	10,776	10,776	901.3	398	300.4	300.4	.027877

TABLE 3.7.3
WOOD RIVER 5

Substation

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 1A (d)

Component Configuration: Series

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss (MW)	Comments
3/23/77	12.4	398	Blew 1436 breaker on 138 KV bus

LOSS OF FUNCTION ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	Capacity Loss (MW)	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	0							0
1975	0							0
1976	0							0
1977	1	7,076	7,076	12.4	398	12.4	12.4	.001752
1973-74	0							0
1973-75	0							0
1973-76	0							0
1973-77	1	32,328	32,328	12.4	398	12.4	12.4	.000384

TABLE 3.7.4

WOOD RIVER 5

High Pressure and Intermediate Pressure Turbine

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 1B (a)

Component Configuration: Series

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss	Comments
12/1/73	2451.5	398	Cracked turbine rotor
3/13/74	13366.0	79	Unit operated without second stage blading-considered as continuation of 12/1/73 outage.

LOSS OF FUNCTION ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	Capacity Loss (MW)	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	1	5,961	5,961	727.9	398	727.9	727.9	.122110
1974	1	6,142	6,142	1723.6 7036.4	398 79	3120.3	3120.3	.508027
1975	1	6,489	6,489	6329.6	79	1256.4	1256.4	.193620
1976	0							0
1977	0							0
1973-74	1	12,103	12,103	9487.9		3848.2	3848.2	.317954
1973-75	1	18,591	18,591	15817.5		5104.6	5104.6	.274574
1973-76	1	25,252	25,252	15817.5		5104.6	5104.6	.202146
1973-77	1	32,328	32,328	15817.5		5104.6	5104.6	.157900

TABLE 3.7.5

WOOD RIVER 5

Low Pressure Turbine

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 1B (b)

Component Configuration: Series

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss (MW)	Comments
2/15/75	28.9	398	Expansion joint (contractor in to vulcanize seal)
2/16/75	16.8	398	Expansion joint leak

LOSS OF FUNCTION ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	Capacity Loss (MW)	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	0							0
1975	2	3,244	3,244	45.7	398	22.8	22.8	.007028
1976	0							0
1977	0							0
1973-74	0							0
1973-75	2	9,296	9,296	45.7	398	22.8	22.8	.002453
1973-76	2	12,626	12,626	45.7	398	22.8	22.8	.001806
1973-77	2	16,164	16,164	45.7	398	22.8	22.8	.001411

TABLE 3.7.6

WOOD RIVER 5

Condenser

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 2A (a)

Component Configuration: Series

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss	Comments
6/22/73	12.5	100	Checked condenser for leaks
7/7/73	6.1	100	Leak in tubes (repair)
7/10/73	6.7	100	Leak in tubes
7/11/73	7.5	100	Leak in tubes
7/12/73	5.5	100	Leak in tubes
7/13/73	8.2	100	Leak in condenser
6/7/76	2.5	100	B side repair tube leaks
9/1/76	10.5	100	A side repair tube leaks
9/2/76	10.5	100	B side repair tube leaks
9/2/76	9.6	100	A side repair tube leaks

LOSS OF FUNCTION ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	Capacity Loss (MW)	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	6	933	933	46.5	100	2.0	2.0	.002014
1974	0							0
1975	0							0
1976	4	1665	1665	33.1	100	2.1	2.1	.001261
1977	0							0
1973-74	6	2017	2017	46.5	100	2.0	2.0	.000992
1973-75	6	3098	3098	46.5	100	2.0	2.0	.000646
1973-76	10	2525	2525	79.6	100	2.0	2.0	.000792
1973-77	10	3233	3233	79.6	100	2.0	2.0	.000619

TABLE 3.7.7

WOOD RIVER 5

Condensate Pumps

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 2D (a-c)

Component Configuration: Series

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss (MW)	Comments
8/22/77	1091.8	35	5B - Condensate pump - bad impeller

LOSS OF FUNCTION ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	Capacity Loss (MW)	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	0							0
1975	0							0
1976	0							0
1977	1	7,076	7,076	1,092	35	96.0	96.0	.013567
1973-74	0							0
1973-75	0							0
1973-76	0							0
1973-77	1	32,328	32,328	1,092	35	96.0	96.0	.002970

TABLE 3.7.8
WOOD RIVER 5
Boiler Feed Pumps

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 3B (a-c)

Component Configuration: Series

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss (MW)	Comments
1/1/73	187.4	55	5A - Bearing and shaft repair
1/15/73	12.5	55	5A - Check bearings
11/2/73	75.5	55	5A - Boiler feed pump (BFP)
4/18/76	28.9	55	5A - BFP speed control
4/21/76	21.6	55	5A - BFP clean suction strainer
5/25/76	35.3	55	5A - BFP maintenance
6/20/76	22.0	55	5A - BFP recirculating bypass line broken
6/23/76	29.5	55	5A - BFP hydraulic leak
6/15/77	210.0	55	5B - BFP speed control
7/1/77	14.2	55	5B - BFP turbine hydraulic oil line

LOSS OF FUNCTION ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	Capacity Loss (MW)	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	3	1,987	1,987	275.4	55	12.7	12.7	.006392
1974	0							0
1975	0							0
1976	5	1,332	1,332	137.3	55	3.8	3.8	.002853
1977	2	3,538	3,538	224.2	55	15.5	15.5	.004381
1973-74	3	4,034	4,034	275.4	55	12.7	12.7	.003148
1973-75	3	6,197	6,197	275.4	55	12.7	12.7	.002049
1973-76	8	3,156	3,156	412.7	55	7.1	7.1	.002250
1973-77	10	3,233	3,233	636.9	55	8.8	8.8	.002722

TABLE 3.7.9
WOOD RIVER 5
High Pressure Feedwater Heaters

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 3C (a-d)

Component Configuration: Parallel (2 in unit)
(2 required for MDC)

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss	Comments
5/13/75	21.8	55	F1 and G1 Heater - Bad relief valve
6/29/76	206.5	55	G2 Heater leak
7/24/76	237.0	55	F1 and G1 heater division plate failed
8/5/76	2.1	55	F2 and G2 testing
8/10/76	13.8	55	F1 and G1 heater relief valve
8/12/76	14.2	55	F2 and G2 heater relief valve

LOSS OF FUNCTION ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	Capacity Loss (MW)	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	0							0
1975	1	12,978	6,489	21.8	55	3.0	3.0	.000462
1976	5	2,664	1,332	473.6	55	13.1	13.1	.009835
1977	0							0
1973-74	0							0
1973-75	1	37,183	18,591	21.8	55	3.0	3.0	.000161
1973-76	6	8,417	4,208	495.4	55	11.4	11.4	.002709
1973-77	6	10,776	5,388	495.4	55	11.4	11.4	.002116

BASIC EQUATIONS

$$eM = \frac{M_1}{2}$$

$$em = m_1 + \frac{m_1^2}{2M_1}$$

TABLE 3.7.10

WOOD RIVER 5

Boiler -- Reheater

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 4A (a)

Component Configuration: Series

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss (MW)	Comments
7/18/73	75.7	398	Reheat heater leak in penthouse

LOSS OF FUNCTION ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	Capacity Loss (MW)	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	1	5,961	5,961	75.7	398	75.7	75.7	.012699
1974	0							0
1975	0							0
1976	0							0
1977	0							0
1973-74	1	12,103	12,103	75.7	398	75.7	75.7	.006255
1973-75	1	18,591	18,591	75.7	398	75.7	75.7	.004072
1973-76	1	25,252	25,252	75.7	398	75.7	75.7	.002998
1973-77	1	32,328	32,328	75.7	398	75.7	75.7	.002342

TABLE 3.7.11

WOOD RIVER 5

Boiler -- Superheater

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 4A (b)

Component Configuration: Series

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss (MW)	Comments
8/25/74	32.7	398	"B" primary superheater leak
9/30/74	73.1	398	Superheater tube leak
10/7/74	39.6	398	Primary superheater tube leak
10/19/74	38.5	398	Primary superheater tube leak
10/28/74	132.5	398	Primary superheater tube leak
11/15/74	49.3	398	Primary superheater tube leak
11/29/74	42.5	398	Superheater out header tube
1/9/75	28.6	398	Superheater tube
9/25/75	45.3	398	Primary superheater
11/22/75	35.1	398	Primary superheater
6/16/77	151.4	398	Superheater out header drain broken
12/2/77	55.5	398	Primary superheater tube leak
12/12/77	121.3	398	Primary superheater tube leak

(Continued...)

WOOD RIVER 5

Boiler -- Superheater (Con't)

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	Capacity Loss (MW)	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	7	877	877	408.2	398	58.3	58.3	.066477
1975	3	2,163	2,163	109.0	398	36.3	36.3	.016782
1976	0							0
1977	3	2,359	2,359	328.2	398	109.4	109.4	.046376
1973-74	7	1,729	1,729	408.2	398	58.3	58.3	.033719
1973-75	10	1,859	1,859	517.2	398	51.7	51.7	.027811
1973-76	10	2,525	2,525	517.2	398	51.7	51.7	.020475
1973-77	13	2,487	2,487	845.4	398	65.0	65.0	.026136

TABLE 3.7.12

WOOD RIVER 5

Boiler--Waterwall Tubes

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 4A (d)

Component Configuration: Series

OUTAGE DATA

Date	Total- Outage Duration (Hours)	Capacity Loss (MW)	Comments
1/7/73	31.2	398	Waterwall at throat A and B furnace
4/10/73	28.0	398	Waterwall at throat B furnace
6/19/73	26.2	398	Waterwall at throat
6/27/73	49.2	398	Tube leak in furnace
8/1/73	39.5	398	Furnace wall tube
10/30/73	60.7	398	Furnace wall tube and waterwall leaks at throat
3/29/74	23.1	398	Waterwall at throat
4/26/74	31.7	398	Waterwall front wall and division wall
4/30/74	30.8	398	Waterwall at throat
5/8/74	24.5	398	Waterwall at throat
5/29/74	22.0	398	Waterwall at throat
6/1/74	24.7	398	Waterwall at throat
7/20/74	27.5	398	Division wall and at throat
8/18/74	30.8	398	Division wall
9/14/74	24.3	398	Waterwall at throat
10/23/74	31.2	398	Waterwall at throat
11/8/74	34.7	398	Division wall
11/22/74	38.5	398	Division wall and throat
12/11/74	26.3	398	Waterwall #1 corner
1/6/75	27.5	398	Division wall and throat
2/13/75	33.2	398	Division wall and throat
2/21/75	30.2	398	Division wall and throat
3/11/75	69.2	398	Division wall and throat
3/24/75	38.7	398	Division wall and throat
4/30/75	69.5	398	Furnace wall leak (safety valve leak also)

WOOD RIVER 5

Boiler -- Waterwall Tubes (Continued)

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss (MW)	Comments
5/10/75	39.8	398	Division wall and throat
5/16/75	34.4	398	Division wall and throat
5/25/75	33.4	398	Division wall and throat
5/28/75	33.2	398	Division wall and throat
6/25/75	38.7	398	Division wall and throat
7/5/75	39.1	398	Throat tube
7/14/75	52.1	398	Division wall and throat
7/24/75	31.2	398	Division wall and throat
7/29/75	115.0	398	Throat
8/8/75	30.1	398	Throat
9/10/75	38.6	398	Waterwall tube (division)
10/31/75	37.5	398	Throat
2/25/76	106.2	398	Waterwall tube
3/13/76	63.0	398	Waterwall tube leak
3/22/76	45.1	398	Waterwall tube rupture
4/7/76	33.4	398	Waterwall tube rupture
4/9/76	24.9	398	Changed waterwall orifice
5/29/76	25.6	398	Waterwall tube leak
7/9/76	28.2	398	Waterwall at screens scalloped bar
5/2/77	33.1	398	Waterwall tube
5/6/77	43.7	398	Throat tube
5/18/77	27.7	398	Waterwall tube
6/3/77	29.7	398	Waterwall tube
7/7/77	29.9	398	Waterwall tube
7/14/77	41.8	398	Waterwall tube
7/23/77	30.8	398	Waterwall tube
7/28/77	22.3	398	Waterwall tube
8/1/77	61.7	398	Waterwall tube
8/13/77	64.6	398	Waterwall tube
8/25/77	45.0	398	Waterwall tube
9/9/77	193.3	398	Remove boiler tube for testing
11/7/77	98.5	398	Waterwall tube leak
12/2/77	55.5	398	Waterwall tube leak

(Continued...)

WOOD RIVER 5

Boiler--Waterwall Tubes (Con't)

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	Capacity Loss (MW)	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	6	994	994	234.8	398	39.1	39.1	.039336
1974	13	472	472	370.1	398	28.4	28.4	.060169
1975	18	360	360	791.4	398	44.0	44.0	.122222
1976	7	951	951	326.4	398	46.6	46.6	.049001
1977	14	505	505	777.6	398	55.5	55.5	.109901
1973-74	19	637	637	604.9	398	31.8	31.8	.049922
1973-75	37	502	502	1396.3	398	37.7	37.7	.075188
1973-76	44	574	574	1722.7	398	39.1	39.1	.068118
1973-77	58	557	557	2500.3	398	43.1	43.1	.077378

TABLE 3.7.13
WOOD RIVER 5
Boiler -- Circulating Pumps

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 4A (e-g)

Component Configuration: Parallel (3 in unit)
(3 required for MDC)

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss	Comments
7/15/74	188.4	160	5C - Bearing trouble
9/24/74	7.3	160	5C - Leaking pump flange
1/11/75	457.0	160	5C - Motor repair

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	Capacity Loss (MW)	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	2	9,213	3,071	195.7	160	39.3	39.5	.012862
1975	1	19,466	6,489	457.0	160	183.7	185.4	.028571
1976	0							0
1977	0							0
1973-74	2	18,154	6,051	195.7	160	39.3	39.4	.006511
1973-75	3	18,591	6,197	652.7	160	87.5	87.9	.014184
1973-76	3	25,252	8,417	652.7	150	87.5	87.8	.010431
1973-77	3	32,328	10,776	652.7	160	87.5	87.7	.008138

BASIC EQUATIONS

$$eM = \frac{M_1}{3} \qquad em = m_1 + \frac{m_1^2}{M_1} + \frac{1}{3} \frac{m_1^3}{M^2}$$

TABLE 3.7.14
WOOD RIVER 5
Boiler -- Economizer

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 4A (i)

Component Configuration: Series

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss (MW)	Comments
7/28/74	66.3	398	Tube leak
1/13/75	72.7	398	Tube leak
8/17/76	58.3	398	Tube (erosion)
8/27/76	31.9	398	Tube (erosion)
9/4/76	343.1	398	Tube leak

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	Capacity Loss (MW)	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	1	6,142	6,142	66.3	398	66.3	66.3	.010795
1975	1	6,489	6,489	72.7	398	72.7	72.7	.011204
1976	3	2,220	2,220	433.3	398	144.4	144.4	.065045
1977	0							0
1973-74	1	12,103	12,103	66.3	398	66.3	66.3	.005478
1973-75	2	9,296	9,296	139.0	398	69.5	69.5	.007416
1973-76	5	5,050	5,050	572.3	398	114.5	114.5	.022673
1973-77	5	6,466	6,466	572.3	398	114.5	114.5	.017708

TABLE 3.7.15

WOOD RIVER 5

Boiler -- Burners

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 4A (j)

Component Configuration: Series

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss (MW)	Comments
6/3/76	47.0	398	5E - A burner tip fell into ash hopper

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	Capacity Loss (MW)	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	0							0
1975	0							0
1976	1	6,660	6,660	47.0	398	47.0	47.0	.007057
1977	0							0
1973-74	0							0
1973-75	0							0
1973-76	1	25,251	25,251	47.0	398	47.0	47.0	.001861
1973-77	1	32,328	32,328	47.0	398	47.0	47.0	.001454

TABLE 3.7.16

WOOD RIVER 5

Ash Hopper

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 4C (c)

Component Configuration: Series

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss (MW)	Comments
8/25/75	18.6	398	Remove wire screen from ash hopper

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	Capacity Loss (MW)	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	0							0
1975	1	6,489	6,489	18.6	398	18.6	18.6	.002866
1976	0							0
1977	0							0
1973-74	0							0
1973-75	1	18,591	18,591	18.6	398	18.6	18.6	.001000
1973-76	1	25,252	25,252	18.6	398	18.6	18.6	.000737
1973-77	1	32,328	32,328	18.6	398	18.6	18.6	.000575

TABLE 3.7.17
WOOD RIVER 5
Pulverizers -- Feeder

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 4D (c-g)

Component Configuration: Parallel (5 in unit)
(5 required for MDC)

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss (MW)	Comments
1/16/73	3.5	60	5D - Patch transition under feeder
1/19/73	9.9	60	5E - Calibrate feeder and feeder chute liner
2/13/73	5.6	60	5B - Metal in feeder
4/22/73	25.5	60	5A - Back belt
5/15/73	11.3	160	5B - Belt torn
7/8/73	5.9	160	5D - Belt ruined
7/22/73	32.0	60	5C - Broken belt
7/27/73	5.2	60	5D - Broken feeder belt
10/13/73	4.3	160	5E - Change feeder belt
11/12/73	11.9	60	5A - Replace feeder belt
11/27/73	10.9	60	5A - Replace feeder belt
5/19/74	5.0	160	5D - Replace feeder belt
5/19/74	2.0	160	5E - Replace belt - cut by debris
9/21/74	9.0	160	5A - Broken drag chain coupling
10/22/74	4.7	160	5B - Replace belt
12/27/74	15.2	160	5E - Repair belt and inlet valve
1/28/75	17.4	160	5E - Broken belt
2/17/75	27.1	160	5E - Replace belt
2/18/75	4.8	160	5C - Replace belt
2/27/75	6.8	160	5E - Replace belt
6/23/75	2.2	160	5B - Bad belt
8/13/75	11.7	160	5B - Bad belt
9/7/75	9.7	160	5B - Bad gears
10/7/75	4.0	160	5C - Slide wire repair
3/3/76	8.4	60	5C - Replace feeder belt
4/26/76	5.9	60	5B - Replace belt
5/8/76	14.5	60	5D - Belt
7/13/76	2.5	60	5D - Replaced belt
7/16/76	30.1	60	5E - Replaced belt
7/24/76	3.0	60	5B - Replaced belt

WOOD RIVER 5

Pulverizers -- Feeder

OUTAGE DATA (Continued)

Date	Total Outage Duration (Hours)	Capacity Loss (MW)	Comments
8/3/76	39.0	60	5C - Repair gear box
10/5/76	28.9	60	5A - Feeder level bar
10/9/76	12.3	60	5C - Calibrate
10/29/76	10.3	260	5D - Feeder motor failed
11/3/76	4.9	160	5D - Calibrate
11/6/76	6.6	160	5B - Replaced belt and calibrate
11/18/76	11.7	160	5A - Bad reel shaft
10/15/77	40.5	60	5D - Belt broken

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	MWH Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	11	2,710	542	126.0	24.4	2.2	2.2	.004059
1974	5	6,142	1,228	35.9	14.4	2.9	2.9	.002362
1975	8	4,055	811	83.7	33.6	4.2	4.2	.005179
1976	13	2,562	512	178.1	37.9	2.9	2.9	.005664
1977	1	35,380	7,076	40.5	6.1	6.1	6.1	.000862
1973-74	16	3,782	756	161.9	38.8	2.4	2.4	.003175
1973-75	24	3,873	775	245.6	72.4	3.0	3.0	.003871
1973-76	37	3,412	682	423.7	110.3	3.0	3.0	.004399
1973-77	38	4,253	851	464.2	116.4	3.1	3.1	.003643

BASIC EQUATIONS

$$eM = \frac{M_1}{5}$$

$$em = m_1 + \frac{2 m_1^2}{M_1} + \frac{2 m_1^3}{M_1^2} + \frac{m_1^4}{M_1^3} + \frac{1}{5} \frac{m_1^5}{M_1^4}$$

TABLE 3.7.18

WOOD RIVER 5

Pulverizer Mills

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 4D (h-1)

Component Configuration: Parallel (5 in unit)
(5 required for MDC)

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss (MW)	Comments
4/24/73	700.9	60	5E - Mill overhaul
5/24/73	442.5	60	5C - Mill overhaul
6/14/73	394.2	60	5D - Mill overhaul
6/17/73	8.5	60	5B - Inspect mill - replace one roll
7/6/73	274.1	60	5B - Mill overhaul
8/10/73	15.3	60	5E - Mill inspection
10/7/73	524.4	60	5A - Broken shaft bearing on mill
5/15/74	3.0	160	5E - Plugged Pyrite chute
2/7/75	89.5	160	5A - Repair seal air housing
8/4/75	13.5	160	5E - Repair pyrites hopper
8/5/75	13.5	160	5E - Repair pyrites hopper
3/8/76	121.7	60	5C - Mill explosion damage to duct work and piping
3/13/76	4.2	160	5A - Sweep off in pyrites section
3/29/76	1.8	60	5B - Remove blockage from pyrites chute
4/26/76	2.6	160	5E - Set dampers
4/27/76	228.2	60	5D - Replace roll
5/10/76	3.7	60	5C - Inspect pyrites sweeps
5/11/76	3.0	60	5D - Mill internal work
5/12/76	3.3	60	5D - Roll adjustment
5/13/76	277.2	60	5A - Overhaul
5/27/76	231.9	60	5D - #3 roll spring broken shaft
6/10/76	2.5	60	5B - Scrap in mill sweeps
6/13/76	80.0	60	5E - Mill explosion
6/24/76	7.7	60	5E - Clean out coal and inspect
6/28/76	22.4	60	5E - Repair coal leak
8/23/76	1.5	60	5E - Adjust rolls and patch air duct
8/30/76	17.4	60	5B - Inspect internals
9/29/76	84.0	60	5E - Roll repair
10/11/76	492.7	60	5A - Mill explosion
10/28/76	5.2	60	5D - Pyrite chute plugged and sweep off

WOOD RIVER 5

Pulverizer Mills

(Continued)

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss (MW)	Comments
11/2/76	8.5	160	5A - Inspect under bowl area
11/15/76	5.6	160	5A - Mill fire - blew roll fill hoses
11/16/76	2.6	160	5B - Remove roll fill hoses
11/16/76	.7	160	5C - Remove roll fill hoses
11/16/76	1.7	260	5D - Remove roll fill hoses
1/8/77	15.3	60	5A - Fire #3 roll (replace coal yard conveyor belt)
2/8/77	41.4	60	5E - Check rolls and internals
2/16/77	13.5	60	5A - Not grinding, sparklers in pyrite
2/19/77	242.1	60	5B - Oil leak in gear box
2/28/77	711.7	160	5E - Mill fire
3/24/77	3.1	260	5D - Pyrite chute plugged
3/25/77	17.3	260	5D - Replaced #2 roll
4/1/77	320.0	60	5C - Mill overhaul
5/16/77	226.3	60	5D - Mill overhaul
	114.3	160	
6/6/77	3.1	60	5D - High bowl differential
6/10/77	14.2	60	5B - #1 roll frozen on bearing
6/27/77	8.2	60	5A - Check #3 roll
8/27/77	49.5	60	5B - Stud broke #3 roll
9/17/77	57.3	60	5D - Blast gate would not open
10/25/77	51.2	60	5D - Roll problem
10/29/77	86.5	60	5C - Internal mill trouble
11/1/77	5.0	60	5E - Check oil in rolls
11/2/77	16.0	60	5B - Check oil in rolls
11/4/77	5.4	60	5A - Check oil in rolls
11/27/77	7.3	60	5D - Minor explosion
12/5/77	225.4	60	5A - Overhaul
12/9/77	8.5	60	5D - #1 Journal Housing Cover broke
12/20/77	6.3	60	5B - Bar stud #2 mill roll
12/20/77	271.0	60	5C - Broke vertical shaft

(Continued...)

WOOD RIVER 5

Pulverizer Mills

(Continued)

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	MWH Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	7	4,258	852	2,359.9	355.8	50.8	52.0	.061033
1974	1	30,710	6,142	3.0	1.2	1.2	1.2	.000195
1975	3	10,815	2,163	116.5	46.8	15.6	15.6	.007212
1976	24	1,388	278	1,610.3	249.7	10.4	10.6	.038129
1977	24	1,474	295	2,519.9	597.7	24.9	25.7	.087119
1973-74	8	7,564	1,513	2,362.9	357.0	44.6	45.1	.029808
1973-75	11	8,451	1,690	2,479.4	403.8	36.7	37.0	.021893
1973-76	35	3,607	721	4,089.5	652.9	18.7	18.9	.026214
1973-77	59	2,740	548	6,609.4	1,250.6	21.2	21.5	.039234

BASIC EQUATIONS

$$eM = \frac{M_1}{5}$$

$$em = m_1 + \frac{2m_1^2}{M_1} + \frac{2m_1^3}{M_1^2} + \frac{m_1^4}{M_1^3} + \frac{1}{5} \frac{m_1^5}{M_1^4}$$

TABLE 3.7.19

WOOD RIVER 5

Pulverizers -- Exhausters

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 4D (m-q)

Component Configuration: Parallel (5 in unit)
(5 required for MDC)

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss (MW)	Comments
1/16/73	2.4	60	5E - Changed exhauster sample lines
5/14/74	1.8	160	5D - Changed coal pipe elbow
4/13/76	31.2	60	5E - Exhauster seal repair
5/7/76	7.2	60	5D - Coal leaks
5/10/76	1.8	60	5D - Coal leaks
5/10/76	2.4	60	5D - Coal leaks
5/10/76	5.2	60	5C - Burner gate leaks
2/8/77	2.6	60	5C - Adjust exhauster seal
2/14/77	2.1	60	5D - Repair coal leak
4/26/77	68.1	260	5E - Rough inboard bearing-exhauster. Lost nut on exhauster
6/22/77	74.8	60	5A - Overhaul exhauster
10/9/77	35.2	60	5B - Coal leaks
10/28/77	3.0	60	5B - Coal leaks

(Continued...)

WOOD RIVER 5
Pulverizers -- Exhausters
(Continued)

LOSS OF FUNCTION ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	MWH Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	1	29,805	5,961	2.4	.4	.4	.4	.000067
1974	1	30,708	6,142	1.8	.7	.7	.7	.000114
1975	0							0
1976	5	6,660	1,332	47.8	7.2	1.4	1.4	.001051
1977	6	5,897	1,179	185.8	62.3*	10.4	10.6	.008991
1973-74	2	30,257	6,051	4.2	1.1	.6	.6	.000099
1973-75	2	46,479	9,296	4.2	1.1	.6	.6	.000065
1973-76	7	18,037	3,607	52.0	8.3	1.2	1.2	.000333
1973-77	13	12,434	2,487	237.8	70.6	5.4	5.4	.002171

* Calculated from equation $= \sum \frac{Mwh \text{ lost}}{MDC}$

BASIC EQUATIONS

$$eM = \frac{M_1}{5}$$

$$em = m_1 + \frac{2m_1^2}{M_1} + \frac{2m_1^3}{M_1^2} + \frac{m_1^4}{M_1^3} + \frac{1}{5} \frac{m_1^5}{M_1^4}$$

TABLE 3.7.20
WOOD RIVER 5
Boiler -- Forced Draft Fans

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 4E (a-b)

Component Configuration: Parallel (2 in unit)
(2 required for MDC)

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss (MW)	Comments
10/3/73	90.2	145	5A - Bad motor
10/3/74	49.0	145	5A - Bad motor lead
1/19/77	656.8	145	5B - Motor failed (long wait on motor rewind)
10/25/77	1.8	145	5B - Balance fan rotor

LOSS OF FUNCTION ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	Capacity Loss (MW)	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	1	11,922	5,961	90.2	145	32.9	32.9	.005519
1974	1	12,283	6,142	49.0	145	17.8	17.8	.002898
1975	0							0
1976	0							0
1977	2	7,076	3,538	658.5	145	120.0	121.0	.03420
1973-74	2	12,103	6,051	139.2	145	25.4	25.4	.004198
1973-75	2	18,591	9,296	139.2	145	25.4	25.4	.002732
1973-76	2	25,252	12,626	139.2	145	25.4	25.4	.002012
1973-77	4	16,164	8,082	797.7	145	72.6	72.8	.009008

BASIC EQUATIONS

$$eM = \frac{M_1}{2} \qquad em = m_1 + \frac{m_1^2}{2M_1}$$

TABLE 3.7.21

WOOD RIVER 5

Combustion Air Preheaters -- Air Heaters

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 4E (c-e)

Component Configuration: Series

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss (MW)	Comments
10/9/74	13.6	205	Washed air preheater coils

LOSS OF FUNCTION ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	Capacity Loss (MW)	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	1	6,142	6,142	13.6	205	7.0	7.0	.001141
1975	0							0
1976	0							0
1977	0							0
1973-74	1	12,103	12,103	13.6	205	7.0	7.0	.000578
1973-75	1	18,591	18,591	13.6	205	7.0	7.0	.000377
1973-76	1	25,252	25,252	13.6	205	7.0	7.0	.000277
1973-77	1	32,328	32,328	13.6	205	7.0	7.0	.000217

TABLE 3.7.22

WOOD RIVER 5

Piping

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 5A

Component Configuration: Series

OUTAGE DATA

Date	Total Outage Duration (Hours)	Capacity Loss	Comments
8/11/73	21.5	398	Sample line on main steam line broke (cool down- 12 hours)
7/14/74	19.2	398	Spray line leaking
6/11/77	16.8	398	Superheater line to 5B boiler feed pump

LOSS OF FUNCTION ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	Capacity Loss (MW)	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	1	5,961	5,961	21.5	398	21.5	21.5	.003607
1974	1	6,142	6,142	19.2	398	19.2	19.2	.003126
1975	0							0
1976	0							0
1977	1	7,076	7,076	16.8	398	16.8	16.8	.002374
1973-74	2	6,051	6,051	40.7	398	20.4	20.4	.003371
1973-75	2	9,296	9,296	40.7	398	20.4	20.4	.002194
1973-76	2	12,626	12,626	40.7	398	20.4	20.4	.001616
1973-77	3	10,776	10,776	57.5	398	19.2	19.2	.001792

Following the third subtable, the basic equations used to relate M_1 to eM and m_1 to em are given for parallel components. For series components, no equations are given, since in this case

$$eM = M_1 \quad \text{and} \quad em = m_1.$$

It should be noted that in the outage data presented only the initial date when the outage began is given. In some cases, these outages were "interrupted" by additional component failures, which resulted in even larger unit outages. Unfortunately this situation, which is a multiple failure, is not handled by the Department of Energy methodology. In these cases, the component causing the greater capacity loss was assigned the entire outage time during the multiple failure. However, when the component causing the larger unit outage was repaired, all additional outage hours were charged against the component, which failed on the initial date, until that component had been returned to service or yet another larger unit outage occurred. Because of this procedure, this has lead to larger outage durations than the time between outages in few cases.

3.4 EQUIVALENT AVAILABILITY ANALYSIS

In this section, the equivalent availability analysis is given for Wood River 5. Section 3.4.1 gives the applicable equivalent availability equations for Wood River 5. Section 3.4.2 analyzes the unit outage data from 1973-1977. This analysis is used to verify the equivalent availability equations. Section 3.4.3 gives equivalent availability predictions from the model and compares these predictions with the unit's actual equivalent availability. Finally, the statistical and sensitivity analysis on the developed meantime-to-outage and meantime-to-restore coefficients are given in section 3.4.4.

The outage data given in Tables 3.5, 3.6, and 3.7.1 - 3.7.22 don't exactly agree with the full outage data shown for Wood River 5 in Table 2.6. This is because the outage data in Table 2.6 was developed using EEI cause codes outage data summed over each calendar year, while Tables 3.5, 3.6, and 3.7.1 - 3.7.22 were developed using outage by outage EEI data.

3.4.1 Equivalent Availability Equations

The equivalent availability for Wood River 5 is found using the equation

$$EA = 1 - U_P - U_C - U_F \quad (3.1)$$

where U_P , the administrative unavailability, is given by

$$U_P = \sum_{i=1}^{N_P} \frac{d_i CL_i}{(T) MDC} \quad (3.2)$$

where

N_P = Number of administrative outages

U_C , the conditional unavailability, is given by

$$U_C = \sum_{i=1}^{N_C} \frac{d_i CL_i}{(T) MDC} \quad (3.3)$$

where

N_C = Number of conditional outages

U_F , the loss of function unavailability, is given by

$$U_F = \left(\frac{em}{eM} \right) \frac{T_o}{T} \quad (3.4)$$

To evaluate $\left(\frac{em}{eM} \right)$ in equation (3.4), it is necessary to use the equations given in Tables 3.8 and 3.9. In Table 3.8, equation 3.5.1 gives $\left(\frac{em}{eM} \right)$ in terms of the five generic level $\left(\frac{em}{eM} \right)$ ratios, which were developed from Figure 3.1. These five generic level $\left(\frac{em}{eM} \right)$ ratios are found by equations 3.5.2 through 3.5.6 in Table 3.8. Equations 3.5.2 through 3.5.6 have been developed from the Wood River 5 subfunction level diagram shown in Figure 3.2. The subfunction level $\left(\frac{em}{eM} \right)$ ratios are evaluated from equations 3.6.1

TABLE 3.8

WOOD RIVER 5

GENERIC AND SUBFUNCTION LEVEL

 $\left(\frac{em}{eM}\right)$ EQUATIONS

* Generic level equations

$$\left(\frac{em}{eM}\right) = \underbrace{\left(\frac{em}{eM}\right)_1}_{\text{power conversion}} + \underbrace{\left(\frac{em}{eM}\right)_2}_{\text{steam condensation}} + \underbrace{\left(\frac{em}{eM}\right)_3}_{\text{feed}} + \underbrace{\left(\frac{em}{eM}\right)_4}_{\text{steam generation}} + \underbrace{\left(\frac{em}{eM}\right)_5}_{\text{shared functions}} \quad (3.5.1)$$

* Subfunction level equations

$$\left(\frac{em}{eM}\right)_1 = \left(\frac{em}{eM}\right)_{1A} + \left(\frac{em}{eM}\right)_{1B} \quad (3.5.2)$$

$$\left(\frac{em}{eM}\right)_2 = \left(\frac{em}{eM}\right)_{2A} + \left(\frac{em}{eM}\right)_{2B} + \left(\frac{em}{eM}\right)_{2C} + \left(\frac{em}{eM}\right)_{2D} + \left(\frac{em}{eM}\right)_{2E} \quad (3.5.3)$$

$$\left(\frac{em}{eM}\right)_3 = \left(\frac{em}{eM}\right)_{3A} + \left(\frac{em}{eM}\right)_{3B} + \left(\frac{em}{eM}\right)_{3C} \quad (3.5.4)$$

$$\left(\frac{em}{eM}\right)_4 = \left(\frac{em}{eM}\right)_{4A} + \left(\frac{em}{eM}\right)_{4B} + \left(\frac{em}{eM}\right)_{4C} + \left(\frac{em}{eM}\right)_{4D} + \left(\frac{em}{eM}\right)_{4E} \quad (3.5.5)$$

$$\left(\frac{em}{eM}\right)_5 = \left(\frac{em}{eM}\right)_{5A} \quad (3.5.6)$$

TABLE 3.9

WOOD RIVER 5

EQUIPMENT LEVEL $\left(\frac{em}{eM}\right)$ EQUATIONS

$$\left(\frac{em}{eM}\right)_{1A} = \left(\frac{em}{eM}\right)_{1Aa-b} + \left(\frac{em}{eM}\right)_{1Ac} + \left(\frac{em}{eM}\right)_{1Ad} \quad (3.6.1)$$

$$\left(\frac{em}{eM}\right)_{1B} = \left(\frac{em}{eM}\right)_{1Ba} + \left(\frac{em}{eM}\right)_{1Bb} \quad (3.6.2)$$

$$\left(\frac{em}{eM}\right)_{2A} = \left(\frac{em}{eM}\right)_{2Aa} \quad (3.6.3)$$

$$\left(\frac{em}{eM}\right)_{2B} = \left(\frac{em}{eM}\right)_{2B} \quad (3.6.4)$$

$$\left(\frac{em}{eM}\right)_{2C} = \left(\frac{em}{eM}\right)_{2Ca-b} \quad (3.6.5)$$

$$\left(\frac{em}{eM}\right)_{2D} = \left(\frac{em}{eM}\right)_{2Da-c} \quad (3.6.6)$$

$$\left(\frac{em}{eM}\right)_{3A} = \left(\frac{em}{eM}\right)_{3Aa-d} + \left(\frac{em}{eM}\right)_{3Ae} \quad (3.6.7)$$

$$\left(\frac{em}{eM}\right)_{3B} = \left(\frac{em}{eM}\right)_{3Ba-c} \quad (3.6.8)$$

$$\left(\frac{em}{eM}\right)_{3C} = \left(\frac{em}{eM}\right)_{3Ca-d} \quad (3.6.9)$$

$$\begin{aligned} \left(\frac{em}{eM}\right)_{4A} = & \left(\frac{em}{eM}\right)_{4Aa} + \left(\frac{em}{eM}\right)_{4Ab} + \left(\frac{em}{eM}\right)_{4Ac} + \left(\frac{em}{eM}\right)_{4Ad} + \left(\frac{em}{eM}\right)_{4Ae-g} \\ & + \left(\frac{em}{eM}\right)_{4Ah} + \left(\frac{em}{eM}\right)_{4Ai} + \left(\frac{em}{eM}\right)_{4Aj} \end{aligned} \quad (3.6.10)$$

$$\left(\frac{em}{eM}\right)_{4B} = \left(\frac{em}{eM}\right)_{4Ba-b} + \left(\frac{em}{eM}\right)_{4Bc} \quad (3.6.11)$$

(Continued...)

