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INSTALLATION AND EVALUATION
OF A NUCLEAR POWER PLANT OPERATOR ADVISOR
BASED ON ARTIFICIAL INTELLIGENCE TECHNOLOGY

Interim Progress Report

and

Second Year Development Plan

by

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1.0 INTRODUCTION

This report details the progress made during the first eight months of the current project year, the progress expected through the end of the Year One, and the plans for Year Two. It also includes a description of the management organization, and budget projections for Year Two.

In Chapter 1, we summarize the progress we've made in meeting the original goals of the project, and the expected progress for Years Two and Three. We then discuss in detail the current project activities by tasks. Chapter 1 comprises the Interim Progress Report.

In Chapter 2, we discuss our plans for Year Two. The goals for the year are summarized, and then the tasks to support these goals are detailed. This Chapter, along with Chapters 3 and 4 comprise the proposal for the Year Two Effort.

1.1 BACKGROUND

Technological innovations have greatly enhanced the capability of engineering systems while at the same time making them operationally complex. Technological innovations have also provided the means to develop advanced man-system interfaces consistent with human capability. In this research, we have applied a knowledge-based systems approach to develop an advanced man/system interface in the form of an Operator Advisor.

The Operator Advisor has been under development at The Ohio State University for the past five years. The Operator Advisor is a combination of four expert systems.

In the first stage of the research, the Dynamic Procedure Management System (DPMS) and Diagnostic and the Sensor Validation System (DVS) were designed and implemented and an initial testing program was completed.

The Dynamic Procedure Management System executed procedures that the operator does after identifying the need for the procedure. The Diagnostic and Sensor Validation System performed the diagnosis and data validation that the operator does when he detects an abnormal condition in the plant.

Originally, the Dynamic Procedure Management System and Diagnostic and Sensor Validation System were not designed to interact. The Dynamic Procedure Management System initiated a procedure only after it was interactively asked to execute it. I.e., the need for a specific procedure was identified externally. Also, neither system had a facility to use on-line data for its decision making.

The first version of DPMS was built in the relatively low level language, Loops. This required filling in the procedural knowledge in terms of Loops primitives. A high level language, DSPL (Design Specialists and Plans Language), along with a shell for filling the procedural knowledge was later developed. This language provides knowledge representation in terms familiar to the domain

personnel. A new version of the Dynamic Procedure Management System was developed using DSPL.

The next stage of the research addressed the provision for access to real on-line plant data and the integration of the two systems.

An intelligent database was developed to access on-line data and act as an interface with the plant. The intelligent database system receives and further processes the data supplied by the plant computers. The goal of this development effort was to enable the Operator Advisor to abstract the pre-processed or unprocessed data to the level required for decision making.

A Plant Status Monitoring System (DPMS) was developed to integrate the two systems. The Plant Status Monitoring System has the capability to perform simple diagnosis to identify fault states requiring procedure execution and fault states consisting of deviations from normality. Examples include: initiating the DPMS to execute the required procedure, initiating the DVS to perform diagnosis to determine the root cause of the identified fault state and deviations from normality, and communicating the results of the diagnosis to DPMS.

The final product of the integration effort has been an Integrated Operator Advisor System that:

1. Directly uses preprocessed or unprocessed plant data as much as possible for its decision making,
2. Detects abnormal plant states requiring procedure execution,
3. Advises the operator on how to execute the procedure, monitors the success of the procedure, and provides actions to maintain plant safety if the procedure is not successful,
4. Diagnoses abnormal plant states to determine their root causes,
5. Diagnoses deviations from normality to map to plant states having well defined control actions,
6. Determines the root cause of deviations from normality, and
7. Identifies suspicious data and provides inferred estimates for them.

The architecture of the Operator Advisor is shown in Figure 1.

The complete Operator Advisor is currently implemented on two Xerox 1109 Lisp Machines in the low level languages Interlisp-D and Loops, and the high level languages CSRL and DSPL. The latter two languages are themselves implemented in Interlisp-D and Loops.

The current effort involves expanding the Operator Advisor to perform diagnostics and fault management on a broader scope of plant systems, implementation of a formal Verification and Validation (V&V) program, and interfacing the Operator Advisor to receive input directly from a plant referenced simulator.

To support these activities, we are porting the Operator Advisor to a Sun 4/330 workstation environment, converting the software from Interlisp-D and Loops to Common Lisp and CLOS (Common Lisp Object System) for better portability and maintenance, and upgrading the intelligent database to use commercial database software.

Figure 1. Operator Advisor Architecture.

1.2 PROGRESS IN ACHIEVING GOALS AND OBJECTIVES

1.2.1 First Year Goals

Four goals were established for the first year of the program. These goals were embodied in the following three milestones that have been pursued by the development team:

1. Install the Operator Advisor on a full scope plant simulator.

Work is progressing to install the Operator Advisor at the Perry Nuclear Power Plant simulator by the end of the current calendar year.

Several activities have been under way in support of this effort. These include selection of a new hardware environment, conversion of the software to operate in the new environment, and development of a serial interface between the AI and simulator computer systems.

As stated in the proposal, it was recognized that the Xerox D machine environment, though an ideal development environment, was not appropriate for a delivery environment. In the proposal we stated we would be moving to either a VAX or a Sun platform. Our decision to move to Sun was based on the relative speeds of the machines, and on the availability of compatible software for the Sun platform. This is discussed in greater detail in Section 1.3.1.

