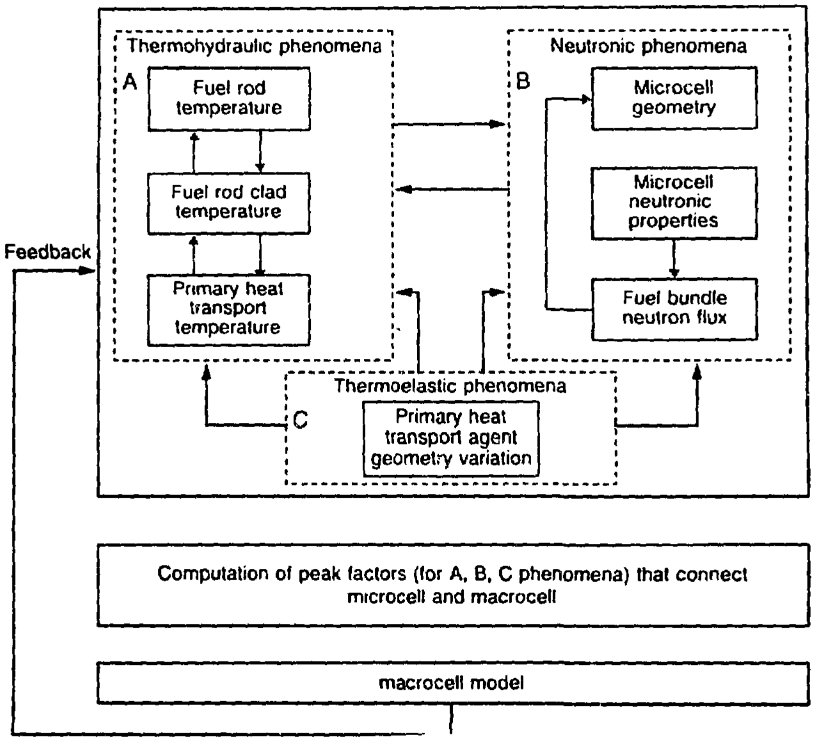


Thermohydraulic phenomena
A
Fuel rod temperature
Fuel rod clad temperature
Primary heat transport temperature
Neutronic phenomena
B
Microcell geometry
Microcell neutronic properties
Fuel bundle neutron flux
Thermoelastic phenomena
C
Primary heat transport agent geometry variation
Feedback
Computation of peak factors (for A, B, C phenomena) that connect microcell and macrocell
macrocell model

Fig 4

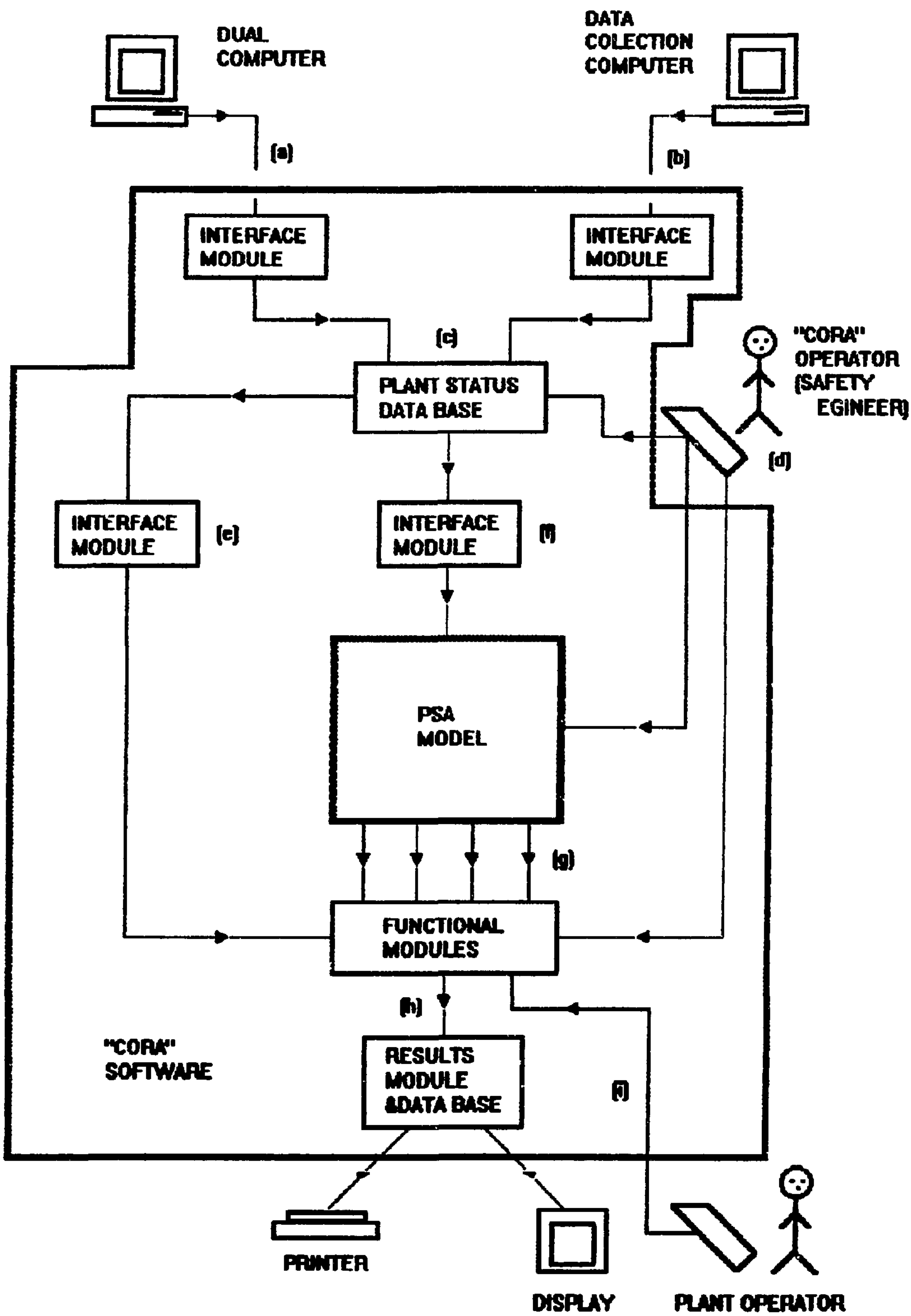
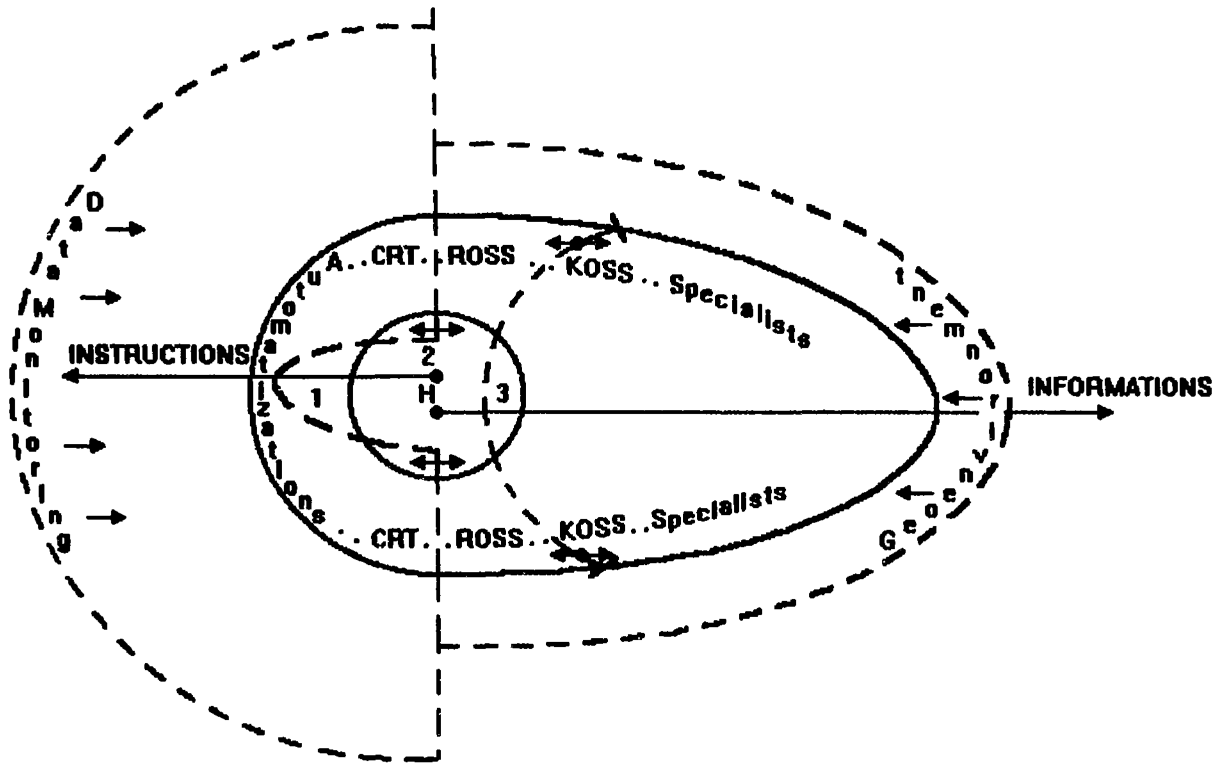


FIG. 5 "CORA" CONCEPTUAL TOP-LEVEL DESIGN

The Man - Machine Dichotomy ?



1. Hard Control (Skill) ⟶ Procedural Behaviour
2. Soft Control (Rule)
3. Creative Control (Knowledge) ⟶ Creative Behaviour

ROSS – Rule Operator Support System

KOSS – Knowledge Operator Support System

OPERATOR SUPPORT SYSTEMS ACTIVITIES AT EPRI

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Introduction

In recent years, the requirements on nuclear power plant personnel to improve availability, reliability, and productivity and to reduce safety challenges to the plant have increased. These personnel are working with more complex systems, and responding to increasing operational, regulatory and productivity demands. As tasks become more complex, involving large numbers of subsystem interrelationships, the potential for human errors increases. Therefore, reliable, integrated information is a critical element for protecting the utility's capital investment and increasing availability, reliability, and productivity. Integrated systems with integrated information access can perform more effectively to increase productivity and enhance safety. Traditionally systems have been implemented in a stand-alone manner which has resulted in increased operation and maintenance costs. Increased competition in the utility industry in the United States makes it essential that these operating and maintenance costs are minimized. Technology can be used to assist plant personnel and reduce the potential for human errors. At the same time, it can support improved productivity and the reduction of overall operating and maintenance costs.

