DOE/ET/34019-1
BAW-1721

February 1982
UC-78

DEVELOPMENT OF A REACTOR COOLANT PUMP MONITORING AND DIAGNOSTIC SYSTEM

Project Management Report:
October 1980 - November 1981

Babcock & Wilcox
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DEVELOPMENT OF A REACTOR-COOLANT PUMP MONITORING AND DIAGNOSTIC SYSTEM

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by

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Work Performed Under
Contract No. DE-AC02-79ET34019

Prepared by

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Development of a Reactor Coolant Pump Monitoring and Diagnostic System — Project Management Report: October 1980 - November 1981

G. A. Sommerfield, D. J. Morris

Key Words: Reactor Coolant Pump, Diagnostic System, Seal Performance, Data Collection, Analysis

ABSTRACT

The objective of the project is to develop a reactor coolant pump monitoring and diagnostic system and collect sufficient data to permit analysts to determine why high outleakage and failures occur at Davis-Besse Nuclear Power Station, Unit 1. This report summarizes the work completed during the first period of performance, October 1, 1980, through November 30, 1981. During this period the members of the Project Team were selected and the detailed work management plans developed to take this project from conception, through detailed engineering, and finally to construction in the early part of 1982.

Information gathered in this program will be useful in the development of better pump seals. Improved seal performance will reduce the frequency of seal replacements, which now result in higher levels of radiation exposure than anticipated. The scope of work described includes system design, equipment selection for the computer-based data collection and diagnostic system, and computer software development to permit data collection and analysis.

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1.1. Introduction

1.1.1. Background

A program entitled "Development of a Reactor Coolant Pump Monitoring and Diagnostic System," Contract No. DE-AC02-79ET34019, was submitted to the United States Department of Energy by the Toledo Edison Company in early 1979. The work was scheduled to start in July 1979, but the additional engineering activity necessitated by the incident at Three Mile Island forced Toledo Edison to ask the Department of Energy for a one-year delay. In October 1980 the Babcock & Wilcox Contract Research Division began working with Toledo Edison to develop a research effort which would increase the understanding of pump seal performance and enable design changes with the ultimate objective of reducing radiation exposure to nuclear plant personnel caused by pump seal leakage failures.

1.1.2. Project Description

The scope of the project covers the selection of input parameters to be monitored, sensor selection for new inputs, equipment selection for the computer-based data collection and diagnostic system, and computer software development to permit data collection and analysis. To accomplish these goals at Davis-Besse Nuclear Power Station, Unit 1, Bechtel Power Corporation is providing engineering services for the installation of the equipment and related cabling. United Engineers & Constructors is responsible for construction of the system as part of the refueling outage scheduled for spring 1982. The data collection phase will follow for 18 months. Work on this project is directed toward analysis of the data collected so that nuclear plant operators can better understand pump seal performance. In addition to this analytical effort, actual seal design modifications are being developed and tested as part of a reactor coolant (RC) pump users group research program that is closely integrated with this project. Several utilities, Babcock & Wilcox, and the pump manufacturer are participating in this users group, which is discussed later in this report under "Related Programs."

1.1.3. Goals

The overall goal of this research program is to reduce the man-rem exposure resulting from frequent replacement of RC pump seals and the possible exposure if a major failure should occur. The immediate objectives of the program are to develop and demonstrate a pump monitoring and diagnostic system that will

1. Alert plant operators to impending RC pump seal failure.
2. Increase monitoring of RC pump and motor performance to examine potential relationships between performance and seal problems.
3. Provide reliable and consistent performance records.

When Toledo Edison began work on this project in October 1980, the interim objectives for the first year of work were as follows:

1. Develop a srtong project team comprising principal subcontractor and Toledo Edison personnel to ensure timely completion of essential tasks.
2. Negotiate subcontracts with Babcock & Wilcox (B&W), Bechtel Power Corporation (Bechtel), and United Engineers & Constructors (UE&C) to accomplish the essential activities of system design, detailed site engineering, and site construction.
3. Develop a detailed project work plan and budget closely coordinated with the need to complete the construction phase during the refueling outage scheduled for spring 1982.

1.1.4. Impact on Man-Rem Exposure

Achievement of the three principal objectives above will avoid high outleakage failures, which will reduce exposure levels from 25-50 man-rem per occurrence to 1-2 man-rem. Reduction in seal maintenance frequency will reduce the 4-8 man-rem exposure associated with replacing four pump seals annually to half of this level in the near term and one-fourth of this level in the long term.

1.2. Major Accomplishments

The following major results were achieved during the period from October 1980 through November 1981:

1.2.1. Babcock & Wilcox

- Developed functional requirements for the monitoring and diagnostic system.
- Received and checked out the equipment specified to build the monitoring and diagnostic system.
- Prepared detailed plans and connection specifications to install the equipment in one equipment cabinet.
- Developed essentially all of the software required for the site computer to function.
- Coordinated this project with the activities planned by the RC pump users group.
- Assisted in coordinating industry research activities with projects, such as this effort sponsored by the United States Department of Energy, and others sponsored by the Electric Power Research Institute (EPRI).

1.2.2. Bechtel Power Corporation

- Completed approximately half of the required engineering documents.
- Resolved a number of hardware selection issues, including signal buffer specification, analog-to-digital conversion, and possible applications for multiplexing.
- Provided input to the construction contractor to aid in developing a realistic construction cost estimate.

1.2.3. United Engineers & Constructors

- Developed several iterations of the construction cost estimate to identify areas where cost could be reduced.
- Began construction planning and ordering material prior to the start of construction.

1.2.4. Toledo Edison Company

- Developed a project team management approach with emphasis on clear, concise, and direct communication among the members.
- Worked closely with the Department of Energy Project Manager to develop a revised budget for the project.
- Prepared a formal cost increase request for the Department of Energy to review, which will permit a quality research and development program to continue with only minimal reductions in technical information.

1.3. Project Status

1.3.1. Schedule

The major constraint impacting the schedule for this project is the timing of the second refueling outage at Davis-Besse Unit 1. An outage is necessary to install the in-containment sensors and associated wiring. Therefore, the engineering work packages were divided into two groups: the outside containment work packages include all the construction activity that can be done without an outage, and the in-containment work package cannot be accomplished until the refueling outage begins. Since many other projects are scheduled for construction concurrently, this project must be part of an overall effort, which must be carefully planned to fit into the time available for the planned outage. At present, the refueling outage is scheduled to begin at the end of February 1982 and continue for 12 weeks.

At this writing, engineering packages are being released and construction planning is beginning. Approximately 8300 man-hours of construction is involved, 30 to 35% of which is designated as pre-outage work. Figure 1 is a chart of the project work schedule.

1.3.2. Cost

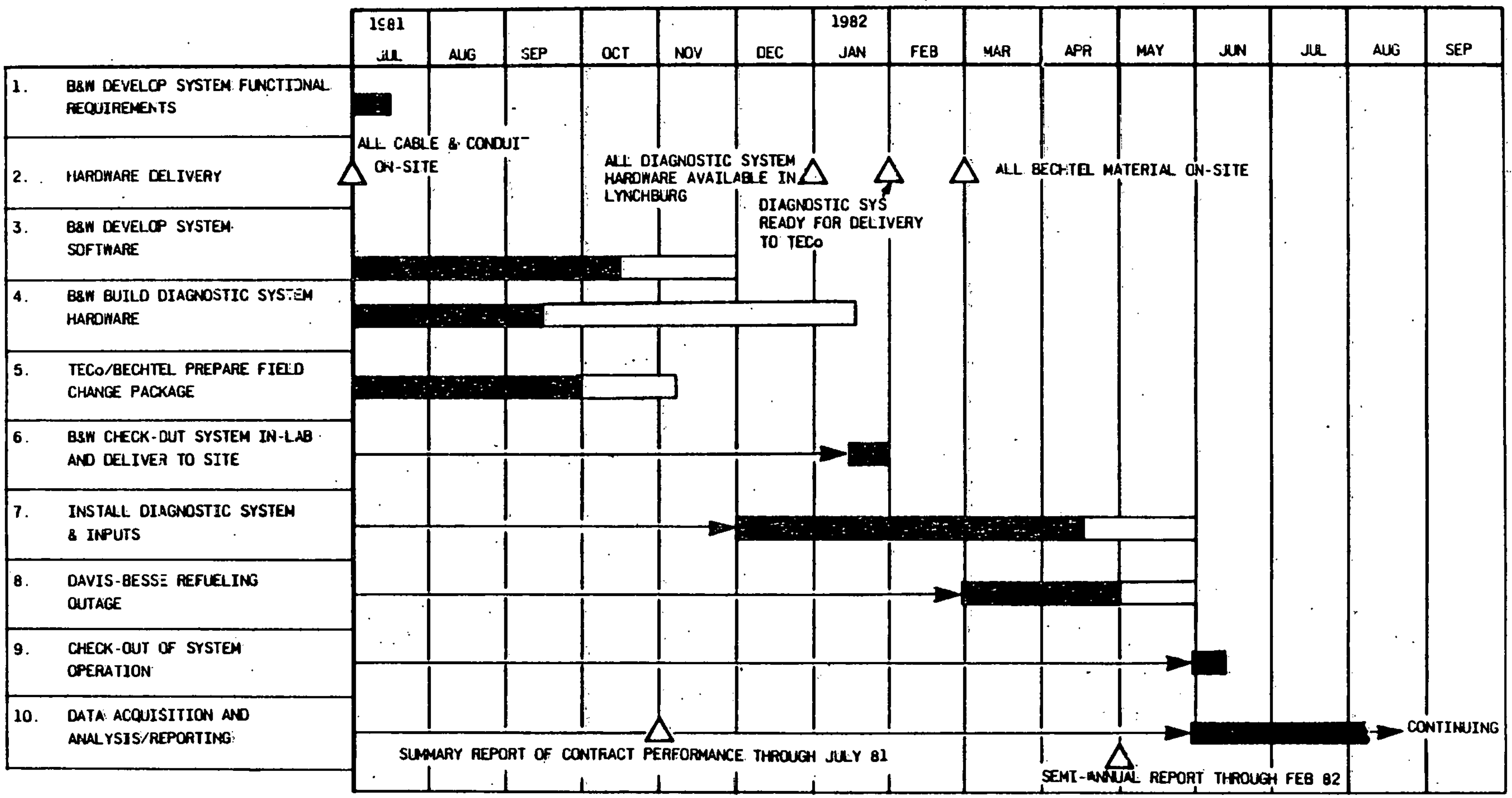
The cost estimate for the original program proposed in 1979 was just under $1 million. Because of the one-year delay and recent experience with retrofit engineering and construction costs at nuclear plants, considerable time was spent re-evaluating the principal cost elements. The revised estimated cost to complete the technical program originally proposed was $2 million. Recognizing that this was beyond the level of funding the Department of Energy would support, additional variations of the construction estimate were made to identify an affordable program and still retain much of the significant technical value in the original proposal.