We also investigated the Sun family of machines and decided to move to a Sun/260 machine. While obtaining quotes, we learned that Sun would be announcing a new family of machines that would be both more powerful and less expensive. Therefore, we decided to collect as much information as possible, and to postpone our purchase until the new machines became available. We have now placed our order for these new machines. Instead of a single machine, for about the same cost, we will be able to obtain two machines (Sun 4/60C and Sun 4/330), each of which will be more powerful than the single machine we had previously specified, and we will have a color graphics capability which will be important for man-machine interface development. We expect delivery of one machine by the end of the summer, and the second machine before the end of the year.

We began converting the software to a version of Xerox Interlisp known as Medley. This work is continuing, and is expected to be completed before the end of November. Once the software conversion is complete, porting of the Operator Advisor to the Sun environment can be completed. This is discussed in greater detail in Section 1.3.2.

About midway through the software conversion process, we received the unfortunate news that Xerox would be closing its subsidiary company, Envos, which had been established to market the Medley software. While

not affecting our short term plans, this development requires that we move more rapidly than we had previously planned to a Common LISP software environment. We will discuss this further later in this report.

Finally, to complete the interface to the plant simulator, we have been developing a serial interface. This effort, done in close cooperation with Perry personnel, is nearly complete. Further details concerning this effort will also be discussed later in the report.

2. Develop and initiate a formal Verification and Validation (V&V) Program.

We have performed V&V since the beginning of the project several years ago. However, this process has never been formalized. This need was recognized at the time of the original proposal, and therefore is an important part of the current effort.

The first step in the process has been to pull together the many formulations of the specifications for the system that have been detailed in several papers published by our group, along with the minutes of our many project meetings. This task is now complete, and a copy of the draft specifications is included in Appendix A.

The next step in this process is to complete the reorganization of the specifications into three documents: (1) General Specifications, (2) Module Specifications, and (3) Software Specifications.

Next, additional specifications as outlined in the new Specification document need to be completed. These include requirements for data input, a maintenance capability, and the man-machine interface.

Finally, a V&V document will be added to the set which will detail the testing program that assures the Operator Advisor is designed to and performs in accordance with the specifications.

The initial phase of this effort will be complete by the end of September. However, since the specifications and the V&V Plan are expected to change continuously as the development program continues, we don't expect these documents to remain static. Thus, in one sense, the V&V Plan will be a living document in accordance with the life cycle of the Operator Advisor, and will never really be complete. However, as a task, the goal to implement a formal V&V Plan will be complete before the end of the current project year.

We have also implemented a program to perform dynamic testing of the Operator Advisor prior to installing it on the Perry simulator. This program, which will result in an M.S. thesis for one member of the project team, will enable us to input time varying data taken from Perry simulator runs into the Operator Advisor. Up to this time, all data has been input by

the user upon demand from the system. This effort is detailed in Section 1.3.6. The current V & V activities are detailed in Section 1.3.3.

3. Design and implement an effective man-machine interface.

We have worked closely with plant personnel to interface the AI computer with the plant simulator. This effort is detailed in Section 1.3.4. Also coupled with this task is an effort to perform dynamic testing of the Operator Advisor.

This task requires an understanding of the Sun workstation environment and operation of the Operator Advisor on the Perry simulator.

Our selection of the Medley software environment was made because we have available browser and graphics capabilities not currently in industry standard formulations of Common LISP. This environment will be extremely helpful to development of the man-machine interface.

We have identified a need for two interfaces to the Operator Advisor. The first of these is a maintenance facility. This facility will serve two purposes. The first is input of new knowledge. The second is modification of the knowledge already in the system. The Medley environment is critical to early development of this interface. This maintenance capability is especially important for adding to the knowledge base in a consistent manner, and to maintaining the system once it is delivered to the plant.

The second interface is for the reactor operators that are using the Operator Advisor. Once the AI computer is connected to the plant simulator, the control room operators will be involved in specifying the screen displays that will provide their link to the Operator Advisor.

The decision to purchase the color graphics capability on the Sun machines will greatly enhance our ability to design an effective man-machine interface for operator use.

4. Expand the number of systems currently handled by the Operator Advisor.

This task is being pursued in a very deliberate manner because of the requirement to assure consistent data and knowledge entry. Specifications have been written to follow a procedure, currently being developed, for this purpose.

One task group is currently reviewing options related to organization of the knowledge in the system. Based on their results, we expect to have several systems added by the end of the summer. We are currently organizing the plant electrical systems for addition to the Operator Advisor. The schedule for other systems and the work of the Knowledge Base Expansion Task Group is detailed in Section 1.3.5.

This task will continue into years two and three as previously noted in the May, 1988, proposal.

1.2.2 Second Year Goals

The second year milestone statement indicated we would be testing the Operator Advisor with plant operators to determine the added value of the Operator Advisor in responding to plant malfunctions. As a result of these tests, we would modify and improve the system. This will be done as stated in the original proposal, and in accordance with the previously stated goals:

1. Continue to expand the Operator Advisor to handle additional systems and malfunctions.
2. Evaluate the response of the plant and operators with and without the Operator Advisor.
3. Modify and improve the Operator Advisor and man-machine interface in accordance with findings from the V&V process, operator evaluations, and response evaluations in Objective 2.

A fourth objective dealt with regulatory approval.