Operational, diagnostic and monitoring errors have all occurred in power plants causing reductions in availability and substantial cost consequences. Plant safety has been challenged due to misinterpretations of data and incorrect assumptions of plant state. The event at Three Mile Island is an example of this. Since this event, a number of operator support systems have been implemented such as the safety parameter display system (SPDS), boiling curve displays or tables, and emergency operating procedure flow charts. Some of these operator support systems utilize expert system technology. They have all been useful in assisting humans in making their decisions.

Expert systems have reached a level of maturity where they offer considerable benefits for operator support systems in nuclear power plants. The ability of expert systems to enhance human expertise makes them an important tool for the nuclear utility industry in the areas of engineering, operations and maintenance. Benefits of expert system applications include comprehensive and consistent reasoning, reduction of time required for activities, retention of human expertise and ability to utilize multiple experts knowledge for an activity.

JAN.0117.P

Background

The Electric Power Research Institute (EPRI) Instrumentation and Control Upgrade Initiative is designed to help utilities upgrade the I&C systems in their plants. Operator support systems are included in this Initiative. The goal of this initiative is "Develop the methodology applicable to each reactor vendor type plant to implement an integrated instrumentation and control (I&C) upgrade plan. Demonstrate the methodology through utility application to at least ten key systems by the year 2000 to achieve enhanced safety, reduction in operating and maintenance costs, increased plant performance and reduced vulnerability to I&C obsolescence.". To support this goal, there are seven technical elements. These are Instrumentation, Control and Protection, Man-Machine Support Systems, Communications, Software Verification and Validation, Maintenance, and Standards and Specifications. Operator support systems are handled under the Man-Machine Support Systems element. Communications provides the infrastructure for making the correct information available to the operator support systems and software verification and validation provides methods to assure the quality of the operator support systems.

Integration is a key word in the EPRI I&C Upgrade Initiative. First, there is the integrated life cycle management plan which looks at the entire plant and evaluates and plans all of the upgrades in an integrated manner. Second, is the integration of the plant systems and information to enhance cooperation between systems. This also supports the reduction of unnecessary duplication of functions and information. Figure 1 shows the integrated I&C upgrade process and figure 2 indicates the methodologies being developed to support the upgrade process.

The objectives of integrating plant systems and information are to improve plant availability and reliability, to reduce operations and maintenance costs, to reduce safety challenges, and to improve performance with existing and new systems. The plant communications and computing architecture of the Communications element supplies the infrastructure which allows the integration of systems and information. This architecture will support the interoperability of operator support systems. The EPRI Plant-Window system of the Man-Machine Support Systems element allows the human to interface with the integrated plant systems and supplies a platform for operator support systems.

The capabilities and benefits for expert systems and their potential for operator support systems was realized by EPRI in 1983. At that time the Control, Diagnostics, and Information Program in the Nuclear Power Division of EPRI initiated activities for developing expert system technology. Since then, expert system technology has been utilized to develop operator support systems building on the utilities' knowledge bases.

Plant Communications and Computing Architecture

The plant communications and computing architecture activities support the operator support systems by providing the mechanism for integrating systems, for providing access to all of the plant's information sources, and for facilitating common interfaces between the human and the machine. Figure 3 is a representation of this architecture. EPRI is developing a generic methodology for the creation of Plant Communications and Computing Architecture Plan (PCCAP) which will define the requirements for the communications and computing architecture at a power plant. EPRI is currently working with five nuclear utility demonstration plants to help them develop their own Plant Communications and Computing Architecture Plans. Feedback from these demonstration plants have been used to improve the generic methodology which can be utilized by all utilities. The use of the methodology has already demonstrated benefits in the demonstration plant activities. The process this methodology describes is shown in figure 4.

Through the use of this generic methodology and its associated workbook [1, 2], both of which will be published by the end of 1993, utilities will be provided road maps and guides to develop their own Plant Communications and Computing Architecture Plan which will support integrated operator support systems. The Plant Communications and Computing Architecture Plan will help the utility to implement a plant communications and computing architecture where:

- Each operator support system will be able to communicate with other internal and external systems.
- The human-machine interface of each operator support system will be consistent in look and feel with other operator support systems.
- Future migration to a new hardware or technology will be completed without excessive down time or a major conversion effort.
- Each operator support system will be maintained at a more reasonable cost.
- Information and functionality will not be unnecessarily duplicated.

Once the utility has completed its own Plant Communications and Computing Architecture Plan, utilities will be able to implement integrated operator support systems which will help to extend plant life, improve efficiency, reduce maintenance costs, reduce operator errors, and improve safety.

EPRI Plant-Window System

The objectives of the EPRI Plant-Window System are to reduce the safety challenges to the plant by presenting more complete, integrated and reliable information to plant staff to better cope with operating and emergency conditions; to increase productivity by eliminating routine manpower-intensive efforts such as recording, integrating and evaluating data and by developing tools to assist in performing monitoring and control activities; to improve consistency and completeness of decision-making activities by developing operator support systems; and to improve information availability so that it is readily obtainable and in the proper form for all groups requiring it. The EPRI Plant-Window System acts as a uniform interface for operator support systems. It plays the role of the window that the human has into the plant. It allows the human to interface with all of the plant systems, software, and databases and to perform any desired activities.

The EPRI Plant-Window System will have direct access to all on-line and archival plant data for use by operations, engineering and maintenance staff. This system will have the ability to allow direct monitoring and control of the plant. The system will be designed to allow a wide variety of operator support systems to be accessible to it in a totally transparent manner as far as to where the system actually resides. It will be able to communicate as desired with other computers and operator support systems throughout the plant. It will be designed in a modular and easily expandable form. The conceptual design for this system is shown in figure 5. The functional requirements for the EPRI Plant-Window System are being developed. A first draft of the functional requirements will be completed by the end of 1993. A demonstration project for the EPRI Plant-Window System is currently being developed with one of the utilities. This limited demonstration will test out some of the capabilities of this type of system. The experience with this prototype will support the utility's future decision making plans concerning integrating systems and consistent human-machine interfaces.

Reactor Water Cleanup System

The Reactor Water Cleanup System (RWCU) was chosen as a demonstration of a CRT-based control system. This system is being developed as if it were a control node on the Integrated Computer System (ICS) on the Browns Ferry Nuclear plant. It is not being implemented at Browns Ferry at this time. To date, the process computer and human-machine interface of the ICS have been used to provide information and the indication of plant parameters, but have no control functions. This effort seeks to extend digital technologies into the area of equipment control. At the same time, the project is evaluating the issues associated with using CRT-based controls.

The RWCU utilizes graphical displays, which are in a mimic form, to represent the system and on-line data relevant to the system. It also has graphic representations for control actions. The system can be operated from the CRT in either a manual mode or an automatic mode. In the former case, all control step actions are performed directly by the operator. In the latter case, the operator initializes the action and the system performs the steps automatically. Behind the system is a set of procedures for all activities related to the RWCU. This allows the system to develop checklists of parameters and actions which must be confirmed before a control action may be taken. If the relevant information is directly available to the system, such as through on-line plant parameters, the system indicates the status of those portions of the checklist. For information the system does not have, the system asks the question of the operator and the operator supplies the information. Once all of the conditions have been satisfied, then the control action is allowed. In the manual mode the system prompts the user to the next step in the procedure. Figures 6 through 10 are illustrations of the screens presented to the user. Figure 6 is the overall system mimic which is part of every screen displayed. Figure 7 is a checklist of preconditions for an action. Figure 8 illustrates a prompt to the operator when the system is in the manual mode and figure 9 shows the mechanism for controlling a valve from the CRT in manual mode. Figure 10 is an illustration of a screen when the system is in automatic flow control.

A RELAP computer code plant model was developed for the simulation of the plant's reactor water cleanup system and the plant itself. This simulation model was used to test the RWCU. It is now being used to demonstrate the system to utility personnel at different utilities. A report on the CRT-based RWCU will be available in early 1994.

Emergency Operating Procedures Tracking System

The Emergency Operating Procedures Tracking System (EOPTS) is a computerized system to help operators select and apply operating procedures during plant emergencies [3, 4, 5]. EOPTS provides the capability to interpret and compile emergency operating procedure logic into a compact, fast-running software module that interfaces to and is co-resident with the nuclear power plant's safety parameter display system (SPDS). It utilizes the same database as the SPDS. The system allows multiple user access and provides real-time notification of emergency procedure steps, on-line explanations for these messages, priority filtering and data quality checking.

Before the event at Three Mile Island, emergency operating procedures were based on events. This required the operations staff to diagnose the event, which was occurring, in order to determine the proper action to take to bring the plant back to a desirable state. After the event at Three Mile Island, the Boiling Water Reactor Owners Group decided that symptom-based emergency procedures were more appropriate. With symptom-based procedures, the operators did not have to diagnose the event to determine the appropriate procedures. Instead, they determined the appropriate procedures by observing the symptoms of the event. The Owners Group created a set of emergency procedure guidelines for developing emergency operating procedures. Over time the number and size of these procedures has grown making them more difficult to use in a textual format during an event. To improve the usefulness of these procedures, most utilities converted their textual procedures into flow chart format. This was a substantial step forward in making the procedures easier to use by the operating staff under stressful conditions. Still, some concerns about the ease of use were expressed when multiple procedures were required and when symptoms changed quickly. The EOPTS was developed to respond to these concerns.

The EOPTS has been fully developed for boiling water reactor (BWR) emergency operating procedures. Initially based on the Boiling Water Reactor Owners Group emergency procedure guidelines, the system has been applied specifically to Taiwan Power Company's Kuo Sheng plant's emergency operating procedures. This system has been implemented as an add-on module to the SPDS developed for the Kuo Sheng plant. The EOPTS has been interfaced to the Kuo Sheng full-scale plant simulator for site acceptance testing and performance evaluation by plant operators as a prelude to actual plant installation. Considerable human factors testing has indicated that the system improves human reliability and efficiency, and helps the operators respond in a time indicative of skill-based response instead of knowledge-based response, which is the prevailing cognitive mode of operators without the system. The system is currently being used at Kuo Sheng for training purposes.

A similar system is being developed for the Tennessee Valley Authority's Browns Ferry plant simulator. The major change between the Kuo Sheng system and the Browns Ferry system is the human-machine interface and the plant-specific procedures. The Kuo Sheng system utilized a textual format for presenting information and guidance to the operator. The Browns Ferry System utilizes a graphical representation. Examples of these are shown in figures 11 through 14. The graphical representation is patterned after the flow charts which the operators are currently using on the plant. Figure 11 is an overview of one of the emergency procedures. Figures 12 through 14 represent detailed steps in the procedure. All of these figures are representation drawings for the screens rather than actual screen pictures. Therefore the textual information has been left off in the drawings for simplicity.