TABLE 3.9 (Continued)

WOOD RIVER 5
EQUIPMENT LEVEL $\left(\frac{em}{eM}\right)$ EQUATIONS

$$\left(\frac{em}{eM}\right)_{4C} = \left(\frac{em}{eM}\right)_{4Ca-b} + \left(\frac{em}{eM}\right)_{4Cc} \quad (3.6.12)$$

$$\left(\frac{em}{eM}\right)_{4D} = \left(\frac{em}{eM}\right)_{4Da} + \left(\frac{em}{eM}\right)_{4Db} + \left(\frac{em}{eM}\right)_{4Dc-g} + \left(\frac{em}{eM}\right)_{4Dh-l} + \left(\frac{em}{eM}\right)_{4Dm-q} \quad (3.6.13)$$

$$\left(\frac{em}{eM}\right)_{4E} = \left(\frac{em}{eM}\right)_{4Ea-b} + \left(\frac{em}{eM}\right)_{4Ec} + \left(\frac{em}{eM}\right)_{4Ed-e} \quad (3.6.14)$$

through 3.6.14, which are given in Table 3.9. Equations 3.6.1 through 3.6.14 have been developed from the Wood River 5 equipment level diagram shown in Figure 3.3. Some simplifications of Figure 3.3 have been used in developing the equations in Table 3.9. They are as follows:

- The 1A(a) and 1A(b) elements have been combined from two parallel elements into one series element. This is done since the exciters are not repairable on-line. Consequently, the DOE equations for parallel components are not applicable.
- The low pressure heaters 3A(a) - 3A(d) have been combined into one element, 3A(a-d), since these elements have not had an outage.

Subfunction equations which have not been expanded to the equipment level are not given in Table 3.9.

3.4.2 Verification of Equivalent Availability Equations

Table 3.10 gives the systems and components with no outages between 1973-1977. Thus the $\left(\frac{e_m}{eM}\right)$ ratios were taken to be zero for these systems and components.

Table 3.11 shows the unavailability coefficients and equivalent availability for Wood River 5 for each of the nine data base periods.

The actual U_F shown in Table 3.11 was computed as follows:

$$U_{\text{Factual}} = \sum_{i=1}^{N_f} \frac{d_i \text{ CL}_i}{(T) \text{ MDC}} \quad (3.7)$$

where

N_f = Number of loss of function outages.

TABLE 3.10		
WOOD RIVER 5		
SYSTEM/COMPONENTS WITH NO OUTAGES (1973-1977)		
Component Identifier	System/Component	$\left(\frac{em}{eM}\right)$ All Cases
2B	Condenser Discharge System	0
2C (a-b)	Condenser Circulating Water Pumps	0
2E (a)	Gland Steam Condenser	0
3A (a-d)	Low Pressure Heaters	0
3A (e)	Deaerating Feed Tank	0
4A (c)	Steam Drum	0
4A (h)	Lower Drums	0
4B (c)	Precipitator	0
4C (a-b)	Sluice Pumps	0
4D (a)	Coal	0
4D (b)	Transporter	0
4E (d-e)	Air Heaters	0

TABLE 3.11				
WOOD RIVER 5				
UNAVAILABILITY COEFFICIENTS AND EQUIVALENT AVAILABILITY				
Calendar Period	U_P	U_C	Actual U_F	EA
1973	.097	.000	.275	.628
1974	.000	.001	.471	.528
1975	.137	.004	.292	.567
1976	.127	.019	.140	.714
1977	.061	.003	.248	.688
1973-74	.049	.000	.373	.578
1973-75	.078	.002	.346	.574
1973-76	.090	.006	.294	.610
1973-77	.084	.005	.286	.615

Table 3.12 gives a comparison of the U_F^{factual} and the U_F computed by the DOE method. The DOE U_F was computed in two ways. First, elements were treated as given in Tables 3.7.1 - 3.7.22. The U_F resulting from this is shown as DOE U_F (parallel). Second, all elements were treated as series. This was done by converting all parallel systems to a single series element. Mathematically, this can be done directly from the information given in Tables 3.7.1 - 3.7.22 by replacing em with m_1 in the U_F computation. The resulting U_F is shown as DOE U_F (series). As can be seen, the two DOE U_F coefficients closely agree with the actual U_F . This is expected since the same data is being used by both procedures. Additionally, this close agreement verifies that the correct equivalent availability equations are being used to model Wood River 5. Further, the DOE series treatment gives slightly better agreement than the DOE parallel treatment.

Table 3.13 shows a comparison of Trident's calculational method of U_F and the published U_F calculational procedure, which involves additional coefficients. As can be seen in the example, both calculational procedures give exactly the same value of U_F for Wood River 5 between 1973-1977.

3.4.3 Equivalent Availability Predictions

Table 3.14 shows the predicted values of U_F using the equivalent availability model data. This prediction technique was similar to that used for Marshall 4 and Turkey Point 4 when the DOE method was applied to these units.* As can be seen, poor agreement is found except when the 1973-1976 data was used to predict the 1977 U_F . In this case, the DOE model predicted a $U_F = .295$, while the actual U_F was .248.

Trident also predicted the Wood River 5 U_F for 1976 and 1977 by making a least squares fit to the $\left(\frac{em}{eM}\right)$ coefficients obtained in Tables 3.7.1 - 3.7.22.

$$\left(\frac{em}{eM}\right) = a T_o + b \quad (3.9)$$

where

- a = slope of least squares fit
- b = intercept of least squares fit
- T_o = unit operational time.

* U. S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Vol. II, February, 1978, pp. 104-107 & 137-140.

TABLE 3.12
WOOD RIVER 5
COMPARISONS OF U_F
1973-1977

Calendar Period	Operational Hours T_o	Period Hours T	DOE U_F $\Sigma \left(\frac{em}{eM} \right) \frac{T_o}{T}$ (Parallel)	DOE U_F $\Sigma \left(\frac{m_1}{eM} \right) \frac{T_o}{T}$ (Series)	Actual U_F
1973	5,961	8,760	.276	.275	.275
1974	6,142	8,760	.472	.471	.471
1975	6,489	8,760	.293	.292	.292
1976	6,660	8,784	.141	.140	.140
1977	7,076	8,760	.250	.248	.248
1973-74	12,103	17,520	.374	.373	.373
1973-75	18,592	26,280	.347	.346	.346
1973-76	25,252	35,064	.295	.295	.294
1973-77	32,328	43,824	.286	.286	.286

TABLE 3.13

COMPARISON OF TRIDENT METHOD AND DOE METHOD
FOR COMPUTATION OF U_F

The DOE method recommends computing U_F from the equation*:

$$U_F = \left[1 - \frac{1}{1 + \left(\frac{em}{eM} \right) \left(\frac{1}{1 - \frac{m'}{M'}} \right)} \right] \left[1 - \frac{T_P}{T} - \frac{T_C}{T} \right] \quad (3.8.1)$$

where

$\frac{m'}{M'}$ = The sum of all ratios of equivalent meantime-to-restore to meantime-to-outage for partial outages

$\frac{em}{eM}$ = The sum of all ratios of equivalent meantime-to-restore to meantime-to-outage for full and partial outages

T_P = Total full power outage time due to administrative events, hours

T_C = Total full power outage time due to conditional events, hours

T = Period time, hours

WOOD RIVER 5 EXAMPLE

Using the data in Tables 3.5, 3.6, and 3.7.1 - 3.7.22 for 1973-77, the following results are obtained:

$$\frac{m'}{M'} = .152 \quad (3.8.2)$$

$$\frac{em}{eM} = .388 \quad (3.8.3)$$

$$\frac{T_P}{T} = .084 \quad (3.8.4)$$

$$\frac{T_C}{T} = .005 \quad (3.8.5)$$

Insertion of equations (3.8.2) - (3.8.5) in equation (3.8.1) results in $U_F = .286$. This compares exactly with the value for U_F found by Trident, which is given in Table 3.12.

* U. S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Vol. II, p. 64, February 1978.

TABLE 3.14			
WOOD RIVER 5			
PREDICTIONS OF EQUIVALENT AVAILABILITY			
Data Base for U_F Prediction	Year Predicted	Predicted U_F DOE Model	Actual U_F
1973	1974	.275	.471
1973-74	1975	.373	.292
1973-75	1976	.346	.140
1973-76	1977	.295	.248
1973-77	1978	.286	—

The resulting $\left(\frac{em}{eM}\right)$ ratios found from this correlation are shown in Table 3.15 for projections for 1976 and 1977. The 1976 projection was based on correlating the $\left(\frac{em}{eM}\right)$ ratios for each component for 1973-1975 with equation (3.9), while the 1977 projection was based on correlating the $\left(\frac{em}{eM}\right)$ ratios for each component for 1973-1976 with equation (3.9). Components with negative projected $\left(\frac{em}{eM}\right)$ ratios for 1976 and 1977 have been treated as having a zero value.

The summation of the $\left(\frac{em}{eM}\right)$ ratios is shown at the bottom of Table 3.15. As can be seen, the following results have been obtained for the 1976 projections:

$$\left(\frac{em}{eM}\right) = .582 \quad (3.10)$$

Also Table 3.15 shows the 1977 projection to be given by

$$\left(\frac{em}{eM}\right) = .469 \quad (3.11)$$

Putting equation (3.10) into equation (3.4) gives a projected U_F for 1976 as

$$U_{F \text{ proj}} = .420 \quad (3.12)$$

1976

This compares poorly with $U_{F \text{ actual}} = .140$ for 1976.

Putting equation (3.11) into equation (3.4) gives a projected U_F for 1977 as

$$U_{F \text{ proj}} = .345 \quad (3.13)$$

1977

This compares with $U_{F \text{ actual}} = .248$ for 1977.

Since these U_F predictions are not that accurate, Trident does not recommend the use of equation (3.9) for predictions of U_F and equivalent availability.

TABLE 3.15
WOOD RIVER 5
LEAST SQUARES FIT TO $\left(\frac{em}{eM}\right)$ COEFFICIENTS
WITH ALL COMPONENTS IN SERIES

Component Identifier	System/Component	1973 -- $\times 10^{-6}$ a	1975 $\times 10^{-6}$ b	1976 $\left(\frac{em}{eM}\right)$ Proj.	1973 -- $\times 10^{-6}$ a	1976 $\times 10^{-6}$ b	1977 $\left(\frac{em}{eM}\right)$ Proj.
1A (a-b)	Generator/Exciter	148	.0985	2,640	394	.0743	2,790
1A (c)	Main Transformer/ Auxiliary Transformer	187,000	-7.97	-0-	164,000	-5.63	-0-
1A (d)	Substation			-0-			-0-
1B (a)	High Pressure and Intermediate Pressure Turbine	92,900	11.9	383,000	184,000	2.88	278,000
1B (b)	Low Pressure Turbine	- 1,580	.1960	3,370	- 825	.122	3,120
2A (a)	Condenser	2,530	-.108	-0-	2,060	- .0616	76.6
2B	Condenser Discharge System			-0-			-0-
2C (a-b)	Condenser Circulating Water Pumps			-0-			-0-
2D (a-c)	Condensate Pumps			-0-			-0-
2E (a)	Gland Steam Condenser			-0-			-0-
3A (a-d)	Low Pressure Heaters			-0-			-0-
3A (e)	Deaerating Feed Tank			-0-			-0-
3B (a-c)	Boiler Feed Pumps	8,030	-.3420	-0-	8,030	-.3420	-0-
3C (a-d)	High Pressure Feedwater Heater	- 103	-.0129	221	- 1,300	-.1300	2,900
4A (a)	Reheater	16,000	-.680	-0-	14,000	-.482	-0-
4A (b)	Superheater	-6,040	2.17	48,800	7,580	.835	34,500
4A (c)	Steam Drum			-0-			-0-
4A (d)	Waterwall Tubes	20,100	2.84	91,800	31,400	1.72	87.00
4A (e-g)	Boiler Circulating Pumps	-6,830	1.12	21,500	- 1,490	.599	17,800
4A (h)	Lower Drums			-0-			-0-
4A (i)	Economizer	-2,930	.596	12,100	- 8,010	1.07	27,300
4A (j)	Burners			-0-	- 893	.0878	1,940
4B (a-b)	Air Heater (gas side)			---			---
4B (c)	Precipitator			-0-			-0-

ont d.

TABLE 3.15

(Continued)

Component Identifier	System/Component	1973 -- $\times 10^{-6}$ a	1975 $\times 10^{-6}$ b	1976 $\left(\frac{em}{eM}\right)$ Proj.	1973 -- $\times 10^{-6}$ a	1976 $\times 10^{-6}$ b	1977 $\left(\frac{em}{eM}\right)$ Proj.
4C (a-b)	Sluice Pumps			-0-			-0-
4C (c)	Ash Hopper	- 6,420	.0799	1,370	- 336	.0498	1,270
4D (a)	Coal			-0-			-0-
4D (b)	Transporter			-0-			-0-
4D (c-g)	Pulverizer Coal System - Feeders	3,870	-.0137	3,520	3,450	.0276	4,340
4D (h-l)	Pulverizer Coal System - Mills	75,200	-3.08	-0-	61,400	-1.71	5,810
4D (m-q)	Pulverizer Coal System - Exhauster	79.5	-.000206	74.3	-44.7	.0120	343
4E (a-b)	Forced Draft Fan	6,850	-.221	1,270	6,490	-.186	494
4E (c-e)	Air Preheater - Air Heaters	39.4	.0293	700	16,400	.00932	464
SA	Piping (entire plant)	4,430	-.112	1,590	4,420	-.111	827
	$\left(\frac{em}{eM}\right)$			.582			.469

Trident has also projected $\left(\frac{em}{eM}\right)$ ratios by making a least squares best fit to cumulative equivalent full power outage time (c) versus unit operational time (T_o) for each component in the equipment level functional diagram. As shown in the DOE methodology* a linear correlation of C versus T_o given by the equation:

$$C = a_c + b_c T_o \quad (3.14)$$

Where

a_c = Correlation intercept

b_c = Correlation slope

yields

$$b_c = \left(\frac{em}{eM}\right) \quad (3.15)$$

Since the cumulative equivalent full power outage time should be zero, when the unit operational time is zero, Trident has also projected $\left(\frac{em}{eM}\right)$ by making a least squares fit to the equation.

$$C = b_c T_o \quad (3.16)$$

Where

$$b_c = \left(\frac{em}{eM}\right) \quad (3.17)$$

The results of these projections are shown in Table 3.16. Projection 1 is obtained by using equation (3.14) and projection 2 is obtained by using equation (3.16). The project years shown in Table 3.16 is based on using the outage for each component up through the previous year. Thus, the 1974 projection is based on outage data for 1973; 1975 projection is based on outage data for 1973-1974; 1978 projection is based on outage data for 1973-1977. The actual values of $\left(\frac{em}{eM}\right)$ are also shown by component for each of the projected years.

* U.S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Vol. III, February, 1978, pp. 64-65.

TABLE 3.16

WOOD RIVER 3

 $\left(\frac{\text{cm}}{\text{mm}}\right)$

PROJECTED BY LEAST SQUARES FIT

Component	1974		1975			1976			1977			1978	
	Proj. 2	Actual	Proj. 1	Proj. 2	Actual	Proj. 1	Proj. 2	Actual	Proj. 1	Proj. 2	Actual	Proj. 1	Proj. 2
Generator/Exciter	.00023	.00431	.00432	.00190	-0-	.00208	.00164	.00384	.00242	.00190	-0-	.00196	.00179
Auxiliary transformer/ Main transformer	.14893	-0-	-0-	.08811	-0-	-0-	.06167	.00284	.00064	.04746	-0-	.00062	.03824
Substation	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	.00177	.00038	.00018
High pressure and low pressure turbine	.12211	.50803	.50805	.27973	.19362	.14508	.27635	-0-	.22148	.23575	-0-	.14971	.19913
Low pressure turbine	-0-	-0-	-0-	-0-	.00703	.00365	.00161	-0-	.00284	.00172	-0-	.00207	.00158
Condenser	.00201	-0-	-0-	.00119	-0-	-0-	.00083	.00136	.00040	.00082	-0-	.00039	.00073
Condensate pumps	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	.01367	.00298	.00140
Boiler feed pump	.00639	-0-	-0-	.00378	-0-	-0-	.00265	.00285	.00090	.00244	.00441	.00183	.00257
High pressure feedwater heaters	-0-	-0-	-0-	-0-	.00046	.00024	.00011	.00984	.00328	.00153	-0-	.00314	.00181
Boiler - reheater	.01270	-0-	-0-	.00751	-0-	-0-	.00526	-0-	-0-	.00402	-0-	-0-	.00323
Boiler - superheater	-0-	.06648	.06645	.02714	.01678	.04071	.02758	-0-	.02552	.02369	.04673	.02726	.02487
Boiler - waterwall tubes	.03939	.06017	.06026	.04791	.12222	.09335	.06572	.04900	.08163	.06789	.11056	.08596	.07199
Boiler - circulating pumps	-0-	.01286	.01280	.00523	.02857	.20284	.01105	-0-	.01504	.01069	-0-	.01066	.00948
Boiler - economizer	-0-	.01080	.01080	.00441	.01101	.01101	.00642	.06505	.02801	.01531	-0-	.02514	.01645
Boiler - burners	-0-	-0-	-0-	-0-	-0-	-0-	-0-	.00706	.00222	.00102	-0-	.00216	.00123
Sluice pumps	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-
Ash hopper	-0-	-0-	-0-	-0-	.00287	.00149	.00066	-0-	.00116	.00070	-0-	.00084	.00064
Pulverizers feeder	.00409	.00216	.00234	.00338	.00518	.00381	.00372	.00566	.00454	.00407	.00087	.00388	.00385
Pulverizers mills	.05969	.00020	.00020	.03539	.00721	.00383	.02644	.03813	.01475	.02613	.08771	.03216	.03210
Pulverizer exhausters	.00007	.00011	.00011	.00009	-0-	.00005	.00007	.00105	.00037	.00021	.00905	.00228	.00114
Boiler forced draft fans	.00552	.00290	.00290	.00445	-0-	.00140	.00332	-0-	.00082	.00260	.03445	.00798	.00563
Air preheaters - Air heaters	-0-	.00114	.00114	.00047	-0-	.00055	.00041	-0-	.00032	.00034	-0-	.00021	.00028
Piping	.00361	.00313	.00313	.00341	-0-	.00151	.00261	-0-	.00088	.00206	.00239	.00109	.00193
Total	.40474	.67249	.67250	.51410	.39514	.52849	.49812	.18578	.40722	.44955	.31161	.36270	.42025

Table 3.17 shows a comparison of the three projections attempted by Trident. Projection 3 is developed from equation (3.9). The percent difference given in Table 3.17 is found by the equation

$$\% \text{ Difference} = \left[\frac{\left(\frac{em}{eM} \right) \text{ Projected} - \left(\frac{em}{eM} \right) \text{ Actual}}{\left(\frac{em}{eM} \right) \text{ Actual}} \right] \quad (3.18)$$

On reviewing the data in Table (3.17), no clear trend is evident in the predictive ability of the various projection methods.

3.4.4 Statistical and Sensitivity Analysis

The statistical analysis on the Wood River 5 components, which is simply a χ^2 test, is shown in Table 3.18. This table shows the upper confidence limit on the meantime-to-outage and the lower confidence limit on the meantime-to-restore. A 90% confidence limit has been used. Table 3.19 gives the sensitivity of the largest outage on the $\left(\frac{em}{eM} \right)$ ratios computed over 1973-1977 at Wood River 5. Tables 3.18 and 3.19 show the large uncertainty in the $\left(\frac{em}{eM} \right)$ ratios for the various components. The significance of this analysis is discussed in Section 5.1.

3.5 IMPROVEMENT PROJECTS

In this section, three improvement projects for Wood River 5 are evaluated. The three improvement projects are as follows:

- Addition of sixth coal pulverizer system;
- Use of continuous maintenance to repair pulverizer outages;
- Installation of new tube bundles in all high pressure heaters.

TABLE 3.17
WOOD RIVER 5
COMPARISON OF PROJECTION METHODS

Data Base for $\left(\frac{em}{eM}\right)$ Predicted	Year Predicted	$C = a_c + b_c T_o$ Projection 1		$C = b_c T_o$ Projection 2		$\left(\frac{em}{eM}\right) = a T_o + b$ Projection 3		Actual $\left(\frac{em}{eM}\right)$
		$\left(\frac{em}{eM}\right)$	% Difference	$\left(\frac{em}{eM}\right)$	% Difference	$\left(\frac{em}{eM}\right)$	% Difference	
1973	1974	--	--	.40474	40%	--	--	.672
1973-1974	1975	.67250	41%	.51410	23%	--	--	.39514
1973-1975	1976	.52849	184%	.49812	168%	.582	213%	.18578
1973-1976	1977	.40722	31%	.44955	44%	.469	51%	.31161
1973-1977	1978	.36270	--	.42025	--	--	--	--

TABLE 3.18

WOOD RIVER 5

χ^2 TEST FOR COMPONENTS
(90% CONFIDENCE LIMIT)

COMPONENT IDENTIFIER	SYSTEM/COMPONENT	1973-1977 M_1 Hours	1973-1977 M_{1L} Hours	1973-1977 m_1 Hours	1973-1977 m_{1u} Hours
1A (a-b)	Generator/Exciter	8,069	4,038	13.4	30.65
1A (c)	Main Transformer/ Auxiliary Transformer	10,758	4,831	300.4	817.8
1A (d)	Substation	32,275	8,298	12.4	117.5
1B (a)	High Pressure and Intermediate Pressure Turbine	32,275	8,298	5,104.6	48,384.8
1B (b)	Low Pressure Turbine	16,137	6,064	22.8	85.7
2A (a)	Condenser	3,227	2,095	2.0	3.2
2B	Condenser Discharge System	---	---	---	---
2C (a-b)	Condenser Circulating Water Pumps	---	---	---	---
2D (a-c)	Condensate Pumps	32,275	8,298	96.0	910.0
2E (a)	Gland Steam Condenser	---	---	---	---
3A (a-d)	Low Pressure Heaters	---	---	---	---
3A (e)	Deaerating Feed Tank	---	---	---	---
3B (a-c)	Boiler Feed Pumps	3,227	2,095	8.8	14.1
3C (a-d)	High Pressure Feedwater Heater	10,758	6,129	11.4	21.7
4A (a)	Reheater	32,275	8,298	75.7	717.5
4A (b)	Superheater	2,483	1,702	65.0	97.8
4A (c)	Steam Drum	---	---	---	---
4A (d)	Waterwall Tubes	556	468	43.1	51.6
4A (e-g)	Boiler Circulating Pumps	32,275	14,413	87.5	238.2
4A (h)	Lower Drums	---	---	---	---
4A (i)	Economizer	6,455	3,480	114.5	238.2
4A (j)	Burners	32,275	8,298	47.0	445.5
4B (a-b)	Air Heater (gas side)	---	---	---	---
4B (c)	Precipitator	---	---	---	---
4C (a-b)	Sluice Pumps	---	---	---	---
4C (c)	Ash Hopper	32,275	8,298	18.6	176.3
4D (a)	Coal	---	---	---	---
4D (b)	Transporter	---	---	---	---
4D (c-g)	Pulverizer Coal System - Feeders	4,246	3,423	3.1	3.9
4D (h-l)	Pulverizer Coal System - Mills	2,735	2,303	18.7	22.4
4D (m-q)	Pulverizer Coal System - Exhauster	12,413	8,512	5.4	8.1
4E (a-b)	Forced Draft Fan	16,137	8,075	72.6	166.3
4E (c-e)	Air Preheater - Air Heaters	32,275	8,298	7.0	66.4
5A	Piping (entire plant)	10,758	4,831	19.2	52.2

TABLE 3.19

WOOD RIVER 5

SENSITIVITY OF $\left(\frac{em}{eM}\right)$ RATIO TO
LARGEST OUTAGE

COMPONENT IDENTIFIER	SYSTEM/COMPONENT	1973-1977 Without largest outage	1973-1977 All outages	Percentage difference
1A (a-b)	Generator/Exciter	.00084	.00166	49.4
1A (c)	Main Transformer / Auxiliary Transformer	.00042	.02792	98.5
1A (d)	Substation	-0-	.00038	100.0
1B (a)	High Pressure and Intermediate Pressure Turbine	-0-	.15816	100.0
1B (b)	Low Pressure Turbine	.00052	.00141	63.1
2A (a)	Condenser	.00053	.00062	14.5
2B	Condenser Discharge System	-0-	-0-	---
2C (a-b)	Condenser Circulating Water Pumps	-0-	-0-	---
2D (a-c)	Condensate Pumps	-0-	.00297	100.0
2E (a)	Gland Steam Condenser	-0-	-0-	---
3A (a-d)	Low Pressure Heaters	-0-	-0-	---
3A (e)	Deaerating Feed Tank	-0-	-0-	---
3B (a-c)	Boiler Feed Pumps	.00267	.00273	2.2
3C (a-d)	High Pressure Feedwater Heater	.00110	.00212	48.1
4A (a)	Reheater	-0-	.00234	100.0
4A (b)	Superheater	.02149	.02618	17.9
4A (c)	Steam Drum	-0-	-0-	---
4A (d)	Waterwall Tubes	.07155	.07752	7.7
4A (e-g)	Boiler Circulating Pumps	.00244	.00815	70.1
4A (h)	Lower Drums	-0-	-0-	---
4A (i)	Economizer	.00710	.01774	60.0
4A (j)	Burners	-0-	.00146	100.0
4B (a-b)	Air Heater (gas side)	-0-	-0-	---
4B (c)	Precipitator	-0-	-0-	---
4C (a-b)	Sluice Pumps	-0-	-0-	---
4C (c)	Ash Hopper	-0-	.00058	100.0
4D (a)	Coal	-0-	-0-	---
4D (b)	Transporter	-0-	-0-	---
4D (c-g)	Pulverizer Coal System - Feeders	.00344	.00365	5.7
4D (h-l)	Pulverizer Coal System - Mills	.02932	.03839	23.6
4D (m-q)	Pulverizer Coal System - Exhauster	.00082	.00217	62.2
4E (a-b)	Forced Draft Fan	.00159	.00902	82.3
4E (c-e)	Air Preheater - Air Heaters	-0-	.00022	100.0
5A	Piping (entire plant)	.00114	.00178	36.0

Sections 3.5.1 - 3.5.3 contain the analysis and show the change in unit equivalent availability for each improvement project.

The following assumptions have been made in evaluating each of the improvement projects:

- No change in Wood River 5 availability due to administrative and conditional outages from that in the 1973-1977 time period. In 1978, Wood River 5 became limited to 360 MW due to environmental reasons. Thus, this assumption implies that this power restriction will be removed before any improvement is implemented. Discussions with Wood River 5 personnel indicated that this restriction should be removed in the near future.
- No change in Wood River 5 availability due to loss of function outages from that in the 1973-1977 time period other than from the improvement itself.

The significance of these two assumptions is that the future availability of Wood River 5 is assumed to be equal to that in the 1973-1977 time period in evaluating the improvement projects.

3.5.1 Addition of Sixth Pulverizer

Wood River 5 needs all five pulverizers operating to reach its maximum dependable capacity of 398 MW. A failure of one drops the maximum unit output to approximately 340 MW. Although Wood River 5 had been recently limited to producing 360 MW for environmental reasons, a sixth pulverizer would remove an historical source of numerous unit load curtailments. Additionally, adding a sixth pulverizer could significantly increase the unit equivalent availability if and when the environmental constraints on the unit are lifted.

Combustion Engineering, which claims to have developed a technique to retrofit additional pulverizers to boilers, has been consulted by Trident on the technical feasibility of this improvement project. The technique involves adding a sixth pulverizer which supplies coal to the boiler in a

"dense" phase. By dense phase, it is meant that the coal to air ratio is approximately ten to one. Since the pipe which transports such dense coal to the boiler needs to be only two inches in diameter, it can be fit between the other large coal lines from the original five pulverizers. Thus, very little boiler modification is needed. A complete technical evaluation of this process is beyond the scope of work authorized by the contract. Assuming the process to be technically feasible, Trident has calculated the change in the equivalent availability for Wood River 5.

Using Tables 3.7.17, 3.7.18, and 3.7.19, Trident has plotted the cumulative equivalent outage time versus operational time for the pulverizer feeders, mills, and exhausters at Wood River 5. Trident plotted outage data after each calendar year, so five points are shown in each of these figures. Each point corresponds to the end of the calendar years 1973-1977. This is shown in Figures 3.4 - 3.6

Figures 3.4 - 3.6 have been used by Trident to project $\left(\frac{em}{eM}\right)$ baseline. This has been done by making a least squares correlation to this plotted outage data using the equations

$$C = a_c + b_c T_o \quad (3.19)$$

Recalling equations (3.14) and (3.15), $\left(\frac{em}{eM}\right)$ baseline is then found as follows:

$$\left(\frac{em}{eM}\right)_{\text{baseline}} = b_c \quad (3.20)$$

Table 3.20 shows the least squares fit coefficients found for the pulverizer feeders, mills, and exhausters. Thus, $\left(\frac{em}{eM}\right)$ baseline for this improvement project is given by:

$$\left(\frac{em}{eM}\right)_{\text{baseline}} = b_c \text{ feeders} + b_c \text{ mills} + b_c \text{ exhausters} \quad (3.21)$$

Putting in the values for the b_c coefficients from Table 3.20 gives

$$\left(\frac{em}{eM}\right)_{\text{baseline}} = .03829 \quad (3.22)$$

Figure 3.4 Least Squares Fit to Cumulative Equivalent Outage Time Versus Operational Time for Pulverizer Feeders at Wood River 5

Figure 3.5 Least Squares Fit to Cumulative Equivalent Outage Time Versus Operational Time for Pulverizer Mills at Wood River 5

Figure 3.6 Least Squares Fit to Cumulative Equivalent Outage Time Versus Operational Time for Pulverizer Exhausters at Wood River 5

<p>TABLE 3.20</p> <p>COEFFICIENTS IN LEAST SQUARES FIT FOR PULVERIZERS</p>		
Pulverizer Component	a_c	b_c
Feeders	- .580	3.878×10^{-3}
Mills	- 1.236	3.213×10^{-2}
Exhausters	-26.74	2.285×10^{-3}

To determine the effect of the sixth pulverizer improvement on the $\left(\frac{em}{eM}\right)$ ratio, Trident reviewed the 1973-77 partial outages due to pulverizers at Wood River 5. This outage data is given in Tables 3.7.17, 3.7.18, and 3.7.19. Trident then assumed that had a sixth pulverizer been present during this period:

- (1) All 60 MW capacity loss outages would have been eliminated;
- (2) All 160 MW capacity loss outages would have been 60 MW capacity loss outages;
- (3) All 260 MW capacity loss outages would have been 160 MW capacity loss outages.

These assumptions are equivalent to assuming that the sixth pulverizer won't fail when in service. This is a very reasonable assumption since the pulverizer's equivalent meantime-to-outage is considerably larger than its equivalent meantime-to-restore.

Table 3.21 shows the hypothetical outage data that would have occurred at Wood River 5 during 1973-1977 if assumptions one through three are made. An analysis of the data in Table 3.21 is given in Table 3.22. Trident used this total $\left(\frac{em}{eM}\right)$ ratio to evaluate the sixth pulverizer improvement.

Thus, for this improvement:

$$\left(\frac{em}{eM}\right) = .00650 \quad (3.23)$$

Putting equations (3.22) and (3.23) into equation (1.27) and the result into equation (1.26) gives:

$$\Delta EA = \left[.03829 - .00650 \right] \frac{T_0}{T} \quad (3.24)$$

For Wood River 5 between 1973-1977;

$$T_0 = 32,328 \quad (3.25)$$

$$T = 43,824 \text{ hours} \quad (3.26)$$

TABLE 3.21
HYPOTHETICAL OUTAGE DATA
IF SIX PULVERIZERS WERE IN UNIT
WOOD RIVER 5
(1973 - 1977)

Date	Total Outage Duration (Hours)	Capacity Loss (MW)
<u>FEEDERS</u>		
5/15/73	11.3	60
7/8/73	5.9	60
10/13/73	4.3	60
5/19/74	5.0	60
5/19/74	2.0	60
9/21/74	9.0	60
10/22/74	4.7	60
12/27/74	15.2	60
1/28/75	17.4	60
2/17/75	27.1	60
2/18/75	4.8	60
2/27/75	6.8	60
6/23/75	2.2	60
8/13/75	11.7	60
9/7/75	9.7	60
10/7/75	4.0	60
10/29/76	10.3	160
11/3/76	4.9	60
11/6/76	6.6	60
11/18/76	11.7	60
<u>MILLS</u>		
5/15/74	3.0	60
2/7/75	89.5	60
8/4/75	13.5	60
8/5/75	13.5	60
(Continued...)		

TABLE 3.21

(Continued)

Date	Total Outage Duration (Hours)	Capacity Loss (MW)
<u>MILLS (Con't)</u>		
3/13/76	4.2	160
4/26/76	2.6	160
11/2/76	8.5	60
11/15/76	5.6	60
11/16/76	2.6	60
11/16/76	.7	60
11/16/76	1.7	60
2/28/77	711.7	60
3/24/77	3.1	160
3/25/77	17.3	160
5/16/77	114.3	60
<u>EXHAUSTERS</u>		
5/14/74	1.8	60
4/26/77	68.1	160

TABLE 3.22

ANALYSIS OF TABLE 3.21 OUTAGE DATA
(1973 - 1977)

Component	Number of Outages	eM	$\frac{\text{MWH Lost}}{\text{MDC}}$	em	$\frac{\text{em}}{\text{eM}}$
Pulverizer Feeder	20	1616.4	28.9	1.4	.00087
Pulverizer Mills	15	2155.2	155.1	10.3	.00478
Pulverizer Exhausters	2	16164.0	27.6	13.8	.00085
TOTAL					.00650

EQUATIONS USED TO DEVELOP TABLE 3.22

$$M_1 = \frac{\text{1973-77 Wood River 5 Operating Time (32328 Hours)}}{\text{Number of Outages}}$$

$$\text{eM} = M_1$$

$$\text{em} = \frac{\text{MWH Lost}}{(\text{MDC}) (\text{number of outages})}$$

Putting equations (3.25) and (3.26) into (3.24) gives:

$$\Delta EA = .0234 \quad (3.27)$$

Thus, equation (3.27) gives the predicted change in equivalent availability resulting from the addition of a sixth pulverizer at Wood River 5.

3.5.2 Continuous Pulverizer Maintenance

Presently, mill outages are repaired by one-shift or two-shift maintenance which extends their duration. Repairs often are not performed on holidays and weekends, further extending pulverizer outages. Thus the improvement project would be to see the ΔEA that could be achieved if all pulverizer outages were immediately repaired.

The continuous maintenance improvement project has the same $\left(\frac{em}{eM}\right)_{\text{baseline}}$ as the sixth pulverizer improvement project. Thus,

$$\left(\frac{em}{eM}\right)_{\text{baseline}} = .03829 \quad (3.28)$$

Trident evaluated the $\left(\frac{em}{eM}\right)$ ratio due to continuous maintenance using the following assumptions:

- (1) Equivalent meantime-to-outage (eM) not affected by improvement;
- (2) Meantime-to-restore equal to the meantime-to-repair.

The time-to-repair each pulverizer outage was collected by Trident during plant visits on June 13-15 to Wood River 5. Table 3.23 gives the time-to-repair pulverizer outages, 1973-1977. The following outages have not been included in Table 3.23 from those given in Table 3.7.17, 3.7.18, and 3.7.19:

- Multiple failure outages;
- Outages repaired by an outside contractor brought into Wood River 5 by Illinois Power;
- Outages extending past the end of 1977.