After approximately two months of analyzing a variety of engineering options and the resulting estimated construction costs, the Project Team determined the most favorable course of action. Of the options considered, monitoring the majority of the parameters from all four pumps and adding new instrumentation to two pumps (one in each coolant loop) emerged as the best compromise. With this change and Toledo Edison increasing their contributions to the project, the cost increase was reduced to $546,000. Tentative approval from the Department of Energy allowed the project to proceed on this basis.

1.3.3. Problems of Current Interest

Essentially, two basic problems face the Project Team at the beginning of the second year. First, managing the construction activity to keep actual costs within the budget is always a challenge. Second, completing the actual construction work within the time available requires that construction progress with no significant delays. While we are confident that the effort can be completed as planned, there is very little room for error or delay. Delivery of some materials is critical, but there will be no problem if the vendor delivers according to his current schedule. For the most part, Toledo Edison and their construction subcontractor should be able to control the outcome of this effort by sound planning and accurate execution.

Figure 1. Project Schedule, RC Pump Monitoring and Diagnostic System Activities and Procurement Milestones



2. SUBCONTRACTOR REPORTS

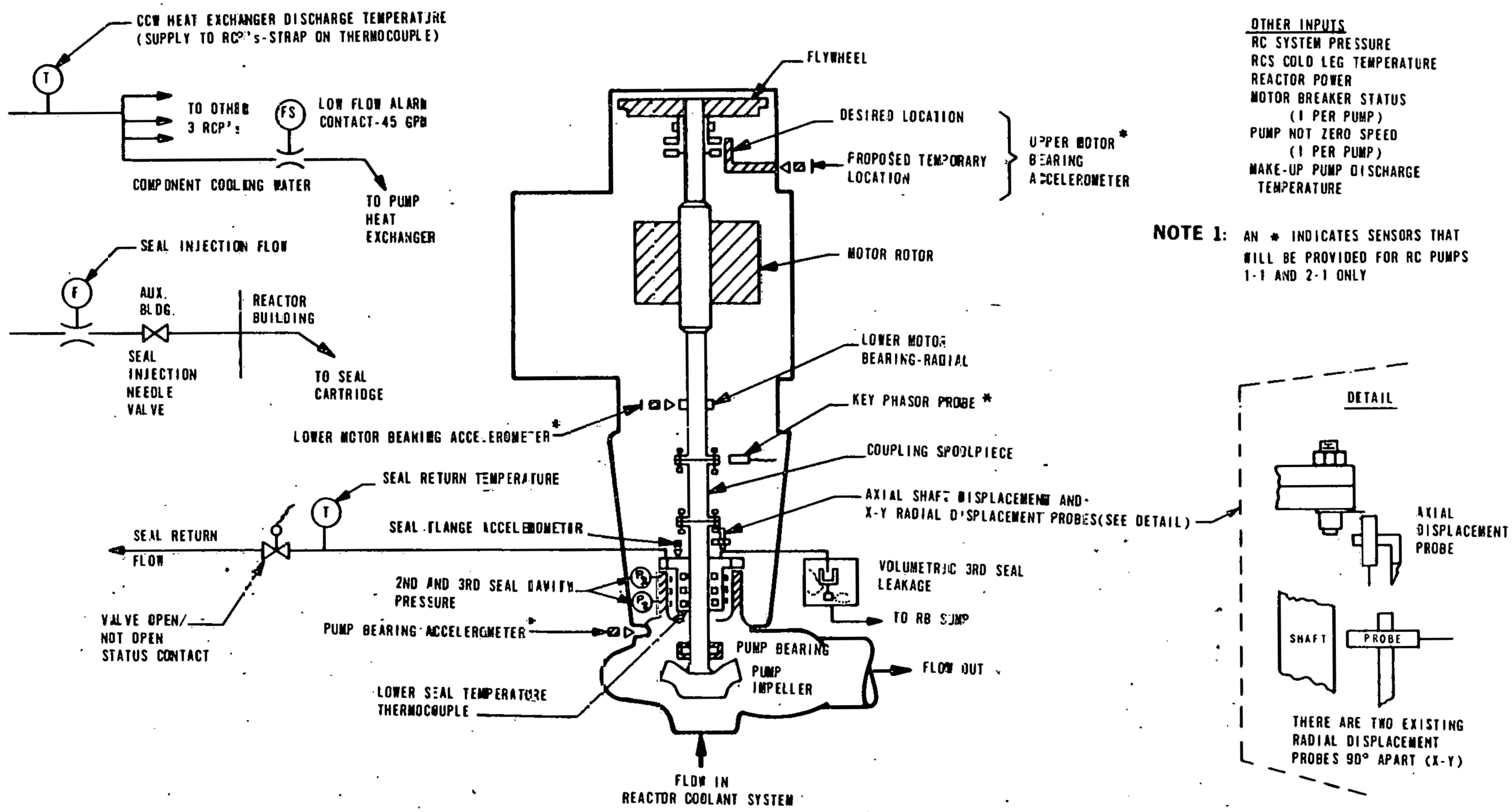
2.1. Bechtel Power Corporation

Bechtel was the engineer and constructor of the Davis-Besse Nuclear Power Station, Unit 1 (Davis-Besse). The firm continues to provide a wide variety of engineering services to Toledo Edison for various retrofit and new construction projects at the plant site. Since Bechtel personnel are totally familiar with the plant, they were a logical choice to perform the detailed engineering required to install the RC pump monitoring and diagnostic system.

While B&W is reponsible for the system design, Bechtel's role is to integrate the system into the Davis-Besse plant. Nearly 50 existing signals have to be located in the existing instrumentation and brought to the diagnostic system. Equipment is also necessary to convert these signals to proper input characteristics, and buffers are required so that no spurious signals enter existing plant instrument systems from the diagnostic system. Another 12 signals are new inputs for this system. Engineering is required to locate these new sensors and route the cables in conduits and cable trays back to the cabinet room. Finally, Bechtel is repsonsible for the interconnecting wiring between the two cabinets that enclose the hardware for this system. Figure 2 is a functional diagram of the system sensor inputs.

When the preliminary construction cost estimate indicated that the estimated construction cost would exceed the budget, Bechtel was helpful in analyzing a number of system design alternatives. Cable and conduit routings were reviewed to determine where the costs were being incurred. Also, once the cost of cable installation was calculated, multiplexing the signals was considered. After the analysis was completed, it was determined that multiplexing would be more expensive and may not be technically feasible because of the radiation environment at certain locations in the plant. UE&C prepared the cost estimates in close communication with the Bechtel engineering staff.

Figure 2. Functional Diagram of Diagnostic System Sensor Inputs



Note: Pump and motor sensor inputs are identical for all for RC pumps except for those indicated by an asterisk (see drawing Note 1).

As of November 30, 1981, the engineering tasks assigned to Bechtel are approximately 50% complete. Detailed exchanges of data with B&W are scheduled to ascertain that all signal levels and engineering units for the various inputs are correct.

2.2. United Engineers & Constructors

UE&C will be the construction contractor for the second Davis-Besse refueling outage. The plant will undergo many modifications during the scheduled refueling outage. One of these will be the installation of the RC pump monitoring and diagnostic system.

Construction costs are expected to make up approximately 30% of the total cost of this project. Because of the importance of construction costs to the budget for the entire program, UE&C prepared a number of cost estimates based on various installation plans. The work inside containment was carefully analyzed, and multiplexing was considered as a possible alternative to reduce installation costs. As it turned out, a hard-wired system was the simplest to install and even less expensive than a system incorporating multiplexing.

UE&C is also ready to proceed on construction as soon as engineering work packages are ready. It is very important to complete as much work as possible outside the containment prior to the outage. The work plans for this project are being integrated with other work scheduled for the outage, so that all the high-priority projects can be completed within the time provided in the outage schedule. According to the present schedule, the refueling outage begins on February 26, 1982, and continues for 12 weeks.