Conclusions

The integration of operator support systems supports the nuclear power plant goals of improved availability and reliability, enhanced safety, reduced operations and maintenance costs, and improved productivity. Two major aspects which supports this integration are discussed in this paper. The first is the plant communications and computing architecture which provides the infrastructure that allows the integration to exist in a easy to implement manner. Open systems concepts are utilized to guarantee interoperability of systems and interchangeability of equipment. The second is the EPRI Plant-Window System which supplies the interface between the human and the plant systems. It implements common human-machine interfaces amongst systems and supports the implementation of diagnostic and decision aids. Work in both of these areas is being done as part of the EPRI Instrumentation and Control Upgrade Program. A number of operator support systems have been developed and are in various stages of implementation, testing and utilization. Two of these, the RWCU and the EOPTS, are described here.

REFERENCES

[1] M. J. Bliss et al, "Plant Communications and Computing Architecture Plan Methodology Manual", EPRI TR-102306 vol. 1, to be published late 1993.

[2] M. J. Bliss et al, "Plant Communications and Computing Architecture Plan Methodology Workbook", EPRI TR-102306 vol. 2, to be published late 1993.

[3] W. Petrick and K. B. Ng, "Emergency Operating Procedures Tracking System," EPRI NP-5250M, June 1987.

[4] J. F. Cheng, R. Chiang, C. C. Yao, A. J. Spurgen, D. D. Orvis, B. K.-H. Sun, D. G. Cain, and C. Christensen, "Evaluation of an Emergency Operating Procedure Tracking Expert System by Control Room Operators," Expert Systems Applications for the Electric Power Industry, EPRI NP-6957, June 1989.

[5] W. C. Chang and J. F. Cheng, "The Utility Experience of Implementing the Emergency Operating Procedure Tracking System," Expert Systems Applications for the Electric Power Industry, EPRI NP-6957, June 1989.

Figure 1

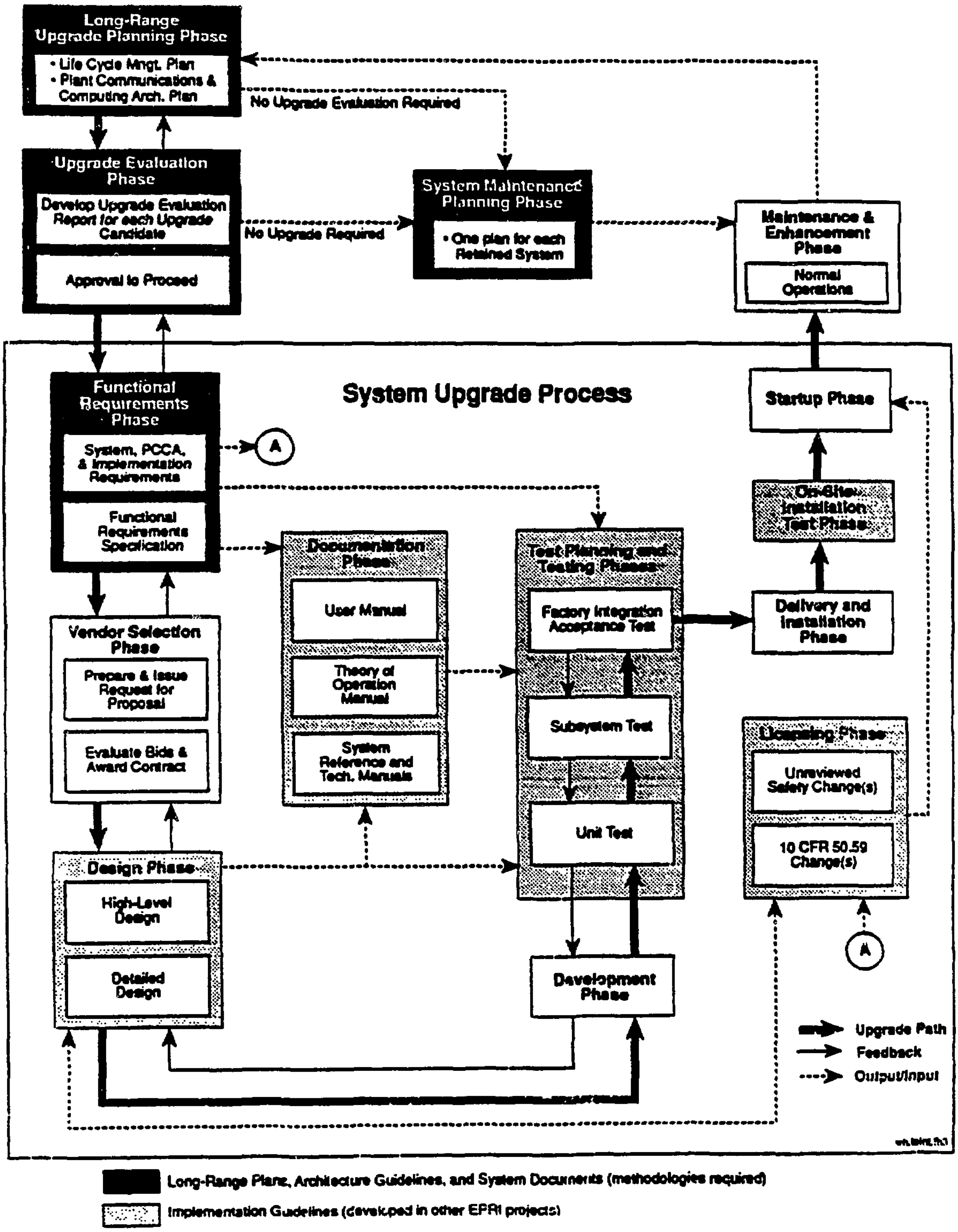
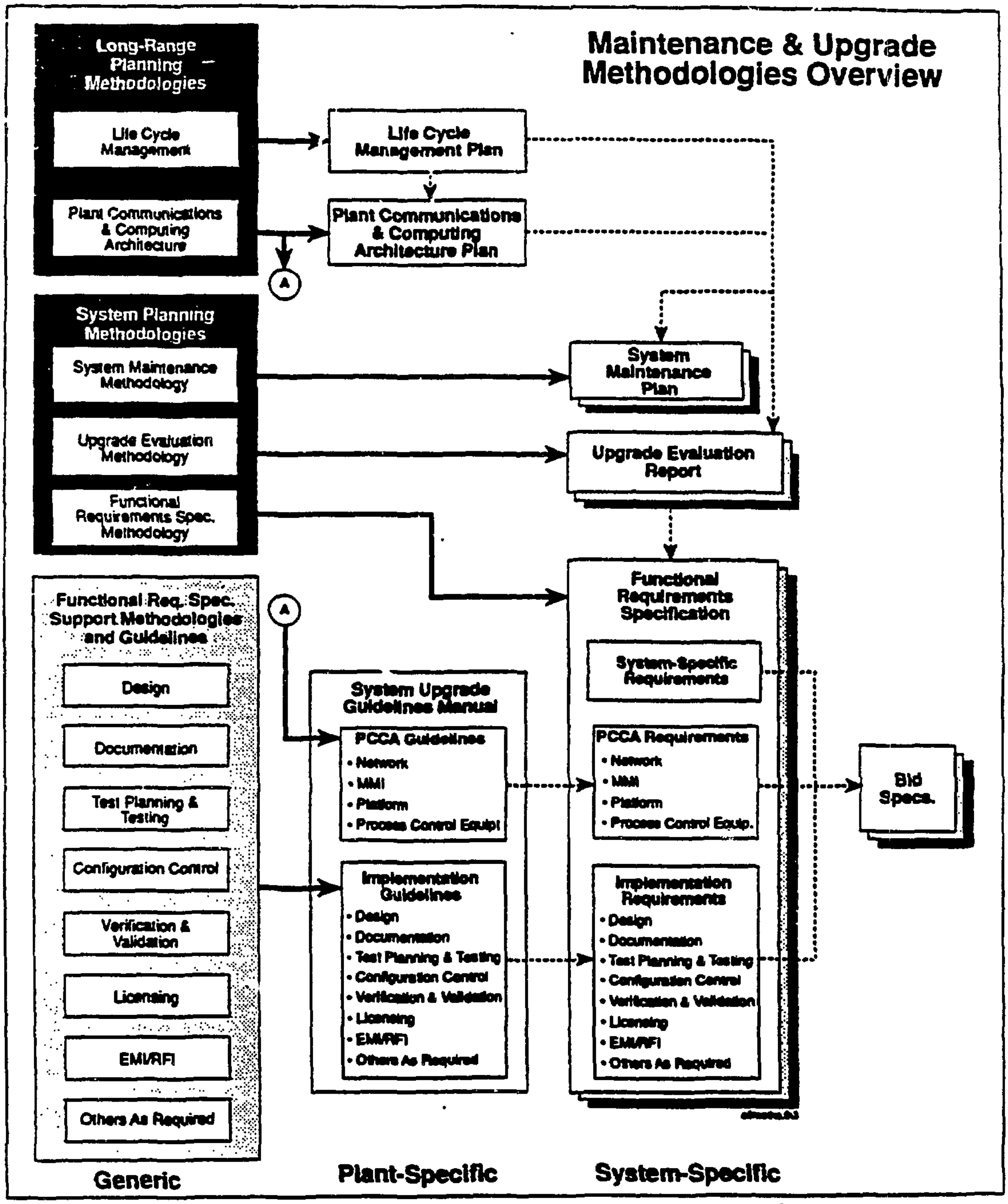

Long-Range Upgrade Planning Phase
• Life Cycle Mngt. Plan
• Plant Communications & Computing Arch. Plan
No Upgrade Evaluation Required
Upgrade Evaluation Phase
Develop Upgrade Evaluation Report for each Upgrade Candidate
Approval to Proceed
No Upgrade Required
System Maintenance Planning Phase
• One plan for each Retained System
Maintenance & Enhancement Phase
Normal Operations
System Upgrade Process
Functional Requirements Phase
System, PCCA, & Implementation Requirements
Functional Requirements Specification
A
Startup Phase
On-Site Installation Test Phase
Documentation Phase
User Manual
Theory of Operation Manual
System Reference and Tech. Manuals
Test Planning and Testing Phases
Factory Integration Acceptance Test
Subsystem Test
Unit Test
Delivery and Installation Phase
Vendor Selection Phase
Prepare & Issue Request for Proposal
Evaluate Bids & Award Contract
Licensing Phase
Unreviewed Safety Change(s)
10 CFR 50.59 Change(s)
Design Phase
High-Level Design
Detailed Design
Development Phase
Upgrade Path
Feedback
Output/Input
Long-Range Plans, Architecture Guidelines, and System Documents (methodologies required)
Implementation Guidelines (developed in other EPRI projects)

Figure 2



Shaded Areas Indicate Methodologies or Guidelines Needed For:

- (black) Plans, Architecture Guidelines, and System Documents
- (white) Generic Vendor Implementation Guidelines

→ Main Path
- - -> Output/Input

Figure 3

Nuclear Power Plant Architecture

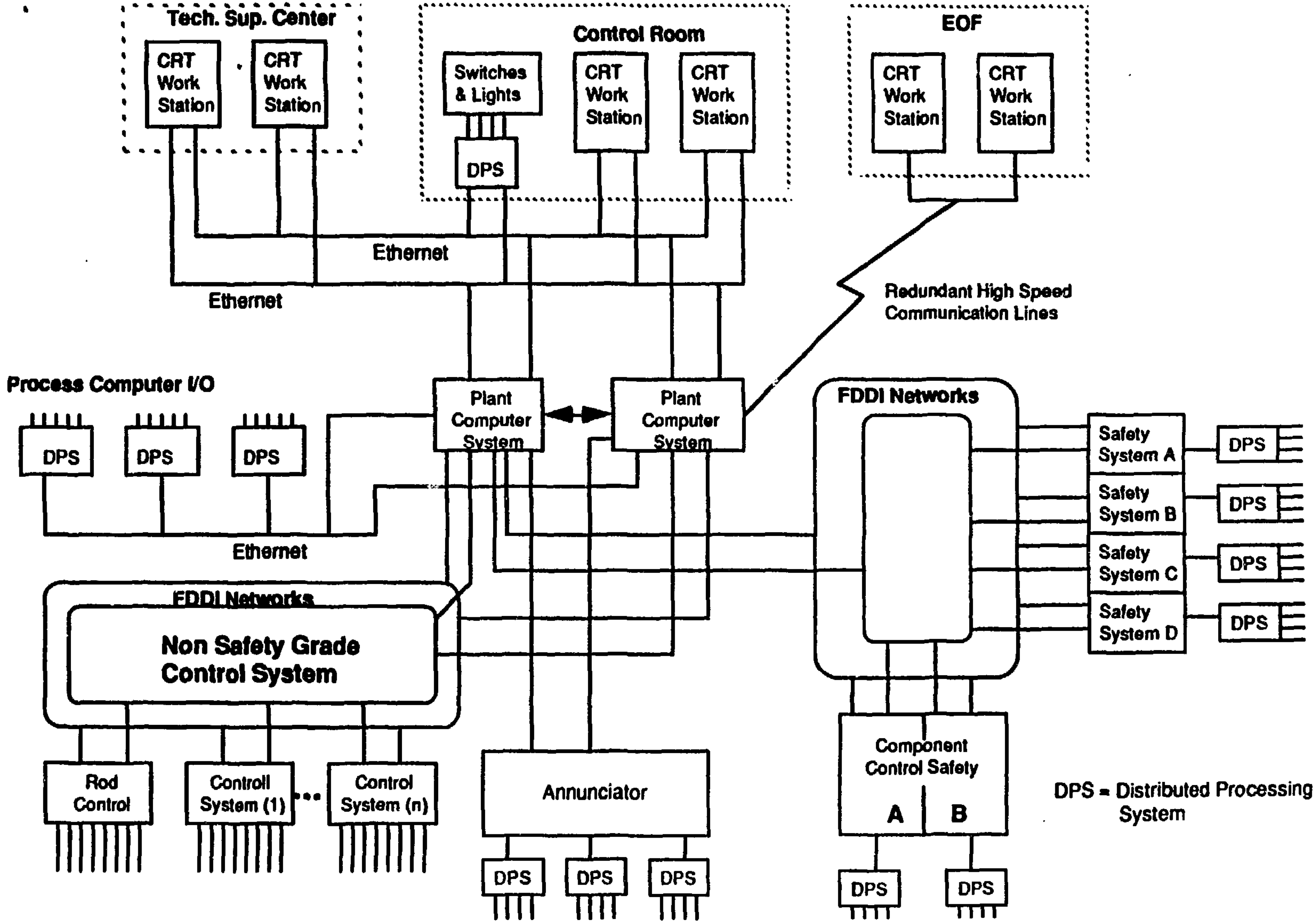
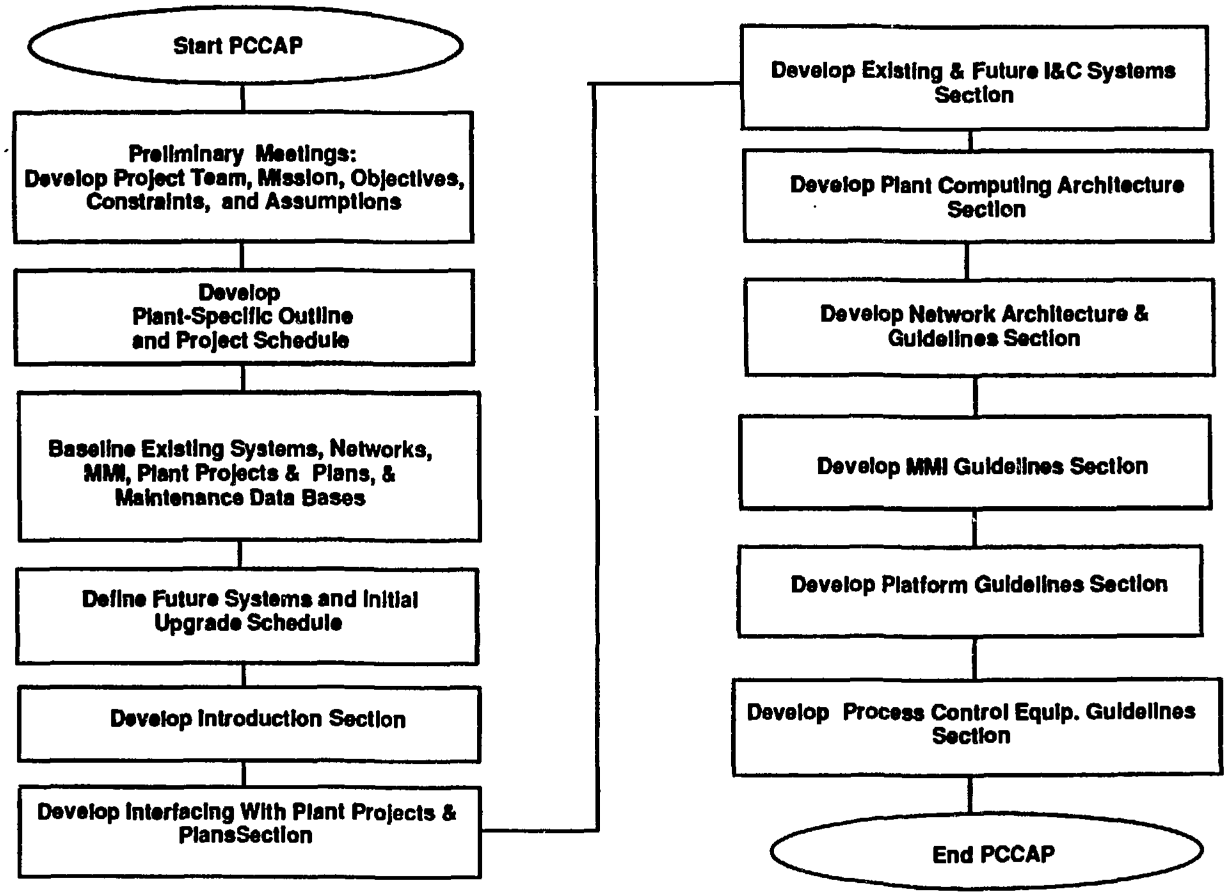