From Table 3.23, the equivalent meantime-to-restore was calculated for the feeder, mills, and exhausters separately as:

$$em = \frac{\sum_{N} \text{MWH Lost for outages in Table 3.23}}{(398) (N)} \quad (3.29)$$

where

MWH Lost = Capacity loss (MW) x time-to-repair

N = Number of outages due to feeders, mills, exhausters shown in Table 3.23

Table 3.24 gives the result of this analysis. The total $\left(\frac{em}{eM}\right)$ ratio is given by:

$$\left(\frac{em}{eM}\right) = .01194 \quad (3.30)$$

Putting equations (3.25), (3.26), (3.28), and (3.30) into equation (1.27) and the result into equation (1.26) gives:

$$\Delta EA = [.03829 - .01194] \left(\frac{32328}{43824}\right) \quad (3.31)$$

TABLE 3.23
TIME TO REPAIR PULVERIZER OUTAGES
WOOD RIVER 5
(1973 - 1977)

Date	Time to Repair	Capacity Loss (MW)
<u>FEEDERS</u>		
1/16/73	3	60
1/19/73	4	60
2/13/73	5.6	60
4/22/73	8	60
5/15/73	4	160
7/8/73	5	160
7/22/73	9	60
7/27/73	3	60
10/13/73	4.3	160
11/12/73	6	60
11/27/73	5.5	60
5/19/74	4	160
5/19/74	2	160
9/21/74	6	160
10/22/74	4	160
12/27/74	3	160
1/28/75	10	160
2/17/75	10.5	160
2/18/75	1.5	160
2/27/75	1	160
6/23/75	2	160
8/13/75	10.2	160
9/7/75	8.5	160
10/7/75	2	160
3/3/76	2	60
4/26/76	4	60
5/8/76	13	60
7/13/76	2.5	60

TABLE 3.23 (Con't)

TIME TO REPAIR PULVERIZER OUTAGES
WOOD RIVER 5
(1973 - 1977)

Date	Time to Repair	Capacity Loss (MW)
<u>FEEDERS (Con't)</u>		
7/16/76	8	60
7/24/76	3	60
10/5/76	16	60
10/9/76	8	60
10/29/76	5.5	260
11/3/76	4	160
11/6/76	4.5	160
11/18/76	10.5	160
10/15/77	6	60
<u>MILLS</u>		
4/24/73	192	60
5/24/73	168	60
6/17/73	6.5	60
7/6/73	72	60
8/10/73	8	60
10/7/73	216	60
5/15/74	2	160
2/7/75	49	160
8/4/75	13.5	160
8/5/75	8	160
3/13/76	3	160
3/29/76	1.8	60
4/26/76	2	160
4/27/76	96	60
5/10/76	3	60
5/11/76	1.5	60
5/12/76	3.3	60

(Continued...)

TABLE 3.23 (Con't)

TIME TO REPAIR PULVERIZER OUTAGES
WOOD RIVER 5
(1973 - 1977)

Date	Time to Repair	Capacity Loss (MW)
	<u>MILLS (Con't)</u>	
5/13/76	144	60
6/10/76	2.5	60
6/13/76	36	60
6/24/76	4	60
6/28/76	5.5	60
8/23/76	1.5	60
8/30/76	13.0	60
9/29/76	40	60
10/11/76	304	60
10/28/76	5.2	60
11/2/76	8.5	160
11/15/76	5	160
11/16/76	2.6	160
11/16/76	.7	160
11/16/76	1.7	260
2/8/77	27	60
2/16/77	13	60
3/25/77	10	260
6/6/77	3.1	60
6/10/77	13	60
6/27/77	8.2	60
8/27/77	8	60
9/17/77	23	60
10/25/77	44	60
10/29/77	28	60
11/1/77	4	60
11/2/77	4	60
11/4/77	4	60
11/27/77	7.3	60
12/9/77	8.5	60
12/20/77	6.3	60

(Continued...)

TABLE 3.23 (Con't)

TIME TO REPAIR PULVERIZER OUTAGES
WOOD RIVER 5
(1973 - 1977)

Date	Time to Repair	Capacity Loss (MW)
	<u>EXHAUSTERS</u>	
1/16/73	1	60
5/14/74	1	160
4/13/76	3	60
5/7/76	7.2	60
5/10/76	1	60
5/10/76	2.4	60
5/10/76	2	60
2/8/77	1.5	60
2/14/77	1.5	60
4/26/77	64	260
6/22/77	49	60
10/9/77	3.5	60
10/28/77	.5	60

TABLE 3.24

em AND eM FOR WOOD RIVER 5
BASED ON TABLE 3.23
(1973 - 1977)

Component	Number of Outages	eM	em	$\frac{em}{eM}$
Pulverizer Feeder	37	874	1.6	.00183
Pulverizer Mills	48	674	5.7	.00846
Pulverizer Exhauster	13	2487	4.1	.00165
TOTAL				.01194

Evaluating equation (3.31) gives:

$$\Delta EA = .0194 \quad (3.32)$$

Thus, equation (3.32) gives the predicted change in equivalent availability for Wood River 5 if continuous maintenance is used to repair pulverizer outages.

3.5.3 Installation Of New Tube Bundles In High Pressure Heaters

Tube leaks in the high pressure feedwater heaters have been occurring at Wood River 5. Approximately 50 tubes have been plugged in both the G_1 and G_2 heaters as of January 1, 1978, while 10-20 tubes have been plugged in the F_1 and F_2 heaters. Feedwater heater tube leaks degrade unit performance and also require outage time-to-repair. Thus, the improvement project of replacing the tube bundles in these heaters was recommended. This project was chosen because it met all the essential criteria for project selection. In addition, the improvement project was selected because Illinois Power is about to undertake this improvement. Trident analyzed this improvement project by only considering the ΔEA due to a change in outage time-to-repair tube leaks. The ΔEA due to degradation in unit performance by not replacing the tube bundles has been neglected.

Figure 3.7 shows the cumulative equivalent hours (C) lost versus operational time for the high pressure heater. From a least squares best fit, Trident obtained the following coefficients for C which are given by:

$$a_c = -31.09 \quad (3.33)$$

$$b_c = .00314 \quad (3.34)$$

Thus putting equation (3.34) into equation (3.15) gives:

$$\left(\frac{em}{eM}\right)_{\text{baseline}} = .00314 \quad (3.35)$$

Figure 3.7 Least Squares Fit to Cumulative Equivalent Outage Time Versus Operational Time for High Pressure Feedwater Heaters at Wood River 5

Trident analyzed $\left(\frac{em}{eM}\right)$ by dividing it into two parts, $\left(\frac{em}{eM}\right)_I$ and $\left(\frac{em}{eM}\right)_{II}$.

Thus,

$$\left(\frac{em}{eM}\right) = \left(\frac{em}{eM}\right)_I + \left(\frac{em}{eM}\right)_{II} \quad (3.36)$$

where

$$\left(\frac{em}{eM}\right)_I \quad \text{is found by considering historical outage of feedwater heater not related to tube leaks}$$

$$\left(\frac{em}{eM}\right)_{II} \quad \text{is based on ratio of new tube bundles}$$

The historical outages of the high pressure feedwater heater due to causes other than tube leaks is given in Table 3.25. In this case, the equivalent meantime-to-restore is found as:

$$em_I = \frac{\sum_{i=1}^5 \text{MWH Lost for Outages in Table 3.25}}{(5) (398)} \quad (3.37)$$

Thus from Table 3.25,

$$em_I = 8.0 \text{ hours} \quad (3.38)$$

The equivalent meantime-to-outage is found as

$$eM_I = \frac{\text{Wood River 5 Operating Time (1973-1977)}}{\text{Number of Outages}} \quad (3.39)$$

<p>TABLE 3.25</p> <p>HIGH PRESSURE FEEDWATER HEATER OUTAGES DUE TO CAUSES OTHER THAN TUBE LEAKS WOOD RIVER 5 (1973 - 1977)</p>		
Date	Total Outage Duration (Hours)	Capacity Loss
5/13/75	21.8	55
7/24/76	237.0	55
8/5/76	2.1	55
8/10/76	13.8	55
8/12/76	14.2	55

Therefore,

$$eM_I = \frac{32328}{5} = 6465 \text{ hours} \quad (3.40)$$

Dividing equations (3.38) by (3.40) gives

$$\left(\frac{em}{eM}\right)_I = .00124 \quad (3.41)$$

Trident evaluated the $\left(\frac{em}{eM}\right)_{II}$ ratio resulting from the improvement by making the assumption that equivalent meantime-to-restore will be that of the single historical outage in the high pressure feedwater heaters due to tube leaks. Thus, from Table 3.7.9, using the outage data of June 29, 1976, the equivalent meantime-to-restore is found as

$$em_{II} = 206.5 \times \frac{55}{398} = 28.5 \text{ hours} \quad (3.42)$$

An equivalent meantime-to-outage for the new tube bundles was not available since Trident had no generic data on this performance. Although the new tube bundles have the same specifications as the old tube bundles, their manufacturer has not been selected at this time. Thus, Trident felt this improvement project could only be evaluated by making a parameter study on the effect of the equivalent meantime-to-outage on the change in unit equivalent availability. The results of this analysis are shown in Figure 3.8.

Figure 3.8 was generated by putting equations (3.41) and (3.42) into equation (3.36). This gives

$$\left(\frac{em}{eM}\right) = .00124 + \frac{28.5}{eM} \quad (3.43)$$

Equations (3.35) and (3.43) were then put into equation (1.27) and the result into equation (1.26) gives:

$$\Delta EA = \left[.00314 - \left(.00124 + \frac{28.5}{eM} \right) \right] \frac{T_o}{T} \quad (3.44)$$

Figure 3.8 Change in Equivalent Availability for Wood River 5 Versus Equivalent Meantime-To-Outage of New High Pressure Feedwater Heaters at Wood River 5

For 1973-1977 at Wood River 5:

$$T_o = 32328 \text{ hours} \quad (3.45)$$

$$T = 43824 \text{ hours} \quad (3.46)$$

Putting equations (3.45) and (3.46) into equation (3.44) gives

$$\Delta EA = \left[.00190 - \frac{28.5}{eM} \right] \left(\frac{32328}{43824} \right) \quad (3.47)$$

Figure 3.8 shows that an $eM = 80,000$ hours would give a $\Delta EA = .00115$, while an $eM = 20,000$ hours would give a $\Delta EA = .00035$ for this improvement project. Also, if the new tube bundles have a meantime-to-outage of 15,000 hours or less, then the ΔEA would be negative.

Discussions with Wood River 5 personnel indicated that the old tube bundles, manufactured by Grisson-Russell, had an expected lifetime of seven years. Assuming that this lifetime would give an equivalent meantime-to-outage equal to the number of hours in seven years, then

$$eM = 7 \times 8760 = 61320 \text{ hours} \quad (3.48)$$

Putting equation (3.48) into equation (3.47) gives

$$\Delta EA = .00106 \quad (3.49)$$

This analysis has been performed by considering only past outages due to the high pressure heaters. Two important factors ignored were:

- Tubes plugged during the Wood River 5 outages;
- Derating that unit would eventually undergo when a large number of heater tubes became plugged.

Inclusion of these factors could significantly change the analysis. These problems are discussed in Chapter 5.

4.0 QUAD CITIES 1 AND 2

This part contains the analysis for Quad Cities using the Department of Energy methodology. A brief background description of Quad Cities is given in 4.1. The functional analysis is presented in 4.2. Section 4.3 gives the outage data collected along with the analysis to determine the meantime-to-outage and meantime-to-restore coefficients. The equivalent availability model for Quad Cities 1 and 2 is developed in 4.4. This model is then applied in 4.5 to evaluate the change in equivalent availability for three improvement projects for Quad Cities 2 and in 4.6 for two improvement projects at Quad Cities 1.

4.1 PLANT DESCRIPTION

Quad Cities employs boiling water nuclear reactors to generate saturated steam. Each unit consists of a nuclear core within a pressure vessel, auxiliary systems to accommodate the operational and safeguard requirements of the nuclear reactor, and necessary controls and instrumentation. Water is circulated through the reactor core, producing steam which is separated from recirculation water, dried in the top of the vessel, and directed to the steam turbine generators. Each unit's turbine system consists of a single high pressure unit and three low pressure units. A conventional regenerative cycle with condensate deaeration and condensate demineralization is employed to give each unit a gross output of 833 MW.

Using equipment manuals, piping and instrument diagrams, and heat balance diagrams, on-line schematics were constructed for both the primary system (reactor and auxiliaries) and the secondary plant (turbine-generator set, condensate, and feedwater systems). It was not intended in this model to divide systems to a level of detail that showed all the active elements in a system. The schematics were, therefore, simplified in detail and corresponded in a general sense to the outage data investigated to date. Only elements that have caused significant numbers of outages or have the probability to do so were documented in the schematics. The schematics were then refined into functional diagrams, which are described in section 4.2.

Trident analyzed the Quad Cities units by first considering their primary and secondary systems:

- Primary System

For modeling purposes, the reactor plant is modeled with six essential systems described below:

- Reactor;
- Recirculation system;
- Reactor clean-up system;
- Residual heat removal system;
- Control rod drive hydraulic system;
- Radioactive waste system.

These systems are also shown on the functional diagrams divided further into their basic components. Safety systems are not evaluated in this study and have, therefore, been omitted from the functional diagrams. The residual heat removal system, while generally considered a major safety system, serves the dual purpose of providing shut-down cooling for the primary system during normal operation. It is, therefore, modeled in this study and shown in the functional diagrams where applicable.

- Secondary System

The secondary plant, at both Quad Cities 1 and 2, is modeled with the following major systems:

- Main steam line system;
- High pressure turbine;

- Low pressure turbine;
- Generator-exciter-main power transformer;
- Main steam condenser;
- Condensate system;
- Feedwater system;
- Circulating water system;
- Off-gas system.

As with the primary side of the plant, these systems are subdivided into components where outage data dictated significant failure rates.

• Major Plant Equipment

The major equipment at Quad Cities falls into four categories:

- Steam Generation;
- Power Conversion;
- Steam Condensation;
- Feed.

Table 4.1 details the various components of the major plant systems showing the number in the unit, the number needed for full power operation, the loss of capacity for component failure, the repairability, and any modifications since 1973.

Table 4.2 lists the loss in unit output for various combinations of feedwater heaters being out of service. There are three parallel strings of heaters for each unit. Additionally, for each unit, the heaters are interconnected with lines and valving such that a single heater from any of the three strings could be valved out. There are, of course, no interconnections between the two units themselves. Thus, as seen in Table 4.2, various combinations of heaters are possible with different levels of loss megawatts for each combination.

TABLE 4.1
MAJOR EQUIPMENT AT QUAD CITIES 1 AND 2

COMPONENT IN GENERIC FUNCTION	NUMBER IN UNIT	NUMBER REQUIRED FOR FULL POWER OPERATION	UNIT CAPACITY LOSS * FOR COMPONENT FAILURE (MW) (Number of Failed Components - MW Lost)	REPAIRABLE WITH UNIT ON LINE	MAJOR MODIFICATION SINCE 1973
STEAM GENERATION					
Reactor	1	1	Full	No	No
Torus-Drywell Vacuum Breaker	12	9	4-Full	No	No
Recirculation System					
Recirculating Pump	2	2	Full	No	No
Jet Pump	20	20	Full	No	No
Reactor Water Clean-Up System					
Clean-Up Pumps	2	1	0	No	No
Regenerative HX Strings	2	1	0	No	No
Nonregenerative HX Strings	2	1	0	No	No
Filter Demineralizers	2	1	0	No	No
Residual Heat Removal System					
Pumps	4	4	Full	Yes	No
Heat Exchangers	2	1	Full (Must be in same string as operable pump)	Yes	No
Control Rod Drive Hydraulic System					
Components per Drive	177				
Suction Filters	2	1	Full	Yes	No
Rod Drive Pumps	2	1	Full	Yes	No
Water Filters	2	1	Full	Yes	No
POWER CONVERSION					
Main Steam Line System					
MSIV Strings	8	8	1 - 202 MW 2 - Full	No	Yes
Main Stop Valves	4	4	Unknown	No	No
Control Valves	4	4	Full	No	No
Bypass Valves	9	9	Full	No	No
Moisture Separators	4	4	Full	No	No
High Pressure Turbine	1	1	Full	No	No
Low Pressure Turbine	3	3	Full	No	No
Generator-Exciter —	1	1	Full	No	No
Main Transformer					
Electrohydraulic Controls	1	1	Variable	No	No

*Based on unit capacity of 809 MW.

MAJOR EQUIPMENT AT QUAD CITIES 1 AND 2
(Continued)

COMPONENT IN GENERIC FUNCTION	NUMBER IN UNIT	NUMBER REQUIRED FOR FULL POWER OPERATION	UNIT CAPACITY LOSS FOR COMPONENT FAILURE (MW) (Number of Failed Components - MW Lost)	REPAIRABLE WITH UNIT ON LINE	MAJOR MODIFICATION SINCE 1973
STEAM CONDENSATION					
Condenser Waterboxes	4	4	1 - 459 MW 2 - Full	No	Yes
Condensate Pumps	4	3	2 - 404 MW	Yes	No
Steam Jet Air Ejector	2	2	Full	Yes	No
Gland Seal Condenser	2	1	Full	Yes	No
Condensate Demineralizers	7	6	1 - 135 MW 2 - 270 MW	Yes	No
Condensate Booster Pumps	4	3	2 - 404 MW	Yes	No
Circulating Water System Pumps	3	3	Full	Yes	No
Spray Canal	1	1	N/A	Yes	Yes
Off Gas System					Yes
Catalytic Recombiners and Water Separators	2	1	Full	No	Yes
Moisture Separator and Gas Reheater	2	1	Full	No	Yes
Charcoal Absorbers	12	6	7 - Full	No	Yes
FEED					
Low Pressure Feedwater Heater Strings	3	See Table 3.2	See Table 3.2	Yes	No
Reactor Feed Pumps	3	2	2 - 459 MW	Yes	No
Feedwater Regulating Valves	2	2	Full	Yes	Yes
High Pressure Feedwater Heater Strings	3	See Table 3.2	See Table 3.2	Yes	No
Feedwater Sparger	4	4	Full	No	No
SHARED SYSTEMS					
Turbine Bypass System	1	1	Full	No	No
Instrument Air System	1	1	Variable	Yes	Yes

TABLE 4.2

CAPACITY LOSS IN MWe FOR FEEDWATER HEATERS
OUT OF SERVICE AT QUAD CITIES

Heater Out	1 String	2 Strings	3 Strings
D (High Pressure)	41	41	0
C	41	41	82
B	123	123	123
C, B, & A	123	164	205
D, C, B, & A	123	123	82
D & C	82	82	41
D, C, & B	123	123	82
C & B	41	123	164
D & B	123	123	123

4.2 QUAD CITIES - FUNCTIONAL ANALYSIS

This chapter of the report contains the functional diagrams and failure mode and effect analysis for Quad Cities.

Figure 4.1 shows the functional diagram at the generic level for Quad Cities. The four basic power plant functions shown in this figure are the same as those given for Wood River 5. They are (1) power conversion, (2) steam condensation, (3) feed, and (4) steam generation. In addition, shared systems have been put into a fifth function as recommended in the Department of Energy methodology.

The functional diagram at the subfunction level is shown in Figure 4.2 for Quad Cities. Similar to Wood River 5, the power conversion function has been divided into the electrical conversion system (1A) and the energy conversion system (1B). The steam condensation function has been divided into nine subfunctions. They are the condensate system (2A), discharge system (2B), cooling water system (2C), off-gas system (2D), condensate feed system (2E), steam jet air ejector system (2F), gland steam condensate system (2G), condensate demineralizer system (2H), and condensate booster feed system (2I). Five subfunctions which compose the feed function are the low pressure heater system (3A), reactor feed system (3B), feed control system (3C), high pressure heater system (3D), and feedwater sparger system (3E). The steam generation function is represented by five subfunctions, which are the control rod drive hydraulic system (4A), energy exchange system (4B), recirculation system (4C), reactor water cleanup system (4D), and the residual heat removal system (4E). The turbine bypass system (5A) and instrument air system (5B) are shown separately since these are shared systems between different generic level functions.

Figure 4.3 depicts the functional diagram at the equipment level for Quad Cities 1 and 2 models, the major different types of components used in the units, as well as showing the number of components in each system and significant interconnections between components and systems. A number of the important valves have been shown in Figure 4.3 because of their importance in unit outages and to the selected improvement projects. Table 4.3 lists all the components shown in Figure 4.3. This table gives the element letter identification used in Figure 4.3, number required for maximum dependable capacity, number in unit, whether components are in series, parallel, or shared, and the table where the component outage data has been tabulated.

FUNCTIONAL DIAGRAM - GENERIC LEVEL

QUAD CITIES 1 AND 2

Figure 4.1

FUNCTIONAL DIAGRAM - SUBFUNCTION LEVEL

QUAD CITIES 1 AND 2

Figure 4.2

QUAD CITIES 1 AND 2

Figure 4.3

TABLE 4.3

EQUIPMENT FUNCTIONAL DIAGRAM AND OUTAGE DATA COLLECTED

QUAD CITIES

FIGURE 4.3 LABEL	SYSTEM/COMPONENT	NUMBER REQUIRED FOR MDC	NUMBER IN UNIT	REMARK	TABLE WHERE OUTAGE DATA TABULATED	
					UNIT 2	UNIT 1
1A (a)	Generator Exciter	1	1	Series	4.8.1	4.11.1
1A (b)	Main Transformer	1	1	Series	4.8.1	4.11.2
1A (c)	Electrical Distribution System	1	1	Series	4.8.1	4.11.2
1B (a-d)	Main Stream Isolation Valves	8	8	Parallel	4.8.2	4.11.3
1B (e)	Main Stream Line- Piping, Relief Valves	-	-	Series	4.8.3	4.11.4
1B (f-i)	Main Stream Line - Control Valves	4	4	Parallel	4.8.4	4.11.5
1B (j)	High Pressure Turbine	1	1	Series	4.8.5	4.11.6
1B (k-n)	Moisture Separators	4	4	Parallel	4.8.6	4.11.7
1B (o-q)	Low Pressure Turbine	3	3	Parallel	4.8.7	No out- ages
1B (r)	Electrohydraulic Control	1	1	Series	No Outages	4.11.8
2A (a)	Condenser	1	1	Series	4.8.8	4.11.9
2B (a)	Spray Canal or River	1	1	Series	4.8.9	4.11.10
2C (a-c)	Condenser Circulating Water Pumps	3	3	Parallel	No Outages	No out- ages
2D (a)	Off-Gas System - Piping	1	1	Series	4.8.10	4.11.11
2D (b-c)	Catalytic Recombiner and Water Separators	1	2	Parallel	4.8.11	No out- ages
2D (d-e)	Moisture Separator- Gas Reheater	1	2	Parallel	No Outages	No out- ages
2D (f-q)	Charcoal Absorbers	6	12	Parallel	No Outages	No out- ages
2E (a-d)	Condensate Pumps	3	4	Parallel	4.8.12	4.11.12
2F (a-b)	Steam Jet Air Ejectors	1	2	Parallel	4.8.13	4.11.13

TABLE 4.3 (Continued)

EQUIPMENT FUNCTIONAL DIAGRAM AND OUTAGE DATA COLLECTED

QUAD CITIES

FIGURE 4.3 LABEL	SYSTEM/COMPONENT	NUMBER REQUIRED FOR MDC	NUMBER IN UNIT	REMARK	TABLE WHERE OUTAGE DATA TABULATED	
					UNIT 2	UNIT 1
2G (a-b)	Gland Seal Condenser	1	2	Parallel	No Outages	No out- ages
2H (a-g)	Condensate Demineralizer	6	7	Parallel	4.8.14	4.11.14
2I (a-d)	Condensate Booster Pumps	3	4	Parallel	No Outages	No out- ages
3A (a-i)	Low Pressure Feedwater Heaters	9	9	Series/ Parallel	4.8.15	4.11.15
3B (a-c)	Reactor Feed Pumps	2	3	Parallel	4.8.16	4.11.16
3B (d)	Feedwater Piping	1	1	Series	4.8.17	4.11.17
3C (a-b)	Feedwater Regulating Valves	2	2	Parallel	4.8.18	4.11.18
3D (a-c)	High Pressure Feedwater Heaters	3	3	Parallel	No Outages	No out- ages
3E (a-b)	Feedwater Spargers	4	4	Parallel	4.8.19	4.11.19
4A (a)	Condensate Storage Tanks	2	2	Series	No Outages	No out- ages
4A (b-c)	Suction Filters	1	2	Parallel	No Outages	No out- ages
4A (d-e)	Pumps	1	2	Parallel	No Outages	No out- ages
4A (f-g)	Water Filters	1	2	Parallel	No Outages	No out- ages
4A (h)	Piping, Flanges	1	1	Series	4.8.20	No out- ages
4B (a)	Reactor	1	1	Series	4.8.21	No out- ages
4B (b)	Torus-to-drywell vacuum breaker	9	12	Parallel	No Outages	4.11.19
4C (a-b)	Recirculation Pumps	2	2	Parallel	4.8.22	4.11.20
4C (c-v)	Jet Pumps	20	20	Parallel	No Outages	No out- ages
					(Continued..)	

TABLE 4.3 (Continued)

EQUIPMENT FUNCTIONAL DIAGRAM AND OUTAGE DATA COLLECTED

QUAD CITIES

FIGURE 4.3 LABEL	SYSTEM/COMPONENT	NUMBER REQUIRED FOR MDC	NUMBER IN UNIT	REMARK	TABLE WHERE OUTAGE DATA TABULATED	
					UNIT 2	UNIT 1
4D (a-b)	Cleanup Pumps	1	2	Parallel	No Outages	No out- ages
4D (c-d)	Regenerative Heat Exchangers	1	2	Parallel	No Outages	No out- ages
4D (e-f)	Nonregenerative Heat Exchanger	1	2	Parallel	No Outages	No out- ages
4D (g-h)	Filter Demineralizers	1	2	Parallel	No Outages	No out- ages
4D (i)	Valves	-	-	Series	4.8.23	No out- ages
4E (a-d)	Residual Heat Removal Pumps	4	4	Parallel	4.8.24	No out- ages
4E (e-f)	Residual Heat Removal Heat Exchangers	1	2	Parallel	No Outages	No out- ages
5A	Turbine Bypass System	9	9	Parallel	No Outages	No out- ages
5B	Instrument Air System	1	1	Series	No Outages	4.11.21

Table 4.4 is the failure mode and effects analysis for Quad Cities. This table was constructed primarily from the information in Table 4.1. It shows for each system component the effect of a failure on the Quad Cities 1 or 2 output.

4.3 OUTAGE DATA

For Quad Cities, obtaining data of the quality necessary to accurately assess the merits of the Department of Energy methodology has required considerable effort. The EEI data does not begin until September 1973 and partial outages do not begin to be regularly reported until the middle of 1975. As a result, Trident has used three primary sources of data for full outages, partial outages, deratings, and ramps:

- Full Outages

For full outages, the AEC/NRC gray book data is used to determine the duration of the outages. This was chosen over the semi-annual data, since gray book data uses generator hours while the semi-annual report uses the hours the reactor was sub-critical.

- Partial Outages

The MW hours lost due to partial outages were calculated graphically from the power performance graphs.

- Plant Deratings

Plant deratings accounted for a significant loss of generating capability at Quad Cities, and yet constitute neither full nor partial outages. Trident obtained plant derating data by analyzing the nearly 2,000 daily Morning Reports. For days in which the Morning Reports were missing, Trident was able to obtain the necessary information by consulting the power performance graphs and interpolating between the neighboring dates for which data were available. An additional problem arose on days for which the power level changed rapidly. The Morning Reports gave the deratings at

0730 on a particular morning and were generally assumed valid for the 24-hour period. Trident adjusted these numbers appropriately for days in which the power level changed significantly in order to more accurately estimate the actual MW hours loss. The deratings for Quad Cities 1 and 2 are incorporated directly in the appropriate data sheets.

- Ramps

The ramps associated with the return to full power after an outage or derating can be extremely long (3 MW/hr) or rather short, depending upon the recent power history of the plant and core. As a result, Trident feels it most appropriate to separate out all ramps and has lumped them under the derating category of fuel preconditioning. In this way, Trident obtains an average MW hours loss associated with an outage. These have been determined, generally, by using the power performance graphs for steep ramps and the Morning Reports for the shallower ramps.

It should be noted that in examining the data at this fine a level, Trident has found that, except in very few instances, outages were the result of multiple failures -- i.e., where at least two components were causing a degradation of generating capability at any one time. Furthermore, the significant MW hours losses due to the deratings do not seem to be handled by the Department of Energy methodology. These problems are discussed in more detail later in the report.

Finally, in calculating the MW hours loss associated with an outage or derating, Trident assumes for Quad Cities 2 a maximum capability of 809 MW prior to May 1, 1974 and 832 MW after this date in order to provide agreement with the plant Morning Reports. For Quad Cities 1, a maximum capability of 800 MW prior to November 1, 1973 and 833 after this date is assumed in order to provide the best agreement with both NRC gray book data and plant Morning Reports.

Tables 4.5.1 and 4.5.2 summarize the components at Quad Cities which have experienced no outages.

TABLE 4.4
FAILURE MODE AND EFFECT ANALYSIS
QUAD CITIES

Functional Hierarchy Level	Failure Mode	Effect on Unit
1. Power Conversion System A. Electrical Conversion System (a) Generator exciter (b) Main transformer (c) Electrical distribution system B. Energy Conversion System (a-d) MSIV strings (e) Main steam line - piping, relief valves (f-i) Main steam line - control valves (j) High pressure turbine (k-n) Moisture separators (o-q) Low pressure turbines (r) Electrohydraulic controls	Fails to operate Fails to operate Fails to operate One fails to operate Two fail to operate Fails to close or open Fails to open Any fail to operate Fails to operate Any fail to operate Any fail to operate Fails to perform function	Full outage Full outage Full outage 202 MW Full outage Full outage Full outage Full outage Full outage Full outage Full outage Full outage
2. Steam Condensation System A. Condensate System (a) Condenser B. Discharge System (a) Spray canal or river	Poor condenser performance due to fouling Loss of use of one waterbox section of condenser Loss of use of two or more waterbox sections of condenser Failure of spray canal modules to meet design specifications High river temperature	Variable reduction in plant capability 459 MW Full outage Variable reduction in plant capability Variable reduction in plant capability
* Based on unit capacity of 809 MW	-187-	(continued...)

FAILURE MODE AND EFFECT ANALYSIS

QUAD CITIES

(continued)

Functional Hierarchy Level	Failure Mode	Effect on Unit
C. Cooling Water System		
(a) Condenser circulating water pumps	Failure of one pump Failure of two pumps	Variable reduction Full outage
D. Off-gas System		
(a) Off-gas system - piping	Any piping failure Failure to meet plant tech specs for off-gas release	Full outage Variable power reduction
(b-c) Catalytic combiner and water separators	Failure of one set to operate Failure of both sets to operate	0 MW Full outage
(d-e) Moisture separator and gas reheater	One set fails to operate Two sets fail to operate	0 MW Full outage
(f-q) Charcoal absorbers	Six or fewer fail to operate Seven fail to operate	0 MW Full outage
E. Condensate System		
(a-d) Condensate Pumps	Failure of one to operate Failure of two to operate Failure of three to operate	0 MW 404 MW Full outage
F. Steam Jet Air Ejector System		
(a-b) Steam jet air ejectors	Failure of one to operate Failure of both to operate	Temporary load reduction Full outage
G. Gland Steam Condensation System		
(a-b) Gland seal condenser	Failure of one to operate Failure of both to operate	0 Full outage
	-188-	(continued...)

FAILURE MODE AND EFFECT ANALYSIS

QUAD CITIES

(continued)

Functional Hierarchy Level	Failure Mode	Effect on Unit
H. Condensate Demineralizer System (a-g) Condensate demineralizers	Loss of one demineralizer Loss of two demineralizers Loss of each additional demineralizer Loss of six demineralizers	135 MW * 270 MW * 135 MW additional * Full outage*
I. Condensate Booster Feed System (a-d) Condensate booster pumps	Failure of one pump Failure of two pumps Failure of three or four pumps	0 MW 404 MW Full outage
3. Feed System		
A. Low Pressure Heater System	Failure of various heaters in different strings Failure to meet design specs	See Table 4.2 for power reductions associated with the possible permutations of heater failures Variable
B. Reactor Feed System (a-c) Reactor feed pumps	One pump fails to operate Two pumps fail to operate All three pumps fail to operate	0 MW 459 MW Full outage
(d) Feedwater piping	Failure of piping rigidity or integrity	Full outage
* Assumes spare demineralizer is being recharged		(continued...)

FAILURE MODE AND EFFECT ANALYSIS

QUAD CITIES

(continued)

Functional Hierarchy Level	Failure Mode	Effect on Unit
C. Feed Control System (a-b) Feedwater regulating valves	Failure of one valve to operate Failure of two valves to operate	Variable power reduction Full outage
D. High Pressure Heater System (a-c) High pressure feedwater heater heaters	Failure of heaters in different strings Unable to meet design specs	See Table 3.4 for power reductions associated with loss of function of high pressure heaters Variable
E. Feedwater Sparger System (a-b) Feedwater spargers	Any fail to operate	Full outage
4. Steam Generation System		
A. Control Rod Drive Hydraulic System		
(a) Condensate storage tanks	Failure of tank integrity	Full outage
(b-c) Suction filters	Failure of one or failure of both	0 MW Full outage
(d-e) Rod drive pumps	Failure of one or failure of both	0 MW Full outage
(f-g) Water filters	Failure of both to operate	Full outage
(h) Piping and flanges		Variable
B. Primary Energy Exchange System		
(a) Reactor	Any malfunction or anomaly	Full outage
(b) Torus-to-drywell vacuum breakers	Failure of 4 to test properly	Full outage
	-190-	(continued...)

FAILURE MODE AND EFFECT ANALYSIS

QUAD CITIES

(continued)

Functional Hierarchy Level	Failure Mode	Effect on Unit
C. Recirculation System (a-b) Recirculation pumps (c-v) Jet pumps	Failure of either pump to operate Failure of any pump to operate	Full outage Full outage
D. Reactor Water Clean-up System (a-b) Clean-up pumps (c-d) Regenerative heat exchangers (e-f) Non-regenerative heat exchangers (g-h) Filter demineralizers (i) Valves	Failure to operate Failure to operate Failure to operate Failure to operate Failure to operate	0 MW for 2 to 3 days 0 MW for 2 to 3 days 0 MW for 2 to 3 days 0 MW for 2 to 3 days 0 MW for 2 to 3 days
E. Residual Heat Removal System (a-d) Residual heat removal pumps (e-f) Residual heat removal heat exchangers	One pump fails Two pumps fail Three pumps fail Failure of one heat exchanger to operate Failure of both heat exchangers to operate	0 MW for 30 days 0 MW for 7 days Full outage 0 MW for 7 days Full outage
5. Shared System A. Turbine Bypass System (a-i) Bypass valves B. Instrument Air	Failure to operate Failure to function	Full outage Full outage

TABLE 4.5.1

QUAD CITIES 2

SYSTEM/COMPONENTS WITH NO OUTAGES (1973-1977)

Component Identifier	System/Component	$\frac{em}{eM}$ All Cases
1B (r)	Electrohydraulic Controls	0
2C (a-c)	Condenser Circulating Water Pumps	0
2D (d-e)	Off-gas System - Moisture Separators Gas Reheater	0
2D (f-g)	Off-gas System - Charcoal Absorbers	0
2G (a-b)	Gland Seal Condenser	0
2I (a-d)	Condensate Booster Pumps	0
3D (a-c)	High Pressure Feedwater Heaters	0
4A (a)	Condensate Storage Tanks	0
4A (b-c)	Suction Filters	0
4A (d-e)	Control Rod Drive Hydraulic System Pumps	0
4A (f-g)	Water Filters	0
4B (b)	Torus-to-Drywell Vacuum Breakers	0
4C (c-v)	Jet Pumps	0
4D (a-b)	Cleanup Pumps	0
4D (c-d)	Regenerative Heat Exchangers	0
4D (e-f)	Nonregenerative Heat Exchangers	0
4D (g-h)	Filter Demineralizers	0
4E (e-f)	Residual Heat Removal Heat Exchangers	0
5A	Turbine Bypass System	0
5B	Instrument Air System	0

TABLE 4.5.2
QUAD CITIES 1
SYSTEM/COMPONENTS WITH NO OUTAGES
(1973 - 1977)

Component Identifier	Component	$\left(\frac{em}{em}\right)$ All Cases
1A (b)	Main Transformer	0
1B (o-q)	Low Pressure Turbine	0
2C (a-c)	Condenser Circulating Water Pumps*	0
2D (b-c)	Catalytic Recombiner & Water Separators	0
2E (d-e)	Moisture Separator Gas Reheater*	0
2D (f-q)	Charcoal Adsorbers*	0
2G (a-b)	Gland Seal Condenser*	0
2I (a-d)	Condensate Booster Pumps*	0
3D (a-c)	High Pressure Feedwater Heaters*	0
3E (a-b)	Feedwater Spargers	0
4A (a)	Condensate Storage Tanks*	0
4A (b-c)	Suction Filters*	0
4A (d-e)	Pumps*	0
4A (f-g)	Water Filters*	0
4A (h)	Piping, Flanges for Control Rod Drive	0
4B (a)	Reactor	0
4C (c-v)	Jet Pumps*	0
4D (a-b)	Cleanup Pumps*	0
4D (c-d)	Regenerative Heat Exchangers*	0
4D (e-f)	Nonregenerative Heat Exchangers*	0
4D (g-h)	Filter Demineralizers*	0
4D (i)	Valves	0
4E (a-d)	Residual Heat Removal Pumps	0
4E (e-f)	Residual Heat Removal Heat Exchangers*	0
5A	Turbine Bypass System*	0
* No outages at Quad Cities 2 either		

Tables 4.6.1 and 4.6.2 list the administrative outages for Quad Cities 2 from March 10, 1973 to December 31, 1977. Tables 4.7.1 and 4.7.2 list the conditional outages between March 10, 1973 and December 31, 1977 at Quad Cities 2. Finally, Tables 4.8.1 to 4.8.24 give the loss of function outages by component chronologically from March 10, 1973 to December 31, 1977 at Quad Cities 2.