2.3. Babcock & Wilcox

2.3.1. Introduction

2.3.1.1. Statement of Problem

RC pump seal failures have resulted in excessive leakage of primary coolant into reactor buildings. In some cases, high airborne activity and surface contamination levels following these failures have resulted in major cleanup efforts and have increased the time and personnel exposure required to refurbish the pump seals. Early warning and avoidance of RC pump seal failures can substantially reduce maintenance time and personnel radiation exposure.

In addition to the concern with high leakage failures, pump seal service life and performance predictability have been a major problem for many utilities. The resultant lost generating capacity and the costs of performing frequent maintenance have had an adverse impact on the utility ratepayer. Frequent maintenance also contributes to significant increases in radiation exposure to maintenance personnel. Improved monitoring and performance analysis during steady-state and transient conditions can provide a means to assist the plant operator in avoiding certain types of seal stress or damage and provide pump performance records that can be used as a basis for improved pump maintenance. Analyses of these data can also be used to identify design improvements that will increase seal service life and reliability.

2.3.1.2. Department of Energy Project

The RC pump monitoring and diagnostic system is being developed by B&W, under subcontract to Toledo Edison and the Department of Energy (DOE), for installation at Toledo Edison's Davis-Besse Unit 1 operating nuclear power plant. This computer-based system will perform automatic data acquisition and performance analysis of the four RC pumps, including the effects of plant and pump environmental conditions. A B&W computer system at the Lynchburg Research Center, linked with Davis-Besse, will be used for on-line data analysis and interaction with the monitoring and diagnostic system during the data acquisition task. Section 2.3.2 contains a detailed project description. Figures 3 and 4 are flow charts of the site and remote computers for the system.

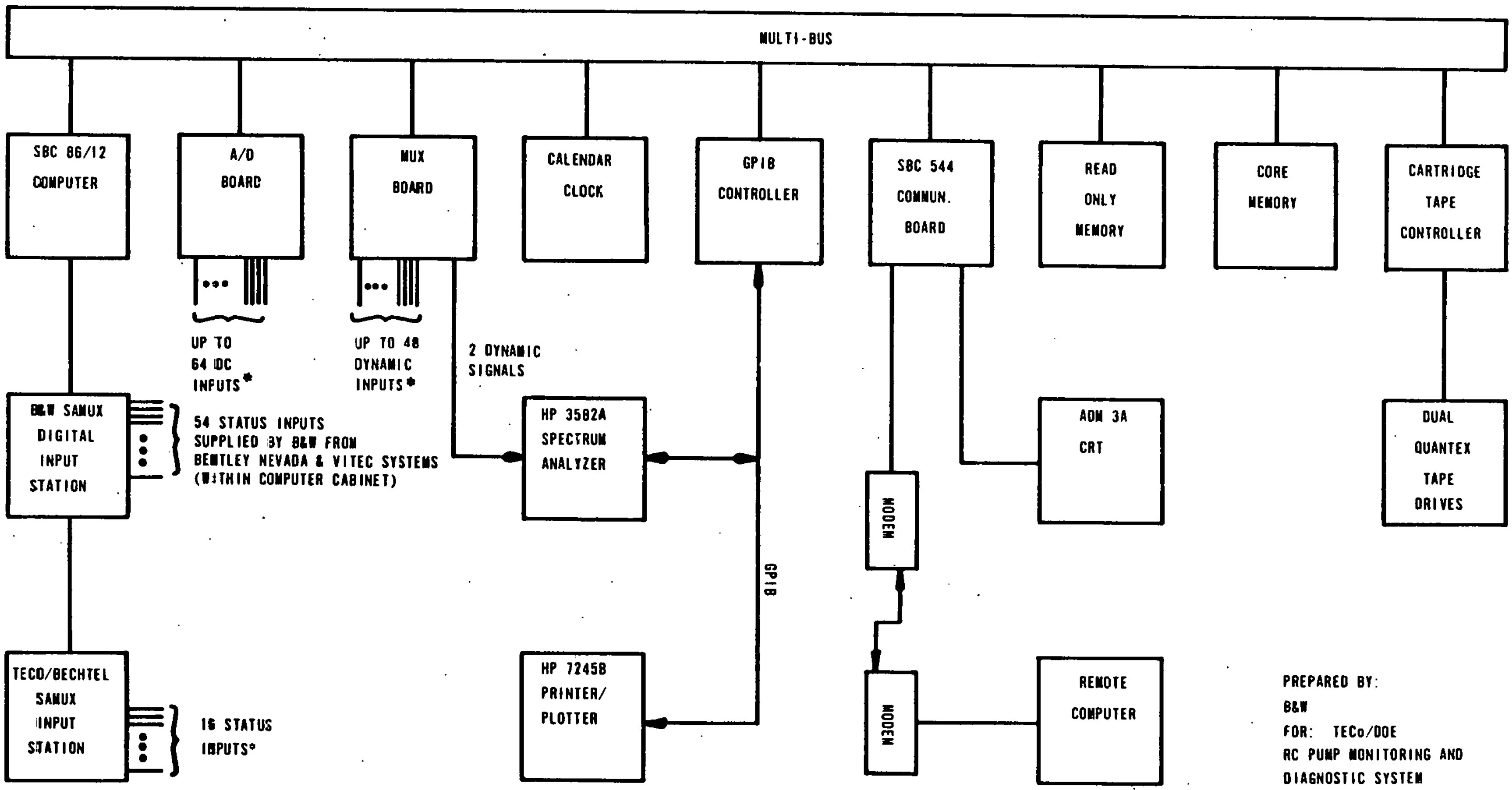
2.3.1.3. Program Objectives

The objectives of this research and development project are to develop and demonstrate a reactor coolant pump monitoring and diagnostic system that will

- Alert plant operators of impending RC pump seal failure.
- Increase monitoring of RC pump and motor performance to examine potential relationships between this performance and seal problems.
- Provide reliable and consistent performance records.

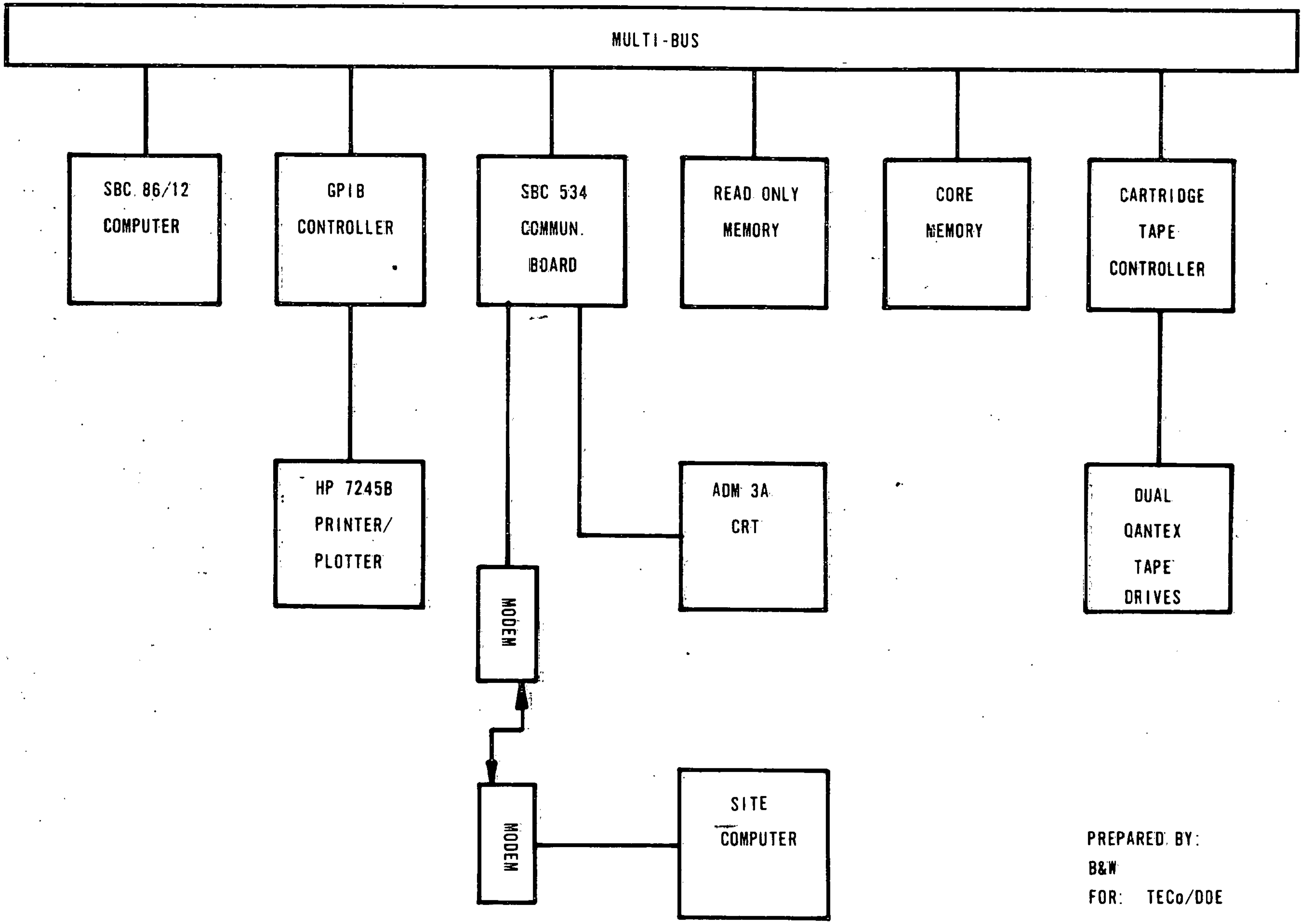
Engineering data of the quality and retrievability to be provided by the diagnostic system are not available in currently operating plants. More important, the limited data that are available usually cannot be time-phase correlated. Relative to failure analysis, it is important to understand the

Figure 3. Site Computer Architecture



*Inputs are supplied by TECo/Bechtel

Figure 4. Remote Computer Architecture



sequence of events in order to identify failure mechanisms. The RC pump monitoring and diagnostic system is designed to address these data gathering and data analysis problems.