4. Begin the testing and regulatory reviews for the installation of the AI Operator Advisor on an actual plant.

This objective also will be pursued in accordance with the original schedule. The V&V Plan is critical to this process, and its implementation will assure that the required documentation will be available for proving the proper operation of the Operator Advisor. Further, as a result of a presentation given (1) at the recent EPRI Conference on Expert System Applications for the Electric Power Industry (Orlando, Fla, June 5-7, 1989), we have decided to involve the Nuclear Regulatory Commission on-site inspectors at Perry in the simulator testing. This seems to be an effective way to begin the informing phase of the regulatory process.

In addition to these objectives, we must add another because of the changing hardware and software environments. This objective is to

5. Begin conversion of the Operator Advisor to Common LISP.

It is unclear at this time how long Modley (See Section 1.2.1, Paragraph 1.) will be supported. In order to not be constrained by commercial successes and failures, we believe a conversion to Common LISP is necessary. However, several options are available that require evaluation.

- a. Continue in the short run with Medley, but develop all new features in Common LISP rather than the Interlisp environment currently being used.

We have already decided to do this. Medley supports both Common LISP and Interlisp. This gives us the advantage of being able to continue development and to have the advantage of the Medley user interface. Then when we switch to a new environment, only what has been developed in the past will need conversion. The process we are following is detailed in Section 1.3.2.

- b. Convert from Medley to KEE.

KEE is said to have a conversion capability that will take our InterLisp work and automatically convert it to KEE and then to Common LISP.

We decided against KEE one year ago because of benchmark tests run at Ohio State on the microVAX machines we were considering at that time. However, now that we are going to be running on Sun machines, we need to revisit this option. KEE is said to run much faster on the Suns, and to have the capability to shed many of its unused functions that previously slowed it down.

KEE has three major advantages. One is that it has become somewhat of an electric industry standard because of the extensive efforts expended by the Electric Power Research Institute. Second, it has extensive user interactive graphics capabilities already built in. Third, a Kee-based system called PLEXSYS could provide us with additional capabilities to interface with plant drawings already in CADD systems.

A disadvantage of converting to a KEE platform is that the software itself is expensive, and such a conversion ties us to another third party product.

- c. Convert directly to Common LISP.

This may be the cleanest approach from the perspective of not relying on any particular company's commercial success. However, it is the most difficult at this time because no industry standard graphics or windowing system is available.

We are investigating this option along with the Laboratory for Artificial Intelligence Research (LAIR) at Ohio State. LAIR is looking at several Common LISP products, and is evaluating them along with the conversion requirements of their Generic Task Tool set, which we are using in the Operator Advisor.

A final decision on how to convert to Common LISP cannot be made at this time. We also cannot project a time schedule for this effort. However, we do

know that the conversion will extend into Project Year Three. Our primary goal must be to not let this need slow down the rest of our development effort.

1.2.3 Third Year Goals

The previous three Year Three goals continue to be appropriate at this time, although we feel that Goal Two might be a little optimistic, especially in light of the software conversions that will be needed, and the long times that are being taken to prove out some systems being developed by others prior to installing them on plants. Two examples are REALM (2), being developed for installation on Indian Point 2, and the EOP Tracking System (3), being developed for installation on the Kuosheng reactors in Taiwan.

The Year Three Goals are:

1. Complete efforts identified for Year Two performance that are delayed due to uncertainties in simulator scheduling and availability of plant data.
2. Pending receipt of regulatory approval, install the Operator Advisor on an operational plant.
3. Incorporate improvements made possible through theoretical extensions resulting from current NSF sponsored research, especially related to the effective use of information in dynamic data, and improved AI methods for using dynamic data.

1.2.4 Contributions to Graduate Education

The following graduate students have participated in the research described in this report:

Prabal Acharyya

B.E. in Electrical Engineering from Indian Institute of Technology at Kharagpur, India

Rajiv Bhatnagar

M.Sc. in Nuclear Engineering from The Ohio State University
M.Tech. in Nuclear Technology from IIT in Kanpur, India
B.Tech. in Mechanical Engineering from IIT in Kanpur, India

Jae-Joo Ha

M.Sc in Nuclear Engineering from The Ohio State University
B.S. in Nuclear Engineering from Seoul National University in Seoul, Korea

Charles Hardy

M.Sc. in Nuclear Engineering from the University of Illinois
B.S. in Mathematics from Case Western Reserve University in Cleveland

Scott Haggerty

B.S. in Nuclear Engineering from New York State University, Albany

Tom Jakubowski

B.S. in Nuclear Engineering from the University of Wisconsin, Madison

Loay Khartabil

B.S. in Electrical Engineering from the University of Houston

Greg Manning

B.S. in Electrical Engineering from the University of Missouri at Rolla

Hari Narayanan

M.Sc. in Computer and Information Science from the University of Rochester

M.E. in Automation from the Indian Institute of Science in Bangalore, India

B.E. in Electrical and Electronics Engineering from Birla Institute of Technology and Science in Pilani, India.

The activities of each student will be discussed in the following paragraphs. These activities have ranged from serving in an advisory capacity to research leading to M.Sc. Theses and Ph.D. Dissertations. In the case of graduate research, the general topic will be included in the discussion of each student's role in the research program.