Figure 4

EPRI PCCAP Methodology Process



300

Figure 5

Conceptual Design

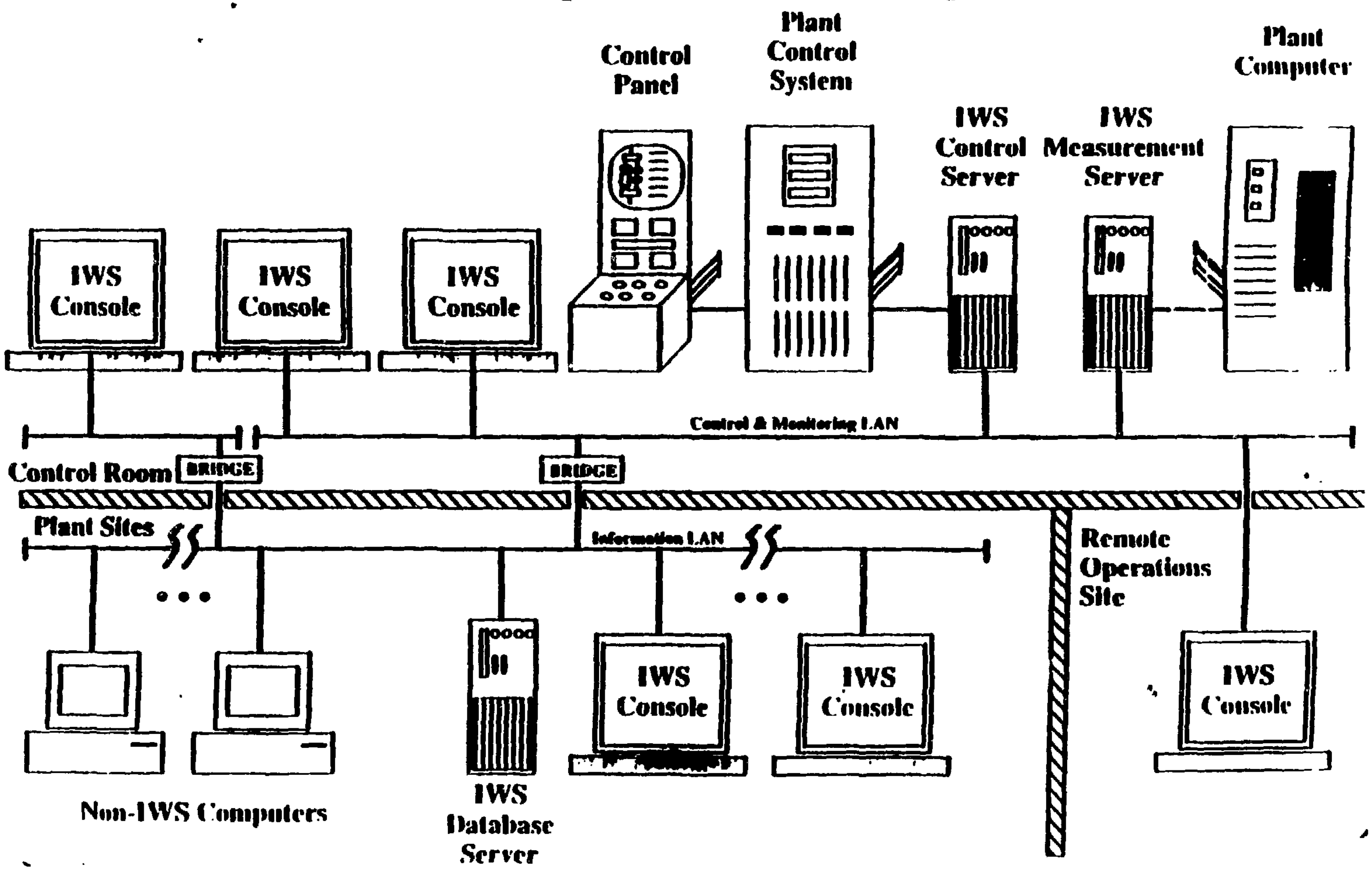
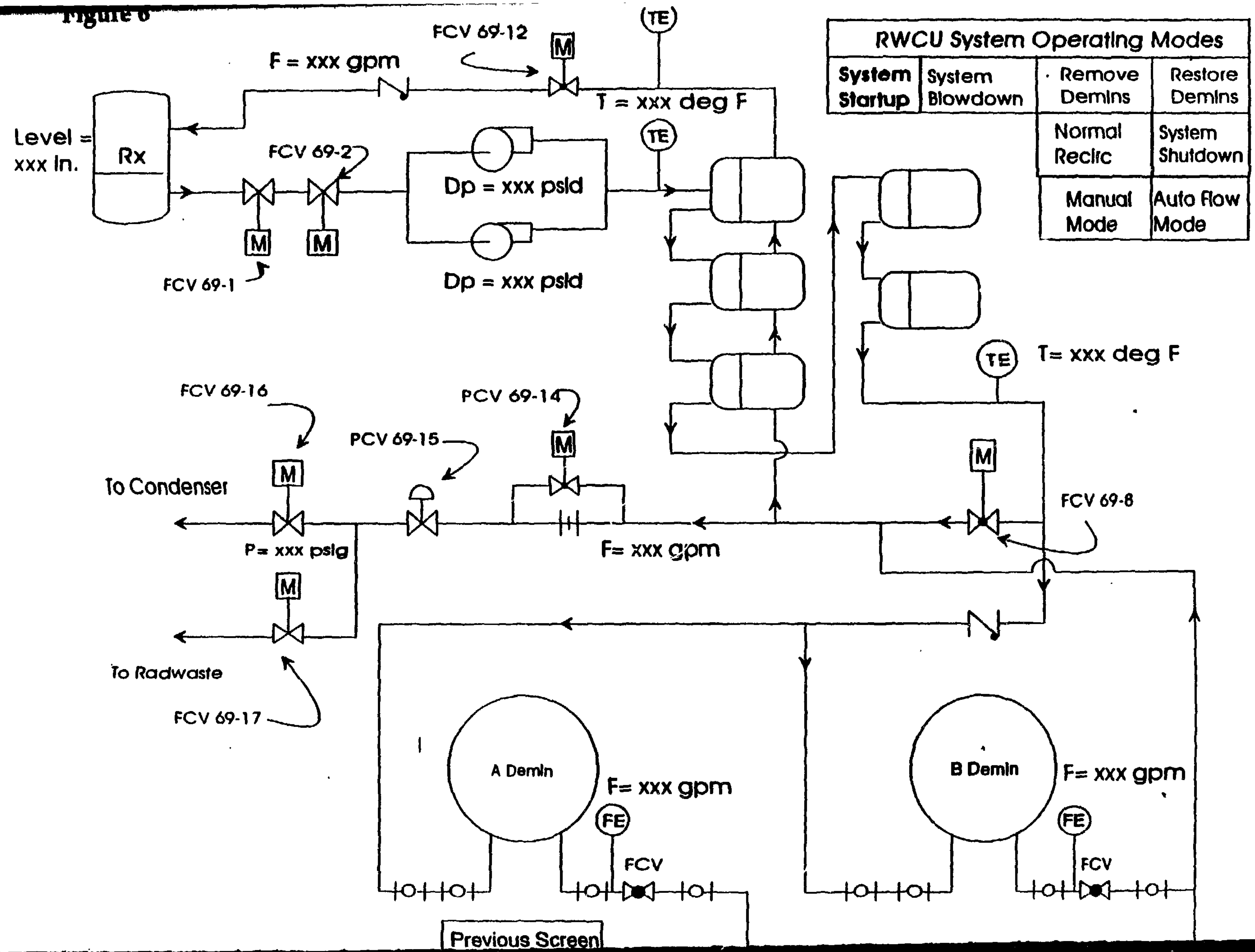


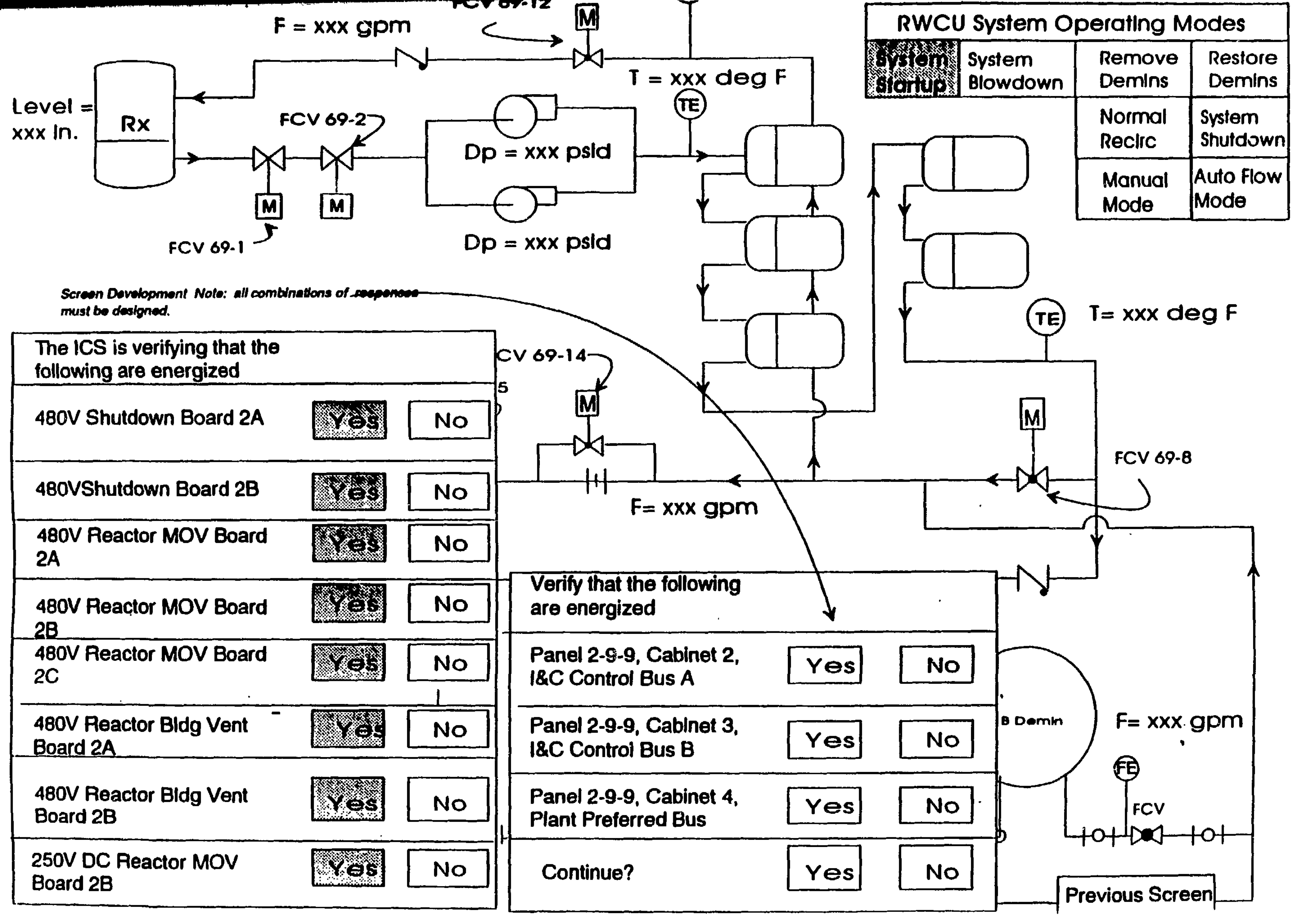
Figure 6



RWCU System Operating Modes
System Startup
System Blowdown
Remove Demins
Restore Demins
Normal Recirc
System Shutdown
Manual Mode
Auto Flow Mode
Level = xxx in.
Rx
F = xxx gpm
FCV 69-12
TE
T = xxx deg F
FCV 69-2
FCV 69-1
Dp = xxx psid
Dp = xxx psid
T= xxx deg F
FCV 69-16
PCV 69-14
PCV 69-15
To Condenser
P= xxx psig
F= xxx gpm
FCV 69-8
To Radwaste
FCV 69-17
A Demin
B Demin
F= xxx gpm
F= xxx gpm
FE
FCV
Previous Screen