These loss of function tables are composed of three subtables. The first subtable gives the component functional diagram information, which includes the component letter identifier and component configuration. The component configuration tells whether the element is being treated in a series or parallel configuration.

The second subtable gives the full and partial outages attributed to the component.

The third subtable gives the analysis of the outage data. This subtable shows for nine data periods

- the number of outages;
- the meantime-to-outage (M_1);
- the equivalent meantime-to-outage (eM);
- the megawatt hours lost;
- $\frac{\text{megawatt hours lost}}{MDC}$;
- the meantime-to-restore (m_1);
- equivalent meantime-to-restore (em);
- $\left(\frac{em}{eM}\right)$ ratio.

Following the third subtable, the basic equations used to relate M_1 to eM and m_1 to em are given for parallel components. For series components no equations are given, since in this case $eM = M_1$ and $em = m_1$.

Table 4.9 lists the administrative outages for Quad Cities 1 from February 18, 1973 through December 31, 1977. Table 4.10 lists the conditional outages for the same period for Quad Cities 1. The loss of function outages are given by component for Quad Cities 1 in Tables 4.11.1 to 4.11.21.

TABLE 4.6.1
QUAD CITIES 2

ADMINISTRATIVE OUTAGES

Source:

Full Outages - NRC Gray Books

Partial Outages - Quad Cities 2 Power Performance Graphs

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
3/10/73	2,000	P	Weekly turbine surveillance
3/16/73	2,000	P	Weekly-monthly turbine tests-condenser reverse flow - recirc pump trip
3/24/73	2,000	P	Reverse condenser flow - off gas sample problem
3/31/73	2,000	P	Weekly turbine test
5/9/73	1,359	P	MSIV relay action verification test
5/19/73	4,369	P	MSIV check
5/27/73	2,912	P	25 Rod scram and turbine control valve surveillance
6/1/73	6,796	P	Reverse condenser flow
6/24/73	854	P	Turbine control valve surveillance and load follow test
6/28/73	3,240	P	MSIV tests (2)
7/1/73	2,097	P	88 Rod scram, surveillance, and condenser flow reversal
7/15/73	4,466	P	Reverse condenser flow-did not succeed
7/18/73	1,922	P	MSIV test
7/22/73	2,330	P	Reverse condenser flow-did not succeed
8/12/73	7,611	P	Surveillance test-reserve flow in condenser-25 control rod scram time tests
8/26/73	7,747	P	25 Control rod scram time tests
9/7/73	29,124	F	Weekend outage-reversal of condenser flow
9/15/73	2,796	P	Perform control rod scram tests-reverse condenser flow
9/16/73	2,796	P	Condenser flow reversal
9/23/73	5,437	P	Condenser flow reversal and turbine surveillance
10/5/73	2,563	P	MSIV surveillance
10/9/73	1,747	P	MSIV surveillance
10/17/73	116,496	F	Scheduled maintenance outage
10/28/73	3,262	P	Station off-gas limit
10/29/73	408	P	MSIV surveillance and weekly and daily turbine tests
11/3/73	524	P	MSIV surveillance
11/5/73	699	P	MSIV surveillance
11/10/73	777	P	MSIV surveillance
11/12/73	1,048	P	MSIV bi-weekly surveillance
11/20/73	1,048	P	MSIV surveillance
11/27/73	1,068	P	MSIV surveillance

TABLE 4.6.1

QUAD CITIES 2

ADMINISTRATIVE OUTAGES (Continued)

Date	Outage MW Hrs. Lost	Full or Partial	Comments
12/1/73	855	P	MSIV surveillance
12/4/73	1,049	P	MSIV surveillance
12/7/73	1,049	P	MSIV surveillance
12/11/73	1,049	P	MSIV surveillance and reverse condenser flow
12/15/73	1,049	P	MSIV surveillance
12/18/73	1,049	P	MSIV surveillance and weekly turbine testing
12/28/73	1,049	P	MSIV surveillance
12/28/73	1,049	P	MSIV surveillance
1/1/74	1,118	P	MSIV surveillance testing
1/8/74	1,118	P	MSIV surveillance
1/15/74	1,118	P	MSIV surveillance
1/19/74	1,118	P	MSIV testing
1/22/74	1,119	P	MSIV surveillance
1/25/74	56,306	F	Snubber inspection
2/2/74	1,118	P	MSIV surveillance
2/5/74	1,118	P	MSIV surveillance
2/9/74	20,946	P	Change rod pattern
2/16/74	1,119	P	MSIV surveillance testing
2/18/74	1,118	P	MSIV surveillance and weekly turbine testing
2/22/74	1,118	P	MSIV surveillance
2/26/74	1,118	P	MSIV surveillance
3/1/74	1,118	P	MSIV testing
3/5/74	1,119	P	MSIV testing
3/8/74	1,118	P	MSIV testing
3/12/74	1,118	P	MSIV surveillance
3/15/74	1,118	P	MSIV surveillance
3/19/74	1,119	P	MSIV surveillance
4/6/74	1,617	P	MSIV testing
4/16/74	1,118	P	MSIV surveillance
4/20/74	1,118	P	MSIV surveillance
4/23/74	1,119	P	MSIV surveillance
4/27/74	1,118	P	MSIV surveillance testing
4/30/74	1,118	P	MSIV surveillance
5/4/74	9,523	P	Rod pattern change
5/8/74	639	P	MSIV surveillance
5/11/74	639	P	MSIV surveillance

TABLE 4.6.1
QUAD CITIES 2

ADMINISTRATIVE OUTAGES (Continued)

Date	Outage MW Hrs. Lost	Full or Partial	Comments
5/15/74	799	P	MSIV testing
5/18/74	639	P	MSIV testing
5/21/74	639	P	Reversed condenser flow and MSIV test
5/27/74	739	P	MSIV surveillance
6/1/74	1,677	P	MSIV surveillance
6/5/74	1,048	P	MSIV testing
7/5/74	389	P	MSIV surveillance
7/7/74	759	P	MSIV surveillance
7/12/74	759	P	MSIV surveillance
7/16/74	5,571	P	Rod pattern change
7/20/74	1,438	P	MSIV surveillance
7/23/74	599	P	MSIV surveillance
7/26/74	479	P	MSIV surveillance
7/30/74	479	P	MSIV surveillance
8/3/74	3,195	P	MSIV surveillance and reverse condenser flow
8/5/74	1,418	P	MSIV testing
8/9/74	14,250	P	Condenser reversal - control rod sequence change - MSIV testing
8/12/74	480	P	MSIV surveillance
8/16/74	1,398	P	MSIV surveillance
8/19/74	559	P	MSIV surveillance
8/24/74	1,118	P	MSIV testing and condenser reversal
8/27/74	2,556	P	MSIV testing and condenser reversal
10/12/74	639	P	MSIV surveillance and condenser reversal
10/25/74	419	P	MSIV surveillance
11/16/74	7,114	P	Changed rod pattern
11/23/74	4,992	P	Rod pattern change
12/2/74	1,158	P	MSIV surveillance
12/23/74	2,492,630	F	Refueling outage [1974: 194,688 Mw hrs lost] [1975: 2,297,942 Mw hrs lost]
4/26/75	1,331	P	Rod pattern exchange
5/9/75	9,505	P	Control rod pattern changed and condenser flow reversed
6/27/75	2,496	P	Reversed condenser flow
7/6/75	2,077	P	Condenser flow reversal
7/19/75	3,514	P	Condenser flow reversal

(Continued...)

TABLE 4.6.1

QUAD CITIES 2

ADMINISTRATIVE OUTAGES (Continued)

Date	Outage MW Hrs. Lost	Full or Partial	Comments
8/2/75	18,051	P	Spray canal testing
9/13/75	240	P	Reverse condenser flow
12/20/75	559	P	MSIV surveillance
1/25/76	659	P	Turbine surveillance
1/30/76	1,198	P	Turbine surveillance
2/7/76	34,778	F	Control rod pattern change-hydraulic snubber inspection
3/7/76	799	P	Turbine test
3/13/76	958	P	Turbine test
3/27/76	7,987	P	Reversed condenser flow and rod sequence exchange
6/27/76	4,313	P	MSIV surveillance, turbine and control valve tests
7/17/76	1,038	P	Turbine control valve problem
8/21/76	19,169	P	Spray canal for performance
8/28/76	12,380	P	Spray canal performance test
9/10/76	958,547	F	Refueling outage
10/28/76	42,182	F	Flush of turbine bearings prior to startup
1/1/77	399	P	Weekly turbine test
1/9/77	1,957	P	Spray canal modules turned off to reduce icing on 345 KV lines
2/5/77	839	P	Weekly turbine test
2/12/77	599	P	Weekly turbine test
4/8/77	23,602	P	Change control rod pattern
4/16/77	1,078	P	Weekly turbine test
4/23/77	1,517	P	Weekly turbine test-control valve and stop valve fast closure tests
5/20/77	4,992	P	Reverse condenser flow
5/23/77	799	P	Reverse condenser flow
10/28/77	1,198	P	MSIV turbine testing
11/22/77	1,100	P	MSIV surveillance

TABLE 4.6.2

QUAD CITIES 2

ADMINISTRATIVE OUTAGES DERATINGS
(All Partial Outages)

Source: Commonwealth Edison Morning Reports

System/Component	Date/Year	Outage(s) MW Hours Lost
MSIV	2/4/74	2,112
	10/11/74	6,768
	11/18/75	1,992
	4/9/76	1,392
	1/14/77	792
Off Gas System	1973	0
	1974	184,934
	1975	430,560
	1976	1,968
	1977	0
Control Rods (Pattern Limitation)	1973	396
	1975	288
	1977	6,167
Fuel Depletion	1975	8,640
	1976	331,728
	1977	248,232

TABLE 4.7.1

QUAD CITIES 2

CONDITIONAL OUTAGES

Source:

Full Outages — NRC Gray Books

Partial Outages — Quad Cities 2 Power Performance Graphs

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
5/2/73	6,472	F	Scram due to erroneous main steam high flow from maintenance
5/17/73	16,180	F	Low condenser vacuum - operator error by Gray Book
7/28/73	145,620	F	Inspection and maintenance of hydraulic snubber
3/23/74	38,832	F	LPCI injection valve bent stem
11/1/74	12,859	P	High off gas release
5/5/75	2,912	F	Accidental trip of 2C reactor feed pump resulting in low vessel level
8/15/75	54,163	F	High activity in drywell due to CAM manifold sample point improperly positioned
2/21/76	8,736	F	Low water level in reactor from control calibration error
7/16/76	23,722	F	Regulatory restriction on river water temperature
5/17/76	336	F	Nuclear engineers running TIP traces
4/5/77	1,440	P	MCPR limit
5/21/77	18,450	P	Load reduction when system went on closed cooling cycle
10/11/77	5,325	F	Low water level resulted while attempting to switch FRV from 2B to 2A
10/26/77	38,355	F	IRM high flux condition developed while withdrawing control rods to make reactor critical

TABLE 4.7.2
QUAD CITIES 2
CONDITIONAL OUTAGES DERATINGS
(All Partial Outages)

Source: Commonwealth Edison Morning Reports

System/Component	Year	Outage(s) MW Hours Lost
Circulating Water System	1973	58,680
	1974	3,387
	1975	20,232
	1976	23,808
	1977	26,208
Computer	1976	1,248
Fuel Densification	1973	19,200
	1974	19,752
Preconditioning (Excluding Ramps)	1974	52,776
	1975	126,000
	1976	231,746
	1977	277,632
Rad Waste	1974	37,968
Ramps	1973	177,383
	1974	131,809
	1975	70,112
	1976	28,654
	1977	64,716
Scram Reactivity	1974	45,288
	1976	108,360
	1977	29,376

TABLE 4.8.1

QUAD CITIES 2

Generator-Exciter -- Main Transformer

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 1A (a-c)

Component Configuration: Series.

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
10/12/73	4,854	F	Lost voltage on essential bus-caused low water level signal
2/17/76	1,597	P	Trouble with generator hydrogen cooler TCV
12/11/76	250	F	Generator off line to check for field ground
1/4/77	4,952	P	Generator exciter field ground alarm required generator field ground tests
2/19/77	520,582	F	Generator taken off line to repair generator field ground caused by copper dust in generator rotor
5/27/77	60,986	F	Balance generator to correct vibration in bearing #10
10/20/77	7,904	F	Reactor scram due to TG load mismatch which occurred when generator field breaker tripped.

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	1	6,236	6,236	4,854	6	6	6	.00096
1974	0			0				0
1975	0			0				0
1976	2	3,570	3,570	1,847	2.2	1.1	1.1	.00031
1977	4	1,930	1,930	594,424	714.4	178.6	178.6	.09254
1973-74	1	13,616	13,616	4,854	6	6	6	.00044
1973-75	1	18,153	18,153	4,854	6	6	6	.00033
1973-76	3	8,431	8,431	6,701	8.2	2.7	2.7	.00032
1973-77	7	4,716	4,716	601,125	722.7	103.2	103.2	.02189

TABLE 4.8.2

QUAD CITIES 2

Main Steam Line System - MSIV Strings

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 1B (a-d)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
6/9/73	1,320	P	Limit switch arm (MSIV) out of alignment on shaft Scram resulted from APRM high flux due to coil failure in MSIV-erratic recirculation pump flow resulted from failure Drifting closure of MSIV
9/16/73	8,090	F	
9/29/73	12,944	F	
1/5/74	29,124	F	Steam leak on MSIV Valves
4/12/74	45,223	F	Loss of instrument air supply to MSIV
5/18/75	7,987	P	Drywell entry to inspect 1B MSIV pilot valve high temperature alarms

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	3	2,079	2,079	22,354	27.6	9.2	9.2	.00443
1974	2	3,690	3,690	74,347	91.9	45.9	45.9	.01245
1975	1	4,537	4,537	7,987	9.6	9.6	9.6	.00212
1976	0							0
1977	0							0
1973-74	5	2,723	2,723	96,701	119.5	23.9	23.9	.00878
1973-75	6	3,026	3,026	104,688	129.1	21.5	21.5	.00711
1973-76	6	4,216	4,216	104,688	129.1	21.5	21.5	.00511
1973-77	6	5,502	5,502	104,688	129.1	21.5	21.5	.00391

TABLE 4.8.3

QUAD CITIES 2

Main Steam Line System -- Piping, Relief Valves

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 1B (e)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
4/30/73	6,472	F	Electromatic Relief Valve 2-203-3C leaking
5/8/73	6,601	P	Fix main steam leak
11/6/73	1,048	P	Main steam line DPIS switches replaced
10/30/76	94,598	F	Reactor scram due to high water level but outage continued due to inoperability of electromagnetic relief valves C & E.
3/25/77	47,507	F	Failed electromatic-relief valve 203-3B was replaced others tested.

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	3	2,079	2,079	14,121	17.4	5.8	5.8	.00280
1974	0							0
1975	0							0
1976	1	7,140	7,140	94,598	113.7	113.7	113.7	.01592
1977	1	7,720	7,720	47,507	57.1	57.1	57.1	.00740
1973-74	3	4,539	4,539	14,121	17.4	5.8	5.8	.00128
1973-75	3	6,051	6,051	14,121	17.4	5.8	5.8	.00096
1973-76	4	6,323	6,323	108,719	131.5	32.8	32.8	.00519
1973-77	5	6,603	6,603	156,226	188.2	37.6	37.6	.00570

TABLE 4.8.4

QUAD CITIES 2

Main Steam Line System -- Control Valves

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 1B (f-i)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
11/17/73	12,944	F	Oil leak on control valve - main turbine
5/24/74	18,720	F	Steam leak #3 control valve
7/2/74	1,747	F	Control Valves failed to open
11/13/76	7,904	F	Turbine control valve failure

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	1	6,236	6,236	12,944	16	16	16	.00257
1974	2	3,690	3,690	20,467	24.6	12.3	12.3	.00333
1975	0							0
1976	1	7,140	7,140	7,904	9.5	9.5	9.5	.00133
1977	0							0
1973-74	3	4,589	4,589	33,401	40.6	13.5	13.5	.00298
1973-75	3	6,051	6,051	33,401	40.6	13.5	13.5	.00224
1973-76	4	6,323	6,323	41,305	50.1	12.5	12.5	.00198
1973-77	4	8,253	8,253	41,305	50.1	12.5	12.5	.00152

TABLE 4.8.5
QUAD CITIES 2

High Pressure Turbine

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 1B (j)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
2/10/76	45,760	F	Turbine steam seal leaks

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	0							0
1975	0							0
1976	1	7,140		45,760	55	55	55	.00770
1977	0							0
1973-74	0							0
1973-75	0							0
1973-76	1	25,293	25,293	45,760	55	55	55	.00218
1973-77	1	33,013	33,013	45,760	55	55	55	.00167

TABLE 4.8.6

QUAD CITIES 2

Moisture Separator

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 1B (k-n)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
10/26/73	6,407	P	Moisture separator drain valve repair
10/25/73	4,854	F	High Moisture separator level - emergency drain valves on separator drain tank failed to open
11/13/73	4,854	F	Moisture separator high level indicator
4/26/75	25,875	F	High level led to turbine trip
11/15/75	11,648	F	Level transmitter for level control valve failed leading to high level in 2B moisture separator

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	3	2,079	2,079	16,115	19.9	6.6	6.6	.00319
1974	0							0
1975	2	2,269	2,269	37,523	45.1	22.6	22.6	.00994
1976	0							0
1977	0							0
1973-74	3	4,539	4,539	16,115	19.9	6.6	6.6	.00146
1973-75	5	3,631	3,631	53,638	65.0	13.0	13.0	.00358
1973-76	5	5,059	5,059	53,638	65.0	13.0	13.0	.00257
1973-77	5	6,603	6,603	53,638	65.0	13.0	13.0	.00197

TABLE 4.8.7

QUAD CITIES 2

Low Pressure Turbine

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 1B (o-q)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
6/30/74	16,141	F	Overspeed trip mechanism failure on turbine

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	1	7,380	7,380	16,141	19.4	19.4	19.4	.00263
1975	0							0
1976	0							0
1977	0							0
1973-74	1	13,616	13,616	16,141	19.4	19.4	19.4	.00142
1973-75	1	18,153	18,153	16,141	19.4	19.4	19.4	.00107
1973-76	1	25,293	25,293	16,141	19.4	19.4	19.4	.00077
1973-77	1	33,013	33,013	16,141	19.4	19.4	19.4	.00059

TABLE 4.8.8

QUAD CITIES 2

Condenser

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 2A (a)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
5/11/73	97,080	F	Condenser tube leaks
4/28/75	39,354	F	Dislodged condenser plug detected by high reactor water conductivity
7/1/74 to 6/2/76	155,744	P	Condenser fouling derating 1974 - 77,528 Mwh lost 1975 - 41,064 Mwh lost 1976 - 37,052 Mwh lost
12/9/76	24	P	Condenser fouling derating
6/13/77	15,912	P	Condenser fouling derating
7/7/77	120	P	Condenser fouling derating
7/13/77	192	P	Condenser fouling derating
7/20/77	96	P	Condenser fouling derating
8/18/77	120	P	Condenser fouling derating
8/25/77	24	P	Condenser fouling derating
9/7/77	1,392	P	Condenser fouling derating
10/4/77	24	P	Condenser fouling derating
10/11/77	504	P	Condenser fouling derating
11/18/77	1,104	P	Condenser fouling derating
12/9/77	2,880	P	Condenser fouling derating

(Continued...)

Condenser (Continued)

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	1	6,236	6,236	97,080	120	120	120	.01924
1974	1	7,380	7,380	77,528	93.2	93.2	93.2	.01263
1975	2	2,268	2,268	80,418	96.7	48.3	48.3	.02130
1976	2	3,570	3,570	37,176	44.7	22.3	22.3	.00626
1977	11	702	702	22,368	26.9	2.4	2.4	.00348
1973-74	2	6,808	6,808	174,608	213.2	106.6	106.6	.01566
1973-75	3	6,051	4,538	255,026	309.8	103.3	103.3	.01707
1973-76	4	4,216	4,216	292,202	354.5	88.6	88.6	.01402
1973-77	15	1,942	1,942	314,570	381.4	25.4	25.4	.01155

TABLE 4.8.9
QUAD CITIES 2
Spray Canal/River

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 2B (a)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost.	Full (F) or Partial (P)	Comments
5/14/74	2,784	P	Spray canal derating
6/3/74	3,672	P	Spray canal derating
8/1/74	17,237	P	Spray canal derating
10/17/74	9,048	P	Spray canal derating
11/8/74	5,424	P	Spray canal derating
5/4/74	23,448	P	Spray canal derating
5/13/74	79,944	P	Temperature limitation derating
7/6/75	330,238	P	Spray canal derating
7/31/75	3,792	P	Temperature limitation derating
8/3/75	5,472	P	Temperature limitation derating
8/6/75	1,032	P	Temperature limitation derating
8/28/75	11,376	P	Temperature limitation derating
11/21/75	144	P	Temperature limitation derating
4/20/76	15,960	P	Temperature limitation derating
5/7/76	27,960	P	Temperature limitation derating
5/19/76	7,334	P	Temperature limitation derating
5/26/76	66,768	P	Temperature limitation derating
6/14/76	28,680	P	Lift station tests
6/20/76	18,408	P	Temperature limitation derating
7/6/76	2,400	P	Temperature limitation derating
7/8/76	3,264	P	Temperature limitation derating
7/20/76	17,280	P	Temperature limitation derating
8/16/76	9,216	P	Lift station tests
8/17/76	3,096	P	Temperature limitation derating
9/14/76	28,272	P	Temperature limitation derating
1/2/77	3,888	P	Temperature limitation derating
5/6/77	14,424	P	Temperature limitation derating
5/25/77	1,296	P	Temperature limitation derating

Spray Canal/River (Continued)

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
6/18/77	2,875	P	Load drop for closed cycle cooling
6/27/77	2,808	P	Temperature limitation derating
7/1/77	39,417	P	Load was reduced to prevent high service water temperature due to poor spray canal performance.
7/9/77	10,303	P	Load was reduced to prevent high service water temperature due to poor spray canal performance
7/16/77	14,776	P	Load was reduced to prevent high service water temperature due to poor spray canal performance.
7/21/77	2,808	P	Lift station tests
9/7/77	4,368	P	Lift station tests
9/8/77	33,408	P	Temperature limitation derating
11/4/77	1,200	P	Temperature limitation derating
11/6/77	54,246	F	Reactor scram due to explosion in cooling canal transformer
12/3/77	192	P	Temperature limitation derating

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	5	1,476	1,476	38,165	45.9	9.2	9.2	.00622
1975	8	567	567	455,446	547.4	68.4	68.4	.12065
1976	12	595	595	228,638	274.8	22.9	22.9	.03849
1977	14	551	551	186,009	223.6	15.9	15.9	.02890
1973-74	5	2,723	2,723	38,165	45.9	9.2	9.2	.00337
1973-75	13	1,396	1,396	493,611	593.3	45.6	45.6	.03268
1973-76	25	1,012	1,012	722,249	868	34.7	34.7	.03432
1973-77	39	846	846	907,898	1091	28.0	28.0	.03305

TABLE 4.8.10

QUAD CITIES 2

Off-Gas Piping

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 2D (a)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
4/14/73	330,072	F	Off-gas modification (piping connections)
6/20/73	777	P	Off-gas piping problems

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	2	3,118	3,118	330,849	409	204.5	204.5	.06559
1974	0							0
1975	0							0
1976	0							0
1977	0							0
1973-74	2	6,808	6,808	330,849	409	204.5	204.5	.03004
1973-75	2	9,077	9,077	330,849	409	204.5	204.5	.02253
1973-76	2	12,646	12,646	330,849	409	204.5	204.5	.01617
1973-77	2	16,506	16,506	330,849	409	204.5	204.5	.01239

TABLE 4.8.11

QUAD CITIES 2

Catalytic Re-combiners

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 2D (b-c)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
3/23/74	127,175	F	Recombiners were cut out and modification of piping.

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	1	7,380	7,380	127,175	157.2	157.2	157.2	.02130
1975	0							0
1976	0							0
1977	0							0
1973-74	1	13,616	13,616	127,175	157.2	157.2	157.2	.01155
1973-75	1	18,153	18,153	127,175	157.2	157.2	157.2	.00866
1973-76	1	25,293	25,293	127,175	157.2	157.2	157.2	.00622
1973-77	1	33,013	33,013	127,175	157.2	157.2	157.2	.00476

TABLE 4.8.12
QUAD CITIES 2
Condensate Pumps

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 2E (a-d)

Component Configuration: Analyzed as both Series and Parallel
(4 in unit) (3 required for MDC)

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
5/24/75	7,867	P	2A condensate pump maintenance - crack at test pressure tap weld

ANALYSIS - Series

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	0							0
1975	1	4,537	4,537	7,867	9.5	9.5	9.5	.00208
1976	0							0
1977	0							0
1973-74	0							0
1973-75	1	18,153	18,153	7,867	9.5	9.5	9.5	.00052
1973-76	1	25,293	25,293	7,867	9.5	9.5	9.5	.00037
1973-77	1	33,013	33,013	7,867	9.5	9.5	9.5	.00029

(Continued...)

Condensate Pumps (Continued)

ANALYSIS - Parallel

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	0							0
1975	1	13,611	1.64×10^6	7,867	9.5	9.5	4.7	≈ 0
1976	0							0
1977	0							0
1973-74	0							0
1973-75	1	54,459	2.6×10^7	7,867	9.5	9.5	4.7	≈ 0
1973-76	1	75,891	5.1×10^7	7,867	9.5	9.5	4.7	≈ 0
1973-77	1	99,037	8.6×10^7	7,867	9.5	9.5	4.7	≈ 0

BASIC EQUATIONS (Parallel)

$$eM = \frac{4M^3m + M^4}{12 M^2m}$$

$$em = \frac{m^4 + 4Mm^3 + 6M^2 m^2}{12 M^2m}$$

TABLE 4.8.13

QUAD CITIES 2

Steam Jet Air Ejectors

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 2F (a-b)

Component Configuration: Treated as both Series and Parallel
(2 in unit) (2 required for MDC)

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
5/31/73	2,019	P	Change steam jet air ejector
5/30/73	699	P	Repair steam jet air ejector
1/8/76	958	P	Steam jet air ejector erratic at full load
3/24/76	6,240	F	Steam jet air ejector air leak caused partial outage

ANALYSIS - Series

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	2	3,118	3,118	2,718	3.4	1.7	1.7	.00054
1974	0							0
1975	0							0
1976	2	3,570	3,570	7,198	8.6	4.3	4.3	.00121
1977	0							0
1973-74	2	6,808	6,808	2,718	3.4	1.7	1.7	.00025
1973-75	2	9,077	9,077	2,718	3.4	1.7	1.7	.00019
1973-76	4	6,323	6,323	9,916	12.0	3	3	.00047
1973-77	4	8,253	8,253	9,916	12.0	3	3	.00036

(Continued...)

Steam Jet Air Ejectors (Continued)

ANALYSIS- Parallel

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	2	6,236	3,118	2,718	3.4	1.7	1.7	.00054
1974	0							0
1975	0			0	0			0
1976	2	7,140	3,570	7,198	8.6	4.3	4.3	.00120
1977	0			0	0	0	0	0
1973-74	2	13,616	6,808		3.4	1.7	1.7	.00025
1973-75	2	18,154	9,077	2,718	3.4	1.7	1.7	.00019
1973-76	4	12,646	6,323	9,916	12.0	3.0	3.0	.00047
1973-77	4	16,506	8,253	9,916	12.0	3.0	3.0	.00036

BASIC EQUATIONS (Parallel

$$em = m_1 + \frac{m_1^2}{2M_1}$$

$$eM = \frac{M_1}{2}$$

TABLE 4.8.14

QUAD CITIES 2

Condensate Demineralizers

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 2H (a-g)

Component Configuration: Treated as Series and Parallel
(7 in unit) (16 required for MDC)

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
8/1/74	936	P	Derating
9/24/74	16,573	P	Repair condensate demineralizers
9/30/74	8,760	P	Derating
10/9/74	6,408	P	Derating
10/22/74	419	P	Condensate demineralizers post strainers repaired
11/1/74	28,224	P	Derating
8/28/75	1,944	P	Derating
1/14/77	3,792	P	Derating
8/4/77	8,928	P	Derating

ANALYSIS - Series

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	6	1,230	1,230	61,320	73.7	12.3	12.3	.00999
1975	1	4,537	4,537	1,944	2.3	2.3	2.3	.00052
1976	0							0
1977	2	3,860	3,860	9,720	11.7	5.8	5.8	.00151
1973-74	6	2,269	2,269	61,320	73.7	12.3	12.3	.00541
1973-75	7	2,593	2,593	63,266	76.0	10.9	10.9	.00419
1973-76	7	3,613	3,613	63,266	76.0	10.9	10.9	.00301
1973-77	9	3,668	3,668	72,986	87.7	9.7	9.7	.00266

Condensate Demineralizers (Continued)

ANALYSIS- Parallel

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	6	7,380	106,830	61,320	73.7	12.3	6.1	.00006
1975	1	27,222	7,544, 599	1,944	2.3	2.3	1.2	≈ 0
1976	0							0
1977	2	23,160	1,863, 677	9,720	11.7	5.8	5.8	≈ 0
1973-74	6	12,870	373,296	61,320	73.7	12.3	12.3	.00002
1973-75	7	14,922	490,661	63,266	76.0	10.9	10.9	$\approx .0001$
1973-76	7	21,042	974,229	63,266	76.0	10.9	10.9	≈ 0
1973-77	9	21,510	1,133, 451	72,986	87.7	9.7	9.7	≈ 0

BASIC EQUATIONS (Parallel)

$$em = \frac{m_1^7 + 7 M_1 m_1^6 + 21 M_1^2 m_1^5 + \dots + 21 M_1^5 m_1^2}{42 M_1^5 m_1}$$

Since $M_1 \gg m_1$

$$em \approx \frac{m_1}{2}$$

$$eM = \frac{M_1}{6} + \frac{M_2}{42m}$$

TABLE 4.8.15
QUAD CITIES 2
Low Pressure Heaters
FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 3A (a-i)

Component Configuration: Treated as both Series and Parallel
(9 in unit) (9 required for MDC)

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
11/3/73	12,349	P	Blockage of tubes in feedwater heater-causing tube breaks
12/12/73	388	P	Work on heaters
12/13/73	388	P	Work on heaters
1973-74	233,904	P	Derating - 1973- Lost 81600 Mwh 1974 -Lost 152,304 Mwh
11/29/76	2,904	P	Derating
1/11/77	12,288	P	Derating
3/31/77	3,984	P	Derating

ANALYSIS - Series

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	4	1,559	1,559	94,725	117.1	29.3	29.3	.01878
1974	1	7,380	7,380	152,304	184.7	184.7	184.7	.02502
1975	0							0
1976	1	7,140	7,140	2,904	3.5	3.5	3.5	.00049
1977	2	3,860	3,860	16,272	19.6	9.8	9.8	.00253
1973-74	4	3,404	3,404	247,029	301.8	75.4	75.4	.02216
1973-75	4	4,538	4,538	247,029	301.8	75.4	75.4	.01662
1973-76	5	5,059	5,059	249,933	305.2	61.0	61.0	.01207
1973-77	7	4,716	4,716	266,305	324.8	46.4	46.4	.00984

Low Pressure Heaters (Continued)

ANALYSIS (Parallel)

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	Total Outage Duration (Hours)	MWH Lost	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	4	14,031	1,559	94,725	117.1	29.3	29.3	.01881
1974	1	66,420	7,380	152,304	184.7	185.2	185.2	.02510
1975	0							0
1976	1	64,260	7,140	2,904	3.5	3.5	3.5	.00049
1977	2	34,740	3,860	16,272	9.8	9.8	9.8	.00253
1973-74	4	30,636	3,404	247,029	75.4	75.4	75.6	.02222
1973-75	4	40,842	4,538	247,029	75.4	75.4	75.6	.01665
1973-76	5	45,531	5,505	249,933	61.0	61.0	61.1	.01208
1973-77	7	42,444	4,716	266,305	46.4	46.4	46.5	.00985

BASIC EQUATIONS (Parallel)

$$eM = \frac{M_1}{9}$$

TABLE 4.8.16

QUAD CITIES 2

Reactor Feed Pumps

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 3B (a-c)

Component Configuration: Treated as both Series and Parallel
(3 in unit) (2 required for MDC)

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
3/4/73	16,120	F	2B reactor feed pump min. recirculating valve (line) repairs
6/22/73	1,942	P	Reactor feed pump trip

ANALYSIS (Series)

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	2	3,118	3,118	18,062	22.3	11.2	11.2	.00358
1974	0							0
1975	0							0
1976	0							0
1977	0							0
1973-74	2	6,808	4,539	18,062	22.3	11.2	11.2	.00164
1973-75	2	9,077	9,077	18,062	22.3	11.2	11.2	.00123
1973-76	2	12,647	12,647	18,062	22.3	11.2	11.2	.00088
1973-77	2	16,507	16,507	18,062	22.3	11.2	11.2	.00068

(Continued...)