Prabal Acharyya enrolled in the Nuclear Engineering Graduate Program in the Autumn quarter of 1988, and begin work on this project in the Winter quarter of 1989. Mr Acharyya has been involved in identification and specification of an appropriate AI workstation configuration for installation of the OA on the Perry Nuclear Power Plant simulator. In the next several months he will be responsible for the workstation checkout and initial testing. He and Mr. Jeff Maresh will be responsible for installation of the workstation on the Perry Simulator. This activity will serve as Mr. Acharyya's M.Sc. project (no thesis required for Ph.D students). At this time, Mr. Acharyya has not identified a Ph.D research topic.

Rajiv Bhatnagar has served as a general advisor in all the aspects of the program. Mr. Bhatnagar is completing his Ph.D. Dissertation which addresses the

integration of the diagnosis and procedure management modules. Therefore, he was responsible for conceptualization and implementation of the intelligent data base and the Plant Status Monitoring System (PSMS). Mr. Bhatnagar's research has also addressed temporal issues and integration of qualitative and quantitative reasoning. Currently, Mr. Bhatnagar is the most knowledgeable individual on all aspects of the Operator Advisor. Therefore, his advice has been invaluable to the progress of the program. He has professionally benefited by being able to participate immediately and directly on the development of applications of his Ph.D. research.

Jae Joo Ha joined the research program during the Winter quarter of 1989. Following completion of a M.Sc Thesis in thermal hydraulics, Mr. Ha completed two courses in AI and has also become familiar with the OA. Prior to enrolling in the Nuclear Engineering Graduate Program, Mr. Ha had several years of industrial experience in Korea working with nuclear power plant design. Beginning this Spring quarter, he began working with Mr. Charles Hardy to evaluate knowledge organization methods and system expansion. Mr. Ha's industrial experience is important to this research. Mr. Ha plans to complete a Ph.D. Dissertation in this area although specifics have not yet been identified.

Scott Haggerty enrolled in the nuclear engineering graduate program in the Winter quarter of 1989. Mr. Haggerty is a Nuclear Power Plant Senior Reactor Operator and Instructor. Since enrolling, he has become familiar with the OA, completed several AI courses, and participated in the development of a detailed specification for the OA, a key component in the V&V program. Mr. Haggerty's extensive nuclear plant operations experience was important in developing specifications for the OA. In the future, Mr. Haggerty will be working with the operators at the Perry Nuclear Power Plant to develop a program to test the OA following its installation. He will also be working with Mr. Jeff Maresh, a human factors consultant from Ohio State (to be named), and the plant operators to develop an appropriate man-machine interface. These activities will provide the foundation for his M.Sc. thesis which he expects to complete in 1990.

Mr. Charles Hardy joined the research program in the spring of 1988. Prior to enrolling at Ohio State, Mr. Hardy had five years of engineering experience at the Perry Nuclear Power Plant. Mr. Hardy has completed several AI courses and has become familiar with the OA. He has provided plant related consultation and is taking the lead role on expansion of the OA by adding plant systems and developing improved methods for knowledge organization (Re: Section 1.3.5). Mr. Hardy's Ph.D. Dissertation will address knowledge organization and representation schemes for fault diagnosis in nuclear power plants and complex engineering systems.

Tom Jakubowski is developing a method for dynamic testing of the OA (Re: Section 1.3.6). This research will provide a means for scenario testing of the OA using data from the Perry Nuclear Power Plant simulator. In this way, we will be able to do rapid dynamic scenario testing. This will be an important component of our verification program for the OA. This research and the testing through use of several Perry Plant scenarios will serve as the basis for Mr.

Jakubowski's M.Sc. Thesis which he expects to complete by the end of this summer quarter.

Loay Khartabil has been involved in evaluation of software environments and conversion of currently used software to new and improved software environments (Re: Section 1.3.2). He, along with Mr. Hari Narayanan, will be responsible for conversion of the OA software to Common Lisp. Mr. Khartabil's M.Sc. Thesis research is directed to methods the OA will use to respond to propagation of events and faults in the Perry Plant Reactor Coolant System by modeling of component/events and by performing conflict resolution.

Greg Manning has been working on the program for the past 18 months and has collaborated with Prabal Acharyya on workstation specification and assessment of commercial data bases. He is initiating research to add the plant electrical system to the OA. This research will provide the foundation for his M.Sc. Thesis.

Hari Narayanan has served as an adviser on AI and software issues. He has collaborated with Loay Khartabil on conversion of the OA to the Common Lisp environment. Mr. Narayanan is pursuing a Ph.D in Artificial Intelligence and his research on this project is providing excellent insight into some of the practical problems in implementation of AI concepts.

1.3 CURRENT ACTIVITIES

Several Task Committees have been established within the project team. This section details their current activities and plans for future work.

1.3.1 Workstation Conversion

Background

The XEROX workstations are ideal platforms for AI development work in universities or laboratories, but are not practical for installing real-time operational systems in an industrial environment. The decision to port the OA to a more appropriate computer system was made before the beginning of the current project year. The salient features examined in selecting a workstation were:

- * Significant software compatibility.
- * High resolution graphical interface.
- * Moderate temperature and cleanliness requirements to operate under exacting plant conditions.
- * Standard operating system, preferably UNIX.
- * Industry standard networking and interfacing capability.

- * High speed for real-time operation.
- * Ability to interface with Gould SEL computers running the SPDS in the Perry simulator.