After contract work began in October 1980, B&W concluded — through field experience, work with the users group, and an analysis of the Byron Jackson RC pump seal — that an improved seal design was also needed. Improvements in such areas as plant systems, operating methods, and maintenance practices alone would not result in achieving needed improvements in seal life and the predictability of performance. Therefore, a utility funded RC Pump Seal Improvement Program was implemented in April 1981 to address both short- and long-term solutions to existing problems with Byron Jackson (BJ) RC pump mechanical face seals. The short-term program includes the installation of a modified seal in certain operating plants, including Davis-Besse. The long-term program includes the development of a completely new seal design. Five utilities, B&W, and Byron Jackson are participating in this program.

The output of the DOE project will assist the current industry effort in two ways:

- Compare performance between the existing Byron Jackson pump seal design and a modified seal to be installed at Davis-Besse.
- Provide a detailed data base upon which to write specifications or to validate predefined specifications, prior to implementation in hardware, for a new seal design.

The data base produced will become available to the nuclear industry and could be used to identify potential improvements in the plant and/or pump design and in operating methods.

The relationship of the RC Pump Monitoring and Diagnostic System Project to the Byron Jackson RC Pump Seal Improvement Program is described further in section 2.3.3.

2.3.2. Project Description

The equipment to be monitored consists of RC pump manufactured by the Byron Jackson Pump Company driven by Westinghouse Corporation motors. Each pump will run at about 9000 hp at cold RC system conditions. Pump heat is used to heat the reactor coolant system (RCS) to 532F to allow reactor startup. The Davis-Besse 1 pumps have a design flow rate of 90,670 gpm at a 358-ft head.

The function of the seals is to restrict the outflow of nominal 2155 psi RCS water from both an idle pump and while operating at 1200 rpm. The RC pump monitoring and diagnostic system will be designed to concentrate on the pump seal problems, including the effects of rotordynamic performance of the pump and motor on seal behavior.

2.3.2.1. System Inputs

Input signals to the system will comprise existing signals from all four RC pumps, new signals primarily related to rotating machinery diagnostics on two of the four pumps, and selected plant parameters that directly or indirectly influence the pump operating environment.

The following signals are common to all four RC pumps (plant parameters):

1. Wide-range RCS pressure.
2. Reactor coolant cold leg temperature.
3. Reactor power.
4. Makeup pump discharge temperature.
5. Component cooling water heat exchanger outlet temperature (CCW supply to RC pumps).

Four channels, one for each RC pump, will be provided as signal inputs to the diagnostic system for each of the following pump parameters:

1. Upper seal leakage.
2. Third seal cavity pressure.
3. Second seal cavity pressure.
4. Seal return outlet (controlled bleed-off) temperature.
5. Seal injection flow.
6. Controlled bleed-off valve position.
7. Component cooling water low flow.
8. Pump motor frame (seal flange) accelerometer.*

- - - - -

*The existing motor frame accelerometers will be moved to the third seal flanges. (The third seal flange is a physical part of the mechanical seal cartridge and is a primary pressure boundary component.)

9. Motor speed not zero.

10. X and Y radial displacement (two per pump), total of eight channels.

11. Motor breaker status.

12. Lower seal temperatures.

13. Axial shaft displacement.

The 1-1 and 2-1 pumps will receive additional new instrumentation. Therefore, two (one per pump) of each of the following sensors will provide input to the diagnostic system:

1. Upper motor bearing accelerometer.

2. Lower motor bearing accelerometer.

3. Pump bearing accelerometer.

4. Key phasor probe.

In addition, a resistance temperature detector (RTD) will be installed in the containment building to provide reference compensation for the lower seal stage thermocouples (since all existing usable penetrations are copper). However, this additional RTD is not an input to the diagnostic system.

The 1-1 and 2-1 pumps are located in opposite RCS loops. The 2-1 pump is located in the same loop as the pressurizer. The No. 2 loop pumps are subjected to longer periods of operation at low RCS pressures since they are needed to provide a driving head for pressurizer spray. Therefore, these pumps are normally the first ones started for heatup and are also the last secured during cooldown. Conversely, the No. 1 loop pumps are the last ones started and the first to be secured during heatup and cooldown, respectively.

Thus, adding full new instrumentation to one pump in each RCS loop should provide a maximum of useful data in terms of rotordynamic analysis at a reduced cost compared to fully instrumenting all four RC pumps. Finally, the failure rate of 1-1 RC pump seals has historically been higher than the other three pump seals for reasons that are not understood. Therefore, the 1-1 pump was chosen, rather than the 1-2 pump, in the No. 1 loop. The 2-1 pump was selected arbitrarily.

2.3.2.2. Site Computer System

In all modes of system operation, the various tasks and decisions made by the system are to be controlled by an Intel 8086 16-bit microcomputer. All system intelligence (or software) used by the computer will be contained in magnetic core memory or read only memories (ROM). Thus, the system will return to the automatic data acquisition mode of operation following a loss of electrical power without human interaction.

The user can select from three modes of system operation: automatic monitoring, pump seal analysis, and vibration analysis. These modes of operation are described briefly below (see Figure 5).

Automatic Monitoring (Figure 6)

The system will continuously gather pump and plant performance data from most of the input sensors listed in section 2.3.2.1. Some inputs, related to rotating machinery diagnostics, will be monitored in a programmed sequence for spectral analysis. Pairs of inputs may also be monitored simultaneously for cross-channel spectral correlation during the sequence.

Performance will be analyzed for each data set arriving in the system computer. The results of these calculations will be compared against setpoint criteria residing in the computer. Any significant changes in pump performance or the detection of previously defined plant transients will cause the computer to take one or more of the following actions:

- Provide a hard copy printout sufficient to identify the change that has taken place; also provide the time/date of change, current value, and appropriate plant parameters. (This action is taken in all cases while in the automatic monitoring mode.)

- Change the data logging frequency. An example might be to record performance data every 5 seconds instead of every 5 minutes. (A dual magnetic tape cartridge system will be used to store and retrieve data. Steady-state and transient recording intervals can be modified by the system operator.)

- Modify the sequence and type of data related to spectral analysis. An example would be to automatically capture pump coastdown or startup rotordynamic information upon sensing a change in motor breaker status.

- Alarm outputs to the Davis-Besse control room can be provided as an inexpensive option at a later date. (This decision would be made by Toledo Edison after the system has proved to be consistent and reliable.)