308

303

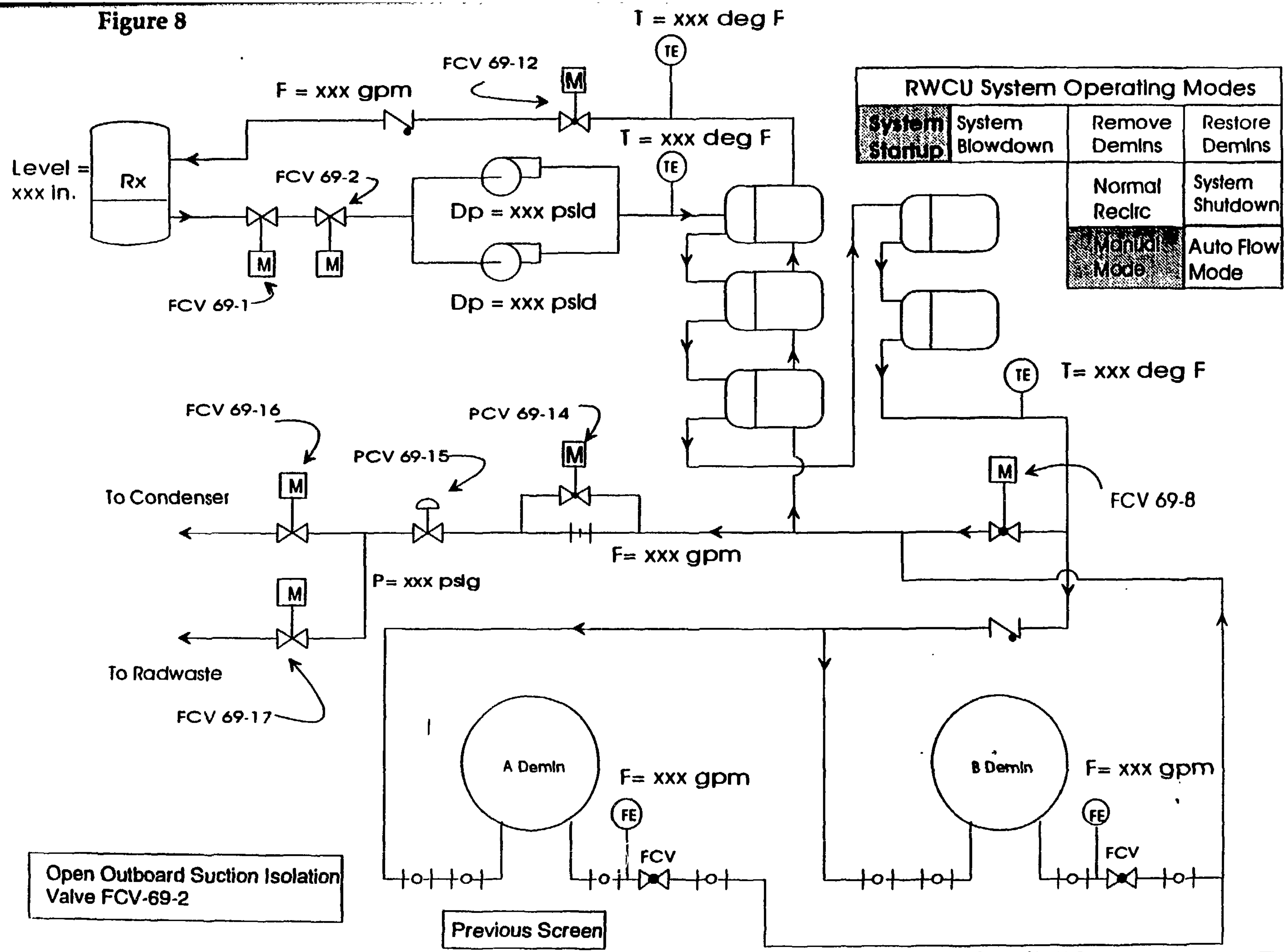


Screen Development Note: all combinations of responses must be designed.

The ICS is verifying that the following are energized		
480V Shutdown Board 2A	Yes	No
480VShutdown Board 2B	Yes	No
480V Reactor MOV Board 2A	Yes	No
480V Reactor MOV Board 2B	Yes	No
480V Reactor MOV Board 2C	Yes	No
480V Reactor Bldg Vent Board 2A	Yes	No
480V Reactor Bldg Vent Board 2B	Yes	No
250V DC Reactor MOV Board 2B	Yes	No

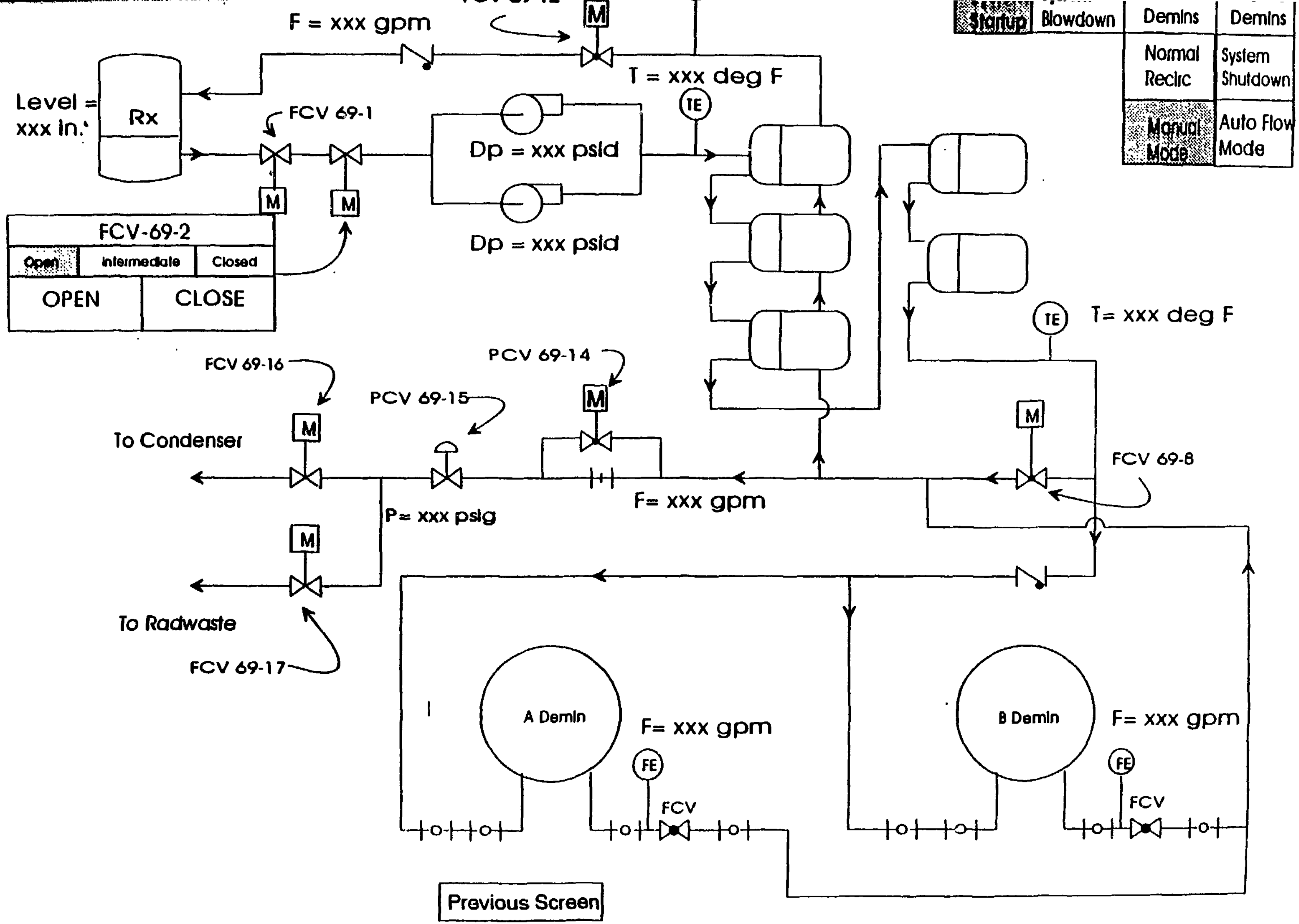
Verify that the following are energized		
Panel 2-9-9, Cabinet 2, I&C Control Bus A	Yes	No
Panel 2-9-9, Cabinet 3, I&C Control Bus B	Yes	No
Panel 2-9-9, Cabinet 4, Plant Preferred Bus	Yes	No
Continue?	Yes	No

Figure 8



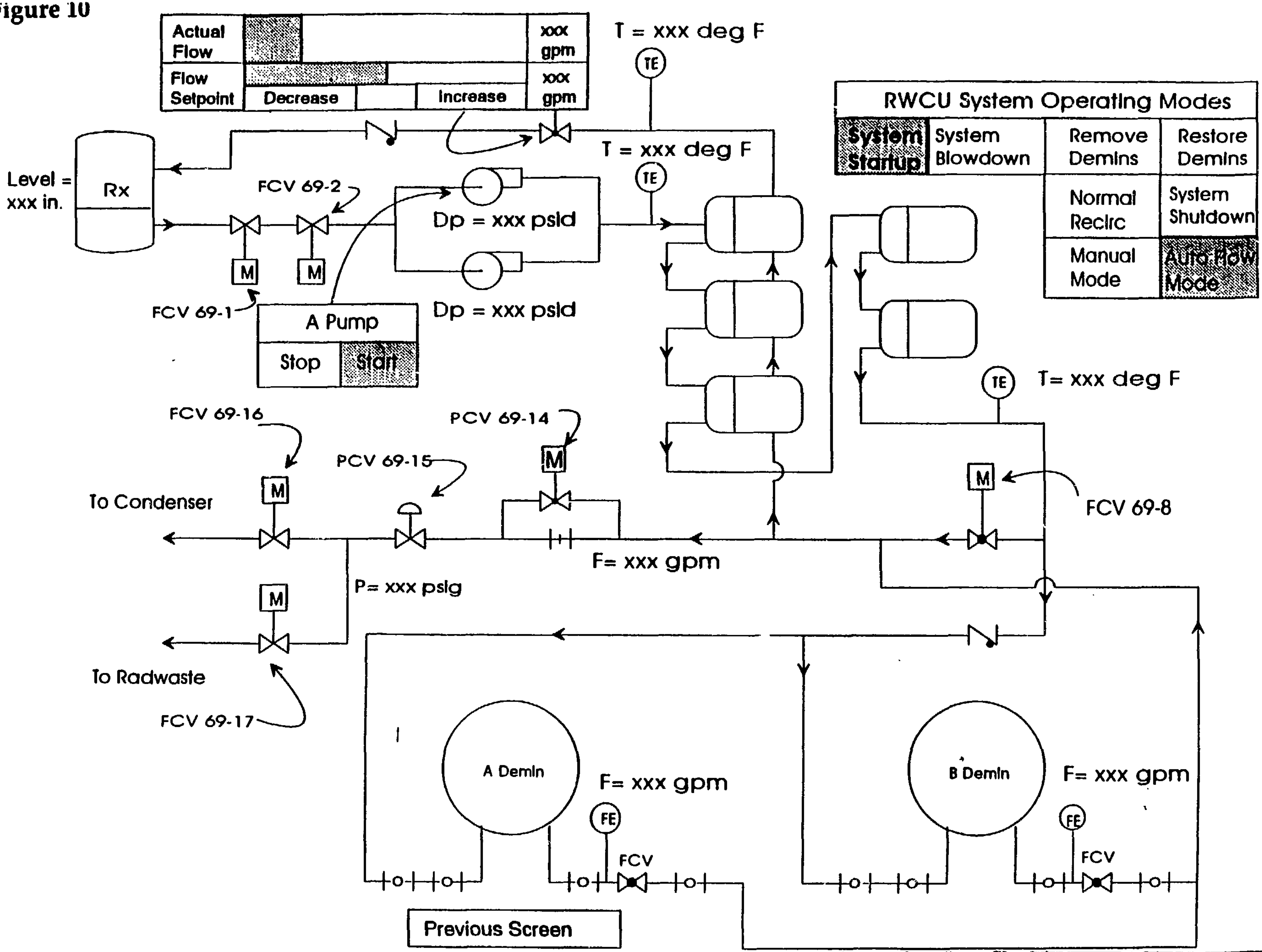
T = xxx deg F
FCV 69-12
F = xxx gpm
RWCU System Operating Modes
System Startup
System Blowdown
Remove Demins
Restore Demins
Normal Recirc
System Shutdown
Manual Mode
Auto Flow Mode
Level = xxx in.
Rx
FCV 69-2
T = xxx deg F
Dp = xxx psid
Dp = xxx psid
FCV 69-1
T= xxx deg F
FCV 69-16
PCV 69-14
PCV 69-15
To Condenser
FCV 69-8
F= xxx gpm
P= xxx psig
To Radwaste
FCV 69-17
A Demin
F= xxx gpm
FE
FCV
B Demin
F= xxx gpm
FE
FCV
Open Outboard Suction Isolation Valve FCV-69-2
Previous Screen