The Sun Microsystems workstation was chosen as the new development platform. The primary plan was to place the workstation in the University and use it for both development and testing purposes. It was intended to be connected to the Perry SPDS through an interface to collect ERIS data. A mid-sized deskside Sun 4/260 server workstation initially appeared to be sufficient as a new platform for the OA system.

Current Plan

In February, Sun Microsystems announced the development of SPARC¹ workstations which would be twice as fast as the existing ones at less than two-thirds of the price of a Sun 4/260. After a thorough evaluation of the projected performance index, it was decided to purchase two of the new systems. This approach also provides separation of testing and development phases by placing one system at Perry and one at the University.

A Sun 4/330 SPARCserver workstation with 16 MIPS integer performance is planned to be installed at the University. One Sun 4/60 (SPARCstation-I) with peripherals will be installed at the Perry site. The operating system on both machines will be Sun-OS version 4.0, based on Berkeley 4.2/4.3 BSD and AT&T System V Unix.

Current work on workstation conversion includes placing the order to Sun and selecting a vendor to supply external hard disks and other peripherals. The recent effort also involves creating a memory map for the new systems and ordering the extra memory banks required.

Justification of the Current Plan

The present XEROX LISP machines are unable to multitask real-time database systems simultaneously with the operation of expert system modules. Additionally, these workstations have been discontinued by XEROX.

The decision to switch from XEROX workstations was made due to their extreme temperature and cleanliness requirements. The Sun SPARC workstations have an operating temperature range of 32 F to 104 F and humidity of 20 to 80%.

Sun provides user-friendly windows and graphical interfaces. Utilizing these features on Gx 8-bit accelerated 2D/3D SPARC workstations better man-machines will be developed. Sun's approach to open system networking would make files

¹SPARC (Scalable Processor Architecture) is Sun's version of RISC (Reduced Instruction Set Computer) microprocessor architecture.

and database on entire systems transparent to the users on both workstations. This would allow testing of the OA on the simulator from the university, simultaneously with the development of the man-machine interface.

The Sun system also provides an excellent platform for the software conversion, which is detailed in Section 1.3.2.

Projected Implementation Schedule

Delivery of the SPARCserver is scheduled for the month of September, considering a 90 days delivery time from Sun. It will take another 7-10 days for installation and connecting the system to the Sun network.

The installation of the SPARCstation at the Perry Simulator is scheduled towards the end of 1989.

1.3.2 Software Conversion

Background

The Operator Advisor (OA) was developed on the Xerox D-lion machines using the Interlisp-D environment. The development began on that platform because all the necessary AI languages, written by the Laboratory of Artificial Intelligence Research (LAIR) at The Ohio State University, were developed on these machines.

About a year ago, a decision was made to change the present development platform to one that is more suitable to deliver the OA. The Common Lisp (CL) language was chosen to be the new development language because the trend in the AI industry is toward standardizing CL as the AI language.

The first option that was considered was using KEE which is an engineering environment that runs on top of CL and can be run on a variety of machines such as the Vax, Sun, Symbolics, Xerox, and TI machines. However, evaluation of the system showed that KEE on the Vax was not acceptable because:

1. KEE takes a lot of memory which will cause the OA system to operate too slowly.
2. Our testing of the system showed that KEE runs very slow on the Vax. Also the system "crashed" many times on the Vax.
3. CL conversion will require a long time for completion because DSPL (the procedure language) did not run on KEE.

Current Plan

The current plan is to :

1. Convert all current files to the Medley environment that runs on the Sun stations.
2. Convert all current files to CL.

Converting the files to the Medley environment began about 8 months ago. There were 34 files that needed conversion, and most of them have now been converted (about 30) to the Lyric environment on the Xerox station. Now we are working on converting the remaining 4 files. Then we are going to port these files to the Medley environment on the Sun which is expected to be an easy routine job since Medley and Lyric are nearly identical environments. After that, the entire system needs to be tested and debugged.

In general, the conversion steps to Medley follows this order:

1. Convert the files from Koto-Loops to Product-Loops (Both of these environments run on the Xerox workstations.).
2. Convert the files from Product-Loops to Lyric-Loops (Lyric also runs on the Xerox workstations.).
3. Test and debug the system.
4. Convert the files to Medley on the Sun station.
5. Test and debug.

We are currently at the third step.

Converting to CL has not yet begun. However, we have not selected the CL version, windowing system and graphics, and object oriented system. We narrowed the list of options to three choices which are still under consideration. Our choice will depend on many factors such as support, maintenance, and user-friendliness. The conversion to CL will start as soon as we make our final decision on the final programming system to use. Also we have decided to write all new programs in CL to make the conversion easier and to familiarize the students with the CL language and environment.

Justification for the Current Plan

1. Why Convert to Medley that runs on the Sun and not start from now to convert to CL?
 - * Because we want to run the OA system on the Sun station by the end of 1989 so that it can be installed on the Perry power plant simulator.
2. Why go to CL?
 - * Envos (the company that supports Interlisp-D) has gone out of business. Therefore, we need to go to a different and more reliable AI system and language.
 - * We selected CL because it is becoming the standard AI language. This will provide us with continuous support, maintenance, portability, and reliability.

Projected Implementation Schedule

1. Converting to Medley.

We expect to have the conversion, debugging, and testing to the Lyric environment to be completed in October or November. Going to Medley on the Sun should require two to three weeks.