Reactor Feed Pumps (Continued)

ANALYSIS (Parallel)

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	2	6,236	2,079	18,062	22.3	11.2	5.6	.00269
1974	0							0
1975	0							0
1976	0							0
1977	0							0
1973-74	2	13,616	4,539	18,062	22.3	11.2	5.6	.00123
1973-75	2	18,153	6,051	18,062	22.3	11.2	5.6	.00092
1973-76	2	25,293	8,431	18,062	22.3	11.2	5.6	.00066
1973-77	2	33,013	11,004	18,062	22.3	11.2	5.6	.00051

BASIC EQUATIONS (Parallel)

$$em = \frac{m_1^2}{6M_1} + \frac{m_1}{2}$$

$$eM = \frac{M_1}{3}$$

TABLE 4.8.17
QUAD CITIES 2
Feedwater Piping
FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 3B (d)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
6/10/74	133,869	F	Flow line to valve severed
7/1/74	11,487	F	Severed instrument air line
5/20/75	15,808	F	Feedwater system repairs to a pressure top line
7/21/75	72,467	F	Feedwater heater flush line leak
8/17/75	179,462	F	Low flow feedwater line break

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	2	3,690	3,690	145,350	174.7	87.4	87.4	.02367
1975	3	1,512	1,512	267,737	322.0	107.0	107.0	.07093
1976	0							0
1977	0							0
1973-74	2	6,808	6,808	145,350	174.7	87.4	87.4	.01284
1973-75	5	3,631	3,631	413,087	496.7	99.3	99.3	.02735
1973-76	5	5,059	5,059	413,087	496.7	99.3	99.3	.01963
1973-77	5	6,603	6,603	413,087	496.7	99.3	99.3	.01504

TABLE 4.8.18
QUAD CITIES 2
Feedwater Regulating Valves

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 3C (a-b)

Component Configuration: Treated as both Series and Parallel
(2 in unit) (2 required for MDC)

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
6/7/73	6,472	F	Fitting in air supply to FRV broke at valve
6/2/74	3,661	F	Feedwater low flow regulating valve AO-2-643 leak- unable to control reactor water level
8/31/74	124,384	F	Broken instrument air line on low flow feedwater reg. valve
8/31/75	113,984	F	Feedwater regulating valve B failed open-lines welded and operator modified
12/24/75	7,238	F	FRV valve failed closed with ruptured diaphragm
6/29/76	4,313	P	Load reduction due to excessive vibration of feed- water regulating valve.
6/30/76	8,784	P	Derating
11/8/76	6,074	F	Feedwater regulating valve failure AO-2-642A
12/3/76	75,130	F	Scheduled weekend maintenance outage (mainly repair of feedwater check valve)
12/11/76	7,904	F	Feedwater regulating valve bent stem
3/23/77	8,902	F	Failure of FRV caused low water level in reactor
5/24/77	4,440	P	Derating
6/13/77	8,570	F	Reactor scram due to loose wire at FRV control station
8/26/77	5,990	F	Reactor scram caused by failure of 2A FRV
9/21/77	8,304	P	Derating
9/22/77	81,536	F	Unit was taken off line for repair of a FRV
11/13/77	10,650	F	Reactor scram on low water level due to 2A FRV failure
11/14/77	6,323	F	Reactor scram due to high water level caused by 2A FRV failure
11/15/77	26,280	P	Derating
11/28/77	15,000	P	Derating
11/28/77	8,570	F	Reactor scram due to low water level caused by 2A FRV failure

Feedwater Regulating Valves (Continued)

ANALYSIS (Series)

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	1	6,236	6,236	6,472	8	8	8	.00128
1974	2	3,690	3,690	128,045	153.9	77.0	77.0	.02085
1975	2	2,269	2,269	121,222	145.7	72.8	72.8	.03211
1976	5	1,428	1,428	102,205	122.8	24.6	24.6	.01721
1977	11	702	702	184,565	221.8	20.2	20.2	.02874
1973-74	3	4,539	4,539	134,517	161.9	54.0	54.0	.01189
1973-75	5	3,631	3,631	255,739	307.6	61.5	61.5	.01694
1973-76	10	2,529	2,529	357,944	430.4	43.0	43.0	.01700
1973-77	21	1,572	1,572	542,509	652.2	31.1	31.1	.01978

ANALYSIS (Parallel)

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	1	12,472	6,236	6,472	8	8.0	8.0	.00128
1974	2	7,380	3,690	128,045	153.9	77.0	77.8	.02107
1975	2	4,538	2,269	121,222	145.7	72.8	74.0	.03262
1976	5	2,856	1,428	102,205	122.8	24.6	24.8	.01735
1977	11	1,402	702	184,565	221.8	20.2	20.5	.02915
1973-74	3	9,078	4,539	134,517	161.9	54.0	54.3	.01196
1973-75	5	7,262	3,631	255,739	307.6	61.5	62.0	.01708
1973-76	10	5,058	2,529	357,944	430.4	43.0	43.4	.01715
1973-77	21	3,144	1,572	542,509	652.2	31.1	31.4	.01995

Feedwater Regulating Valves (Continued)

BASIC EQUATIONS (Parallel)

$$em = m_1^2 + \frac{m_1^2}{2M_1}$$

$$eM = \frac{M_1}{2}$$

TABLE 4.8.19

QUAD CITIES 2

Feedwater Spargers

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 3E (a-b)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
9/13/74	239,200	F	Replaced reactor feedwater spargers

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	1	7,380	7,380	239,300	287.5	287.5	287.5	.03896
1975	0							0
1976	0							0
1977	0							0
1973-74	1	13,616	13,616	239,200	287.5	287.5	287.5	.02111
1973-75	1	18,153	18,153	239,200	287.5	287.5	287.5	.01584
1973-76	1	25,293	25,293	239,200	287.5	287.5	287.5	.01137
1973-77	1	33,013	33,013	239,200	287.5	287.5	287.5	.00071

TABLE 4.8.20

QUAD CITIES 2

Control Rod Drive Hydraulic System

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 4A (h)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
3/19/76	75,379	F	Leak in CRD flange

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	0							0
1975	0							0
1976	1	7,140	7,140	75,379	90.6	90.6	90.6	.01269
1977	0							0
1973-74	0							0
1973-75	0							0
1973-76	1	25,293	25,293	75,379	90.6	90.6	90.6	.00358
1973-77	1	33,013	33,013	75,379	90.6	90.6	90.6	.00274

TABLE 4.8.21

QUAD CITIES 2

Reactor

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 4B (a)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
9/26/74	9,318	F	APRM high flux signal (spurious signal)
10/3/75	691,475	F	Core maintenance

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	1	7,380	7,380	9,318	11.2	11.2	11.2	.00152
1975	1	4,537	4,537	691,475	831.1	831.1	831.1	.18318
1976	0							0
1977	0							0
1973-74	1	13,616	13,616	9,318	11.2	11.2	11.2	.00082
1973-75	2	9,077	9,077	700,793	842.3	421.2	421.2	.04640
1973-76	2	12,646	12,646	700,793	842.3	421.2	421.2	.03330
1973-77	2	16,506	16,506	700,793	842.3	421.2	421.2	.02551

TABLE 4.8.22

QUAD CITIES 2

Recirculation Pumps

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 4C (a-b)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
6/15/73	58,248	F	Mechanical seal failure
9/25/73	19,416	F	Valve packing leak on recirculating pump drain line
11/24/73	3,369	P	Recirculating pump trip
12/7/73	1,825	P	Recirculating pump speed problem
1/28/74	8,640	P	Derating
4/6/74	36,062	P	Burned out transformer caused reactor recirc pump to trip
4/8/74	17,736	P	Derating
8/31/74	10,733	F	Reactor recirculation MG set oil pump trip, start of standby caused sudden recirc pump speed increase and scram
10/17/74	2,662	F	Reactor recirculation MG set oil pump 2A1 tripped automatic start of 2A2 caused scram
12/8/74	2,496	P	2B reactor recirc pump valves closed and 2B pump tripped
12/9/74	51,888	P	Derating
5/19/75	599	P	Replace MG set brushes
6/16/75	1,518	P	Replace brushes on 2A recirculating MG set
7/7/75	3,295	P	Replace worn MG set brushes on both MG sets
9/20/75	4,752	P	MG set brushes replaced
1/11/76	3,994	F	Change brushes recirculating MG set
12/21/77	300	P	Change brushes on reactor recirc MG set

(Continued...)

Recirculation Pumps (Continued)

ANALYSIS (Series)

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	4	1,559	1,559	82,858	102.4	25.6	25.6	.01642
1974	7	1,054	1,054	130,217	158.6	22.7	22.7	.02150
1975	4	1,134	1,134	10,164	12.2	3.0	3.0	.00269
1976	1	7,140	7,140	3,994	4.8	4.8	4.8	.00067
1977	1	7,720	7,720	300	0.4	0.4	0.4	.00005
1973-74	11	1,238	1,238	213,075	261.1	23.7	23.7	.01917
1973-75	15	1,210	1,210	223,239	273.3	18.2	18.2	.01505
1973-76	16	1,581	1,581	227,233	278.1	17.4	17.4	.01099
1973-77	17	1,942	1,942	227,533	278.4	16.4	16.4	.00843

TABLE 4.8.23

QUAD CITIES 2

Reactor Cleanup System - Valves

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 4D (i)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
6/8/74 6/19/74	5,591 61,402	P F	Valve MO-2-1201-80 leaking Seal leak on check valve 2-1201-81

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	2	3,690	3,690	66,993	80.5	40.3	40.3	.01091
1975	0							0
1976	0							0
1977	0							0
1973-74	2	6,808	6,808	66,993	80.5	40.3	40.3	.00591
1973-75	2	9,076	9,076	66,993	80.5	40.3	40.3	.00462
1973-76	2	12,647	12,647	66,993	80.5	40.3	40.3	.00318
1973-77	2	16,506	16,506	66,993	80.5	40.3	40.3	.00244

TABLE 4.8.24

QUAD CITIES 2

Residual Heat Removal Pumps

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 4E (a-d)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
10/14/74 ^	8,237	F	Repair packing on RHRS valve 1001-164D in drywell

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	1	7,380	7,380	8,237	9.9	9.9	9.9	.00134
1975	0							0
1976	0							0
1977	0							0
1973-74	1	13,616	13,616	8,237	9.9	9.9	9.9	.00073
1973-75	1	18,153	18,153	8,237	9.9	9.9	9.9	.00055
1973-76	1	25,293	25,293	8,237	9.9	9.9	9.9	.00039
1973-77	1	33,013	33,013	8,237	9.9	9.9	9.9	.00030

TABLE 4.9
QUAD CITIES 1

ADMINISTRATIVE OUTAGES

Source:

Full Outages - NRC Gray Books

Partial Outages - Quad Cities 1 Power Performance Graphs

Date	Outage Hours Lost	Full (F) or Partial (P)	Comments
3/3/73	1,840	F	Weekly Turbine surveillance
3/10/73	1,840	P	Weekly Turbine surveillance
4/1/73	1,840	P	Weekly Turbine surveillance
5/3/73	110,400	F	Shutdown margin testing
5/9/73	1,920	F	Turbine overspeed testing
6/2/73	17,165	P	50% turbine test
6/10/73	3,840	P	75% turbine test
6/22/73	12,595	P	Reverse condenser flow and rod scram timing
10/10/73	12,480	P	MSIV surveillance testing
10/20/73	1,056	P	MSIV surveillance testing
10/23/73	1,920	P	MSIV surveillance testing
10/27/73	1,690	P	MSIV surveillance testing
11/3/73	1,280	P	MSIV surveillance testing
11/7/73	1,340	P	MSIV surveillance testing
11/17/73	1,960	P	MSIV surveillance testing
11/24/73	2,000	P	MSIV surveillance testing
11/28/73	1,610	P	MSIV surveillance testing
12/1/73	1,840	P	MSIV surveillance testing
12/4/73	1,840	P	MSIV surveillance testing
12/12/73	1,380	P	MSIV surveillance testing
12/15/73	15,400	P	Control rod movement for flux shaping
12/19/73	2,080	P	MSIV testing
12/22/73	1,380	P	MSIV testing
12/25/73	1,380	P	MSIV testing
12/29/73	2,800	P	MSIV testing
1/8/74	2,320	P	MSIV surveillance
1/12/74	1,120	P	MSIV surveillance
1/22/74	1,620	P	MSIV surveillance
1/26/74	2,040	P	MSIV surveillance
1/29/74	1,620	P	MSIV surveillance
2/9/74	1,500	P	MSIV surveillance

QUAD CITIES I

ADMINISTRATIVE OUTAGES (Continued)

Date	Outage MW Hrs. Lost	Partial or Full	Comments
2/12/74	1,200	P	MSIV surveillance
2/16/74	1,200	P	MSIV surveillance
2/19/74	1,200	P	MSIV surveillance
2/23/74	1,380	P	MSIV surveillance
2/27/74	680	P	MSIV surveillance
3/31/74	2,238,104	F	First Refueling outage
7/21/74	12,680	P	Startup tests
8/3/74	4,510	P	MSIV test
8/7/74	7,000	P	MSIV test
8/14/74	2,040	P	MSIV test
8/18/74	3,800	P	MSIV test
8/20/74	2,500	P	MSIV test
8/25/74	4,320	P	MSIV test
8/27/74	3,290	P	MSIV test
9/8/74	2,320	P	MSIV test
9/10/74	3,120	P	MSIV test
9/15/74	2,800	P	MSIV test
9/18/74	2,800	P	MSIV test
9/22/74	1,680	P	MSIV test
9/25/74	1,680	P	MSIV test
9/29/74	2,080	P	MSIV test
10/2/74	1,680	P	MSIV test
10/4/74	55,561	F	Shutdown to inspect welds on recirculating piping in drywell as per NRC directive
10/8/74	3,998	F	Turbine load reject scram while doing weekly turbine test
10/26/74	1,480	P	MSIV test
12/24/74	2,720	P	MSIV test and reversed condenser flow
12/31/74	1,680	P	MSIV test
3/15/75	400	P	MSIV test
3/18/75	168	P	Check reactor thermal power
3/23/75	2,680	P	Reverse condenser flow
3/27/75	6,720	P	Reverse condenser flow
3/28/75	1,752	P	Reverse condenser flow
4/6/75	4,600	P	Reverse condenser flow

(Continued...)

QUAD CITIES 1

ADMINISTRATIVE OUTAGES (Continued)

Date	Outage MW Hrs. Lost	Partial or Full	Comments
4/13/75	2,640	P	Reverse condenser flow
4/20/75	2,480	P	Reverse condenser flow
4/27/75	1,880	P	Reverse condenser flow
4/29/75	1,920	P	Reverse condenser flow
5/1/75	456	P	Fuel depletion
6/22/75	1,050	P	Weekly turbine test
6/29/75	2,000	P	Reverse condenser flow
7/10/75	3,100	P	Last minute decision to forego weekend outage
7/21/75	2,000	P	Reverse condenser flow
7/28/75	750	P	Reverse condenser flow
8/1/75	4,450	P	Reverse condenser flow
8/30/75	1,000	P	Reverse condenser flow
9/19 -			
12/31/75	565,008	P	Fuel depletion
9/27/75	2,400	P	Weekend partial outage - cause unspecified, but usually to reverse condenser flow.
10/14/75	2,280	P	Cause unspecified
11/2/75	2,200	P	Weekend partial outage - cause unspecified, but usually to reverse condenser flow
11/16/75	440	P	Reverse condenser flow
1/1 -			
1/2/76	14,784	P	Fuel depletion
1/3/76	1417,682	F	Refueling outage
3/13/76	12,800	P	Scram timing
3/14 -			
3/16/76	40,728	P	Startup tests
4/23/76	800	P	Weekly turbine test
5/8/76	840	P	Weekly turbine test
6/13 -			
6/14/76	1,080	P	Control rod pattern limit
8/23/76	1,056	P	Control rod pattern limit
8/27/76	2,376	P	Control rod pattern limit

1976
Low System Demand Total=
4,932 MWH
(2 partial outages)

QUAD CITIES 1

ADMINISTRATIVE OUTAGES (Continued)

Date	Outage MW Hrs. Lost	Partial or Full	Comments
9/25/76	4,704	P	Reverse condenser flow
11/25/76	2,244	P	Low system demand
11/27/76	2,736	P	Reverse condenser flow
12/25/76	2,688	P	Low system demand
12/31/76	4,224	P	Reverse condenser flow
1/16/77	2,900	P	Reverse condenser flow
1/26 —			
2/4/77	6,408	P	Control rod pattern derating
2/1 —			
3/19/77	114,312	P	Fuel depletion
3/3/77	400	P	Reverse condenser flow
3/3/77	320	P	Reverse condenser flow
3/6/77	440	P	Reverse condenser flow
3/11/77	120	P	Reverse condenser flow
3/12/77	240	P	Reverse condenser flow
3/20/77	1042,166	F	Cycle 3 refueling
6/3/77	600	P	Control rod pattern derating
6/8/77	11,640	P	Load dispatcher limit
6/14/77	19,409	F	Low system demand
6/19/77	10,840	P	Low system demand
6/25 —			
6/28/77	1,368	P	Control rod pattern derating
7/13/77	3,600	P	Low system demand
7/22/77	24,440	P	Low system demand
7/26/77	89,200	P	Low system demand
8/8/77	34,240	P	Low system demand
8/13/77	274,723	F	Low system demand
8/31 —			
9/2/77	672	P	Control rod pattern derating
9/2/77	19,160	P	Low system demand
9/11/77	201,170	F	Low system demand
9/25/77	24,600	P	Low system demand
9/28/77	207,834	F	Unit placed in reserve shutdown

QUAD CITIES 1

ADMINISTRATIVE OUTAGES (Continued)

Date	Outage MW Hrs. Lost	Partial or Full	Comments
10/12/77	56,240	P	Low system demand
10/15/77	1,200	P	Control rod pattern change
10/30/77	13,880	P	Low system demand
11/1/77	360	P	MSIV testing
11/2/77	26,080	P	Low system demand
11/12/77	2,880	P	Low system demand
11/18/77	7,360	P	Control rod pattern change
11/24/77 thru 11/28/77	1,680	P	Control rod derating

1977 Low System Demand
4 Full outages at 705136 MWH
12 Partial outages at 316800 MWH

TABLE 4.10
QUAD CITIES 1

CONDITIONAL OUTAGES

Source:

Full Outages — NRC Gray Books

Partial Outages — Quad Cities 1 Power Performance Graphs

Date	Outage MW Hrs. Lost	Partial or Full	Comments
3/21/73	32,640	F	Repaired RCIC testable check valve
5/18/73	54,400	F	Replaced diesel generator turbo-charger
6/30/73	7,296	P	High river temperature derating
7/12/73	8,832	P	High river temperature derating
8/1/73	102,400	F	Repaired snubbers and steam leaks
8/17/73	201,869	P	High river temperature derating
9/1/73	17,818	P	High river temperature derating
9/15/73	5,491	P	High river temperature derating
9/19/73	612	P	Average planar heat generation rate considerations
9/22/73	163,200	F	Inspected and replaced snubbers
10/3/73	32,000	F	Repaired RCIC leaks and MSIV pilot valve
10/12/73	6,400	F	False reactor low water level and scram
10/17/73	6,400	F	Shutdown due to operator error
10/30/73	6,400	F	Scram caused by maintenance error on EHC system
12/12/73	1,032	P	Preconditioning and hold due to Xenon concentration gradient
12/13/73	720	P	Preconditioning and fuel densification
12/12/73 and 12/15/73	1,680	P	Preconditioning and fuel densification
12/19/73	120	P	Fuel densification derating
12/20/73 — 12/31/73	10,080	P	Fuel densification derating
7/22/74	15,994	F	Replaced burned out diesel generator cooling water pump motor
8/19/74 and 8/20/74	1,728	P	Rad waste derating
8/4/74 — 9/19/74	4,308	P	Circulating water temperature derating
9/9/74 and 9/10/74	869	P	Rad waste derating

(Continued...)

QUAD CITIES 1

CONDITIONAL OUTAGES (Continued)

Date	Outage MW Hrs. Lost	Partial or Full	Comments
9/12/74 9/27/74 -	228	P	Rad waste derating
9/29/74	4,248	P	Rad waste derating
10/10/74	19,825	F	Off gas explosion when worker cut into drainline with grinder
11/2/74	18,159	F	Core spray system injection valve 1-1402-6A packing leak
11/20/74 11/25/74 -	1,608	P	Core flow calibration derating
11/27/74	1,320	P	Core flow calibration derating
12/27/74	264	P	Core flow calibration derating
1/9/75	80,551	F	Inspect four-inch recirculating piping for cracks
2/27/75	6,331	F	Rx scram when FRV closed when 1A RFP converter was accidentally removed
4/7/75	6,200	P	RCIC valve leaking into drywell due to blown packing
4/20/75 and 4/21/75	1,776	P	Radwaste deratings
5/8/75	7,997	F	Error in inputting vessels level transmitter-calibration signal led to turbine trip
5/13/75	5,998	F	Erroneous test signal resulted in turbine trip and scram during stop valve tests
5/15/75 -			
9/21/75 7/9/75 -	946	P	Circulating water temperature
9/21/75	7,175	P	Scram reactivity derating
7/23/75	912	P	Uncertainty in flow control line derating
7/29/75	1,128	P	HPCI test
8/6/75	2,664	P	Hold for pull of additional rods
10/2/75	5,680	P	HPCI Leakage at testable check valve

QUAD CITIES 1

CONDITIONAL OUTAGES (Continued)

Date	Outage MW Hrs. Lost	Partial or Full	Comments
3/14/76	11,246	F	Control rod pattern change
5/17/76	5,748	F	Reactor scram due to low vacuum signal caused by error while performing routine surveillance
5/25/76	5,998	F	Generator brought on-line with inadequate condenser vacuum
7/27/76	10,829	F	Leak in drywell
10/9/76	35,319	F	Snubber inspection
4/27/76	216	P	Core instrument calibration
5/21/76			
-			
10/5/76	10,872	P	Circulating water temperature derating
8/12/76			
-			
8/14/76	2,352	P	High LPRM readings
9/12/76			
-			
10/8/76	18,336	P	MCPR derating
11/27/76			
-			
12/31/76	44,712	P	Scram reactivity derating
1/1/77			
-			
2/2/77	67,920	P	Scram reactivity derating
1/22/77			
and			
1/23/77	144	P	Circulating water temperature derating
2/15/77			
-			
2/18/77	8,160	P	Scram reactivity derating
5/11/77	3,250	F	Generator tripped due to operator error
5/17/77			
-			
8/29/77	29,040	P	Circulating water temperature derating
6/29/77	246,164	F	Instrument mechanic error during condenser low vacuum instrument surveillance
7/17/77	927,664	F	Operator error led to scram while testing #3 control valve
10/26/77	240	P	Computer derating
11/16/77	309	F	Operator error during MSIV surveillance testing

QUAD CITIES 1

CONDITIONAL OUTAGES (Continued)

Source:

Full Outages - NRC Gray Books

Partial Outages - Quad Cities 1 Power Performance Graphs

Date	Outage Hours Lost	Full (F) or Partial (P)	Comments
5/9/73	25,152	P	Preconditioning
5/22/73	26,784	P	Preconditioning
5/29/73	2,859	P	Preconditioning
6/7/73	4,147	P	Preconditioning
7/6/73	27,360	P	Preconditioning and ramp down
8/6/73	10,406	P	Preconditioning and ramp down
8/11/73	30,739	P
9/13/73	13,901	P	
10/1/73	20,851	P	
10/5/73	28,800	P	
10/13/73	19,046	P	
10/31/73	8,448	P	
11/5-11/6/73	1,920	P	
11/12/73	8,860	P	
11/22/73	12,600	P	
12/8/73	19,760	P	
1/7/74	9,280	P	
1/16/74	9,120	P	
1/21/74	7,880	P	
2/1/74	25,430	P	
3/2/74	11,800	P	
7/24/74	32,600	P	Preconditioning deratings
7/28/74	47,920	P	
5/4-8/7/74	6,919	P	
8/9/74	13,200	P	
8/11-8/16/74	14,616	P	
9/1/74	31,030	P	
10/3/74	11,800	P	
10/9/74	16,720	P	
10/18/73	46,040	P	
10/27-11/1/74	4,704	P	
11/4/74	51,440	P	
11/18-11/19/74	1,992	P	
11/28/74	32,240	P	
12/16/74	12,140	P	

QUAD CITIES 1

CONDITIONAL OUTAGES (Continued)

Date	Outage MW Hrs. Lost	Partial or Full	Comments
2/21/75	24,880	P	Preconditioning deratings
2/25/75	15,200	P	
2/27/75	8,000	P	
3/1/75	6,900	P	
3/5 --			
3/6/75	2,112	P	
3/6/75	29,000	P	
3/29/75	6,240	P	
3/31/75	744	P	
4/22/75	768	P	
5/5/75	20,700	P	
5/8/75	5,880	P	
5/9/75	8,200	P	
5/10 --			
5/12/75	1,440	P	
5/14/75	480	P	
5/17/75	8,400	P	
5/20/75	12,400	P	
6/12 --			
6/13/75	12,288	P	
6/13/75	27,000	P	
6/19/75	144	P	
6/30/75	864	P	
7/16 --			
7/17/75	2,784	P	
7/21 --			
7/22/75	6,648	P	
7/27/75	8,000	P	
7/30/75	240	P	
8/5/75	144	P	
8/8/75	312	P	
8/21/75	8,640	P	
8/22/75	2,832	P	
8/27/75	12,040	P	
8/28 --	17		
8/29/75	4,776	P	
9/13/75	5,740	P	
9/22/75	288	P	

QUAD CITIES 1
CONDITIONAL OUTAGES (Continued)

Date	Outage MW Hrs. Lost	Partial or Full	Comments
4/8/76	3,960	P
4/11/76	3,624	P	
4/11/76	5,520	P	
4/16 --			
4/21/76	16,728	P	
5/4/76	192	P	
5/18/76	3,200	P	
5/28 --			
5/29/76	11,040	P	
5/25/76	17,800	P	
5/30/76	12,400	P	
6/8/76	22,640	P	
6/21/76	5,304	P	
7/16/76	5,680	P	
7/19/76	5,200	P	
7/24/76	7,320	P	
7/27/76	10,560	P	
8/6/76	6,000	P	
8/8/76	19,120	P	
8/18/76	8,560	P	
8/25/76	2,736	P	
8/26/76	2,496	P	
9/4/76	19,584	P	
9/28/76	1,104	P	
10/5/76	744	P	
10/11 --			
10/28/76	16,056	P	
10/11/76	20,184	P	
10/31/76	2,880	P	
11/1/76	5,256	P	
11/7/76	9,360		
11/8/76	3,720	P	
11/10/76	8,040	P	
11/13/76	14,580	P	
11/21/76	1,560	P	
12/11/76	2,160	P	
12/13/76	480	P	
3/15/76	43,200	P	
4/6/76	15,100	P	

Preconditioning deratings

QUAD CITIES 1
CONDITIONAL OUTAGES (Continued)

Date	Outage MW Hrs. Lost	Partial or Full	Comments
1/1/77	9,920	P	<p style="text-align: center;">Preconditioning deratings</p>
1/3/77	14,600	P	
1/7/77	12,240	P	
1/24 --			
1/25/77	696	P	
2/15/77	11,220	P	
5/16/77	23,660		
5/23/77	6,520	P	
5/30/77	6,520		
6/1/77	1,960		
6/6/77	4,120	P	
6/15/77	16,160	P	
6/20/77	5,840	P	
6/22/77	19,160	P	
6/29/77	6,400	P	
7/1/77	1,224	P	
7/4/77	4,080	P	
7/10/77	4,400	P	
7/14/77	3,080	P	
7/17/77	5,380	P	
8/4/77	4,280	P	
8/27/77	15,800	P	
9/22/77	29,200	P	
10/9/77	16,000	P	
10/21/77	23,400	P	
11/1/77	5,136	P	
11/7/77	14,280	P	
11/13/77	1,200	P	
11/17/77	9,880	P	
11/19/77	2,080	P	
12/3/77	3,680	P	
12/11/77	11,140	P	
12/15/77	31,760	P	
2/5/77	8,280	P	
11/29 --			
11/30/77	1,296	P	

QUAD CITIES 1
CONDITIONAL OUTAGES
OFF-GAS DERATING

Source:

Full Outages - NRC Gray Books

Partial Outages - Quad Cities 1 Power Performance Graphs

Date	Outage Hours Lost	Full (F) or Partial (P)	Comments
4/13/73 to 4/16/73	5,400	P	High off gas derating
4/16/73 to 4/18/73	9,120	P	High off gas derating
4/18/73 to 4/23/73	6,600	P	High off gas derating
5/9/73 to 5/18/73	11,558	P	High off gas derating
5/27/73 to 5/28/73	2,016	P	High off gas derating
6/11/73 to 6/23/73	13,210	P	High off gas derating
6/25/73 to 7/1/73	5,760	P	High off gas derating
7/10/73	4,877	P	High off gas derating
7/31/73	27,648	P	High off gas derating
8/8/73	3,187	P	High off gas derating
10/19/73	19,162	P	High off gas derating
11/2/73 to 11/5/73	5,040	P	High off gas derating
11/1/73	2,448	P	High off gas derating
11/7/73	360	P	High off gas derating
11/8/73	360	P	High off gas derating
11/14/73	1,440	P	High off gas derating
11/15/73	1,440	P	High off gas derating
11/16/73	1,440	P	High off gas derating

QUAD CITIES 1
CONDITIONAL OUTAGES
OFF-GAS DERATING

Date	Outage MW Hrs. Lost	Partial or Full	Comments
11/17/73	3,200	P	High off gas derating
11/19/73	1,440	P	High off gas derating
11/20/73	1,200	P	High off gas derating
11/24 to 12/8/73	18,480	P	High off gas derating
2/5 to 2/15/74	7,200	P	High off gas derating
2/15 to 3/1/74	20,160	P	High off gas derating
3/4 to 3/5/74	3,360	P	High off gas derating
3/6 to 3/13/74	5,040	P	High off gas derating
3/13 to 3/18/74	4,200	P	High off gas derating
12/6 to 12/11/74	2,064	P	High off gas derating

QUAD CITIES 1
CONDITIONAL OUTAGES
SCRAM REACTIVITY DERATING

Source:

Full Outages - NRC Gray Books

Partial Outages - Quad Cities 1 Power Performance Graphs

Date	Outage Hours Lost	Full (F) or Partial (P)	Comments
3/13 — 3/23/74	3,696	P	Scram reactivity derating
3/25 — 3/31/74	2,352	P	Scram reactivity derating

TABLE 4.11.1
QUAD CITIES 1

Generator

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 1A(a)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
8/26/75	15,244	F	Inspected generator circuit breaker after unit tripped off grid and scrambled
6/23/76	442,240	F	Repair of generator field ground
11/9/76	9,663	F	Loss of generator field
2/10/77	43,483	F	Hydrogen leak in generator repaired

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	0							0
1975	1	7,447	7,447	15,244	18.3	18.3	18.3	.00246
1976	2	2,857	2,857	451,903	542.5	271.3	271.3	.09496
1977	1	7,027	7,027	43,483	52.2	52.2	52.2	.00743
1973-74	0							0
1973-75	1	19,255	19,255	15,244	18.3	18.3	18.3	.00095
1973-76	3	8,323	8,323	467,147	560.8	186.9	186.9	.02246
1973-77	4	7,999	7,999	510,630	613.0	153.3	153.3	.01916

TABLE 4.11.2

QUAD CITIES 1

Electrical Distribution System

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 1A(c)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
1/9/75	5,748	F	Loss of essential service bus

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	0							0
1975	1	7,447	7,447	5,748	6.9	6.9	6.9	.00093
1976	0							0
1977	0							0
1973-74	0							0
1973-75	1	19,255	19,255	5,748	6.9	6.9	6.9	.00036
1973-76	1	24,968	24,968	5,748	6.9	6.9	6.9	.00028
1973-77	1	31,995	31,995	5,748	6.9	6.9	6.9	.00022

TABLE 4.11.3
QUAD CITIES 1

MSIV Strings

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 1B (a-d)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
7/16/73	307	P	MSIV test on 1-203-1B failed to get proper relay action
7/22/74	19,992	F	Lapped leaky MSIV

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	1	6,361	6,361	307	0.4	0.4	4.0	.00006
1974	1	5,447	5,447	19,992	24.0	24.0	24.0	.00441
1975	0							0
1976	0							0
1977	0							0
1973-74	2	5,904	5,904	20,299	24.0	12.2	12.2	.00207
1973-75	2	9,628	9,628	20,299	24.4	12.2	12.2	.00127
1973-76	2	12,484	12,484	20,299	24.4	12.2	12.2	.00098
1973-77	2	15,998	15,998	20,299	24.4	12.2	12.2	.00076

QUAD CITIES 1

Main Steam Line - Piping

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 1B(e)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
11/4/74	4,332	F	Unit taken off system to repair a steam leak on restricting orifice RO-1-3041-5
12/13/74	55,978	F	Repaired main steam line drain leaks and inspected drywell snubbers
8/19/75	37,402	F	Steam seal relief valve repaired after low condenser vacuum scram
7/30/76	150,523	F	Replace leaking electromatic relief valve
11/1/76	103,875	F	Replace "C" and "E" relief valves

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	2	2,724	2,724	60,310	72.4	36.2	36.2	.01329
1975	1	7,447	7,447	37,402	44.9	44.9	44.9	.00603
1976	2	2,857	2,857	254,398	305.4	152.7	152.7	-.5345
1977	0							0
1973-74	2	5,904	5,904	60,310	72.4	36.2	36.2	.00613
1973-75	3	6,418	6,418	97,712	117.3	39.1	39.1	.00609
1973-76	5	4,994	4,994	352,110	422.7	84.5	84.5	.01692
1973-77	5	6,399	6,399	352,110	422.7	84.5	84.5	.01321

TABLE 4.11.5
QUAD CITIES 1

Turbine Control Valve

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 1B (f-i)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
10/16/73	3,840	F	Repaired turbine control valve steam leak
11/9/73	59,976	F	Cap screw lodged in turbine control valve seat (also work on CRD system)
7/27/74	25,157	F	Turbine control valve stem leak
5/12/77	18,909	F	Rx scram caused by control valve malfunction

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	2	3,181	3,181	$\frac{3,840^*}{59,976}$	$\frac{4.8^*}{72.0^*}$	38.4	38.4	.01207
1974	1	5,447	5,447	25,157	30.2	30.2	30.2	.00554
1975	0							0
1976	0							0
1977	1	7,027	7,027	18,909	22.7	22.7	22.7	.00323
1973-74	3	3,936	3,936	88,973	107.0	35.7	35.7	.00907
1973-75	3	6,418	6,418	88,973	107.0	35.7	35.7	.00556
1973-76	3	8,323	8,323	88,973	107.0	35.7	35.7	.00429
1973-77	4	7,999	7,999	107,882	129.7	32.4	32.4	.00405

TABLE 4.11.6

QUAD CITIES 1

High Pressure Turbine

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 1B (j)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
8/7/76	10,996	F	Balance turbine
8/15/76	17,576	F	Balance turbine
8/15/76	7,164	F	Balance turbine
10/23/76	324	P	Turbine test
5/11/77	12,495	F	High vibration led to turbine trip
5/11/77	11,162	F	Turbine taken off line for balancing
5/14/77	22,741	F	Turbine taken off line for balancing
8/13/77	5,415	F	Turbine thrust bearing wear detector circuitry failed leading to turbine trip
12/1/77	8,640	P	Turbine gland steam exhauster tripped and wouldn't restart

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	0							0
1975	0							0
1976	4	1,428	1,428	36,060	43.3	10.8	10.8	.00756
1977	5	1,405	1,405	60,453	72.6	14.5	14.5	.01032
1973-74	0							0
1973-75	0							0
1973-76	4	6,242	6,242	36,060	43.3	10.8	10.8	.00173
1973-77	9	3,555	3,555	96,513	115.9	12.9	12.9	.00363

TABLE 4.11.7

QUAD CITIES 1

Moisture Separator

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 1B (k-n)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
3/20/73	36,000	F	Drain tank level control valve defective leading to scram from high level
2/28/74	27,073	F	Moisture separator drain tank level control caused scram
10/13/74	85,549	F	Repair vibration damage to moisture separator drain tank 1B (support leg damaged and cracks in piping)
11/8/76	7,580	F	Turbine trip due to high moisture separator level due to failure of emergency drain valve
1/7/77	4,415	F	High level in moisture separator caused scram
9/21/77	666	F	MSDT level transmitter failed from excess vibration
9/21/77	8,080	F	MSDT level transmitter failed from excess vibration

TABLE 4.11.7 (Continued)

QUAD CITIES 1

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	1	6,361	6,361	36,000*	45.0*	45.0	45.0	.00707
1974	2	2,724	2,724	112,622	135.2	67.6	67.6	.02482
1975	0							0
1976	1	5,713	5,713	7,580	9.1	9.1	9.1	.00159
1977	3	2,342	2,342	13,161	15.8	5.3	5.3	.00226
1973-74	3	3,936	3,936	148,622	180.2	60.1	60.1	.01526
1973-75	3	6,418	6,418	148,622	180.2	60.1	60.1	.00936
1973-76	4	6,242	6,242	156,202	189.3	47.3	47.3	.00758
1973-77	7	4,571	4,571	169,363	205.1	29.3	29.3	.00641

* Based on MDC = 800 MW

TABLE 4.11.8

QUAD CITIES 1

Electrohydraulic Control (EHC)

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 1B (r)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
3/16/73	12,000	F	Turbine-generator load mismatch caused low EHC oil pressure spike and reactor scram
3/26/73	9,600	F	EHC circuit board fault caused unstable pressure control leading to high flux scram
3/30/73 to 4/7/73	3,840	P	EHC oil pressure problems
12/8/73	6,664	F	Repaired EHC oil leak
1/31/74	9,996	F	EHC oil leak at stop valve
3/2/74	4,665	F	Turbine stop valve closed causing reactor scram
3/24/74	9,663	F	Turbine stop valve closure while testing no. 3 stop valve
8/10/74	6,664	F	Repaired EHC oil leak at turbine control valve
8/15/76	7,747	F	Low EHC oil pressure
10/31/76	8,747	F	Low EHC oil pressure
5/15/77	5,581	F	EHC oil leak to no. 1 control valve

TABLE 4.11.8 (Continued)

QUAD CITIES 1

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	4	1,590	1,590	$\frac{25,440^*}{6,664}$	$\frac{31.8^*}{8}$	9.9	9.9	.00626
1974	4	1,362	1,362	30,998	37.2	9.3	9.3	.00683
1975	0							0
1976	2	2,857	2,857	16,494	19.8	9.9	9.9	.00347
1977	1	7,027	7,027	5,581	6.7	6.7	6.7	.00095
1973-74	8	1,476	1,476	63,102	77.0	9.6	9.6	.00652
1973-75	8	2,407	2,407	63,102	77.0	9.6	9.6	.00400
1973-76	10	2,497	2,497	79,596	96.8	9.7	9.7	.00388
1973-77	11	2,909	2,909	85,177	103.5	9.4	9.4	.00323

* Based on 800 MW MDC

TABLE 4.11.9

QUAD CITIES 1

Condenser

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 2A (a)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
1/1/74	121,951	F	Plugged tube leaks
8/4/74 thru 12/31/74	28,944	P	Condenser performance derating
3/1/75 thru 1/11/76	267,240	P	Condenser performance derating
5/1/75	65,974	F	Plugged 25 tubes (maintenance also performed on other components)
7/24/75	54,062	F	Plugged leaking condenser tubes
12/12/76	2,544	P	Condenser performance derating
1/1/77 thru 12/31/77	75,192	P	Condenser performance derating
3/1/77	264	P	Condenser performance derating

(Continued...)