Figure 5. Executive Routine Software Flow Chart

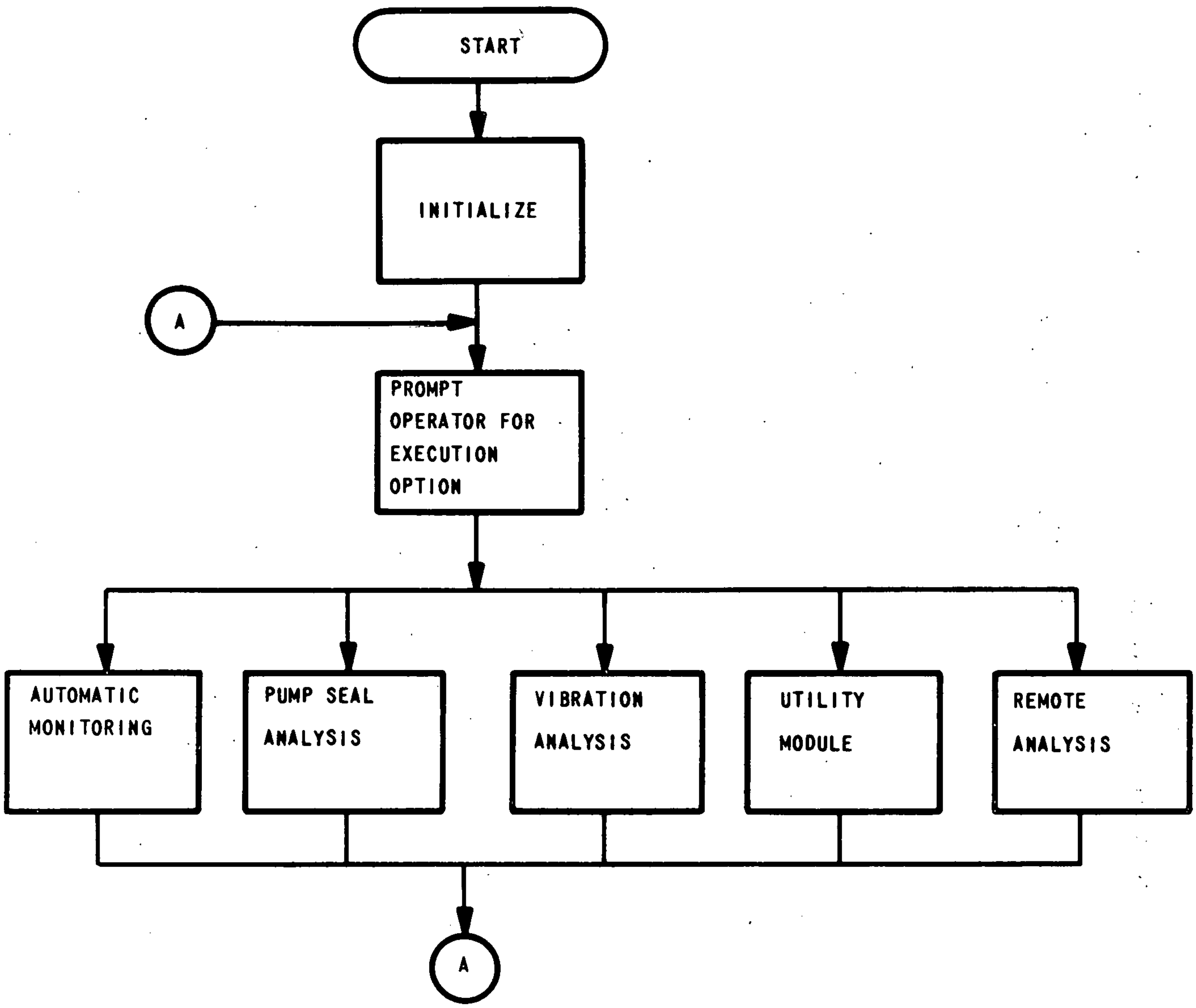
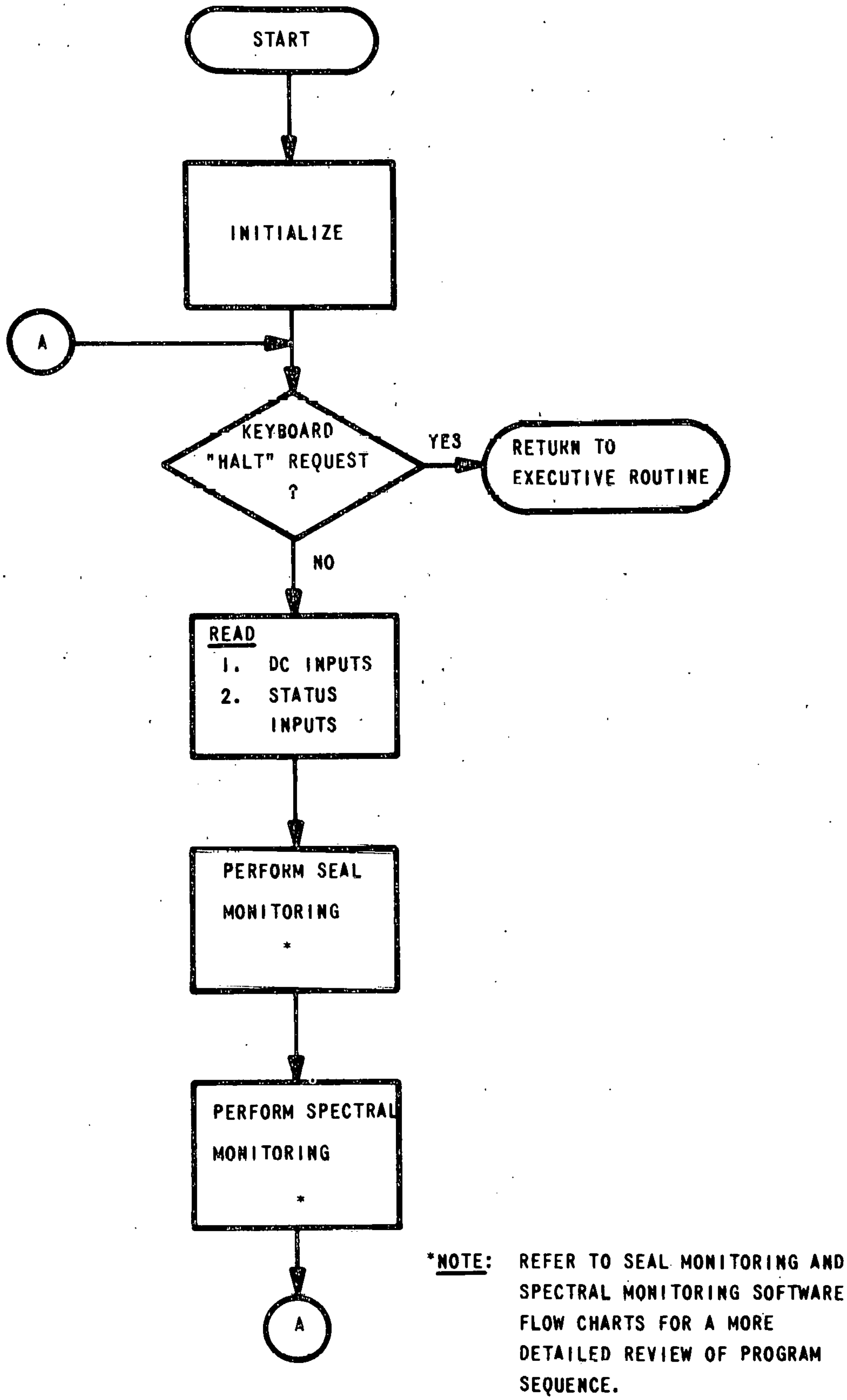


Figure 6. Automatic Monitoring Software Flow Chart



The actions listed above are designed to provide detailed reliable and consistent performance records and, as a future option, to automatically alert plant operators of significant changes in performance.

Pump Seal Analysis (Figure 7)

The pump seal analysis mode of operation will include several user-oriented options to inspect and interpret recorded data. Both RC pump performance and plant parameter data can be evaluated in this mode. Inspection and interpretation of data include the ability to plot selected performance parameters and perform trend analysis.

Program setpoint constants, including those used for alarms and transient identification, can be inspected and/or changed by the user. Finally, the user can request a seal status report. The printed report would include a "snapshot" of both pump and plant conditions existing at the time the request was made and the results of performance calculations. The status of any existing alarm or transient condition would also be provided in the report.

Vibration Analysis (Figure 8)

Spectral analysis data can be inspected and interpreted in a manner similar to the pump seal analysis mode of operation. Individual spectral plots can be printed on the printer/plotter, including cross-correlation spectra of two channels.

Other features of vibration analysis include the ability to change the program sequence for spectral analysis, change alarm levels, and take manual control of the spectrum analysis.

2.3.2.3. Remote Computer

A remote computer system will be available for use during the data acquisition and analysis task. This system, shown in Figure 4, will be located at B&W facilities in Lynchburg, Virginia.

The remote computer will have the same capability as the site computer to inspect and interpret data stored on magnetic tape cartridges. In addition, the remote computer will be able to communicate with the site computer (Figure 3) via a telephone link for a variety of functions. Two primary objectives will be addressed in designing the functions that can be performed via the remote computer telephone link:

Figure 7. Seal Monitoring Software Flow Chart

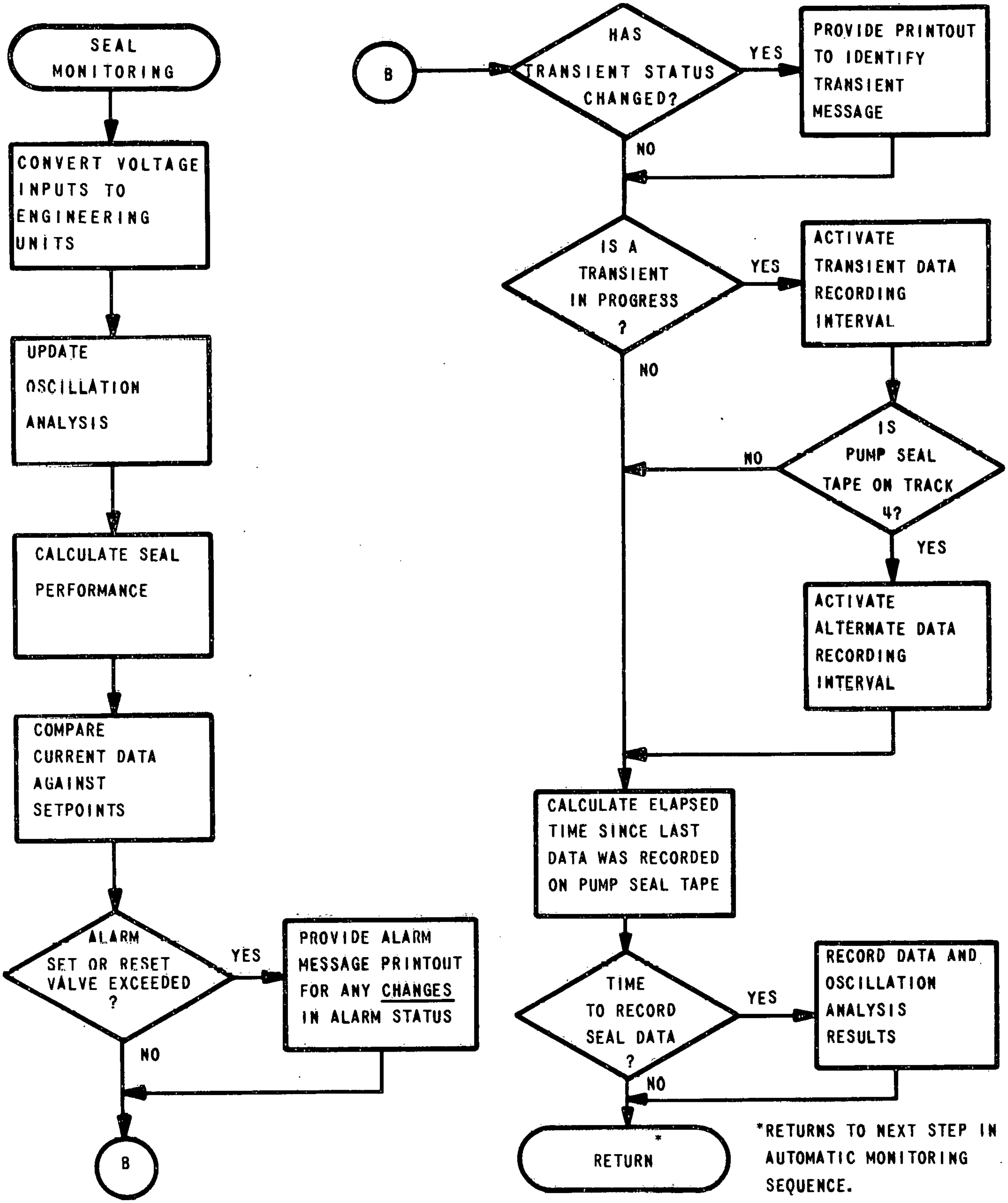
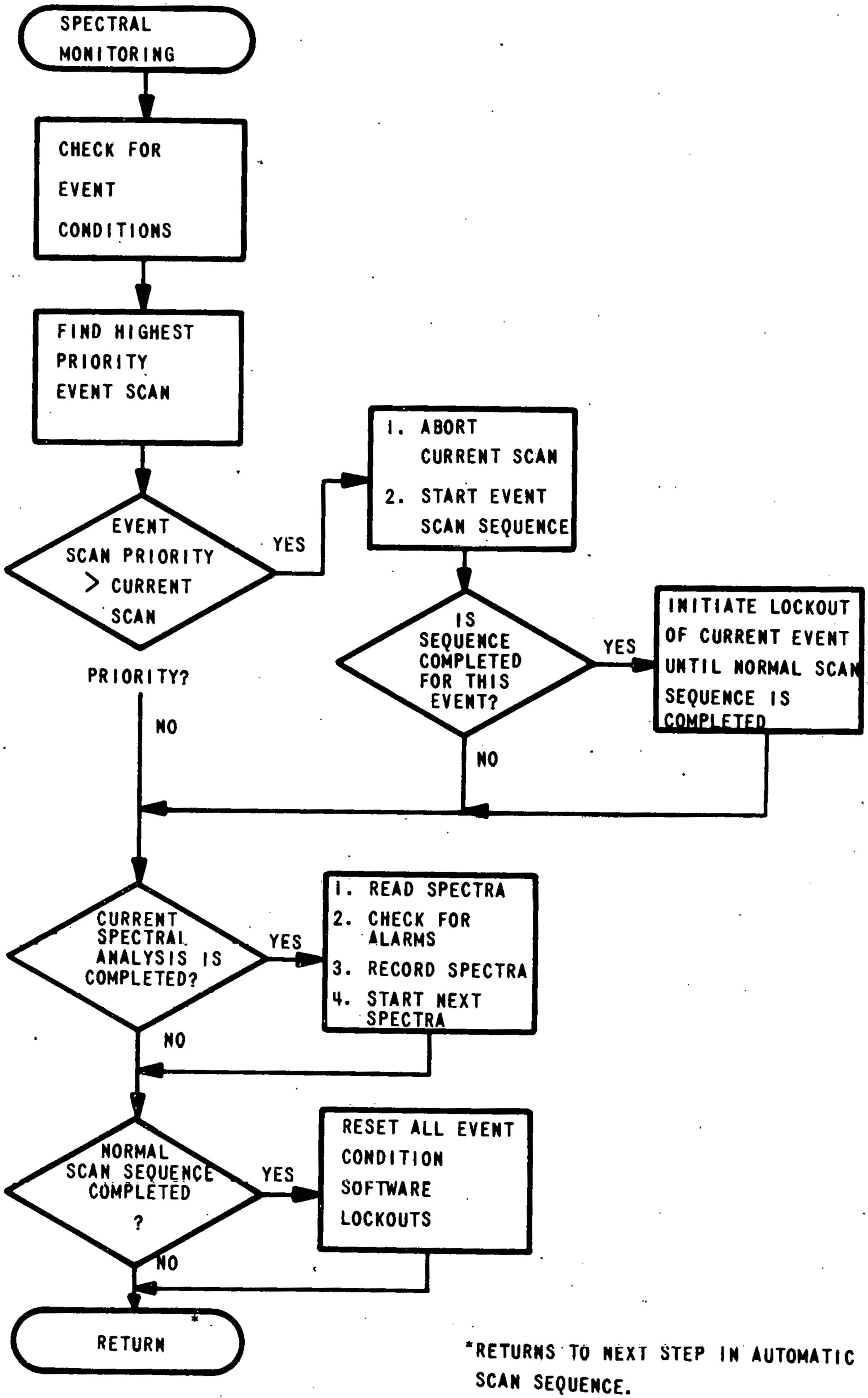


Figure 8. Spectral Monitoring Software Flow Chart



- Provide the ability to obtain on-line data via the telephone line.

- Maximize the ability to change setpoints and software control functions remotely.

More important, these remote functions will be independent to the extent that, where possible, NO assistance would be required at the site computer to carry out a given function.

2.3.3. Related Programs

2.3.3.1. Introduction

The uses of the diagnostic system data to Toledo Edison (TECo) have been described by the program objectives. These data are expected to benefit other programs which are evolving within the nuclear industry to solve problems with RC pump seals. The participants in these programs include the Department of Energy, the Electric Power Research Institute, and a utility organization. The utility organization comprises five utilities, Babcock & Wilcox, and the Byron Jackson Pump Company. The overall program is called the Pump Seal Improvement Program (PSIP),

Representatives of DOE, EPRI, the PSIP, and others met in November 1981 to review current pump seal efforts. The potential benefits of information exchanges, rescheduling, consolidation, and/or new program efforts are expected to be considered as a result of this review. Examination of these areas may result in a more comprehensive and coordinated effort to resolve pump seal problems. The avoidance of duplicated effort is also viewed as a potential benefit.

Since it has become clear that data from the TECo/DOE project are likely to be used by the PSIP group, it is appropriate to describe the PSIP structure and program direction in more detail.

2.3.3.2. PSIP Description

The following utilities are participating in the program:

Utility	Plant Site/Units
Toledo Edison (TECo)	Davis-Besse Unit 1
Arkansas Power & Light (AP&L)	Arkansas Nuclear One (ANO) Units 1 and 2
Florida Power Corp. (FPC)	Crystal River Unit 3
Consumers Power Company (CPCo)	Midland Units 1 and 2
Maine Yankee (MY)	Maine Yankee

All of these plants have Byron Jackson reactor coolant pumps. The nuclear steam system (NSS) vendor for both Maine Yankee and ANO Unit 2 is Combustion Engineering. For all other units, B&W supplied the NSS. Midland Units 1 and 2 are under construction with hot functional testing to begin in 1983/1984. The units listed for TECo, AP&L, FPC, and MY are operating units that have exprienced varying degrees of difficulty with RC pump seals.

The PSIP Project Team consists of an executive steering committee and a technical committee. The executive steering committee comprises officers from B&W, Byron Jackson, and each of the five utilities. The technical committee includes engineering and/or program management representatives from each company. The activity level has been such that both the executive and technical committees have been meeting every four to six weeks. The program was started as a result of a technical conference held by B&W in Atlanta in March 1981. The accepted charter of the group consists of short- and long-term goals, which are stated as follows:

- Short Term — To reduce lost capacity days due to seal problems by 50% (in approximately one year).
- Long Term — Increase average seal life to three to four fuel cycles (based on a cycle of about 18 months).

The major elements of the short-term program, which are underway, consist of Phases I and II. The long-term program will include complete redesign of the seals for the BJ pumps and their implementation in the field. Planning, scheduling, and cost proposals are being formulated for the Phase III program at this time.

The short- and long-term programs and the relationship of the TECo/DOE RC pump monitoring and diagnostic system project to these programs are described below.

2.3.3.2.1. Short-Term Program — Phases I and II

Design Upgrade

The technical committee agreed that certain minor modifications to the existing BJ seal design had a high potential for improving seal life and performance stability. A test program for the modified seal was completed successfully in early November in the Seal Test Laboratory at Byron Jackson's Los Angeles facilities.

Modified or partially modified pump seal cartridges have also been installed in two RC pumps at Maine Yankee, one pump at ANO-1, and three at Davis-Besse Unit 1. The three Davis-Besse pumps have only increased seal staging flow implemented, which is considered a very minor (although important) change.

Recommendations regarding further implementation of modified or partially modified seals will be formulated after formal review of the test program at Byron Jackson. Field experience up to that time will also be a part of the data base on which the recommendations will be based.

Operating Environment

In many cases, short seal life has been attributed (in part) to the environment in which the seals must operate. The seals are sometimes subjected to pressure and temperature transients, frequent start/stop cycles, off-design operating conditions, or other perturbations that have had an obvious effect on seal performance. The seal operating environment is largely determined by the seal injection system, component cooling water system, and controlled bleed-off system. In addition, plant operating procedures and methods can be important factors in the pump and pump seal environment.

These factors are under continuous evaluation by the group. Procedural and minor hardware changes have been made or are being considered. The emphasis so far has been to devise changes that can be implemented in a timely, cost-effective manner. The need for more extensive hardware changes will be considered after evaluating the changes in performance that occur as a result of implementing less costly modifications to hardware and operating procedures.

Instrumentation

Currently, pump seal performance data are not generally available to plant operators in a format consistent with recommended operating limits. Further, much of the data that are available cannot be time-phase correlated.