Following conversion to Medley, we will begin installing the OA system on the simulator.

2. Converting to Common Lisp.

After choosing the programming system, we expect the conversion to require approximately one year of efforts by two graduate students. This estimate is based on the following:

Conversion of each file will go through five steps. It will take a graduate student, who is reasonably familiar with Interlisp-D, CL, CSRL (the diagnosis language), DSPL, Loops (an object oriented language), the new object system, and the internals of the OA system about two to three weeks to convert each of the 34 OA system files.

The conversion steps are:

- a. Conversion from Interlisp-D to CL.
- b. Conversion from Loops to the Object system.
- c. Conversion of CSRL and DSPL commands.

- d. Conversion of graphics commands.
- e. Debugging and testing.

1.3.3 V&V Program Development

Background

Validation is the process of confirming that software being developed performs a function that actually helps the user. Verification is the process of confirming that the software operates correctly, that is, that it is internally correct. A plan is required to assure the Operator Advisor is validated and verified at every stage of the development process.

A formal V&V Plan had not been implemented prior to the current project year. However, the Operator Advisor was designed in accordance with a generalized task analysis of the actions taken by reactor operators under abnormal and emergency operating conditions. This served to provide a design basis for a system that would help the operators perform their jobs during plant transients. Then during development, the OA had undergone periodic testing using the Perry simulator to verify that its functions operated properly.

A V&V Plan requires three sets of documents to put it into place. The first is the specification documents, the second is the V&V Plan, and the third is the procedures necessary to put the plan into action. The V&V Plan details the checks that are required to assure the system is designed and operates in accordance with the specifications. The procedures are part of both the specifications and the V&V Plan. They contain the details for assuring the implementation of both documents.

Current Plan

During the past eight months, the outline for a formal V&V Plan has been completed, and a draft specification document has been developed. A copy of the draft specifications and a copy of a paper presented at the recent EPRI Conference on Expert System Applications for the Electric Power Industry are included in the Appendices. The paper provides a more detailed discussion of the V&V Program.

Two working committees were established to develop the Specifications for the Operator Advisor. The first committee was tasked with development of the specifications. The second was a review committee that provided an independent look at the specifications, and that recommended the present format.

A third committee has now been formed to serve as the long term working group to implement the V&V Plan. This working group consists of selected members from the two earlier committees. The members of this working group all have some plant operations related experience.

This working group has the responsibility to complete the specification document, to complete the V&V Plan, and to develop the procedures that will be followed as the Operator Advisor is expanded.

The draft specifications have been formulated into three sections.

The first section includes the general specifications for the application of the Operator Advisor to assure that it meets user needs. This section contains specifications related to the generalized task analysis, and will provide the basis for the validation of the Operator Advisor.

The second section includes the detailed system specifications. It specifies how each of the general specifications should be met at the functional level. This includes the division of the Operator Advisor into its sub systems, specifications for the operation of each sub system, specifications for interconnections and communications, hardware specifications, man-machine interface specifications, and data/knowledge input specifications. This section will be used by the system programmers to translate the system requirements into code, and by the V&V team as the test standard.

The third section will include the software design specifications, including requirements for specific tools to use, and rule and object structures. It will describe how the Operator Advisor shall be built. It will specify requirements for programming procedures, and will serve as the standard for the exhaustive testing of the rules, objects, inference strategies, and communications paths.

Justification for the Current Plan

The V&V Plan for the Operator Advisor is being developed using the recommendations of two Electric Power Research Institute documents: (1) EPRI NP-5978, "Verification and Validation of Expert Systems for Nuclear Power Plant Applications," August, 1988, and (2) EPRI NP-5236, "Approaches to the Verification & Validation of Expert Systems for Nuclear Power Plants," July, 1987.

A new initiative is being started by the NRC and EPRI to develop a standard for the V&V of expert systems. Our research team will stay abreast of developments from this initiative. Proposals for this effort are due into the NRC in early July.

Strict adherence to the V&V Plan will provide the documentation trail for demonstrating that the Operator Advisor performs in accordance with the specifications. This documentation will provide the primary basis for obtaining approval for moving the Operator Advisor from the Perry simulator to the Perry Nuclear Power Plant.

Projected Implementation Schedule

Several parts of the V&V Program will be complete by the end of September, 1989. The specifications for the Operator Advisor will be completed in their initial form. The V&V Plan will be in a first draft by that time. Procedures are expected to be completed for data/knowledge acquisition and entry. Testing procedures will be identified, but not yet complete.

The specification documents are expected to change as the Operator Advisor expands and further development is completed. This will be a living document. In particular, specifications for the operator interface will develop as the operators have an opportunity to interact with the system. The V&V Plan will change in accordance with the specifications, although it should be more static.

Testing procedures will not be complete until actual testing is started on the simulator and we are able to have interactions with the plant operators.

The V&V Program has already been implemented in that the Operator Advisor is being developed in accordance with the specifications in the draft specification document. Full implementation of the V&V Program will occur when the V&V Plan is complete and as the testing procedures are put into place. This will occur incrementally throughout the second year of the development program.

1.3.4 Simulator Interface Development

Background

Prior to installing the Operator Advisor expert system on an operating nuclear power plant, the system will be fully tested on the full function plant simulator at the Perry Nuclear Power Plant. All of the plant variables required to verify and validate the Operator Advisor are available from the ERIS software package running on the simulator. A dedicated Gould 32/77 minicomputer system running Version 1.5E of the MPX operating system serves as the host for ERIS.