TABLE 4.11.9 (Continued)

QUAD CITIES I

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	2	2,724	2,724	150,895	181.1	90.6	90.6	.03326
1975	3	2,482	2,482	344,220	413.2	137.7	137.7	.05548
1976	2	2,856	2,856	45,600	54.7	27.4	27.4	.00959
1977	2	3,514	3,514	75,456	90.5	45.3	45.3	.01289
1973-74	2	5,904	5,904	150,895	181.1	90.6	90.6	.01535
1973-75	5	3,851	3,851	495,115	594.3	118.9	118.9	.03088
1973-76	6	4,161	4,161	540,715	649.1	108.2	108.2	.02600
1973-77	8	3,999	3,999	616,171	739.7	92.5	92.5	.02312

TABLE 4.11.10

QUAD CITIES 1

Spray Canal

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 2B (a)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
8/4/74 thru 11/1/74	13,164	P	Spray canal derating
11/19/74 and 11/20/74	96	P	Spray canal derating
12/3/74	48	P	Spray canal derating
5/5/75 thru 6/22/75	43,032	P	Spray canal derating
7/7/75 thru 12/31/75	32,904 103,392	P	Spray canal derating Temperature limit on service water derating
7/12/75	15,520	P	Spray canal test
7/19/75	14,920	P	Spray canal test
8/2/75	20,520	P	Spray canal test
8/7/75	5,120	P	Spray canal test
9/10/75	1,060	P	Spray canal test
1/1/76 thru 11/12/76	239,640	P	Spray canal derating
5/19/76	2,440	P	Anticipated high condenser back pressure
5/20/76	14,700	P	High service water from poor spray canal performance
6/5/76	36,400	P	Load reduced due to limitation on service water
6/22/76	44,520	P	Limitations on service water
7/20/76	46,040	P	Lift station on spray canal
8/28/76	36,000	P	Spray canal test
12/14/76 thru 12/31/76	17,856	P	Spray canal derating
1/1/77 thru 6/28/77	16,632	P	Spray canal derating

(Continued...)

QUAD CITIES 1

Spray Canal

OUTAGE DATA (Continued)

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
1/9/77	660	P	Load reduction from icing of 345 KV lines due to spray canal
5/22/77	12,000	P	Poor spray canal performance
5/26/77	19,280	P	Poor spray canal performance
5/31/77	4,160	P	Poor spray canal performance
6/5/77	8,040	P	Poor spray canal performance
6/11/77	38,440	P	Poor spray canal performance
6/18/77	3,560	P	Poor spray canal performance
7/2/77	28,400	P	Poor spray canal performance
7/9/77	12,960	P	Poor spray canal performance
7/11/77 thru 12/31/77	58,776	P	Spray canal derating
7/16/77	8,400	P	Poor spray canal performance
8/6/77	29,480	P	Poor spray canal performance
10/24/77	8,720	P	Poor spray canal performance
11/6/77	11,412	F	Spray canal auxiliary transformer failure

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0					0		0
1974	3	1,816	1,816	13,308	16.0	5.3	5.3	.00293
1975	7	1,064	1,064	236,468	283.9	40.6	40.6	.03816
1976	8	714	714	437,596	525.3	65.7	65.7	.09196
1977	15	468	468	260,920	313.2	20.9	20.9	.044619
1973-74	3	3,936	3,936	13,308	16.0	5.3	5.3	.00135
1973-75	10	1,926	1,926	249,776	299.9	30.0	30.0	.01557
1973-76	17	1,469	1,469	687,372	825.2	48.5	48.5	.03304
1973-77	31	1,032	1,032	948,292	1,138.4	36.7	36.7	.03558

TABLE 4.11.11

QUAD CITIES 1

Off-Gas Piping

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 2D(a)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
4/21/73	234,400	F	Off-gas System installation modification

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	1	6,361	6,361	234,400*	293.0*	293.0	293.0	.04606
1974	0							0
1975	0							0
1976	0							0
1977	0							0
1973-74	1	11,808	11,808	234,400	293.0	293.0	293.0	.02481
1973-75	1	19,255	19,255	234,400	293.0	293.0	293.0	.01522
1973-76	1	24,968	24,968	234,400	293.0	293.0	293.0	.01174
1973-77	1	31,995	31,995	234,400	293.0	293.0	293.0	.00916

TABLE 4.11.12

QUAD CITIES 1

Condensate Pump

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 2E(a-d)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
4/7/73	15,360	F	Condensate pump seal failure led to low vacuum scram
4/28/76	800	P	1D condensate pump problems
12/10/77	1,280	P	1A condensate pump motor bearing burned out

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	1	6,361	6,361*	15,360	19.2	19.2	19.2	.00302
1974	0							0
1975	0							0
1976	1	5,713	5,713	800	1.0	1.0	1.0	.00018
1977	1	7,027	7,027	1,280	1.5	1.5	1.5	.00021
1973-74	1	11,808	11,808	15,360	19.2	19.2	19.2	.00163
1973-75	1	19,255	19,255	15,360	19.2	19.2	19.2	.00100
1973-76	2	12,484	12,484	16,160	20.2	10.1	10.1	.00081
1973-77	3	10,665	10,665	17,440	21.7	7.2	7.2	.00068

TABLE 4.11.13

QUAD CITIES 1

Steam Jet Air Ejector

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 2F (a-b)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
1/8/74	5,568	P	Low vacuum in condenser
1/9/74 thru 1/16/74	16,800	P	Low vacuum in condenser
1/17/74	4,400	P	Low vacuum in condenser
1/20/74	17,993	F	Installed drain line at SJAE discharge
1/1/75	880	P	Repair of SJAE abnormalities
1/1/75	1,800	P	Correct condenser vacuum problems
3/4/75	2,220	P	SJAE problems
3/13/75	1,400	P	SJAE problems
5/16/75 thru 5/19/75	18,552	P	SJAE deratings

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	4	1,362	1,362	44,761	53.7	13.4	13.4	.00984
1975	5	1,489	1,489	24,852	29.8	6.0	6.0	.00403
1976	0							0
1977	0							0
1973-74	4	2,952	2,952	44,761	53.7	13.4	13.4	.00454
1973-75	9	2,139	2,139	69,613	83.5	9.3	9.3	.00435
1973-76	9	2,774	2,774	69,613	23.5	9.3	9.3	.00335
1973-77	9	3,555	3,555	69,613	33.5	9.3	9.3	.00262

QUAD CITIES 1

Condensate Demineralizers

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 2H (a-g)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
8/21/74 thru 8/24/74	506	P	Derating
9/30/74	264	P	Derating
4/23/75 thru 4/29/75	4,920	P	Derating
8/27/75	12,048	P	Derating
12/10/76	6,914	F	Stuck vent valve in condensate demineralizer
11/23/77	4,920	P	Shortage of condensate demineralizers

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	2	2,724		770	.9	.5		.00018
1975	2	3,724		16,968	20.4	10.2		.00274
1976	1	5,713		6,914	8.3	8.3		.00145
1977	1	7,027		4,920	5.9	5.9		.00084
1973-74	2	5,904			.9	.5		.00008
1973-75	4	4,814			21.3	5.3		.00110
1973-76	5	4,994			29.6	5.9		.00118
1973-77	6	5,333			35.5	5.9		.00111

TABLE 4.11.15

QUAD CITIES 1

Feedwater Heaters

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 3A (a-i)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
8/26/73	16,704	P	Repaired flange leak in drain line from 1D2 heater to 1C2
11/2 --			
11/7/73	6,240		Feedwater heater derating
11/7/73	1,248		Feedwater heater derating
11/8/73	1,248		Feedwater heater derating
11/14/73	1,248		Feedwater heater derating
11/15/73	1,248		Feedwater heater derating
11/16/73	1,248		Feedwater heater derating
11/19/73	1,248		Feedwater heater derating
11/20/73	1,248		Feedwater heater derating
11/24/73			Feedwater heater derating
to,	17,472		Feedwater heater derating
12/8/73			
12/12/73	1,248		Feedwater heater derating
12/13/73	1,248		Feedwater heater derating
12/14/73			
and	2,496		Feedwater heater derating
12/15/73			
12/19/73	1,248		Feedwater heater derating
12/20/73			
thru			
12/31/73	14,976		Feedwater heater derating
1/9/74			
to	8,736	P	Heater problems
1/16/74			
1/17/74	1,760	P	Heater problems
1/22/74	14,280	P	Heater problems
2/5/74			
thru	4,992	P	Heater problems
2/28/74			

QUAD CITIES 1

Feedwater Heaters

OUTAGE DATA (Continued)

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
3/4/74 and 3/5/74 3/6/74 thru 3/12/74 3/13/74 thru 3/17/74 3/18/74 thru 3/30/74 8/4/74 thru 9/20/74 12/20/74 thru 12/31/74	2,496 8,736 4,560 24,960 47,027 3,168	P P P P P P	Heater problems Heater problems Heater problems Heater problems Heater problems Heater problems
11/18/76 thru 11/26/76	6,744	P	Feedwater heater derating

TABLE 4.11.15

QUAD CITIES 1

(Continued)

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	15	424	424	$\frac{16,704^*}{53,664}$	$\frac{20.9^*}{64.4}$	5.7	5.7	.01344
1974	10	545	545	120,715	144.9	14.5	14.5	.02661
1975	0							0
1976	1	5,713	5,713	6,744	8.1	8.1	8.1	.00142
1977	0							0
1973-74	25	472	472		230.2	9.2	9.2	.01949
1973-75	25	770	770		230.2	9.2	9.2	.01195
1973-76	26	960	960		238.3	9.2	9.2	.00958
1973-77	26	1,231	1,231		238.3	9.2	9.2	.00747

* Based on 800 MW MDC.

TABLE 4.11.16

QUAD CITIES 1

Reactor Feed Pump

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 3B (a-c)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
4/9/73	4,800	P	Flange gasket leak on 1B RFP
2/24/75	21,825	F	Tracer test tap leak on 1C RFP discharge line
6/21/77	23,324	F	Leak in 3/4" pressure tap on feedwater pump discharge line
7/25/77	11,800	P	Decreased load due to operation of only 1 feed pump
12/19/77	560	P	Switch feed pumps
12/25/77	3,680	P	Switch feed pumps

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	1	6,361	6,361*	4,800*	6.0	6.0	6.0	.00094
1974	0							0
1975	1	7,447	7,447	21,825	26.2	26.2	26.2	.00352
1976	0							0
1977	4	1,757	1,757	39,364	47.3	11.8	11.8	.00672
1973-74	1	11,808	11,808	4,800	6.0	6.0	6.0	.00051
1973-75	2	9,628	9,628	4,800	32.2	16.1	16.1	.00167
1973-76	2	12,484	12,484	26,625	32.2	16.1	16.1	.00249
1973-77	6	5,333	5,333	65,989	79.5	13.3	13.3	.00249

TABLE 4.11.17

QUAD CITIES 1

Feedwater Piping

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 3B (d)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
3/25/76	231,407	F	Inspect welds on low flow regulating piping. Repair welds where 6" flowline ties into 24" feedwater line

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	0							0
1975	0							0
1976	1	5,713	5,713	231,407	277.8	277.8	277.8	.04863
1977	0							0
1973-74	0							0
1973-75	0							0
1973-76	1	24,968	24,968	231,407	277.8	277.8	277.8	.01113
1973-77	1	31,995	31,995	231,407	277.8	277.8	277.8	.00868

QUAD CITIES 1

Feedwater Regulating Valves

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 3C (a-b)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
3/19/73	4,800	F	Electrical control failure led to low water level signal
6/6/73	6,400	F	Reactor scram due to low water level due to malfunction in level master controller.
9/12/73	8,000	F	Feedback positioner came loose on FRV causing valve to go full open leading to turbine trip and scram
10/12/74	18,743	F	Shut down to repair leaks of feedwater check valve 220-58B and steam flow sensing line element
3/21/76 to 3/23/76	16,992	P	Feedwater regulating valve derating
4/9/76 and 4/10/76	8,256	P	Feedwater regulating valve derating
5/2/76	6,120	P	Load reduced to test 1B feedwater regulating valve
5/21/76	66,890	F	Repair feedwater check valve

(Continued...)

TABLE 4.11.18 (Continued)
QUAD CITIES 1

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	3	2,120	2,120	19,200*	24.0*	8.0	8.0	.00319
1974	1	5,447	5,447	18,783	22.5	22.5	22.5	.00413
1975	0							0
1976	4	1,428	1,428	98,258	118.0	29.5	29.5	.02066
1977	0							0
1973-74	4	2,952	2,952	37,943	46.5	11.63	11.63	.00394
1973-75	4	4,814	4,814	37,943	46.5	11.63	11.63	.00242
1973-76	8	3,121	3,121	136,201	164.5	20.56	20.56	.00659
1973-77	8	3,999	3,999	136,201	164.5	20.56	20.56	.00514

* Based on 800 MW MDC

TABLE 4.11.19

QUAD CITIES 1

Vacuum Breaker

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: (not yet assigned)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
12/12/77	49,397	F	Unit shut down to repair suppression chamber to drywell vacuum breaker

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	0							0
1974	0							0
1975	0							0
1976	0							0
1977	1	7,027	7,027	49,397	59.3	59.3	59.3	.00844
1973-74	0							0
1973-75	0							0
1973-76	0							0
1973-77	1	31,995	31,995	49,397	59.3	59.3	59.3	.00185

Reactor Recirculation Pump

FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 4C (a-b)

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
7/7/73	35,200	F	Repaired leak on reactor recirculation pump discharge bypass valve
5/28/73	8,832	P	Reactor recirculation pump trip
11/21/73	33,320	F	Repaired leaky recirculation pump suction valve
8/27/74	120	P	MG set outage
1/13/75	793,016	F	Recirculation pipe cracks
9/20/75	2,940	P	Changed MG set brushes
11/6/75	240	P	A recirculation pump tripped
11/30/75	1,360	P	Changed MG set brushes
10/25/76	1,200	P	MG set trip
2/12/77	52,562	F	Failed inboard seal on reactor recirculating pump 1A
2/18/77	6,600	P	Low oil level indication in 1A reactor recirculating pump
7/20/77	4,560	P	1B1 reactor recirculating MG set oil pump tripped causing 1B reactor recirculating MG set to trip
9/6/77	85,716	F	1B recirculating MG set tripped and would not restart. Seal on 1A recirculating pump also replaced

(Continued...)

TABLE 4.11.20 (Continued)

QUAD CITIES 1

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	3	2,120	2,120	$\frac{44,032}{33,320}$	$\frac{55.0}{40.0}$	31.7	31.7	.01495
1974	1	5,447	5,447	120	0.1	0.1	0.1	.00002
1975	4	1,862	1,862	797,556	957.5	239.4	239.4	.12857
1976	1	5,713	5,713	1,200	1.4	1.4	1.4	.00025
1977	4	1,757	1,757	149,438	179.4	44.9	44.9	.02555
1973-74	4	2,952	2,952	77,472	95.1	23.8	23.8	.00806
1973-75	8	2,407	2,407	875,028	1052.6	131.6	131.6	.05467
1973-76	9	2,774	2,774	876,228	1054.0	117.1	117.1	.04221
1973-77	13	2,461	2,461	1025,666	1233.4	94.9	94.9	.03856

* Based on 800 MW MDC

TABLE 4.11.21
QUAD CITIES 1

Instrument Air
FUNCTIONAL DIAGRAM INFORMATION

Component Identifier: 5B

Component Configuration: Series

OUTAGE DATA

Date	Outage MW Hrs. Lost	Full (F) or Partial (P)	Comments
8/10/73	20,000	F	Loss of instrument air supply to MSIV led to valve closure and scram
1/3/77	6,497	F	Instrument air dryer switching failure caused low pressure, allowing several control rods to drift

ANALYSIS

Year	Number of Outages	M ₁ (Hours)	eM (Hours)	MW Hours Lost	MW Hours Lost MDC	m ₁ (Hours)	em (Hours)	$\frac{em}{eM}$
1973	1	6,361	6,361	20,000	25.0*	25.0	25.0	.00393
1974	0							0
1975	0							0
1976	0							0
1977	1	7,027	7,027	6,497	7.8	7.8	7.8	.00111
1973-74	1	11,808	11,808	20,000	25.0	25.0	25.0	.00212
1973-75	1	19,255	19,255	20,000	25.0	25.0	25.0	.00130
1973-76	1	24,968	24,968	20,000	25.0	25.0	25.0	.00100
1973-77	2	15,998	15,998	26,497	32.8	16.4	16.4	.00103

The information in these tables is used later to compute the Department of Energy unavailability factors U_P , U_F and U_C .

4.4 EQUIVALENT AVAILABILITY ANALYSIS

In this section, the equivalent availability analysis is given for Quad Cities. Section 4.4.1 gives the applicable equivalent availability equations. Section 4.4.2 analyzes the unit outage data from 1973-1977. This analysis is used to verify the equivalent availability equations. Section 4.4.3 gives equivalent availability predictions from the model and compares these predictions with the units actual equivalent availability. The statistical and sensitivity analysis on the developed meantime-to-restore and meantime-to-outage coefficients is given in section 4.4.4.

4.4.1 Equivalent Availability Equations

The equivalent availability for Quad Cities is found from the equation

$$EA = 1 - U_P - U_C - U_F \quad (4.1)$$

where

U_P , administrative unavailability, is given by

$$U_P = \sum_{i=1}^{N_P} \frac{\text{Megawatt hours lost in administrative outages}}{(T) (MDC)} \quad (4.2)$$

where

N_P = number of administrative outages

U_C , the conditional unavailability, is given by

$$U_C = \sum_{i=1}^{N_C} \frac{\text{Megawatt hours lost in conditional outages}}{(T) (MDC)} \quad (4.3)$$

where

N_c = number of conditional outages

U_F , the loss of function unavailability, is given by

$$U_F = \left(\frac{em}{eM} \right) \frac{T_o}{T} \quad (4.4)$$

To evaluate $\left(\frac{em}{eM} \right)$ in equation (4.4) it is necessary to use the equations given in Tables 4.12 and 4.13. In Table 4.13, equation (4.5.1) gives $\left(\frac{em}{eM} \right)$ in terms of the five generic level $\left(\frac{em}{eM} \right)$ ratios, which are developed from Figure 4.1. These five generic level $\left(\frac{em}{eM} \right)$ ratios are found by equations (4.5.2) - (4.5.6) in Table 4.12. Equation (4.5.2) - (4.5.6) have been developed from the Quad Cities subfunction level diagram shown in Figure 4.2. The subfunction level $\left(\frac{em}{eM} \right)$ ratios are evaluated from equations (4.6.1) through (4.6.2), which are given in Table 4.13. Equations (4.6.1) through (4.6.2) have been developed from the Quad Cities equipment level diagram shown in Figure 4.3.

Some simplifications from the equipment level functional diagram have been made in developing the equations in Table 4.13. They are as follows:

1. The following parallel systems have each been treated as a single series element, because their components are not repairable with the unit on line:
 - electrohydraulic controls
 - main steam isolation valves
 - main steam control valves
 - moisture separator off the high pressure turbine
 - low pressure turbine
 - catalytic recombiners in the off-gas system
 - feedwater spargers
 - torus to drywell vacuum breakers

TABLE 4.12

QUAD CITIES

GENERIC AND SUBFUNCTION LEVEL

 $\left(\frac{em}{eM}\right)$ EQUATIONS

• Generic level equations

$$\left(\frac{em}{eM}\right) = \underbrace{\left(\frac{em}{eM}\right)_1}_{\text{power conversion}} + \underbrace{\left(\frac{em}{eM}\right)_2}_{\text{steam condensation}} + \underbrace{\left(\frac{em}{eM}\right)_3}_{\text{feed}} + \underbrace{\left(\frac{em}{eM}\right)_4}_{\text{steam generation}} + \underbrace{\left(\frac{em}{eM}\right)_5}_{\text{shared functions}} \quad (4.5.1)$$

• Subfunction level equations

$$\left(\frac{em}{eM}\right)_1 = \left(\frac{em}{eM}\right)_{1A} + \left(\frac{em}{eM}\right)_{1B} \quad (4.5.2)$$

$$\begin{aligned} \left(\frac{em}{eM}\right)_2 = & \left(\frac{em}{eM}\right)_{2A} + \left(\frac{em}{eM}\right)_{2B} + \left(\frac{em}{eM}\right)_{2C} + \left(\frac{em}{eM}\right)_{2D} + \left(\frac{em}{eM}\right)_{2E} + \left(\frac{em}{eM}\right)_{2F} \\ & + \left(\frac{em}{eM}\right)_{2G} + \left(\frac{em}{eM}\right)_{2H} + \left(\frac{em}{eM}\right)_{2I} \end{aligned} \quad (4.5.3)$$

$$\left(\frac{em}{eM}\right)_3 = \left(\frac{em}{eM}\right)_{3A} + \left(\frac{em}{eM}\right)_{3B} + \left(\frac{em}{eM}\right)_{3C} + \left(\frac{em}{eM}\right)_{3D} + \left(\frac{em}{eM}\right)_{3E} \quad (4.5.4)$$

$$\left(\frac{em}{eM}\right)_4 = \left(\frac{em}{eM}\right)_{4A} + \left(\frac{em}{eM}\right)_{4B} + \left(\frac{em}{eM}\right)_{4C} + \left(\frac{em}{eM}\right)_{4D} + \left(\frac{em}{eM}\right)_{4E} \quad (4.5.5)$$

$$\left(\frac{em}{eM}\right)_5 = \left(\frac{em}{eM}\right)_{5A} + \left(\frac{em}{eM}\right)_{5B} \quad (4.5.6)$$

TABLE 4.13

QUAD CITIES

EQUIPMENT LEVEL $\left(\frac{em}{eM}\right)$ EQUATIONS

$$\left(\frac{em}{eM}\right)_{1A} = \left(\frac{em}{eM}\right)_{1A\ a} + \left(\frac{em}{eM}\right)_{1A\ b} + \left(\frac{em}{eM}\right)_{1A\ c} \quad (4.6.1)$$

$$\begin{aligned} \left(\frac{em}{eM}\right)_{1B} = & \left(\frac{em}{eM}\right)_{1B\ a-d} + \left(\frac{em}{eM}\right)_{1B\ e} + \left(\frac{em}{eM}\right)_{1B\ f-i} + \left(\frac{em}{eM}\right)_{1B\ j} \\ & + \left(\frac{em}{eM}\right)_{1B\ k-n} + \left(\frac{em}{eM}\right)_{1B\ o-q} + \left(\frac{em}{eM}\right)_{1B\ r} \end{aligned} \quad (4.6.2)$$

$$\left(\frac{em}{eM}\right)_{2A} = \left(\frac{em}{eM}\right)_{2A\ a} \quad (4.6.3)$$

$$\left(\frac{em}{eM}\right)_{2B} = \left(\frac{em}{eM}\right)_{2B\ a} \quad (4.6.4)$$

$$\left(\frac{em}{eM}\right)_{2C} = \left(\frac{em}{eM}\right)_{2C\ a-c} \quad (4.6.5)$$

$$\left(\frac{em}{eM}\right)_{2D} = \left(\frac{em}{eM}\right)_{2D\ a} + \left(\frac{em}{eM}\right)_{2D\ b-c} + \left(\frac{em}{eM}\right)_{2D\ d-e} + \left(\frac{em}{eM}\right)_{2D\ f-q} \quad (4.6.6)$$

$$\left(\frac{em}{eM}\right)_{2E} = \left(\frac{em}{eM}\right)_{2E\ a-d} \quad (4.6.7)$$

$$\left(\frac{em}{eM}\right)_{2F} = \left(\frac{em}{eM}\right)_{2F\ a-b} \quad (4.6.8)$$

$$\left(\frac{em}{eM}\right)_{2G} = \left(\frac{em}{eM}\right)_{2G\ a-b} \quad (4.6.9)$$

(Continued...)

TABLE 4.13 (Continued)

QUAD CITIES
EQUIPMENT LEVEL $\left(\frac{em}{eM}\right)$ EQUATIONS

$$\left(\frac{em}{eM}\right)_{2H} = \left(\frac{em}{eM}\right)_{2H \text{ a-g}} \quad (4.6.10)$$

$$\left(\frac{em}{eM}\right)_{2I} = \left(\frac{em}{eM}\right)_{2I \text{ a-d}} \quad (4.6.11)$$

$$\left(\frac{em}{eM}\right)_{3A} = \left(\frac{em}{eM}\right)_{3A \text{ a-i}} \quad (4.6.12)$$

$$\left(\frac{em}{eM}\right)_{3B} = \left(\frac{em}{eM}\right)_{3B \text{ a-c}} + \left(\frac{em}{eM}\right)_{3B \text{ d}} \quad (4.6.13)$$

$$\left(\frac{em}{eM}\right)_{3C} = \left(\frac{em}{eM}\right)_{3C \text{ a-b}} \quad (4.6.14)$$

$$\left(\frac{em}{eM}\right)_{3D} = \left(\frac{em}{eM}\right)_{3D \text{ a-c}} \quad (4.6.15)$$

$$\left(\frac{em}{eM}\right)_{3E} = \left(\frac{em}{eM}\right)_{3E \text{ a-b}} \quad (4.6.16)$$

$$\left(\frac{em}{eM}\right)_{4A} = \left(\frac{em}{eM}\right)_{4A \text{ a}} + \left(\frac{em}{eM}\right)_{4A \text{ b-c}} + \left(\frac{em}{eM}\right)_{4A \text{ d-e}} + \left(\frac{em}{eM}\right)_{4A \text{ f-g}} + \left(\frac{em}{eM}\right)_{4A \text{ h}} \quad (4.6.17)$$

$$\left(\frac{em}{eM}\right)_{4B} = \left(\frac{em}{eM}\right)_{4B \text{ a}} + \left(\frac{em}{eM}\right)_{4B \text{ b}} \quad (4.6.18)$$

$$\left(\frac{em}{eM}\right)_{4C} = \left(\frac{em}{eM}\right)_{4C \text{ a-b}} + \left(\frac{em}{eM}\right)_{4C \text{ c-v}} \quad (4.6.19)$$

(Continued...)

TABLE 4.13 (Continued)

QUAD CITIES

EQUIPMENT LEVEL $\left(\frac{em}{eM}\right)$ EQUATIONS

$$\begin{aligned} \left(\frac{em}{eM}\right)_{4D} &= \left(\frac{em}{eM}\right)_{4D \text{ a-b}} + \left(\frac{em}{eM}\right)_{4D \text{ c-d}} + \left(\frac{em}{eM}\right)_{4D \text{ e-f}} + \left(\frac{em}{eM}\right)_{4D \text{ g-h}} \\ &\quad + \left(\frac{em}{eM}\right)_{4D \text{ i}} \end{aligned} \quad (4.6.20)$$

$$\left(\frac{em}{eM}\right)_{4E} = \left(\frac{em}{eM}\right)_{4E \text{ a-d}} + \left(\frac{em}{eM}\right)_{4E \text{ e-f}} \quad (4.6.21)$$

$$\left(\frac{em}{eM}\right)_{5A} = \left(\frac{em}{eM}\right)_{5A} + \left(\frac{em}{eM}\right)_{5B} \quad (4.6.22)$$

2. The residual heat removal system pumps have been treated as a single series element, because of the variable effect of component failure. As shown in the failure modes and effect analysis (Table 4.4), the failure of one pump results in 0 MW derating if the pump is repaired in 30 days and failure of two pumps results in 0 MW derating, if the pumps are repaired within seven days. Exceeding these periods, unit technical specifications require a full outage. Such an outage is actually a loss of function and conditional outage. However, the DOE method gives no details as how to evaluate such a situation. Thus, Trident has considered this system as a single series element.
3. The torus-to-drywell vacuum breakers have been considered in the loss-of-function category since they were a source of concern to the units and were considered to be a potential improvement project. And, indeed, if more than three of the breakers fail, the unit is required to shut down. As described above, such an outage is actually a loss-of-function and a conditional outage. Trident has chosen to consider this system in the loss-of-function category.

4.4.2 Verification of Equivalent Availability Equations

Tables 4.14 and 4.15 shows the unavailability coefficients and equivalent availability for Quad Cities for each of the nine data base periods. The actual U_F was computed by the equation

$$U_{F \text{ actual}} = \sum_{i=1}^{N_f} \frac{\text{Megawatt hours lost by loss of function outage}}{(T) (MDC)} \quad (4.7)$$

where

N_f = number of loss of function outages

TABLE 4.14
QUAD CITIES 2

UNAVAILABILITY COEFFICIENTS AND EQUIVALENT AVAILABILITY

Calendar Period	U_P	U_C	U_F Actual	EA
1973	.039	.071	.118	.772
1974	.077	.047	.179	.697
1975	.381	.038	.231	.350
1976	.194	.058	.083	.665
1977	.040	.063	.146	.751
1973-74	.060	.058	.152	.730
1973-75	.174	.051	.180	.595
1973-76	.180	.053	.154	.613
1973-77	.151	.055	.153	.641

TABLE 4.15
QUAD CITIES 1

UNAVAILABILITY COEFFICIENTS AND EQUIVALENT AVAILABILITY

Calendar Period	U_P	U_C	U_F Actual	EA
1973	.033	.174	.094	.699
1974	.332	.063	.082	.523
1975	.084	.051	.206	.659
1976	.206	.066	.218	.511
1977	.140	.162	.100	.599
1973-74	.195	.114	.087	.604
1973-75	.156	.092	.129	.623
1973-76	.169	.085	.152	.594
1973-77	.168	.081	.141	.610

Tables 4.16 and 4.17 give the comparison of actual U_F and the U_F computed by using the equations of Table 4.13 and the results of the data analysis in Tables 4.8.1 - 4.8.24 and Tables 4.11.1 - 4.11.21. For Quad Cities 2, all elements were first treated as being in series. From this assumption, U_F (series) was calculated. As a second computation, those elements which were in parallel were treated as such, and U_F (parallel) was calculated. As can be seen in Table 4.16, U_F (series) and U_F (actual) closely agree, as they must. This close agreement verifies that the correct equations are being used. For the parallel treatment, U_F (parallel) and U_F (actual) were fairly close, although the agreement is not as good as in the previous case. Since the series evaluation of U_F must theoretically give the same result as U_F (actual), the parallel treatment will generally not give the correct value of U_F (actual). The series and parallel coefficient are close when the number of components required for MDC, r , is equal to the number present in the unit, n , but become more divergent as $n-r$ increases. This significant deficiency in the model is discussed more fully in section 5.1.7. Based upon this realization, Trident has chosen to treat all Quad Cities 1 components as series elements. A comparison of U_F (series) and U_F (actual) in Table 4.17 shows excellent agreement, which verifies that the proper coefficients and equations are being used to analyze Quad Cities 1.

4.4.3 Equivalent Availability Predictions

As mentioned earlier, Trident has made a serious effort to determine the best method to use in predicting future equivalent availabilities. The methods employed are described below and are the results summarized in Tables 4.18 through 4.24.

The first predictive method is a simple method employed by the DOE methodology. The method assumes the value for U_F over a data base period will be the U_F value for the next year. Tables 4.18 and 4.19 summarize these results for Quad Cities.

The second technique used was a least squares fit to the $\left(\frac{em}{eM}\right)$ coefficients according to the equation:

$$\left(\frac{em}{eM}\right) = a T_0 + b \quad (4.8)$$

where

a = slope of least squares fit

b = intercept of least squares fit

T_0 = unit operational time

The slope and intercept of the least squares fit are used to project the $\left(\frac{em}{eM}\right)$ coefficient for the year to be predicted. For example, the 1976 projection was based on correlating the $\left(\frac{em}{eM}\right)$ ratios for each component for 1973-1975 with equation (4.8), while the 1977 projection was based on correlating the $\left(\frac{em}{eM}\right)$ ratios for each component for 1973-1976 with equation (4.8). Components with negative $\left(\frac{em}{eM}\right)$ projected ratios for 1976 and 1977 have been treated as having a zero value. Table 4.20 shows the coefficients found for various components at Quad Cities 2. The summation of these $\left(\frac{em}{eM}\right)$ ratios are shown later in Tables 4.23 and 4.24 to the actual values of the coefficients. (The $\frac{em}{eM}$ projection just described is termed projection 3 in Tables 4.23 and 4.24.) As Tables 4.23 and 4.24 show, this predictive method does not yield very accurate results and is not recommended. It should be noted that Trident also tried higher order fits to the $\left(\frac{em}{eM}\right)$ versus T_0 plots, without any increase in the accuracy of the projections.

The next predictive method tried for $\left(\frac{em}{eM}\right)$ was a least squares fit to the cumulative outage time (C) versus unit operational time T_0 for each component in the equipment level functional diagram. As shown in the DOE methodology,* a linear correlation of C versus T_0 given by the equation:

$$C = a_c + b_c T_0 \quad (4.9)$$

where

a_c = correlation intercept

b_c = correlation slope

yields

$$b_c = \left(\frac{em}{eM}\right)$$

* U. S. Department of Energy, Powerplant Productivity Improvement Study, Vol. III, p. 71, Feb. 1978

The results of this predictive method for Quad Cities is shown in Tables 4.21 and 4.22, under the heading of "Projection 1." The sums overall components are shown on these tables, and compared to the other predictive methods in Tables 4.23 and 4.24. As shown, this method yields the best result when the data base is limited to only a couple of years. The results of this approach for Quad Cities 2 is shown in Table 4.20. As with Wood River 5, this technique was found to yield consistently poorer results than the other methods and so was not used on Quad Cities 1.

The fourth predictive method used is very similar to the previous method except that the least squares fit of cumulative outage time (C) versus unit operational time (T_o) is theoretically forced to go through the origin, as it physically must. Again, by fitting to the equation

$$C = b_c T_o \quad (4.10)$$

the least squares slope b_c is just the desired coefficient $\left(\frac{em}{eM}\right)$. The results of this analysis for each component for Quad Cities 1 and 2 are shown in Tables 4.21 and 4.22 and compared to other predictive methods under the title "Projection 2" in Tables 4.23 and 4.24. Projection 3 shows the results obtained using equation (4.8). As shown in the tables, this predictive method seems to work best when the data base is large enough to include several years. Nevertheless, the tables show the predictive capabilities of these methods are extremely limited due to the random nature of the data.

Lastly, a trend analysis* was performed on selected components to test if the failure rate was indeed a constant. If the cumulative outage time C is assumed to be proportional to the n^{th} power of the cumulative unit operational time T_o , then

$$C = a_n T_o^n$$

Taking the logarithm of both sides yields

$$\log C = n (\log T_o) + (\log a_n)$$

* U. S. Department of Energy, Powerplant Productivity Improvement Study, Vol. III, p. 73, Feb. 1978

Performing a least squares fit on $\log C$ versus $\log T_0$ will yield a slope of n : If

$n > 1$ the failure rate is increasing with time

$n = 1$ the failure rate is constant (as assumed in the methodology)

$n < 1$ the failure rate is decreasing with time

The anti-log of the $\log C$ axis intercept represents $\left(\frac{em}{eM}\right)$ if $n=1$. The results of the analysis showed few components with values of n close to 1.

Examples of the results of the trend analysis is contained in Table 4.25.

4.4.4 Statistical and Sensitivity Analysis

The statistical analysis on the Quad Cities 2 components, which is simply a χ^2 test, is shown in Table 4.26. This table shows the upper confidence limit on the meantime-to-restore. A 90% confidence limit has been used. The large variations in these quantities for most components is quite apparent. Tables 4.27 and 4.28 give the sensitivity of the largest outage on the $\left(\frac{em}{eM}\right)$ ratios for the various components at Quad Cities. The significance of this analysis and the results are discussed in section 5.1.5.