204



F = xxx gpm
M
T = xxx deg F
TE
Startup
Blowdown
Demins
Demins
Normal Reclrc
System Shutdown
Manual Mode
Auto Flow Mode
Level = xxx in.
Rx
FCV 69-1
Dp = xxx psid
Dp = xxx psid
FCV-69-2
Open
Intermediate
Closed
OPEN
CLOSE
TE
T= xxx deg F
FCV 69-16
PCV 69-14
PCV 69-15
To Condenser
FCV 69-8
F= xxx gpm
P= xxx psig
To Radwaste
FCV 69-17
A Demin
F= xxx gpm
FE
FCV
B Demin
F= xxx gpm
FE
FCV
Previous Screen

Figure 10



Actual Flow
xxx gpm
Flow Setpoint
Decrease
Increase
xxx gpm
T = xxx deg F
TE
RWCU System Operating Modes
System Startup
System Blowdown
Remove Demins
Restore Demins
Normal Recirc
System Shutdown
Manual Mode
Auto Flow Mode
Level = xxx in.
Rx
FCV 69-2
FCV 69-1
M
Dp = xxx psid
A Pump
Stop
Start
T = xxx deg F
T= xxx deg F
FCV 69-16
PCV 69-14
PCV 69-15
FCV 69-8
To Condenser
F= xxx gpm
P= xxx psig
To Radwaste
FCV 69-17
A Demin
B Demin
F= xxx gpm
FE
FCV
Previous Screen

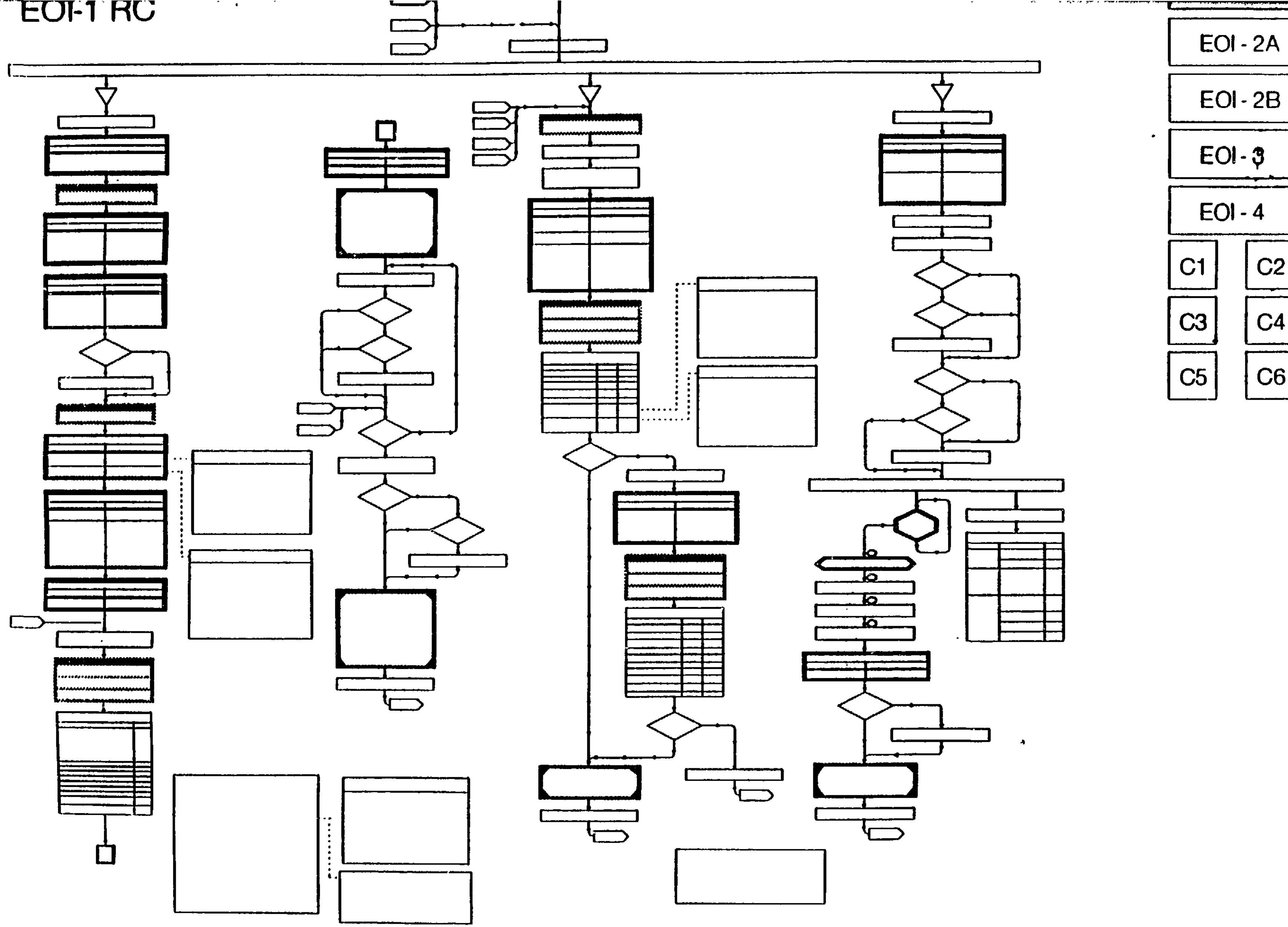
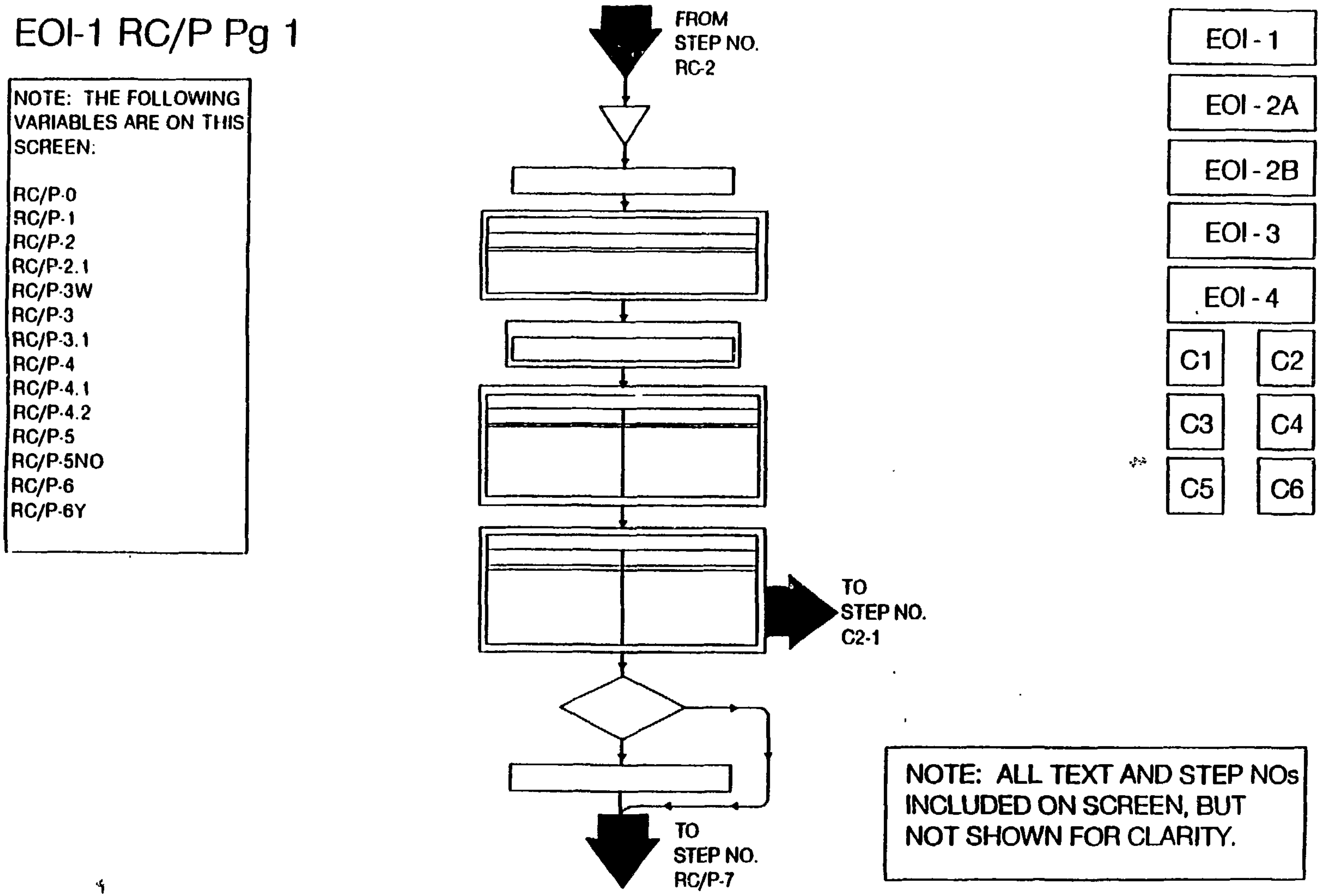
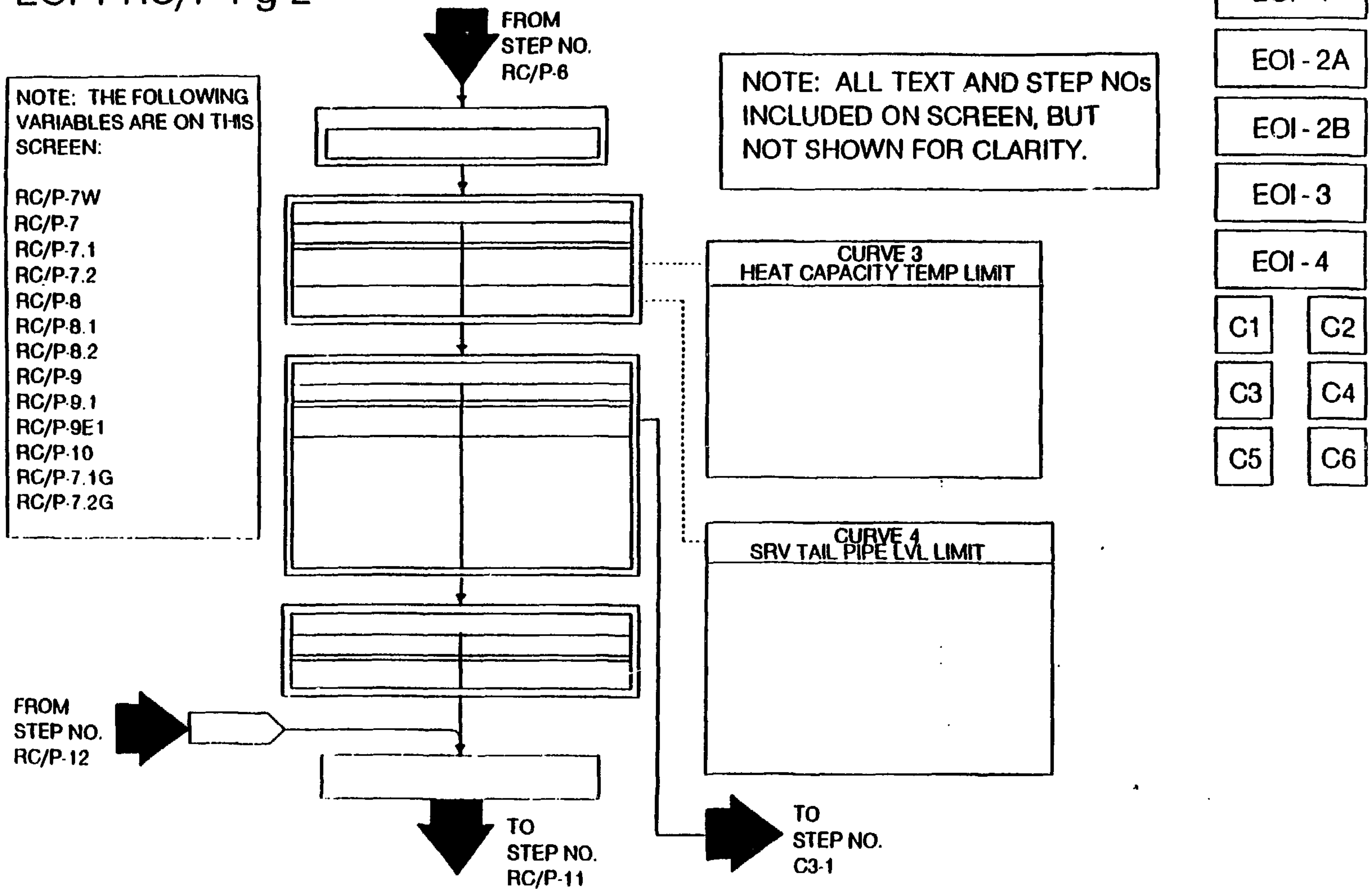