In the original proposal, it was determined that the ERIS host on the simulator would be either a DEC VAX 11/780 or a Gould 32/77 minicomputer. The host for the Operator Advisor was specified as either a DEC MicroVAX III or a Xerox 1108/09 minicomputer. It was initially proposed to install an ETHERNET communications interface between the ERIS host and the workstation hosting the Operator Advisor. DECNET or TCP/IP software protocols were also specified. All of the above hardware and software products are commercially available. Because of the uncertainty of the required data volume and content, serial communications between the two computers was ruled out as a feasible option. It was also ruled out because of the excessive system load that would be incurred on both the VAX and Xerox minicomputers due to architectural features.

Current Plan

During the course of the past project year, the plant simulator and Operator Advisor workstation configurations have become more defined. A Sun Microsystems workstation will be used as the host for the Operator Advisor expert system. The staff at the Perry simulator have informed us that we would initially have ERIS available to us on the Gould 32/77 but should expect to move to a DEC VAX as early as mid-1990 because of simulator facility upgrades. In addition, the data requirements to validate and verify the Operator Advisor have been further defined. As a result, the current plan is to implement a serial communications interface between the two computers. Communications will be performed at a 9600 baud rate using an accepted protocol such as XMODEM or YMODEM.

Justification for the Current Plan

After evaluating IEEE-488, ETHERNET, and serial communications interfaces, a serial communications interface was chosen to transfer data from the Gould 32/77 to the Sun 4 workstation for several reasons:

1. The simulator facility at the nuclear plant may undergo a major upgrade involving totally new hardware while the current project is in progress. If a more elaborate and costly interface were implemented, it was determined that the hardware and associated software on the Gould would be unusable. The effect would represent a monetary loss on products that may never have been used as well as several months of down time while the new interface was being developed.
2. It was determined that approximately 350 16-bit integer numbers could be sent over the serial interface operating at 9600 baud each second. This figure includes the overhead associated with data organization and error checking. These variables will not all be sent at regular intervals but rather sent in packet format according to some sample plan.
3. In cooperation with the Perry simulation facility software specialist, Gould 32/77 system bench marks were performed to verify the efficiency of the proposed serial interface. It was determined that this amount of data could be passed over a serial port continuously at 9600 baud without causing degradation to ERIS.
4. Sun Microsystems was contacted to determine the efficiency of the proposed serial interface. According to Sun, the Sun 4 workstations have a dedicated microprocessor to handle all serial communications which is separate from the main processor. As a result, serial communications at 9600 baud could be handled with no perceptible system degradation.
5. Because of the relative simplicity of serial communications, minimal hardware cost is encumbered, and the software written on the Gould could

be modified rapidly for another microcomputer if the hardware upgrade occurs.

6. Gould determined that no device drivers for the ETHERNET board on the Gould 32/77 were available for Version 1.5E of the MPX operating system. It was further determined that the Gould 32/77 could not support Version 3.X of the operating system, the version which supports ETHERNET devices. As a result, approximately four to six person months would be required to develop the device drivers.

As a result of the above decision, a communications interface will be implemented effectively and efficiently without causing any delays to the overall project schedule.

Projected Schedule

The low-level communication routines will be tested on the Gould 32/77 at the Perry Nuclear Power Plant during June 1989. The corresponding routines will be developed during July 1989 for the Sun workstation. The basic structure of the high-level programs to sample, packetize, and transmit data on the Gould and receive and store data on the Sun will be developed through September 1989. The sample plan will be implemented as required by the expert system programmers.

Although the communications interface represents a crucial component in the Operator Advisor, once fully defined, it is straight forward to develop and adapt to the needs of the system. Since no problems are anticipated in the development of the interface, no delays in the second year project schedule are anticipated should Perry purchase a new simulator computer.

1.3.5 Knowledge Base Expansion

Background

To date, the development of the Operator Advisor System knowledge base has concentrated primarily on the plant feedwater system. This system was chosen because it is complex enough to demonstrate all of the functionality of the Operator Advisor, while being compact enough that one researcher could compile all of the knowledge required by the Expert System. The design of the Operator Advisor based on a single, albeit large, plant system was very advantageous in that it ensured that the knowledge base would be self-consistent.

However, a useful Operator Advisor must contain knowledge concerning nearly all plant systems. We have long recognized that in an effort of this magnitude we could not continue having a single researcher compile, input, and maintain the entire knowledge base. On the other hand, it is vital that knowledge be added in a consistent and organized manner. Thus a large part of our recent development effort has been aimed at designing a framework and methodology for the addition of knowledge.

Current Plan

There were two major considerations in developing a knowledge base expansion plan:

1. Knowledge must be added according to a detailed procedure, so that researchers working on separate plant systems will organize the knowledge in the same way.
2. As knowledge is added to the Operator Advisor, accurate and detailed records of the information sources must be maintained.

After extensive review and analysis of various knowledge representation schemes, it was decided that these criteria could best be met by organizing the Operator Advisor knowledge base according to plant systems. Since this is the way most plant procedures and design data is organized, and the way plant operators learn about the plant, it was deemed the most efficient way to add new knowledge. In particular, knowledge will be added to the knowledge base in discrete packets, representing individual plant systems. These packets will be, as far as possible, independent of one another.