TABLE 4.16
QUAD CITIES 2
COMPARISONS OF U_F

Calendar Period	Operational Hours T_o	Period Hours T	DOE U_F $\Sigma \left(\frac{em}{eM} \right) \frac{T_o}{T}$ (Parallel)	U_F $\Sigma \left(\frac{em}{eM} \right) \frac{T_o}{T}$ (Series)	Actual U_F
1973	6,236	7,344	.118	.118	.118
1974	7,380	8,760	.171	.179	.179
1975	4,537	8,760	.230	.231	.231
1976	7,140	8,784	.083	.083	.083
1977	7,720	8,760	.145	.146	.146
1973-74	13,616	16,104	.146	.151	.152
1973-75	18,153	24,864	.176	.179	.180
1973-76	25,293	33,648	.152	.154	.154
1973-77	33,013	42,408	.150	.154	.153

TABLE 4.17
QUAD CITIES I
COMPARISONS OF U_F

Calendar Period	Operational Hours, T_o	Period Hours, T	DOE U_F $\Sigma \left(\frac{em}{eM} \right) \frac{T_o}{T}$ (series)	U_F (actual)
1973	6,361	7,608	.093	.094
1974	5,447	8,760	.082	.082
1975	7,447	8,760	.206	.206
1976	5,713	8,784	.218	.218
1977	7,027	8,760	.100	.100
1973-74	11,808	16,368	.087	.087
1973-75	19,255	25,128	.129	.129
1973-76	24,968	33,912	.152	.152
1973-77	31,995	42,672	.141	.141

TABLE 4.18			
QUAD CITIES 2			
PREDICTIONS OF LOSS OF FUNCTION UNAVAILABILITY			
Data Base for U_F Predictions	Year Predicted	Predicted U_F EA Model	Actual U_F
1973	1974	.118	.179
1973-74	1975	.151	.231
1973-75	1976	.179	.083
1973-76	1977	.154	.146
1973-77	1978	.159	-

TABLE 4.19			
QUAD CITIES I			
PREDICTIONS OF LOSS OF FUNCTION UNAVAILABILITY			
Data Base for U_F Predictions	Year Predicted	Predicted U_F EA Model	Actual U_F
1973	1974	.094	.082
1973-74	1975	.087	.206
1973-75	1976	.129	.218
1973-76	1977	.152	.100
1973-77	1978	.141	—

TABLE 4.20

QUAD CITIES 2

LEAST SQUARES FIT TO $\left(\frac{em}{eM}\right)$ COEFFICIENTS

WITH ALL COMPONENTS IN SERIES

TASK III FIGURE 3.3 LABEL	SYSTEM/COMPONENT	1973 $\times 10^{-6}$ a	1975 $\times 10^{-6}$ b	1976 $\times 10^{-6}$ $\frac{em}{eM}$ Proj.	1973 $\times 10^{-6}$ a	1976 $\times 10^{-6}$ b	1977 $\times 10^{-6}$ $\frac{em}{eM}$ Proj.
1A (a-c)	Generator Exciter- Main Transformer Switchyard	-.0545	1270	-0-	-.0332	1040	-0-
1B (a-d)	Main Steam Isolation Valves	.260	3480	10,060	.0160	6100	6630
1B (e)	Piping and Relief Valves	-.159	3700	-0-	.113	770	4500
1B (f-i)	Control Valves	-.0196	2850	2,300	-.0378	3040	1790
1B (j)	High Pressure Turbine	-0-	-0-	-0-	.107	-1150	2390
1B (k-n)	Moisture Separator	.00690	2660	2,830	-.00595	2790	2600
1B (o-q)	Low Pressure Turbine	.0997	-430	2,090	.0346	270	1410
2A (d)	Condenser	.212	20,010	14,648	.242	20,340	14,219
2B (a)	Spray Canal	2.52	-19,920	43,850	2.05	-14,870	52,850
2D (a)	Off gas piping	-5.27	99,340	-0-	-2.80	72,780	-0-
2D (b-c)	Catalytic recombiners	.808	-3,500	16,900	.279	2,200	11,400
2E (a-d)	Condensate Pump (series)	.0394	-330	670	.0245	-170	640
2F (a-b)	Steam Jet Air Ejector (series)	-.0303	710	-0-	-.00436	430	290
2H (a-g)	Condensate Demineralizers (series)	.383	-1,720	8,100	.137	980	5,510
3A (a-i)	Low Pressure Heaters (series)	-.113	20,700	17,800	-.395	23,300	10,300
3B (a-c)	Reactor Feed Pumps (series)	-.204	47,300	-0-	-.139	4,030	-0-
3B (d)	Reactor Feed System Piping	2.27	-15,400	42,000	1.15	-3,600	34,500
3C (a-b)	Feedwater Regulating Valves (series)	1.32	-6,670	26,700	.840	-1,760	26,000
3E (a-b)	Feedwater Spargers	1.47	-6,400	30,970	.510	4,000	20,850
4A (h)	Piping and Flanges for CRD hydraulic system	-0-	-0-	-0-	.177	-1,900	3,930
4B (a)	Reactor	3.53	-29,000	60,280	2.20	-14,630	57,890
4C (a-b)	Reactor Recirculation pumps	-.0678	17,739	16,020	-.316	20,410	9,970
4D (i)	Reactor Water Cleanup System Valve Valves	.428	-1,910	8,910	.145	1,130	5,920
4E (a-d)	Residual Heat Removal Pumps	.0513	-220	1,070	.0175	140	720

TABLE 4.21

QUAD CITIES 2

(cm)
(cm) PROJECTED BY LEAST SQUARES FIT

System/Component	1974		1975			1976			1977			1978	
	Proj. 2	Actual	Proj. 1	Proj. 2	Actual	Proj. 1	Proj. 2	Actual	Proj. 1	Proj. 2	Actual	Proj. 1	Proj. 2
Generator-Exciter-Main transformer	.00096	-0-	-0-	.00053	-0-	-0-	.00041	.00031	.00011	.00036	.09254	.02304	.01064
MSIV strings	.00443	.01245	.01245	.00802	.00212	.00890	.00748	-0-	.00518	.00621	-0-	.00321	.00521
Main steam line -- Piping, relief valves	.00279	-0-	-0-	.00154	-0-	-0-	.00119	.01592	.00561	.00333	.00740	.00709	.00446
Control Valves	.00257	.00333	.00333	.00291	-0-	.00219	.00251	.00133	.00170	.00223	-0-	.00119	.00189
High pressure turbine	-0-	-0-	-0-	-0-	-0-	-0-	-0-	.00770	.00271	.00117	-0-	.00254	.00140
Moisture separator	.00319	-0-	-0-	.00176	.00994	.00342	.00284	-0-	.00277	.00270	-0-	.00197	.00235
Low pressure turbine	-0-	.00263	.00263	.00118	-0-	.00172	.00111	-0-	.00097	.00093	-0-	.00059	.00077
Condenser	.01924	.01263	.01263	.01628	.02130	.01562	.01675	.00626	.01281	.01529	.00348	.00998	.01351
Spray Canal	-0-	.00622	.00622	.00279	.12065	.04557	.02058	.03849	.04951	.02794	.02890	.04514	.03039
Off-gas piping	.06559	-0-	-0-	.03620	-0-	-0-	.02807	-0-	-0-	.02169	-0-	-0-	.01725
Catalytic recombiners	-0-	.02130	.02130	.00954	-0-	.01398	.00902	-0-	.00786	.00752	-0-	.00478	.00620
Condensate pumps	-0-	-0-	-0-	-0-	.00208	.00072	.00031	-0-	.00058	.00035	-0-	.00041	.00032
SJAE	.00055	-0-	-0-	.00030	-0-	-0-	.00023	.00121	.00042	.00036	-0-	.00040	.00036
Condensate demineralizers	-0-	.00999	.00999	.00447	.00052	.00673	.00430	-0-	.00382	.00361	.00151	.00272	.00315
Low pressure heaters	.01878	.02502	.02503	.02158	-0-	.01642	.01863	.00049	.00940	.01511	.00253	.00641	.01260
Reactor feed pumps	.00358	-0-	-0-	.00197	-0-	-0-	.00153	-0-	-0-	.00118	-0-	-0-	.00094
Feedwater piping	-0-	.02367	.02367	.01061	.07093	.03994	.02058	-0-	.02852	.02007	-0-	.01985	.01767
Feedwater regulating valve	.00128	.02085	.02085	.01005	.03212	.02473	.01415	.01721	.02271	.01569	.02874	.02383	.01763
Feedwater spargers	-0-	.03896	.03896	.01745	-0-	.02556	.01649	-0-	.01437	.01375	-0-	.00875	.01134
CRD Hydraulic system	-0-	-0-	-0-	-0-	-0-	-0-	-0-	.01269	.00447	.00192	-0-	.00419	.00231
Reactor	-0-	.00152	.00152	.00068	.18318	.06400	.02788	-0-	.05165	.03079	-0-	.03658	.02827
Recirculation pumps	.01642	.02150	.02149	.01869	.00269	.01502	.01652	.00067	.00891	.01356	.00005	.00559	.01111
Reactor clean-up system valves	-0-	.01091	.01091	.00489	-0-	.00716	.00462	-0-	.00402	.00385	-0-	.00245	.00318
Residual heat removal pumps	-0-	.00134	.00134	.00060	-0-	.00088	.00057	-0-	.00049	.00047	-0-	.00030	.00039
Total	.13938	.212	.21432	.17204	.44547	.29256	.21577	.102	.23859	.21008	.16515	.21051	.20324

TABLE 4.22

QUAD CITIES I

 $\left(\frac{\text{cm}}{\text{ft}}\right)$
 PROJECTED BY LEAST SQUARES FIT

System/Component	1974		1975			1976			1977			1978	
	Proj. 2	Actual	Proj. 1	Proj. 2	Actual	Proj. 1	Proj. 2	Actual	Proj. 1	Proj. 2	Actual	Proj. 1	Proj. 2
Electrohydraulic Control System	.00626	.00683	.00683	.00646	-0-	.00271	.00480	.00347	.00263	.00431	.00095	.00025	.00381
Vacuum breaker	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	.00844	.00187	.00085
Instrument air dryer	.00393	-0-	-0-	.00219	-0-	-0-	.00170	-0-	-0-	.00132	.00111	.00025	.00116
Generator	-0-	-0-	.00246	-0-	.00246	.00147	.00059	.09496	.02649	.01206	.00743	.02756	.01513
Electrical distribution system	-0-	-0-	-0-	-0-	.00093	.00056	.00022	-0-	.00045	.00025	-0-	.00032	.00023
MSIV strings	.00006	.00441	.0041	.00147	-0-	.00175	.00139	-0-	.00110	.00116	-0-	.00072	.00096
Main steam line piping	-0-	.01329	.01329	.00434	.00603	.00892	.00557	.05345	.02049	.01148	-0-	.01840	.01209
Control Valve	.01207	.00554	.00554	.00854	-0-	.00220	.00695	-0-	.00139	.00549	.00323	.00162	.00474
High pressure turbine	-0-	-0-	-0-	-0-	-0-	-0-	-0-	.00756	.00202	.00091	.01032	.00429	.00214
Moisture separator	.00707	.02482	.02482	.01342	-0-	.00986	.01069	.00159	.00664	.00904	.00226	.00499	.00781
Condenser	-0-	.03326	.03325	.01085	.05548	.04665	.02370	.00959	.03782	.02474	.01289	.03085	.02383
Spray Canal	-0-	.00293	.00293	.00105	.03816	.02414	.01083	.09196	.04352	.02257	.04462	.04742	.02839
Off-gas piping	.04606	-0-	-0-	.02569	-0-	-0-	.01996	-0-	-0-	.01546	-0-	-0-	.01231
Condensate pump	.00302	-0-	-0-	.00168	-0-	-0-	.00131	.00018	.00005	.00103	.00021	.00009	.00085
SJAE	-0-	.00984	.00986	.00322	.00403	.00633	.00402	-0-	.00440	.00365	-0-	.00302	.00310
Condensate demineralizer	-0-	.00018	.00017	.00005	.00274	.00172	.00071	.00145	.00175	.00095	.00084	.00156	.00101
Feedwater heaters	.01341	.02661	.02660	.01616	-0-	.01057	.01405	.00142	.00704	.01155	-0-	.00473	.00948
Reactor feed pump	.00094	-0-	-0-	.00053	.00352	.00212	.00126	-0-	.00170	.00126	.00672	.00273	.00180
Feedwater piping	-0-	-0-	-0-	-0-	-0-	-0-	-0-	.04863	.01296	.00584	-0-	.01283	.00705
Feedwater regulator valves	.00377	.00413	.00413	.00390	-0-	.00164	.00290	.02066	.00654	.00486	-0-	.00613	.00499
Reactor recirculation pumps	.01493	.00002	.00002	.00834	.12857	.07748	.03754	.00025	.06217	.03964	.02555	.05081	.03849
Total	.17916	.13186	.13186	.10789	.24192	.19813	.14819	.33517	.23916	.17755	.12457	.22244	.18022

TABLE 4.23

QUAD CITIES 2

COMPARISON OF PROJECTION METHODS

Data Base for $\left(\frac{em}{eM}\right)$ Predictions	Year Predicted	$C = a_c + b_c T_o$ Projection 1		$C = b_c T_o$ Projection 2		$\left(\frac{em}{eM}\right) = a T_o + b$ Projection 3		Actual $\left(\frac{em}{eM}\right)$
		$\left(\frac{em}{eM}\right)$	% error	$\left(\frac{em}{eM}\right)$	% error	$\left(\frac{em}{eM}\right)$	% error	
1973	1974 /	-0-	-0-	.14948	45%	-0-	-0-	.212
1973-74	1975	.21232	52%	.17204	61%	-0-	-0-	.445
1973-75	1976	.29256	187%	.21577	112%	.30520	199%	.102
1973-76	1977	.23859	44%	.21008	27%	.27431	66%	.165
1973-77	1978	.21051	---	.20324	---	---	---	---

TABLE 4.24

QUAD CITIES 1

COMPARISON OF PROJECTION METHODS

Data Base for $\left(\frac{em}{eM}\right)$ Predictions	Year Predicted	Projection 1		Projection 2		Projection 3		Actual $\left(\frac{em}{eM}\right)$
		$\left(\frac{em}{eM}\right)$	% error	$\left(\frac{em}{eM}\right)$	% error	$\left(\frac{em}{eM}\right)$	% error	
1973	1974	-0-	-0-	.17916	35.9%	-0-	-0-	.13186
1973-74	1975	.13186	45%	.10789	55.4%	-0-	-0-	.24192
1973-75	1976	.19813	41%	.14819	55.8%	-0-	-0-	.33512
1973-76	1977	.23916	92%	.17755	42.5%	-0-	-0-	.12460
1973-77	1978	.2224	-0-	.18022	-0-	-0-	-0-	-0-

TABLE 4.25
TREND ANALYSIS

QUAD CITIES 2		QUAD CITIES 1	
Component	n	Component	n
Feedwater Regulating Valve	2.64	Feedwater Regulating Valve	1.22
Moisture Separator	.848	Moisture Separator	.8555
Condenser	.729	Electrohydraulic Control	.555

TABLE 4.26

QUAD CITIES 2

 χ^2 TEST FOR COMPONENTS
(90% CONFIDENCE LIMIT)

Component Identifier	SYSTEM/COMPONENT	1973-1977 M_1 Hours	1973-1977 M_{1L} Hours	1973-1977 m_1 Hours	1973-1977 m_{1U} Hours
1A (a-c)	Generator Exciter				
	Main Transformer	4,716	2,805	103.2	185.5
1B (a-d)	Main Steam Isolation Valves	5,502	3,135	21.5	41.0
1B (e)	Piping and Relief Valves	6,603	3,560	37.7	77.4
1B (f-i)	Control Valves	8,253	4,130	12.5	28.7
1B (j)	High Pressure Turbine	33,013	8,488	55.0	521.3
1B (k-n)	Moisture Separator	6,603	3,560	13.0	26.7
1B (o-q)	Low Pressure Turbine	33,013	8,488	19.4	183.9
2A (d)	Condenser	1,942	1,553	25.4	37.3
2B (a)	Spray Canal	846	684	28.0	35.0
2D (a)	Off Gas Piping	16,506	6,203	204.5	768.8
2D (b-c)	Catalytic Recombiners	33,013	8,488	157.2	1490.0
2E (a-d)	Condensate Pump (Series)	33,013	8,488	9.5	89.7
2F (a-b)	Steam Jet Air Ejector (Series)	8,253	4,130	3.0	6.9
2H (a-g)	Condensate Demineralizers (Series)	3,668	2,324	9.8	16.2
3A (a-i)	Low Pressure Heaters (Series)	4,716	2,805	46.4	69.8
3B (a-c)	Reactor Feed Pumps (Series)	16,507	6,203	11.2	42.1
3B (d)	Reactor Feed System Piping	6,603	3,560	99.3	204.1
3C (a-b)	Feedwater Regulating Valves (Series)	1,173	1,572	31.1	42.6
3E (a-b)	Feedwater Spargers	33,013	8,488	287.5	2725.0
4A (h)	Piping and Flanges for CRD Hydraulic system	33,013	8,488	90.6	858.8
4B (a)	Reactor	16,506	6,202	421.2	3991.9
4C (a-b)	Reactor Recirculation Pumps	1,942	1,401	16.4	23.4
4D (i)	Reactor Water Cleanup System Valves	16,506	6,203	40.3	151.3
4E (a-d)	Residual Heat Removal Pumps	33,013	8,488	9.9	93.8

TABLE 4.27

QUAD CITIES 2
SENSITIVITY OF $\left(\frac{em}{eM}\right)$ RATIO TO
LARGEST OUTAGE

Component Identifier	SYSTEM/COMPONENT	1973-1977 All Outages	1973-1977 Without Largest Outage	Percentage Difference
1A (a-c)	Generator Exciter Main Transformer - Electrical Distribution System	.02189	.01150	47.5
1B (a-d)	Main Steam Isolation Valves	.00391	.00222	43.2
1B (e)	Piping and Relief Valves	.00570	.00397	30.4
1B (f-i)	Control Valves	.00152	.00084	44.7
1B (j)	High Pressure Turbine	.00167	-0-	100.0
1B (k-n)	Moisture Separator	.00197	.00103	47.7
1B (o-q)	Low Pressure Turbine	.00059	-0-	100.0
2A (d)	Condenser	.01309	.00588	55.1
2B (a)	Spray Canal	.03305	.02102	36.4
2D (a)	Off-Gas Piping	.01239	.00003	99.8
2D (b-c)	Catalytic Recombiners	.00476	-0-	100.0
2E (a-d)	Condensate Pump (series)	.00029	-0-	100.0
2F (a-b)	Steam Jet Air Ejector (Series)	.00036	.00014	61.1
2H (a-g)	Condensate Demineralizers (Series)	.00266	.00163	38.7
3A (a-i)	Low Pressure Heaters (Series)	.00984	.00119	87.9
3B (a-c)	Reactor Feed Pumps (Series)	.00068	.00007	89.7
3B (d)	Reactor Feed System Piping	.01504	.00851	43.4
3C (a-b)	Feedwater Regulating Valves (Series)	.01978	.01537	22.3
3E (a-b)	Feedwater Spargers	.00871	-0-	100.0
4A (h)	Piping and Flanges for CRD Hydraulic system	.00274	-0-	100.0
4B (a)	Reactor	.02551	.00034	98.7
4C (a-b)	Reactor Recirculation pumps	.00843	.00625	25.9
4D (i)	Reactor Water Cleanup System Valves	.00244	.00020	91.8
4E (a-d)	Residual Heat Removal Pumps	.00030	-0-	100.0

TABLE 4.28
QUAD CITIES 1
SENSITIVITY OF $\left(\frac{em}{eM}\right)$ RATIO TO
LARGEST OUTAGE

Component Identifier	System/Component	1973-1977 All Outages	1973-1977 Without Largest Outage	Percentage Difference
1A (a)	Generator	.01916	.00257	86.6
1A (c)	Electrical Distribution System	.00022	-0-	100.0
1B (a-d)	MSIV Strings	.00076	.00012	84.2
1B (e)	Main Steam Line - Piping	.01321	.00756	42.7
1B (f-i)	Turbine Control Valve	.00405	.00180	55.6
1B (j)	High Pressure Turbine	.00363	.00277	23.7
1B (k-n)	Moisture Separator	.00641	.00320	59.6
1B (r)	Electrohydraulic Control	.00323	.00277	13.5

2A (a)	Condenser	.02362	.01327	43.8
2B (a)	Spray Canal	.03507	.02607	24.9
2D (a)	Off-Gas Piping	.00916	-0-	100.0
2E (a-d)	Condensate Pump	.00068	.00008	88.2
2F (a-b)	Steam Jet Air Ejector	.00262	.00192	26.7
2H (a-g)	Condensate Demineralizers	.00111	.00066	40.5

3A (a-i)	Feedwater Heaters	.00747	.00568	24.0
3B (a-c)	Reactor Feed Pump	.00249	.00161	35.3
3B (d)	Feedwater Piping	.00868	-0-	100.0
3C (a-b)	Feedwater Regulator Valves	.00514	.00263	51.8

4B (b)	Vacuum Breaker	.00185	-0-	100.0
4C (a-b)	Reactor Recirculation Pump	.03856	.00880	77.2

5B	Instrument Air	.00103	.00024	76.7

4.5 IMPROVEMENT PROJECT EVALUATION - QUAD CITIES 2

Improvement projects for Quad Cities 2 are evaluated in this part of the report. The three improvement projects evaluated are:

- Modification of feedwater regulating valves;
- Installation of Amertap system;
- Installation of cooling towers.

Trident evaluated these improvement projects using the following assumptions concerning Quad Cities 2 outages after the projects have been implemented:

- (1) No change in the Quad Cities 2 conditional full outage rate from that in the 1973-77 period. Quad Cities 2 is changing from 7x7 fuel assemblies to 8x8 fuel assemblies. These 8x8 assemblies will reduce the megawatt hours lost due to fuel preconditioning. However, this change affects only conditional partial outages and consequently the conditional full outages rate should not be affected by this change.
- (2) No change in the Quad Cities 2 loss of function outage rate from that in the 1973-77 period except as affected by the improvement project.

Thus, assumptions (1) and (2) imply from equation (1.33) that the future availability of Quad Cities 2 can be evaluated as

$$\left(\frac{T_o}{T}\right)_{\text{future}} = \left(\frac{T_o}{T}\right)_{\text{historical}} - \left(\frac{\Delta T_P}{T}\right) \quad (4.11)$$

where

$$\left(\frac{T_o}{T}\right)_{\text{future}} = \text{Quad Cities 2 availability after improvement project implemented}$$

$$\left(\frac{T_o}{T}\right)_{\text{historical}} = \text{Quad Cities 2 availability from 1973-77}$$

$$\left(\frac{\Delta T_P}{T} \right) = \text{Future change in administrative unavailability from that in 1973-77 period due to full outages}$$

Trident evaluated $\left(\frac{\Delta T_P}{T} \right)$ by considering the effect of the torus modification as required by Nuclear Regulatory Commission, since this modification will significantly affect the Quad Cities 2 planned outage unavailability.

From discussions with Quad Cities personnel, the complete torus modification may require 19 weeks of additional planned outage time. Since the remaining lifetime of Quad Cities 2 is 35 years, Trident estimates the future change in administrative unavailability averaged over the remaining life of Quad Cities 2 to be given by

$$\left(\frac{\Delta T_P}{T} \right) = \frac{19/52}{35} = .014 \quad (4.12)$$

For Quad Cities between 1973-77

$$T_O = 33013 \text{ hours operation time} \quad (4.13)$$

$$T = 42408 \text{ hours period time} \quad (4.14)$$

Putting equations (4.12), (4.13), and (4.14) into equation (4.11) gives

$$\left(\frac{T_O}{T} \right)_{\text{future}} = .764 \quad (4.15)$$

Equation (4.15) is used by Trident in equation (1.26) when evaluating the ΔEA from each improvement project at Quad Cities 2.

4.5.1 Modification of Feedwater Regulating Valves

Boiling water reactors need good feedwater control in order to maintain reactor vessel water levels within narrow limits. The feedwater regulating valves installed in Quad Cities have a short stroke (2") as well as produce high turbulence which results in poor flow regulation. Consequently, many

reactor scrams have occurred at Quad Cities 2 due to the feedwater regulating valves. Better flow control could be obtained if the feedwater regulating valves were replaced with drag valves having a longer stroke. Drag valves are composed of a series of discs and orifices, which produce smooth flow characteristics.

Thus, this improvement project involves an evaluation of the change in equivalent availability if the feedwater regulating valves on Quad Cities 2 were replaced with drag valves.

Figure 4.4 shows the cumulative equivalent outage time (C) versus operational time. A least squares fit to equations with the data plotted in Figure 4.8 has produced the following correlation coefficients for (C):

$$a_c = -146.97 \quad (4.16)$$

$$b_c = 2.383 \times 10^{-2} \quad (4.17)$$

Putting equation (4.17) into equation (1.29) gives

$$\left(\frac{em}{eM}\right)_{\text{baseline}} = b_c = .02383 \quad (4.18)$$

Trident evaluated $\left(\frac{em}{eM}\right)$ after the implementation of improvement projects by dividing it into two parts as follows:

$$\left(\frac{em}{eM}\right) = \left(\frac{em}{eM}\right)_I + \left(\frac{em}{eM}\right)_{II} \quad (4.19)$$

where

$$\left(\frac{em}{eM}\right)_I \text{ is due to historical outages on feedwater regulating valves not affected by drag valve installation}$$

$$\left(\frac{em}{eM}\right)_{II} \text{ is due to outages caused by drag valve}$$

Table 4.29 shows four feedwater regulating valve outages that occurred at Quad Cities 2 between 1973-77 that would still have occurred even if a drag valve had been installed. Tables 4.29 and 4.30 were developed by reviewing

Figure 4.4 Least Squares Fit to Cumulative Equivalent Outage Time Versus Operational Time for Feedwater Regulating Valves at Quad Cities 2

TABLE 4.29

FEEDWATER REGULATING VALVE OUTAGES
NOT AFFECTED BY DRAG VALVE
QUAD CITIES 2
(1973 - 1977)

Date	Outage MW Hours Lost	Full (F) or Partial (P)
12/3/76	75,130	F
5/24/77	4,440	P
6/13/77	8,570	F
9/21/77	8,304	P

TABLE 4.30

FEEDWATER REGULATING VALVE OUTAGES
POTENTIALLY REMOVED BY DRAG VALVE

QUAD CITIES 2

(1973 - 1977)

Date	Outage MW Hours Lost	Full (F) or Partial (P)
6/7/73	6,472	F
6/2/74	3,661	F
8/31/74	124,384	F
8/31/75	113,984	F
12/24/75	7,238	F
6/29/76	4,313	P
6/30/76	8,784	P
11/8/76	6,074	F
12/11/76	7,904	F
3/23/77	8,902	F
8/26/77	5,990	F
9/22/77	81,536	F
11/13/77	10,650	F
11/14/77	6,323	F
11/15/77	26,280	P
11/28/77	15,000	P
11/28/77	8,570	F

feedwater regulating valve outages (Table 4.11.18) with Quad Cities personnel. Table 4.30 shows 17 feedwater regulating valve outages at Quad Cities 2 potentially eliminated by installation of the drag valve.

Using the data only in Table 4.29, Trident evaluated $\left(\frac{em}{eM}\right)_I$ as:

$$\left(\frac{em}{eM}\right)_I = .00351 \quad (4.20)$$

where

$$em_I = \frac{\sum_{i=1}^4 \text{megawatt hours lost in outages in Table 4.29}}{(4) (832)} \quad (4.21)$$

$$eM_I = \frac{\text{Quad Cities 2 operating time, 1973-77}}{4} \quad (4.22)$$

The Quad Cities 2 operating time for 1973-77 was 33013 hours.

Trident evaluated $\left(\frac{em}{eM}\right)_{II}$ in the following manner. First, Trident assumed if an outage occurred on the drag valve the equivalent meantime-to-restore (em_{II}) would be same as that of outages in 1973-77, which would have been potentially removed by the drag valves. These outages are given in Table 4.30. Thus,

$$em_{II} = \frac{\sum_{i=1}^{17} \text{megawatt hours lost in outages in Table 4.30}}{17 (832)} \quad (4.23)$$

Evaluation of equation (4.23) gives

$$em_{II} = 31.5 \text{ hours} \quad (4.24)$$

Putting equations (4.15), (4.18), (4.20), and (4.24) into equations (1.26) and (1.27) gives the change in equivalent availability for the improvement project as

$$\Delta EA = \left[.02383 - .00351 - \frac{31.5}{eM_{II}} \right] (.764) \quad (4.25)$$

Equation (4.25) relates the ΔEA versus the equivalent meantime-to-outage of the drag valve. Figure 4.5 shows equation (4.25) plotted and thus gives

Figure 4.5 Change in Equivalent Availability Versus Equivalent Meantime-to-Outage of Drag Valve at Quad Cities 2

the ΔEA for varying equivalent meantime-to-outage of the drag valve. The maximum ΔEA that could be obtained from this improvement would occur if the drag valve never caused an outage ($eM_{II} \rightarrow \infty$). In this limiting case, equation (4.25) gives the following result:

$$\lim_{eM \rightarrow \infty} \Delta EA = .0155 \quad (4.26)$$

Quad Cities personnel felt that it is realistic to assume a very large equivalent meantime-to-outage of the drag valve. This is evidenced by the fact that no outages or reactor scrams have occurred at Quad Cities 2 that are attributable to the drag valve, since one was installed in early 1978.

4.5.2 Install Amertap System

Fouling of the condenser at Quad Cities 2 has resulted in numerous deratings of the unit. The megawatt hours lost due to fouling are given in Table 4.8.8. The fouling is due to scale buildup on the inside of the condenser tubes. There are a number of methods available to reduce condenser fouling. One method is to install an Amertap system. The Amertap system involves circulating sponge balls through the condenser tubes. In addition, the sponge balls can be specially coated to enhance their cleaning effectiveness. Thus, the improvement project involves the evaluation of the ΔEA at Quad Cities 2, if condenser fouling is reduced by the installation of an Amertap system.

Figure 4.6 shows the equivalent cumulative outage time versus operational time for the condenser at Quad Cities 2. A least squares fit of the data plotted in Figure 4.6 to equation (1.28) yields the following correlation coefficients:

$$a_c = 83.63 \quad (4.27)$$

$$b_c = 9.975 \times 10^{-3} \quad (4.28)$$

Putting equation (4.28) into equation (1.29) gives

$$\left(\frac{em}{eM} \right)_{\text{baseline}} = .00997 \quad (4.29)$$

Figure 4.6 Least Squares Fit to Cumulative Equivalent Outage Time Versus Operational Time for Condenser at Quad Cities 2

TABLE 4.31

CONDENSER OUTAGES NOT CAUSED BY FOULING
QUAD CITIES 2
(1973 - 1977)

Date	Outage MW Hours Lost	Full (F) or Partial (P)
5/11/73	97,080	F
4/28/75	39,354	F

While Amertap systems can have short meantime-to-outage, they can be repaired with the unit on line. Also, when the Amertap system is removed from service, there will be no immediate drop in unit capacity. Thus, in this case $em_{II} = 0$ and consequently

$$\left(\frac{em}{eM}\right)_{II} = 0 \quad (4.35)$$

Putting equation (4.35) into (4.34) gives

$$\lim_{em_{II} \rightarrow 0} \Delta EA = .00374 \quad (4.36)$$

Trident has also evaluated the ΔEA for varying em_{II} and eM_{II} of the Amertap system. This analysis is shown in Figure 4.7. The value of $em_{II} = 25.4$ hours has been plotted in Figure 4.7 since it is the em for 1973-1977 condenser outages at Quad Cities 2. In addition, Figure 4.7 shows ΔEA for $em_{II} = 12.7$, 30, and 50 hours.

4.5.3 Installation of Cooling Towers

Cooling of the Quad Cities plant is provided by a spray canal. However, Quad Cities 2 has suffered numerous deratings due to poor performance of this spray canal. Table 4.8.9 lists the numerous outages associated with the spray canal. Direct Mississippi River water cooling would eliminate this restriction; however, this currently is not environmentally allowable except in emergency situations. Alternately cooling towers could be installed to provide additional cooling.

Thus, this improvement project involves an evaluation in the change in equivalent availability if cooling towers are installed with sufficient capacity to eliminate Quad Cities 2 deratings due to poor spray canal performance.

Figure 4.8 shows the cumulative equivalent outage time (C) versus operational time for the spray canal. A least squares fit to equation (1.28) with the data plotted in Figure 4.8 has produced the following correlation coefficients for (C):

$$a_c = -349.3 \quad (4.37)$$

$$b_c = 4.511 \times 10^{-2} \quad (4.38)$$

Thus, putting equation (4.38) into equation (1.29) gives

$$\left(\frac{em}{eM}\right)_{\text{baseline}} = .04511 \quad (4.39)$$

The $\left(\frac{em}{eM}\right)$ ratio with the improvement is evaluated similarly to the other two improvement projects. Thus $\left(\frac{em}{eM}\right)$ is divided into two parts as follow:

$$\left(\frac{em}{eM}\right) = \left(\frac{em}{eM}\right)_I + \left(\frac{em}{eM}\right)_{II} \quad (4.40)$$

where

$\left(\frac{em}{eM}\right)_I$ is due to historical outages on spray canal between 1973-77 not related to spray canal cooling

$\left(\frac{em}{eM}\right)_{II}$ is due to outages caused by failure of cooling tower

Table 4.32 shows five spray canal outages not related to spray canal cooling performance at Quad Cities 2 between 1973-77. This table was constructed by reviewing Table 4.8.9. From Table 4.32, $\left(\frac{em}{eM}\right)_I$ is calculated as:

$$\left(\frac{em}{eM}\right)_I = .00362 \quad (4.41)$$

where em_I and eM_I are evaluated as:

$$em_I = \frac{\sum_{i=1}^5 \text{megawatt hours lost in outage in Table 4.32}}{5 \text{ (832)}} \quad (4.42)$$

$$eM_I = \frac{\text{Quad Cities 2 operating time, 1973-77}}{5} \quad (4.43)$$

The 1973-77 Quad Cities 2 operating time is 33013 hours.

Figure 4.7 Change in Equivalent Availability Versus Equivalent Meantime-to-Outage for Amertap System at Quad Cities 2 with $em_{II} = 12.7, 25.4, 30, \text{ and } 50$ Hours

Figure 4.8 Least Squares Fit to Cumulative Equivalent Outage Time Versus Operational Time for Spray Canal at Quad Cities 2

TABLE 4.32

OUTAGES NOT CAUSED BY
TEMPERATURE LIMITATION DERATING
QUAD CITIES 2
(1973 - 1977)

Date	Outage MW Hours Lost	Full (F) or Partial (P)
6/14/76	28,680	P
8/16/76	9,216	P
7/21/77	2,808	P
9/7/77	4,368	P
11/6/77	54,246	F

The $\left(\frac{em}{eM}\right)$ ratio with the improvement is evaluated similarly to the feed-water regulating valve improvement. Thus, $\left(\frac{em}{eM}\right)$ ratio is divided into two parts as follows:

$$\left(\frac{em}{eM}\right) = \left(\frac{em}{eM}\right)_I + \left(\frac{em}{eM}\right)_{II} \quad (4.30)$$

where

$\left(\frac{em}{eM}\right)_I$ is due to historical outages on condenser between 1973-77 not related to condenser fouling

$\left(\frac{em}{eM}\right)_{II}$ is due to outages caused by failure of Amertap system

Table 4.31 shows two condenser outages not related to fouling at Quad Cities 2 between 1973-77. This table was constructed by reviewing Table 4.8.8. From Table 4.31 $\left(\frac{em}{eM}\right)_I$ is calculated as:

$$\left(\frac{em}{eM}\right)_I = .00507 \quad (4.31)$$

where em_I and eM_I are evaluated as:

$$em_I = \frac{\frac{97080}{809} + \frac{39354}{832}}{2} \quad (4.32)$$

$$eM_I = \frac{\text{Quad Cities 2 operating time, 1973-77}}{2} \quad (4.33)$$

em_I has been evaluated in equation (4.31) using a MDC of Quad Cities 2 of 809 MW up to April 30, 1974 and 832 MW after this date. The 1973-77 Quad Cities 2 operating time is 33013 hours.

Putting equation (4.15), (4.29), and (4.31) into equations (1.26) and (1.27) give the ΔEA for the improvement as

$$\Delta EA = \left[.00997 - .00507 - \left(\frac{em}{eM}\right)_{II} \right] (.764) \quad (4.34)$$

Putting equations (4.15), (4.39), and (4.41) into equations (1.26) and (1.27) give the ΔEA for the improvement as

$$\Delta EA = \left[.0451 - .00362 - \left(\frac{em}{eM} \right)_{II} \right] (.764) \quad (4.44)$$

Equation (4.44) relates the ΔEA to the (em/eM) ratio due to outages caused by failure of the cooling tower. The maximum ΔEA from this improvement project is found when

$$\left(\frac{em}{eM} \right)_{II} = 0 \quad (4.45)$$

In this case, the ΔEA is found by putting equation (4.45) into (4.44) which gives

$$\lim_{\left(\frac{em}{eM} \right)_{II} \rightarrow 0} \Delta EA = .0317 \quad (4.46)$$

Physically, equation (4.46) implies failure of the cooling tower would result in no reduction in Quad Cities 2 capacity. Deratings could occur with a cooling tower at Quad Cities if the return water temperature to the circulating and service water systems is 95°F or greater or if the return water temperature to the circulating water system is greater than the temperature of the Mississippi River. However no deratings would occur if the additional required cooling could be handled by either the spray canal or the Mississippi River while the cooling tower is out of service.

Figure 4.9 shows the ΔEA for various $\left(\frac{em}{eM} \right)$ of cooling tower as given by equation (4.44). As can be seen, the ΔEA shown in Figure 4.9 is less than that given by equation (4.46).

Figure 4.9 Change in Equivalent Availability Versus $\left(\frac{em}{eM}\right)$ of Cooling Tower at Quad Cities 2

4.6 IMPROVEMENT PROJECT EVALUATION - UNIT 1

Improvement projects for Quad Cities 1 are evaluated in this section of the report. The two improvement projects evaluated are:

- * Moisture drain separator tank modification;
- * Electromatic relief valve modification.

Trident evaluated these improvement projects using the same assumptions concerning Quad Cities 1 outages as used for Quad Cities 2 outages. Thus, the future availability of Quad Cities 1 is given by:

$$\left(\frac{T_o}{T}\right)_{\text{future}} = \left(\frac{T_o}{T}\right)_{\text{historical}} - \left(\frac{\Delta T_p}{T}\right) \quad (4.47)$$

Assuming the same torus modification on Unit 1 as on Unit 2, the future change in administrative unavailability from that in the 1973-77 period due to full outages is found to be

$$\left(\frac{\Delta T_p}{T}\right) = .014 \quad (4.48)$$

For Quad Cities 1 between 1973-77

$$T_o = 31995 \text{ hours of operation time} \quad (4.49)$$

$$T = 42672 \text{ hours of period time} \quad (4.50)$$

Putting equations (4.48), (4.49), and (4.50) into equation (4.47) gives

$$\left(\frac{T_o}{T}\right)_{\text{future}} = .736 \quad (4.51)$$

Equation (4.51) is used by Trident in equation (1.26) when evaluating the ΔEA from each improvement project at Quad Cities 1.