A variety of approaches has been discussed to address these concerns. Additional instrumentation would provide the plant operator with appropriate information to avoid equipment failure. Proper time-phase correlation of data in conjunction with additional instrumentation would provide reliable and consistent performance records to:

- Properly judge the need for maintenance and avoid unnecessary tasks of this nature.

- Provide sufficient engineering data for failure analysis.

- Provide a detailed data base on which to formulate a new seal design, i.e., accurately quantify the operating environment.

The TECo/DOE Pump Monitoring and Diagnostic System Project will demonstrate an automated method for providing the data in the format required to make these maintenance- and performance-related decisions.

In addition to the TECo/DOE project, B&W has begun to write functional specifications for a pump monitoring system for AP&L and FPC. This system will essentially be a scaled down version of the TECo/DOE project, with less new instrumentation and no built-in spectral analysis capability. Therefore, these systems will not have the ability to provide the data required to correlate seal performance with pump/motor rotordynamics.

However, these systems will provide some time-phase correlated data and improved performance data to the plant operators. A proposal to build the systems will be provided to the FPC and AP&L after functional requirements have been agreed upon and the hardware configuration has been selected.

Other Areas

Maintenance, training, and quality assurance (QA) are other areas that require more attention. These areas of concern are being reviewed by the PSIP group with a number of specific corrective actions taken by the utilities. The judgment is that significant improvements in pump seal performance will result if better procedures and training programs are provided to both plant operators and maintenance personnel. The seal operating history suggests that many cost-effective QA improvements could be implemented, especially in the area of replacement parts.

2.3.3.2.2. Long-Term Program — Phase III

The long-term goal of the PSIP group is to achieve an average seal life of three to four fuel cycles. The consensus of the PSIP group is that the current BJ seal design cannot achieve that goal, and a new seal design will be necessary.

A proposed program to develop a new seal design is under consideration by the PSIP group. The Phase III effort would produce a new design which would be ready for prototype installation in the operating plants in 1984 or 1985.

A listing of preliminary design specifications has been generated to serve as a basis for a conceptual design. The vendor will have the design responsibility. Other members in the PSIP group will have access to design-related materials and will provide input to design specifications and design review/analysis functions. Essential ingredients to the Phase III effort include the following:

- An accurate data base characterizing the pump seal operating environment.
- Development of a new seal design.
- Analytical/computer verification of the design against operating environmental data.
- Design and fabrication of a new or modified test facility that can duplicate the field operating environment.
- Fabrication of test seals.
- A test program of at least 5000 hours to verify the design.
- Fabrication and implementation of prototype seal cartridges in operating plants.
- Assessment of prototype seal performance to determine the desirability of widespread implementation of the new design.

The TECo/DOE RC Pump Monitoring and Diagnostic System Project will provide the needed detailed operating environmental data. The other proposed monitoring systems, discussed earlier for FPC and AP&L, probably will not be implemented in time to produce data for the seal design or test facility design activities in Phase III. Also, the proposed systems would not provide seal performance data correlated with spectral analysis of rotordynamic performance.

The TECo/DOE project is scheduled to provide the desired data immediately following the spring 1982 Davis-Besse refueling outage. The characterization of rotordynamics as related to pump, pump seal, and plant performance will be a valuable asset. It will help to ensure that a new seal design can meet or exceed performance goals.

2.3.4. Task 1 — System Design and Interface Requirements

B&W work on this task is about 90% complete. The task is expected to be completed in January 1982.

Summary Status of Completed Work

Subtask 1.1 — Determine Major Site Interfaces

This subtask was completed in January 1981 when an interface and installation plan was issued.

Subtask 1.2 — Develop System Functional Requirements

A draft version was completed in July 1981. Comments and revisions to the document were solidified in September 1981. Preparation of a final document will be completed in December 1981.

Subtask 1.3 — Select and Interface System Hardware

This subtask is about 70% complete. The work remaining is primarily installation of the equipment in the cabinet. A revised hardware listing was prepared in January 1981 to take advantage of improved equipment and to provide a detailed listing of miscellaneous hardware.

Subtask 1.4 — Prepare Station Modification Interface Requirements

This subtask is about 85% complete; final interface drawings are being prepared. A B&W representative entered the Davis-Basse containment building at the end of November 1981 to select final sensor locations with Bechtel and UE&C representatives. This subtask should be completed in December 1981; it includes a scheduled Project Team meeting with B&W/Bechtel/TECo and UE&C.

Subtask 1.5 — Prepare Station Modification Details

This is primarily a TECo/Bechtel task. Bechtel is expected to complete the field change package material in December 1981. B&W is reviewing the preliminary material to ensure proper interface.

Interface issues have been a long and complex task, starting with the first Project Team meeting in October 1980. Several significant activities were not anticipated in the original workscope estimates:

- A technical feasibility assessment of implementing the project in a TECo computer (as opposed to a separate microcomputer system specified by B&W).

- A higher level of effort was required for proper interface in terms of correspondence, coordination, and Project Team meetings.
- Evaluation of various project cost alternatives. These evaluations resulted in the current workscope for the project while retaining the maximum technical value.

A summary of work that has been completed and the work remaining to complete Task 1 is provided below for each of the five subtasks within Task 1.

2.3.4.1. Subtask 1.1 — Determine Major Site Interfaces

Work on this subtask began in October 1980 and was completed in January 1981 with the delivery of an interface and installation plan. Extra work and Project Team meetings were required in the early stages of the contract to achieve an appropriate level of understanding among Project Team members. Project Team meetings were held in October and November 1980 and in January and February 1981.

Initial technical issues evolved around the equipment cabinet for the diagnostic system and the use of an existing computer system. It was agreed that in addition to a cabinet for the diagnostic system, a separate cabinet would be needed to isolate the majority of input signals to the system. Concerns included (1) isolation of potential interference between the plant computer and the DOE project system multiplexers (since many of the desired inputs would be supplied from the plant computer input cabinets); and (2) since the diagnostic system is an R&D project, additional isolation was prudent to ensure that a malfunction within the system would not result in transmitting false information or a loss of parameters to Davis-Besse plant operators.

Physical space to locate two cabinets was at an extreme premium. The DOE project cabinets were competing for physical space that would otherwise have been occupied by other equipment required to be installed at Davis-Besse. Alternative locations were investigated, including the cabinet room (adjacent to the operator area in the Davis-Besse control room) and the cable penetration rooms. The cable penetration rooms are located in the radiation access control area (RACA), which was determined to be an undesirable environment for those who would operate the diagnostic system. After a significant effort on the part of TECo and Bechtel, the currently planned location in the Davis-Besse cabinet room was finalized (adjacent to the control room).

Another alternative considered was to implement the DOE project functionally within a separate TECo somputer system. TECo had purchased two Prime 550 computer systems to be used in conjunction with the required Emergency Response Center. B&W provided a technical evaluation of this alternative at TECO's request. Several problems were cited with regard to this approach:

- Interface difficulty in terms of B&W attempting to write appropriate software for a TECo computer. A duplication of software development effort would also have been required to implement remote analysis capability for a separate B&W computer system. Optimizing system software during Task 4 would require a similar duplicated effort.

- Prioritization of software tasks within the TECo computer as opposed to the advantages of a dedicated system.

- Installation of separate cabinets would still be required to provide rotating machinery diagnostic functions and other hardware-related requirements. Thus, it was determined that very little space would be saved at a high cost premium.

- There were concerns about the ability to implement diagnostic system functional requirements in the TECo computer. The large number of inputs to the TECo computer would have restricted the effective input signal sampling rate to the point where additional hardware would be necessary for functional interface.

The conclusions reached were (1) a separate dedicated computer would very probably be required to implement the project on a TECo computer, (2) total program costs would increase substantially, and (3) little or no physical space would be saved. Therefore, TECo and B&W agreed that the B&W-specified computer system would be a requirement to proceeding with the contract work.

The original schedule for the project called for the refueling outage to begin between October 1, 1981, and April 1982. The schedule called for B&W, TECo, Bechtel, and UE&C to be ready for diagnostic system installation at the beginning of October. Therefore, procurement of materials, planning, scheduling, and allocation of manpower resources were all of critical importance to support this schedule. Major activities at that stage of contract work included the following:

- Prioritization of inputs to the diagnostic system to ensure that basic functions would be implemented first if all work could not be completed on time.

- Determination of interface requirements was required to finalize hardware needed and the detailed engineering workscope.

- Seismic qualification of both the diagnostic system cabinet and the Bechtel-designed interface/buffer cabinet (to ensure that neither cabinet would become a missile hazard in the cabinet room during a seismic event).

- Identification of new diagnostic system inputs beyond those listed in the March 1979 technical proposal. These changes added technical value to the project by incorporating the benefits of B&W experience with RC pumps in the interim time frame.

- Changes to major equipment identified in the March 1979 proposal for the diagnostic system. These changes were made to accommodate improved functional capability with the latest equipment in a cost-effective manner. These changes also reflected the benefit of additional experience with Byron Jackson pumps. Expeditious identification of miscellaneous hardware, such as rack mounts, connectors, miscellaneous electronic equipment, and spare parts, was required.

To summarize, it is reasonable to state that the coordination and the accomplishments of the Project Team during the first few months of the contract were significant. The leadership and teamwork that evolved reflected a sense of dedication to meeting program objectives.

After February 1981, the refueling outage schedule gradually moved outward to its present schedule to begin February 26, 1982. During this time, recommendations for and evaluations of cost reduction alternatives were made. This ultimately led to the current reduced scope of the project in terms of cost while retaining the maximum technical benefit.