EOI-1 RC
EOI - 2A
EOI - 2B
EOI - 3
EOI - 4
C1
C2
C3
C4
C5
C6

Figure 12



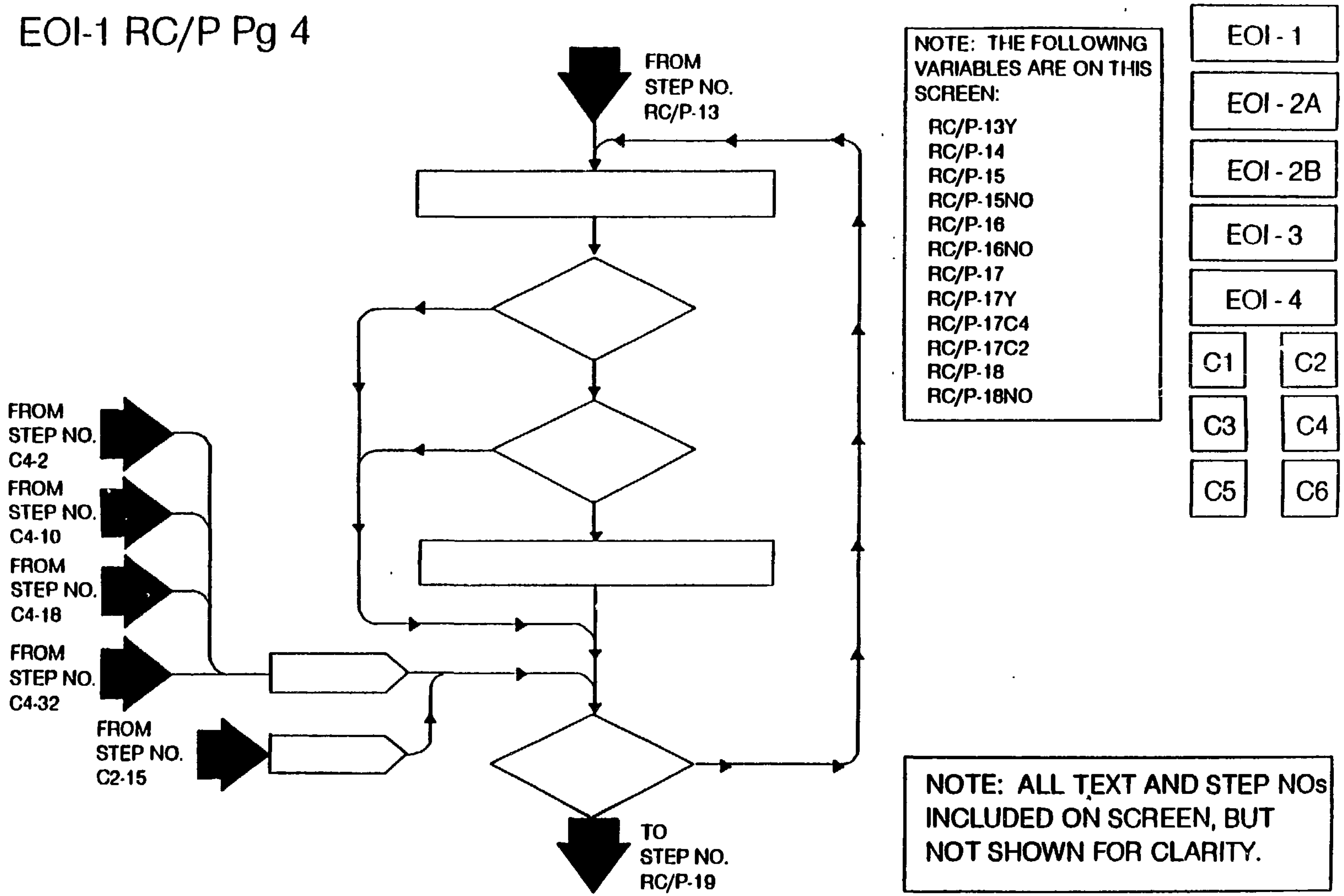
308

EOI-1 RC/P Pg 2



309

Figure 14


EOI-1 RC/P Pg 4
FROM STEP NO. RC/P-13
NOTE: THE FOLLOWING VARIABLES ARE ON THIS SCREEN:
RC/P-13Y
RC/P-14
RC/P-15
RC/P-15NO
RC/P-16
RC/P-16NO
RC/P-17
RC/P-17Y
RC/P-17C4
RC/P-17C2
RC/P-18
RC/P-18NO
EOI - 1
EOI - 2A
EOI - 2B
EOI - 3
EOI - 4
C1
C2
C3
C4
C5
C6
FROM STEP NO. C4-2
FROM STEP NO. C4-10
FROM STEP NO. C4-18
FROM STEP NO. C4-32
FROM STEP NO. C2-15
TO STEP NO. RC/P-19
NOTE: ALL TEXT AND STEP NOs INCLUDED ON SCREEN, BUT NOT SHOWN FOR CLARITY.

EPRI/NPD

Operator Support System Activities at EPRI

Joseph Naser
Electric Power Research Institute

IAEA CRP Meeting on Operator Support Systems in Nuclear Power Plants
Budapest, Hungary

JAN.8120.P Control Diagnostics & Information

EPRI/NPD

EPRI Integrated I&C Upgrade Initiative

- Research and Development
- Demonstration Plants
- Licensing Stabilization

JAN.8120.P Control Diagnostics & Information

EPRI/NPD

Operator Support Systems

- Provide reliable information
- Support decision making
- Enhance productivity
- Potential for reducing costs

JAN.8120.P Control Diagnostics & Information

EPRI/NPD

Integrated Systems

- Improve plant availability and reliability
- Reduce operations and maintenance costs
- Improve productivity
- Reduce safety challenges

JAN.8120.P Control Diagnostics & Information

EPRI/NPD

Plant Communications and Computing Architecture

- Infrastructure
  - integrate systems
  - provide access to information
  - facilitate common human-machine interfaces
- Reduce unnecessary duplication
  - functions
  - data
- Support enhanced functionability
- Support new systems

JAN.8120.P Control Diagnostics & Information

EPRI/NPD

Methodology

- Develop utility specific plan
- Current system and networks
- Desired systems
- Supporting architecture
- Migration plan

JAN.8120.P Control Diagnostics & Information

EPRI/NPD

Status

- Utilized at demonstration plants
- Feedback
  - methodology
  - workbook
- Publish by end of 1993

JAN8130.P Control Diagnostics & Information

EPRI/NPD

EPRI Plant-Window™ System

- Window for human into plant systems
- Supports
  - monitoring
  - control
  - engineering analysis
  - maintenance activities
  - decision-making
  - diagnostics
  - management

JAN8130.P Control Diagnostics & Information

EPRI/NPD

EPRI Plant-Window™ System

- Facilitate the effective introduction and use of digital technology in nuclear plants
- Computer environment resident on distributed platforms located throughout the plant
- Provide a flexible and expandable support structure to allow phased upgrades

JAN.9120 P Control Diagnostics & Information

EPRI/NPD

EPRI Plant-Window™ System

- Provide access to systems and functional applications to support the operators, engineers, and maintenance staff of a nuclear power plant
- Facilitates spatial and functional integration
  - Transparent access to plant data
  - A common, consistent user interface
  - Management of information and resources
- Support the definition of standardized applications and interface conventions

JAN.9120 P Control Diagnostics & Information

EPRI/NPD

Flexible And Expandable Support Structure

- Implementation yields tailored solutions to each user's need
- Standardized interfaces and functional objects allow a phased upgrade approach
- Integrated functionality and consistency in user interfaces promote enhanced safety and productivity
- Environment capabilities accommodate the use of existing computer hardware

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Control Diagnostics & Information

EPRI/NPD

Status

- Functional requirements being developed
- First draft end of 1993
- Demonstration prototype

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