4.6.1 Moisture Separator Drain Tank Modification

Present design of moisture drain tank has resulted in high vibration levels during reactor startup. This has caused instrumentation to fail, causing level to rise in the drain tank and to back up into the moisture separator, which results in a turbine trip. The improvement project would be to move transmitters off the drain tank and install new faster acting valves, which should eliminate the problem.

Figure 4.10 shows the cumulative equivalent outage time (C) versus operational time for moisture separator system of which the drain tank is a component. A least squares fit to equation (1.28) with the data plotted in Figure 4.10 has produced the following correlation coefficient:

$$b_c = .00499 \quad (4.52)$$

Putting equation (4.10) into equation (1.29) gives

$$\left(\frac{em}{eM}\right)_{\text{baseline}} = b_c = .00499 \quad (4.53)$$

Trident evaluated $\left(\frac{em}{eM}\right)$ after implementation of improvement projects by dividing it into two parts as follows:

$$\left(\frac{em}{eM}\right) = \left(\frac{em}{eM}\right)_I + \left(\frac{em}{eM}\right)_{II} \quad (4.54)$$

where

$\left(\frac{em}{eM}\right)_I$ is due to historical outages on moisture separator not affected by drain tank modification

$\left(\frac{em}{eM}\right)_{II}$ is due to outages caused by drain tank after modification

From Table 4.11.7 the only outage not affected by the drain tank between 1973-1977 occurred on October 13, 1974. Thus $\left(\frac{em}{eM}\right)_I$ is found as:

Figure 4.10 Least Squares Fit to Cumulative Equivalent Outage Time Versus Operational Time for Moisture Separator Drain Tank at Quad Cities 1

$$\left(\frac{em}{eM}\right)_I = \frac{\text{Megawatt hours lost in October 13, 1974 outage}}{(MDC) (T_o)} \quad (4.55)$$

where

MDC = 833 MW for Quad Cities 1

T_o = 31995 operating hours for 1973-77 time period

Evaluating equation (4.55) gives

$$\left(\frac{em}{eM}\right)_I = \frac{85549}{(833) (31995)} = .00321 \quad (4.56)$$

Trident evaluated $\left(\frac{em}{eM}\right)_{II}$ in the following manner. First, Trident assumed that if an outage occurred on the drain tank the equivalent meantime-to-restore would be the same as that of the outages in the 1973-77 period, which are potentially removed by the improvement. These six outages are shown in Table 4.11.7 (exclude the October 13, 1974 outage since it is not affected by improvement). Thus

$$em_{II} = \frac{\frac{36,000}{800} + \frac{\sum_{i=1}^5 \text{Megawatt hours lost in outages affected by improvement}}{(833)}}{6} \quad (4.57)$$

Evaluating equation (4.57) gives (4.58)

$$em_{II} = 17.1 \text{ hours}$$

em_{II} has been evaluated in two parts in equation (4.57) since the MDC of Quad Cities 1 has been taken by Trident to be 800 MW up to November 1, 1973 and 833 after this date. Thus for the outage which occurred on March 20, 1973, in Table 4.11.7 the megawatt hours lost were divided by 800. For all other outages, of which there were five, the megawatt hours lost were divided by 833, since these outages occurred after November 1, 1973.

Putting equations (4.51), (4.53), (4.56), and (4.58) into equations (1.26) and (1.27) gives

$$\Delta EA = .00499 - .00321 - \frac{17.1}{eM_{II}} \quad (.736) \quad (4.59)$$

Equation (4.59) relates the ΔEA versus the equivalent meantime-to-outage after the improvement. In the limiting case, where as a result of the improvement no future outages occurred on the moisture separator drain tank, then $eM_{II} \rightarrow \infty$. In this situation, equation (4.59) gives the following result:

$$\lim_{eM_{II} \rightarrow \infty} \Delta EA = .00131 \quad (4.60)$$

Figure 4.11 shows the ΔEA that would be obtained for various meantime-to-outages of the improvement. As can be seen, all ΔEA shown are limited by equation (4.60).

4.6.2 Modification of Electromatic Relief Valves

The present valve design has two problems. First, the locking arm has broken off or fallen off some of the valves. Second, disc retainer threads are fretting, which causes valves not to operate. Although several fixes are available, none are certain to correct the problem. Thus, the improvement project involved determining the ΔEA that could be obtained from eliminating the electromatic relief valve problem. This ΔEA will then be used by the Energy Resources Center to determine the amount of funds that Commonwealth Edison could spend to solve the problem.

The electromatic relief valves are a component of the main steam line piping. Thus, Figure 4.12 shows the cumulative equivalent outage time (C) for main steam line piping versus operational time at Quad Cities 1. A least squares fit to equation (1.28) with the data plotted in Figure 4.12 has produced the following correlation coefficient:

$$b_c = .01840 \quad (4.61)$$

Figure 4.11 Change in Equivalent Availability Versus Equivalent Meantime-To-Outage of Moisture Drain Tank Improvement at Quad Cities 1

Figure 4. 12 Least Squares Fit to Cumulative Equivalent Outage Time Versus Operational Time for Main Steam Line Piping and Relief Valves at Quad Cities 1

Putting equation (4.61) into equation (1.29) gives

$$\left(\frac{em}{eM}\right)_{\text{baseline}} = b_c = .01840 \quad (4.62)$$

Trident evaluated $\left(\frac{em}{eM}\right)$ after implementation of the improvement project by considering the main steam line piping outages (Table 4.11.6) at Quad Cities 1 between 1973-77 that still would have occurred even if the electromatics did not cause an outage. Those outages not related to the electromatics are shown in Table 4.33.

Using the data in Table 4.33, Trident evaluated $\left(\frac{em}{eM}\right)$ as

$$\left(\frac{em}{eM}\right) = \frac{\sum_{i=1}^3 \text{Megawatt hours lost in outages in Table 4.33}}{(T_o) \text{ MDC}} \quad (4.63)$$

where

MDC = 833 MW for Quad Cities 1

T_o = 31995 operating hours for 1973-77 period

Evaluating equation (4.63) gives

$$\left(\frac{em}{eM}\right) = \frac{97712}{(833)(31995)} = .00367 \quad (4.64)$$

Putting equations (4.51), (4.62), (4.64), into equations (1.26) and (1.27) gives

$$\Delta EA = \left[(.01840 - .00367) \right] (.736) \quad (4.65)$$

Evaluating equation (4.65) gives

$$\Delta EA = .0108 \quad (4.66)$$

Equation (4.66) gives the ΔEA that could be obtained if the outages associated with the electromatics were eliminated.

TABLE 4.33
OUTAGES NOT RELATED TO
ELECTROMATICS IN MAIN STEAM LINE PIPING
QUAD CITIES 1
1973-77

Date	Outage MW Hours Lost	Full (F) or Partial (P)
11/4/74	4,332	F
12/13/74	55,978	F
8/19/75	37,402	F

5.0 CRITIQUE OF DEPARTMENT OF ENERGY METHODOLOGY

As part of the power plant productivity improvement study, Trident was to critique the Department of Energy methodology. In section 5.1, Trident discusses problems encountered in applying the methodology. In section 5.2, Trident shows that there are certain facets of the methodology which could be simplified. Finally, part 6 of this report provides Trident's observations and recommendations for methodology improvement.

5.1 PROBLEMS ENCOUNTERED IN APPLYING DEPARTMENT OF ENERGY METHODOLOGY

Trident has identified nine problem areas with the methodology, which are as follows:

- Multiple failure outages;
- Components unreparable without unit outage;
- Nonidentical parallel components;
- Outage duration data;
- Statistical analysis;
- U_F projection;
- Meantime-to-outage concept;
- Evaluation of $\left(\frac{em}{eM}\right)$ with improvement;
- Trend projection of $\left(\frac{em}{eM}\right)$ without improvement.

Each of the above problems is discussed in this section of the report.

5.1.1 Multiple Failure Outages

The Department of Energy methodology assumes that all loss of function failures are independent and nonoverlapping. Thus, this assumption implies that a failed component will be restored to service before another component fails. This condition was, in general, not found to be true at Wood River 5 or Quad Cities 1 and 2, nor at other plants where Trident has evaluated outage data.

Unit outages which involve more than a single component are called multiple failure outages. In practice, there are several ways in which multiple failure outages can occur. For example:

- Simultaneous failure of two components can occur which produces a unit outage;
- A single failed component can produce a unit outage -- after shutdown, another component can be found to have failed although it was not the shutdown cause.
- When there is a full outage due to a single failure, work is often performed on other than the failed component. Without this work, such unfailed components would eventually produce a unit outage. The assumption of no multiple failures overlooks significant component repair work performed at a unit during a full outage.

Partial outages quite frequently become multiple failures. When the second failed component produces no further decrease in unit output the second failure is termed a noncurtailing outage. For example, at Wood River 5 the unit operated from December 1, 1973 to February 16, 1976 with second stage blading removed from the high pressure turbine. This resulted in a 79 MW decrease in the maximum unit output. Component failures which resulted in outages less than this were noncurtailing. Thus, failures such as one mill, one condensate pump, or one turbine feed pump resulted in noncurtailing outages during this period and were not considered in establishing unavailability coefficients.

Trident concludes, on the basis of analysis performed, that accounting for multiple failures could significantly change the $\left(\frac{em}{eM}\right)$ coefficients computed for the various components. For example, Table 5.1 shows all the outages in which the ash hopper was repaired, along with the repair time between 1973-1977 at Wood River 5. If this repair work had not been performed, eventually a unit outage would result. As shown in table 3.7.16, only the outage on August 25, 1975 was actually charged against the ash hoppers in computing the $\left(\frac{em}{eM}\right)$ coefficients. If Table 5.1 is used to compute the ash hopper $\left(\frac{em}{eM}\right)$, using only the repair time for the outage duration, a significant change in $\left(\frac{em}{eM}\right)$ is obtained. In this case, the following coefficients are found:

$$eM = M_1 = \frac{32328}{16} = 2020.5 \text{ hours} \quad (5.1)$$

$$em = m_1 = \frac{211.6}{16} = 13.2 \text{ hours} \quad (5.2)$$

Dividing equation (5.2) by (5.1) gives:

$$\left(\frac{em}{eM}\right) = \frac{13.2}{2020.5} = .00653 \quad (5.3)$$

This compares with an $\left(\frac{em}{eM}\right) = .000576$ that was given for 1973 to 1977 in Table 3.7.16. Thus, accounting for multiple failures could change the $\left(\frac{em}{eM}\right)$ ratio by a factor of over 10.

Trident found at Wood River 5 and Quad Cities nearly all outages were multiple failures. Trident was thus faced with the problem of how to divide the outage time. At Wood River 5 and Quad Cities, full outage duration time was assigned entirely to the component which initiated the full outage. Additional components which were repaired during the resulting outage were neglected. Thus, components such as the ash hopper at Wood River 5 have artificially low $\left(\frac{em}{eM}\right)$ ratios.

TABLE 5.1

WOOD RIVER 5

OUTAGES WHERE ASH HOPPER WAS REPAIRED

Date	Time to Repair (Hours)	Comments
1/7/73	10	Ash hopper
6/29/73	3	5B - Ash hopper
8/11/73	4	5A and 5B - Ash hopper (slight glass breakage and hydraulic door packing)
4/30/74	1	Ash hopper
5/29/74	8	Fly ash hopper
8/26/74	2	Ash hopper
9/30/74	5	Air heater hopper
10/19/74	8	Hydroveyor fly ash
11/15/74	8	Ash hopper overflow
1/10/75	2	5A - Clinker grinder
3/26/75	4	Air separator
8/25/75	18.6	Remove wire screen from ash hopper
2/25/76	2	Screen removal
3/13/76	32	Worked on hopper
8/19/76	52	Fly ash system
8/27/76	26	Hopper
5/18/77	26	Fly ash

5.1.2 Components not Repairable without Unit Outage

As stated in section 1.3.4, equation (1.11), which is used to compute the equivalent meantime-to-outage (eM) for identical parallel components, is valid only if the components are repairable with the unit on line. Equation (1.11) is the only relationship given for parallel components in the DOE method to find eM. However, Trident found many examples of parallel components which are repairable only during a full outage. Examples of such components are the exciters at Wood River 5 and the reactor recirculation pumps at Quad Cities.

For convenience, equation (1.11) is repeated below:

$$eM = \frac{\sum_{j=r}^n \binom{n}{j} M_1^j m_1^{n-j}}{n \binom{n-1}{r-1} M_1^{r-1} m_1^{n-r}} \quad (1.11)$$

where

n = Total number of parallel items

r = Number of items required for full operation

$$\binom{n}{j} = \frac{n!}{j! (n-j)!}$$

M_1 = Equivalent meantime-to-outage for one of the identical components, hours

m_1 = Equivalent meantime-to-restore for one of the identical items, hours

eM = Equivalent meantime-to-outage of entire system, hours

The basis of equation (1.11) is clearly defined in reference D2 in the DOE report* as applying only to parallel components that are repairable on line.

* Einhorn, S. J., Reliability Prediction for Repairable Redundant Systems, Proceedings of the IEEE, pp. 312-317, February 1963.

Thus, Trident feels it is invalid to apply equation (1.11) to parallel components which are repairable only after unit shutdown. For an unrepairable parallel component, Trident recommends eM should be calculated as follows:

$$eM = \sum_{j=r}^n \binom{n}{j} \int_0^{\infty} p^j (1-p)^{n-j} dt \quad (5.3)$$

where

p = Probability of component operating at time t .

Assuming the exponential failure law is valid, as done in the DOE methodology*, the probability a component is operational at time t is given by

$$p = e^{-\lambda t} \quad (5.4)$$

where

λ = Failure rate, hr^{-1}

Thus, the equivalent meantime-to-outage for one component is given by

$$M_1 = \frac{1}{\lambda} \quad (5.5)$$

Equation (5.5) is a direct consequence of the exponential failure law.

Trident also believes similar limitations apply to the equivalent meantime-to-restore equation for parallel identical items, which is equation (1.9) in section 1.3.4.

* U. S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Vol. II, p. E-17, February 1978.

Trident feels the inadequacy of equation (1.11) may have not been revealed by either case study on Turkey Point 4 and Marshall 4 in the DOE methodology because both units had a small percentage of their outages attributable to identical parallel systems. The sensitivity analysis* showed such systems accounted for 6.9% of the U_F at Marshall 4 and 9.9% at Turkey Point 4.

However, Trident, in analyzing Wood River 5 and Quad Cities, felt the use of equation (5.3) would have involved a major modification to the DOE methodology. Such a modification was not the intent of the study. Trident felt the only approach which maintains consistency with the techniques in the DOE methodology, was to model unrepairable parallel systems as a single series element. Thus, all such systems have been so modeled in this analysis.

5.1.3 Nonidentical Parallel Components

Also, equations (1.9) and (1.11) are only valid for identical parallel components. Again, no alternate relationship is available for nonidentical components. Trident found several nonidentical parallel components in the units studied. For example, the three condensate pumps and the three boiler feed pumps at Wood River 5 are nonidentical parallel components. This is evidenced by the fact that, depending upon which of three pumps fail, different unit capacity losses result. Trident handled this problem by modeling nonidentical parallel systems as a single series element. This was done to maintain consistency with the techniques of the DOE methodology.

5.1.4 Outage Duration Data

The DOE method uses only a single coefficient to describe the repair of equipments (i. e., meantime-to-restore coefficient). Thus, significant details about the repair process can be lost. Factors which could influence the outage duration time include:

* U. S. Department of Energy, Powerplant Productivity Improvement Study, Vol. II, p. 108, p. 141, Feb. 1978

- Severity of problem
- Component cool-down and warm-up time;
- Spare parts;
- Proper tools on-site;
- The degree to which two and three-shift maintenance was used to accomplish repairs;
- Man-hours required for repair;
- Repair crew size;
- Number of failed components.

A component could have a large meantime-to-restore, not because of its time to repair, but because there is a spare parts problem or even low system demand. In the latter case, management may decide it doesn't need full unit output and, therefore, only schedules repairs on a low priority basis. Trident found the latter reason to be a frequent contributor to the extension of pulverizer outages at Wood River 5. Trident believes that such effects should be considered when projecting the meantime-to-restore coefficient. However, modification of the DOE method to account for the outage repair details was beyond the scope of the project.

5.1.5 Statistical Analysis

A statistical analysis has been performed on the meantime-to-restore and meantime-to-outage coefficients as recommended in the DOE methodology. The DOE methodology says the statistical analysis, which is simply a χ^2 test, should be combined with the "point" estimates in order to arrive at a "historical" estimate for the coefficients*. However, the methodology doesn't give any definite procedures as to how this should be accomplished. Trident has thus used only the point estimates in arriving at the "historical" estimates of the meantime-to-restore and meantime-to-outage coefficients.

* U. S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Vol. II, pp. C-6 and C-9, February 1978.

However, the χ^2 test showed that large uncertainties existed in the $\left(\frac{em}{eM}\right)$ ratios computed. For example, from Table 4.8.18, the feedwater regulating valves were found to have 21 outages. Thus, the feedwater regulating valves had a fairly significant number of outages. Also, Table 4.8.18 shows that the $\left(\frac{em}{eM}\right)$ ratio for the 1973-1977 period for the series treatment is equal to .01995. However, from the χ^2 analysis for Quad Cities 2, which is given in Table 4.26:

$$M_{1L} = 1,572 \text{ hours} \quad (5.6)$$

$$m_{1u} = 42.6 \text{ hours} \quad (5.7)$$

Since in series treatment, $eM = M_1$ and $em = m_1$, dividing equation (5.7) by equation (5.6) gives:

$$\frac{em_u}{eM_L} = \frac{m_{1u}}{M_{1L}} = \frac{42.6}{1572} = .02710 \quad (5.8)$$

The percentage difference from $\left(\frac{em}{eM}\right)$ ratio computed by equation (5.8) and that given in Table 4.8.18 for 1973-1977 is:

$$\% \text{ difference} = \left[\frac{.02710 - .01995}{.01995} \right] = 35.6\% \quad (5.9)$$

Thus, the χ^2 test shows that a 35.6% difference could exist in the $\left(\frac{em}{eM}\right)$ ratio used in the DOE analysis for the feedwater regulating valves. Components with fewer outages would have a larger uncertainty, while those with more outages would have less uncertainty.

5.1.6 U_F Predictions

As shown in section 3.4.2 for Wood River 5 and section 4.4.2 for Quad Cities, the predicted value of U_F doesn't necessarily yield good agreement with the actual value of U_F . Trident believes better predictions might be

possible if the computed $\left(\frac{em}{eM}\right)$ coefficients had a larger data base. Trident reviewed outage data from other BWR units, as given in the NPRDS and NRC gray books. However, data from these sources was not in a form readily adaptable to compute the meantime-to-outage and meantime-to-restore coefficients in the DOE methodology.

5.1.7 Meantime-To-Outage Concept

As discussed in sections 3.4.2 and 4.4.2, better agreement was obtained for loss of function availability in the validation tests when the DOE parallel component equations (1.9) and (1.11) were not used. Further, different $\left(\frac{em}{eM}\right)$ ratios were obtained for the same component, depending upon whether it was treated in parallel or a series configuration. For example, as shown in Table 4.8.16, the reactor feed pumps at Quad Cities 2 have an $\left(\frac{em}{eM}\right) = .0068$ for 1973-1977 in a series configuration, but an $\left(\frac{em}{eM}\right) = .00051$ for 1973-1977 in a parallel configuration.

Trident believes this discrepancy would be removed if em and eM for parallel components were computed using components meantime-to-failure, not meantime-to-outage. However, this would involve modifying the DOE method to account for noncurtailing outages since such outages are presently not handled by the methodology.

5.1.8 Evaluation of $\left(\frac{em}{eM}\right)$ with Improvement Projects Implemented

Trident believes there is no problem in determining the $\left(\frac{em}{eM}\right)$ ratio with the improvement project implemented if the project involves adding additional redundancy to the unit. In this case, em and eM can be determined by either reviewing historical data or using the DOE equations for parallel identical equations. Thus, for example, the improvement of adding a sixth pulverizer at Wood River 5 was not difficult to analyze.

However, Trident did not find the analysis as simple if the improvement project involved adding a different type of component or a modification to an existing component in the unit. In this case, outage data on the new component or modification is needed to evaluate em and eM for the improvement. This data may be difficult to obtain for the following reasons:

- No central data base is available from which the meantime-to-outage or meantime-to-restore can be obtained for power plant components;
- Component may be untested in a power plant environment; thus, no relevant outage data may exist on the component;
- Use of outage data from other operating units, if available, may be misleading since maintenance and operating practices vary from unit to unit which can affect the meantime-to-outage and meantime-to-restore of a component.

5.1.9 Trend Projection of em and eM with Improvement not Implemented

Trident believes the projection techniques in the DOE methodology when improvements are not implemented are another possible source of error. The projection of em and eM can be distorted since the outage data on which the projection is based is essentially random. Generally, few components in a power plant have a statistically large number of outages. Thus, potentially large statistical fluctuation exists in the cumulative equivalent outage hours which the DOE method projects. Consequently, this increases the uncertainty in the value of $\left(\frac{em}{eM}\right)$ baseline.

The DOE method says a decision should be made between a geometric projection or a linear projection. Again, the randomness of the outage data makes this decision difficult. Thus, it is quite possible to choose

the wrong type of projection. This could lead to an inaccurate value of $\left(\frac{em}{eM}\right)$ for the improvement. Trident found a significant difference in projecting the $\left(\frac{em}{eM}\right)$ ratio depending on the projection method used. For example, two projections of $\left(\frac{em}{eM}\right)$ are shown in Table 4.22 for the feedwater regulating valve at Quad Cities 1. Projection 2 is based on using the fact that the cumulative outage time (C) for the feedwater regulator valve is zero, when the unit operational time is zero. Projection 1 doesn't use this constraint. The percentage difference for the $\left(\frac{em}{eM}\right)$ ratios between these projections is given by:

$$\% \text{ difference} = \left(\frac{.00613 - .00499}{.00613} \right) = 18.6\%$$

Where

.00612 = $\left(\frac{em}{eM}\right)$ projection 1 of FRV for 1978 (Table 4.22)

.00499 = $\left(\frac{em}{eM}\right)$ projection 2 of FRV for 1978 (Table 4.22)

5.2 SIMPLIFICATIONS TO DEPARTMENT OF ENERGY METHODOLOGY

Trident considers that there are certain facets of the methodology which could be simplified. For example, the report appears to be unnecessarily complicated in developing the unavailability coefficients equations. This section discusses the simplifications used by Trident in evaluating Wood River 5 and Quad Cities.

5.2.1 Simplified U_F Equation

The following expression is given for U_F for a single element unit in the DOE methodology*:

* U. S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Vol. II, P. 27, February 1978.

$$U_F = \left[1 - \frac{1}{1 + \left(\frac{em}{eM} \right) K} \right] K_T \quad (5.10)$$

where

$\left(\frac{em}{eM} \right)$ is the summation of $\left(\frac{em}{eM} \right)$ for all n unit series elements.

Trident believes the expression for U_F can be simplified so the factors K and K_T are eliminated.

• Derivation of Simplified U_F Expression

Let

T_F = Full power outage time due to loss of function, hours

T_F' = Equivalent full power outage time due to partial load reduction caused from loss of function, hours

T_O = Unit operational time (at full and reduced load), hours

T = Period hours

m = Meantime-to-restore full outage, hours

M = Meantime-to-outage of full outages, hours

m' = Equivalent meantime-to-restore for partial outages, hours

M' = Meantime-to-outage of partial outages, hours

Thus, the unit unavailability due to loss of function is given by:

$$U_F = \frac{T_F + T_F'}{T} \quad (5.11)$$

Assuming, as in the DOE methodology*, that outage times are proportional to unit operational times, then T_F and T_F' can be expressed as:

* U. S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Vol. II, p. A-8, February 1978.

$$T_F = \left(\frac{m}{M}\right) T_o \quad (5.12)$$

$$T_{F'} = \left(\frac{m'}{M'}\right) T_o \quad (5.13)$$

Substituting equations (5.12) and (5.13) into equation (5.11) gives:

$$U_F = \frac{\frac{m}{M} T_o + \frac{m'}{M'} T_o}{T} \quad (5.14)$$

Equation (5.14) can be written as

$$U_F = \left(\frac{m}{M} + \frac{m'}{M'}\right) \frac{T_o}{T} \quad (5.15)$$

However, the following definition is given in the DOE methodology*:

$$\left(\frac{em}{eM}\right) = \left(\frac{m}{M} + \frac{m'}{M'}\right) \quad (5.16)$$

Substituting equation (5.16) into (5.15) gives

$$U_F = \left(\frac{em}{eM}\right) \frac{T_o}{T} \quad (5.17)$$

Therefore, equation (5.17) is identical to equation (5.10). Equation (5.17) is simpler to use since it doesn't involve determining the K or K_T coefficients. Since it was identical but simpler, Trident used equation (5.17) rather than equation (5.10) when evaluating Wood River 5 and Quad Cities.

5.2.2. Alternate Up Equation

The DOE methodology** recommends computing the administrative unavailability as:

* U. S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Vol. II, p. A-10, February 1978.

** Ibid, P. 20.

$$U_{P2}^1 = \sum_{i=1}^n \frac{(\overline{CL} \times d_p)_i}{T \times MDC} \quad (5.18)$$

where

T = Period, hours

MDC = Maximum dependable capacity

d_p = Average planned outage duration

$\overline{CL}$ = Average planned outage loss

i = Planned outage type

n = Number of planned outage types

As given in Table 1.4 in section 1.3.4, Trident used for Quad Cities 1 and 2:

$$U_P = \frac{\sum_{i=1}^{N_p} \text{Megawatt Hours Lost in Administrative Outages}}{(T) (MDC)} \quad (5.19)$$

while for Wood River 5, Trident used:

$$U_P = \frac{\sum_{i=1}^{N_p} d_i CL_i}{(T) (MDC)} \quad (5.20)$$

where

N_p = Number of administrative outages

d_i = i^{th} administrative outage duration, hours

CL_i = i^{th} administrative outage capacity loss, MW

The denominators of equations (5.18) through (5.20) are all the same and equal to the gross generation capacity of the unit in megawatt hours. However, the numerator must give the total megawatt hours due to planned outages since the fundamental definition for U_P^* is:

* U. S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Vol. II, p. 20, February 1978.

$$U_P = \frac{\text{Megawatt Hours Lost by Administrative Outages}}{\text{Megawatt Hours Capability of Unit}} \quad (5.21)$$

Both equation (5.19) and (5.20) give the exact total megawatt hours lost by administrative outages. Thus, they are completely consistent with the fundamental definition. However, equation (5.18) computes the megawatt hours by multiplying the average capacity loss by the average outage duration of type i. Thus, mathematically, equation (5.18) is slightly different from equation (5.21). However, for most situations, this difference is not that significant. However, equation (5.18), since it involves the summation of the product of averages, only approximates the fundamental definition for U_P . Thus Trident's use of equations (5.18) and (5.20) led to slightly more accurate calculations of U_P than would have been obtained by using equation (5.18).

5.2.3 Alternate U_C Equation

Trident's equations for calculating the conditional unavailability are given by equations (1.4) and (1.5) in Table 1.5. These equations are slightly different from the equation to calculate U_C in the DOE methodology*. This is because the U_C calculated in the DOE methodology involves multiplying average conditional outage capacity loss by average conditional outage duration for conditional outages of a given type. Conversely, Trident's equations (1.4) and (1.5) simply find U_P by summing the megawatt hours in conditional outages. Trident's argument for using this slight modification is analogous to that given in the previous section.

* U. S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Vol. II, p. 22, February 1978.

6.0 OBSERVATIONS ON APPLICATION OF DEPARTMENT OF ENERGY METHODOLOGY

The Department of Energy (DOE) methodology is a technique designed to assess the impact of an improvement project or corrective action on unit productivity parameters such as heat rate, capacity factor, availability, or equivalent availability. To date, only details for the assessment of improvement projects on a powerplant's equivalent availability have been published. The DOE methodology analyses:

- the effect of component redundancy on unit equivalent availability,
- the effect of component reliability on unit equivalent availability,
- a component's outage trend to project the component's future outage rate;

and presents the results in a documented organized approach to power-plant productivity assessment. While the DOE methodology has additional capabilities, such as identifying root causes and evaluating corrective actions for a unit's lost productivity, it was the purpose of this study to consider only the impact of improvement projects on a unit's equivalent availability.

Section 6.1 summarizes the change in equivalent availability Trident obtained when applying the DOE methodology to three Illinois units. Trident's evaluation of the methodology is given in section 6.2. Recommendations for improvements in the methodology are given in section 6.3.

6.1 SUMMARY OF RESULTS

Table 6.1 shows the maximum change in equivalent availability (ΔEA) predicted for various improvement projects evaluated at Wood River 5 and Quad Cities 1 and 2. As can be seen, some of the improvements have a significant effect on the unit equivalent availability. For example,

TABLE 6.1		
MAXIMUM CHANGE IN EQUIVALENT AVAILABILITY FOR IMPROVEMENT PROJECTS EVALUATED		
Unit	Improvement Project	Δ EA (Maximum)
Wood River 5	Install sixth pulverizer	.0234
	Continuous pulverizer maintenance	.0194
	Addition of new tube bundles	.00106

Quad Cities 2	Install drag valve	.0155
	Install Amertap system	.00374
	Install cooling tower	.0317

Quad Cities 1	Moisture drain tank modification	.00131
	Electromatic relief valves modification	.0108

installing cooling towers at Quad Cities 2 could increase the equivalent availability up to .0317. The cost of the improvements were not evaluated as part of the study. Evaluation of the cost of these projects will be accomplished in a separate phase of the Illinois Powerplant Productivity Study.

6.2 DOE METHODOLOGY OBSERVATIONS

Trident evaluated the DOE methodology by applying it to three units at Illinois powerplants. Trident found the Department of Energy methodology is valid in that it appropriately applies statistical techniques to powerplant performance data to calculate a detailed assessment of a unit's future productivity performance. Trident further concludes that certain deficiencies exist in the methodology, many of which reflect in the uncertainty of the results obtained and/or complicate the application of the methodology or interpretation of results.

Trident evaluated the uncertainty in the ΔEA calculated for the improvement projects shown in Table 6.1. While the exact uncertainty for each improvement project is not possible to calculate, Trident could draw some approximate limits from its analysis. For example, as shown in section 5.1.5, the feedwater regulating valve $\left(\frac{em}{eM}\right)$ ratio statistically has a variance of 35.6%. As discussed in section 5.1.9, the trend projection for the feedwater regulating valve $\left(\frac{em}{eM}\right)$ can change by 18.6% by the addition of a single point. Also, as discussed in section 5.1.1, inclusion of the multiple failures can change the $\left(\frac{em}{eM}\right)$ ratio in the case of the ash hopper at Wood River 5 by a factor of 10. Since ΔEA is proportional to the magnitude of the $\left(\frac{em}{eM}\right)$ ratio, the uncertainty in $\left(\frac{em}{eM}\right)$ is approximately equal the uncertainty in ΔEA . From these considerations, Trident believes a high uncertainty exists in the ΔEA shown for the various improvement projects in Table 6.1.

Trident further concludes that some of the uncertainty of results can be eliminated through further development of the procedure. This continued development of the procedures should be pursued to make the methodology more useful and simpler to apply by the utility industry.

For the most part, deficiencies noted here have been discussed in the various preceding sections. For convenience, these limitations are listed below. Also, the section in which a detailed discussion of the deficiency is given is listed in parenthesis.

- Multiple failures not handled (section 5.1.1);
- Components not repairable without full unit outage not handled (section 5.1.2);
- Nonidentical parallel components not handled (section 5.1.3);
- Causes of outage duration not handled (section 5.1.4);
- Quantification lacking in certain areas in the methodology;

The DOE methodology suggests performing a statistical analysis of the outage data to find the meantime-to-restore and meantime-to-outage coefficients. However, no quantitative method is given as to how this statistical analysis should be combined with the coefficients calculated from the unit's outage history.

The DOE methodology suggests plotting the outage data and then using either a linear or geometric projection to predict a component's future outage rate. Again, no quantitative criteria are given as to how a decision should be made between which of these two projections to use.

In the above cases, the methodology gives a qualitative discussion as to how to proceed. However, this discussion is of limited use, especially to persons unfamiliar with the techniques being applied.

- Difficulty in reproducing results shown in the DOE report;

The report contains little of the data used in applying the methodology in the two test cases presented. The DOE report applies the methodology to Turkey Point 4 and Marshall 4. Generally, the meantime-to-restore and meantime-to-outage coefficients as well as the unavailability coefficients (U_P , U_C , U_F) could not be reproduced for either unit.

- * Inconsistencies in the DOE report;

Similar parallel subfunctions have different expressions between the two case studies given in the DOE report. For example, at Turkey Point 4, the $\left(\frac{em}{eM}\right)$ ratio for the condensate pumping subfunction ($n = 3$, $r = 2$) is given by*

$$\left(\frac{em}{eM}\right) = \frac{m^3 + 3 Mm^2}{3 M^2m + M^3} \quad (6.1)$$

At Marshall 4, the $\left(\frac{em}{eM}\right)$ ratio for the condenser cooling water pumping subfunction ($n = 3$, $r = 2$) is given by**

$$\left(\frac{em}{eM}\right) = \frac{m^3 + 3 Mm^2}{2M^2m} \quad (6.2)$$

Since these components have the same n and r values, they should have identical $\left(\frac{em}{eM}\right)$ ratios. No explanation is given for the difference in the denominator of equations (6.1) and (6.2). Only equation (6.1) is derivable from the parallel equations given in the DOE methodology***.

- * Equations unnecessarily complex (section 5.2.1);
- Tedious calculations;

Trident found the calculations required in the DOE methodology often to be tedious and time consuming. Trident believes the hand calculational approach when used in the DOE methodology to be inefficient, considering the ready availability of data processing equipment within the utility industry. Automating the process would reduce manpower requirements and would also permit expanding the number of elements modeled.

* U. S. Department of Energy, Powerplant Productivity Improvement Study, HCP/B60830-02, Vol. II, p. 131, February 1978.

** Ibid, p. 90.

*** Ibid, p. 58.

- DOE report format;

The DOE report can be followed and understood by persons with reliability, statistics, and powerplant background. However, it appears to be extremely difficult for persons without such training to employ the methodology on the basis of the instructions given in the report. In addition, the DOE report is too long to be used as a working manual. Methodology is not a substitute for engineering talent and experience.

- Administrative and conditional outages not modeled.

Trident found the majority of outages at Quad Cities 1 and 2 were not due to loss of function outages, but due to administrative and conditional outages. Also, a significant number of administrative and conditional outages were found at Wood River 5. The DOE methodology finds the administrative and conditional unavailability for a unit by simply averaging historical outages in this category. There is no modeling of the events or systems which produce an administrative or conditional outage. For example, failures of safety systems are treated as a conditional outage in the DOE methodology. A more refined assessment would attempt to determine the failure rates of the individual components in the safety system. From this information, a model could be constructed for the safety system to calculate its affect on the unit's unavailability. Such a model would then allow an analysis of the effect of component redundancy and reliability on the unit equivalent availability.

Finally, Trident found utility industry data bases such as Nuclear Regulatory Commission gray books or NPRDS not adequate to supply the generic outage data in a format which the methodology can use. Generic data is defined as data outside the unit under study. The EEI data base is useful only if it can supply the generic data in an outage-by-outage format. However, such information is not publicly available. Without generic data, the DOE methodology predictions are statistically less credible.

Trident used 11.5 engineering man-months and 3.5 clerical man-months to apply the methodology to three units. This compares favorably with the 3-6 man-month effort per unit suggested in the DOE report.

However, Trident drew heavily on utility personnel to collect the information required in the DOE methodology.

6.3 RECOMMENDATIONS

Based on the preceding conclusions, Trident recommends the following actions to be taken to improve the methodology and make it a better predictive tool for utility management.

- Modification of methodology to handle multiple failures;
- Modification of methodology to handle nonidentical parallel components;
- Modification of methodology to handle components not repairable with the unit on line;
- Modification of methodology to incorporate details of outage duration;
- Modification of methodology to incorporate simplifications in U_F calculations;
- Refinement of methodology to quantitatively define procedures to handle such areas as the statistical analysis and meantime-to-outage and meantime-to-restore trend projections;
- Development of a handbook type format for presentation of methodology which concisely describes the equations and procedures to be followed in a step-by-step manner;
- Develop procedures for implementation of the DOE methodology into a computer based system;
- Modification of methodology to model administrative and conditional outages.