Also during this time, RC pump seal problems at Davis-Besse and other B&W customer plants were creating very serious problems in terms of forced outages, lost generating capacity, and concerns about high leakage failure/radiation exposure (such as the failure at ANO-1 on May 10, 1980).

In order to respond properly to the serious nature of these problems, B&W requested schedule extensions to address the immediate concerns of pump seals. The primary criterion has been to ensure that the major goal of installing the diagnostic system at Davis-Besse on schedule would not be jeopardized.

As a result of the efforts to resolve pump seal problems, a B&W/Byron Jackson pump seal users group program, primarily funded by the utilities, was formed as described in section 2.3 of this report. The TECo/DOE diagnostic system is now considered to be an important supplement to that program, as previously described.

2.3.4.2. Subtask 1.2 — Develop System Functional Requirements

A draft version of diagnostic system functional requirements was completed in July 1981. This work is about 95% complete. The final document is to be released in early December 1981. Work remaining for completion is to review comments, primarily of an editorial nature, and final document preparation. All technical content has been completed and agreed to by all necessary technical and administrative personnel in the project. Software development and hardware interface have continued based on these agreements.

Section 2.2 of this report describes only briefly a few of the key requirements of the diagnostic system. The "user friendly" approach has been emphasized in developing these requirements. The system is designed to display functional options to the user, each of which is selected by two or three keystrokes on the operator keyboard. As a result, during normal operation in using the system, the need to refer to a system operating manual should be minimal.

The majority of effort in this subtask was related to the following major items:

1. Development of functional criteria to perform on-line analysis of seal cavity pressure oscillations.
2. Mapping a multi-level matrix to functionally describe pump and plant conditions in terms of (a) detecting instrument malfunctions, (b) performance-related alert/alarm set and reset levels, and (c) criteria on which to determine data storage intervals.
3. Data retrieval, analysis, and plotting requirements.
4. Requirements for rotating machinery diagnostics.

The only significant difficulty encountered was in the area of rotating machinery diagnostics. B&W had established a previous experience basis in this area with the development of the CASA system. An incorporation of the same technology into the RC pump monitoring and diagnostic system had been planned.

The goal was to obtain detailed rotordynamic data and attempt to correlate these data with pump and pump seal performance.

It was determined in developing the functional requirements that a high potential existed for improving total system performance by making a few changes. The changes that were desired would provide for interruptions to the normal spectral analysis sequence in order to obtain detailed data in a desired area. The interruption would occur as a result of a change in some status indicator or exceeding a software setpoint. An example would be to obtain an immediate spectral analysis of a given pump during startup or coastdown. It was recognized that much valuable data would not be gathered if this function could not be implemented.

Upon completion of the draft functional requirements, certain problems were identified. For example, a continuously stuck faulty alarm condition would have resulted in continuously gathering certain spectral data on one RC pump while ignoring the other three pumps. As a result of meetings and some brainstorming, the Project Team members from B&W's Lynchburg Research Center (LRC) facility produced a functional scheme. Their scheme was accepted as a sound and viable solution for finalizing the functional requirements. It involves a four-level priority interrupt scan sequence, which adequately addresses all of the identified technical problems.

2.3.4.3. Subtask 1.3 — Select and Interface System Hardware

This subtask is about 70% complete. It is currently scheduled for completion in January 1982. The major item left to complete this work is to assemble the diagnostic system in the cabinet. Delivery of a cabinet to the LRC is scheduled for January 1, 1982, and final assembly will take two weeks.

Electrical checkout and interfacing of the wide variety of electronic equipment for this project has been a long and complex task. It was difficult to determine how to fit all of the equipment into the cabinet while retaining system operator interface equipment in appropriate positions.

Seismic analysis of the cabinet for the diagnostic system has not proceeded smoothly. A preliminary analysis was unable to conclude satifactory response for the cabinet based on previous data for a similar cabinet. It is a requirement that neither the cabinet nor the equipment inside will become a missile hazard in the cabinet room during a safe shutdown earthquake (SSE) event. B&W and TECo have agreed to a plan that delivers a qualified cabinet to the LRC by January 1, 1982.

The cabinet will be structurally modified and additional tests and analyses will be performed to meet this schedule. Both B&W and TECo have identified timely completion of this item as critically important to the total project schedule for installation of the diagnostic system.

As described in section 2.2, a remote analysis computer system will be built at the LRC. This system will be available for use in this project during the data acquisition task. All major hardware components for the system have been purchased and received by B&W to support this project.

There was a considerable delay before an Intel SBC-337 Math Module suitable for use in the diagnostic system was received. This module was actually ordered by B&W for the remote computer, but it is being used temporarily for development of the site computer.

The two modules for the site computer (including one spare) have not been received by B&W. It is B&W's understanding that the long delays (nearly a year) have been due to severe problems with production yields on these modules at Intel. It is anticipated that an appropriate number of modules will be available by the time the diagnostic system is installed in spring 1982. These modules were introduced as a new product in the fall of 1980 and offered distinct technical improvements to system design.

During checkout of the Vitec accelerometer monitoring panel, a problem was found with the reset function. The panel has been returned to the vendor for repairs. The project schedule is not impacted by this malfunction.

It has been determined that an additional hardware interface will be necessary to meet system functional requirements. B&W will need to purchase separate signal conditioning equipment to provide average radial shaft displacement and axial shaft displacement to the DC input multiplexer. Resolution is expected without impacting the project schedule.

2.3.4.4. Subtask 1.4 — Prepare Station Modification Interface Requirements

This subtask is about 80% complete. It has primarily involved follow-up activities, meetings, and telephone conversations to clarify the interfaces between the B&W-specified system and Bechtel engineering work following completion of subtask 1.1. Sketches were also prepared to depict termination panel layout and location in the site computer cabinet.

A B&W/TECo/Bechtel interface meeting was held in late November 1981. In response to this meeting, B&W will prepare interface drawings that will best meet Bechtel/TECo needs. This meeting and subsequent interface drawings to be released will complete this subtask. These drawings will take the place of a B&W Station Modification Plan, previously thought to be necessary.

It is appropriate to note that work within this subtask has included B&W personnel traveling to the Davis-Besse site to work with Bechtel/TECo in identifying the best locations and plans for installation of new in-containment sensors at the RC pumps. Both the RC pump and motor vendors were also contacted to obtain technical concurrence with accelerometer mounting techniques and locations.

2.3.4.5. Subtask 1.5 — Prepare Station Modification Details

This is primarily a TECo/Bechtel subtask. B&W will discuss and review the Bechtel-prepared field change material in an advisory capacity to ensure that interface issues have been properly addressed. Most of this work is expected to be completed in December 1981, in accordance with the current schedule and proposed Project Team meeting date.

2.3.5. Task 2 — System Development and Station Modifications

Work performed within this task has been on subtask 2.1, "Develop System Software." Software development began in April 1981 and is being carried out at the LRC. The work is proceeding at an accelerated pace to meet the scheduled completion date of December 1, 1981. Work on subtask 2.2, "Check Out System In-Lab," and subtask 2.3, "Execute Station Modifications," will not begin until January 1982.

Software development for the site computer system is nearing completion. Most of the pump seal analysis computer routines are operational, incuding seal performance calculations, seal alarm functions, and seal status reports. Significant portions of the seal magnetic tape query program are in place and are being tested. In November 1981, microcomputer-controlled seal analysis was demonstrated to TECo and Bechtel personnel on the LRC prototype system.

The major remaining software task is the completion of rotating machinery analytical and diagnostic routines. Work in the rotating machinery area has centered on providing computer-to-spectrum analyzer communications and computer control of the dynamic signal multiplexer. The remaining routines to be written will make heavy use of these hardware interface functions while monitoring rotating machinery instrumentation.

An obstacle to software development progress has been the late delivery of the Intel SBC-337 Math Module. This delay was partially overcome through the use of a Math Module "emulator" provided by Intel. In addition, implementation of some system functions has had to await firming up of the system functional requirements.

Several areas in software development will provide unique capabilities, and have presented a special challenge:

Cavity Pressure Oscillation Analysis

Functional requirements specify that for an effective analysis, all cavity pressure channels must be sampled at least 10 times per second during automatic monitoring. Note that this computation must be performed continuously on all four RC pumps and "in parallel" with the seal performance and spectral analysis computations.

User-Defined Data Recording Intervals

In order to maximize the lifetime of a magnetic tape, the computer should record performance at long time intervals during steady-state operation and rapidly during pump transients. The site computer implements this feature by allowing separate, user-defined recording intervals for normal and transient operating modes. The user can specify a third interval to limit recording when track 4 (last track) of the tape cartridge has been reached.

User-Friendly Setpoint Update

The site computer uses a sophisticated alarm detection algorithm including multi-level alarm set/reset thresholds, transient set/reset values, and a four-priority-level spectral analysis sequence. To provide a "user-friendly" method for maintaining the large data base of setpoints, the site computer has been equipped with a series of simple setpoint "menus." From these CRT-displayed menus, the non-computer-oriented user can quickly query and update any constant or setpoint in the data base.

Performance History Query

The performance history of the pumps will be recorded on magnetic tape by the site computer, which will allow the user to query this history data base and produce user-defined plots and printouts of pump parameters over selected time frames.

The majority of the pump seal analysis portion of the software has been generated. Much of the rotating machinery diagnostic software has also been completed. Software for the site computer is scheduled for completion in December 1981. Software for the remote analysis computer is scheduled to be implemented in January 1982.