To implement this organization, a certain amount of top level reorganization of the Operator Advisor classification hierarchies has been necessary. As was stated earlier, the original knowledge base structure represented a single plant system, with no means for adding separate systems to the hierarchies. This problem was rectified by the introduction of a top level structure in which the feedwater system is one of many systems.

In addition, a procedure has been developed to ensure the correct and detailed documentation of every system as it is added to the knowledge base. This procedure requires that a complete set of supporting documentation be reviewed and approved prior to the addition of any new system or data to the knowledge base.

Justification for the Current Plan

The idea of expansion by system is based on the concept of modularity. There are numerous merits to this approach:

- * Each module can be developed and tested independently. This is extremely important for the verification and validation effort.
- * New knowledge cannot affect the correctness of previously entered data.
- * Maintenance of the expert system is facilitated since all knowledge concerning a particular plant system is found in a single "location".

- * Documentation is greatly simplified. Each module added to the expert system has a corresponding documentation module.

The importance of adequate documentation in a system of this size cannot be overstated. The value of detailed documentation to the verification and validation efforts alone will justify the time devoted to the compilation and maintenance of these records.

Projected Implementation Schedule

The current schedule calls for the addition of 14 systems by January, 1990. These systems and the proposed implementation schedule are shown in Table 1. As seen in the figure, the schedule is heavily weighted toward Nuclear Steam Supply systems and Containment systems. This is appropriate as these systems are the most important to plant safety and, as such, are more useful for demonstrating the full functionality of the Operator Advisor.

The remainder of the plant systems to be added to the Operator Advisor are listed in Table 2. Addition of these systems will commence in 1990. However, because of the uncertainty in the schedule for the installation of the system on the Perry simulator, there is at present no schedule for the addition of these systems.

Table 1 - Knowledge Expansion Schedule

System Number/System Name	Implementation Date
B21 Main Steam Main Steam System Automatic Depressurization System Nuclear Boiler Process Instrumentation Nuclear Steam Supply Shutoff System	8/31/89
R10 AC Electrical	9/30/89
E22A High Pressure Core Spray	10/30/89
E22B High Pressure Core Spray D/G	10/30/89
T23 Reactor Containment	10/30/89
E12 Residual Heat Removal	11/31/89
E21 Low Pressure Core Spray	11/31/89
B33 Reactor Recirculation	12/31/89
C71 Reactor Protection	12/31/89
E31 Leak Detection	1/15 '90
P57 Safety Related Instrument Air	1/31/90

Table 2 - Additional Systems for Knowledge Expansion

System Number	System Name
C11	Control Rod Drive Rod Control and Information Control Rod Drive Hydraulic
C22	Redundant Reactivity Control
C41	Standby Liquid Control
C51	Nuclear Instrumentation Startup Range Monitoring Intermediate Range Monitoring Power Range Monitoring
C91	Process Computer
D17	Radiation Monitoring Airborne Radiation Monitoring Process Radiation Monitoring
D19	Post Accident Radiation Monitoring
D21	Area Radiation Monitoring
D23	Containment Atmosphere Monitoring
E32	MSIV Leakage Control
E51	Reactor Core Isolation Cooling
G33	Reactor Water Cleanup
G41	Fuel Pool Cooling and Cleanup
G42	Suppression Pool Cooling
G43	Suppression Pool Makeup
M11	Containment Vessel Cooling
N21	Condensate
N31	Main Turbine
N32	Steam Bypass and Pressure Control
N41	Main Generator
N64	Off-Gas
N71	Circulating Water System
P42	Emergency Closed Cooling
P45	Emergency Service Water
P11	Condensate Transfer and Storage
P41	Service Water
P43	Nuclear Closed Cooling
P44	Turbine Building Closed Cooling
P50	Containment Vessel Chilled Water
P51	Service Air
P52	Instrument Air
R42	DC Electrical
R43	Standby Diesel Generator

1.3.6 Dynamic Testing

Background and Current Plan

Research is ongoing to assess the performance of the existing Operator Advisor system when presented with real-time nuclear power plant transients indicating the presence of an off-normal event. The work being performed is presently providing information about how the system responds to the inadvertent opening of a main steam line safety relief valve (SRV).

Work toward this goal has included the following. First, an appropriate scenario for testing of the system was selected. Selection of the inadvertent SRV opening was made because it would involve testing each module of the Operator Advisor. Secondly, real-time plant sensor data was acquired by running the scenario at the Perry Nuclear Power Plant simulator. The parameters relevant to the scenario were monitored and output for later use. After this, the real-time data was programmed into the system database for access by the Plant Status Monitoring System. Because procedural knowledge is incomplete in the present form of the Operator Advisor, certain procedures were necessarily programmed into the Dynamic Procedure Management System module. Also requiring an update, the Plant Status Monitoring System now contains the conditions with which to test for occurrence of the scenario. The groundwork has been laid for testing of the scenario at this time.

Justification for the Current Plan

This work is being done in support of the overall V&V effort for the Operator Advisor. During this simulation, verification can be performed for each of the system modules. The processes of event identification, event diagnosis, and procedural management as performed by the Operator Advisor can be tested. More interestingly, the performance of the integrated system can be examined for small variations on the original scenario.

It is expected that this project will provide a good indication of how adept the system is at responding to a legitimate nuclear power plant malfunction. This will be important as the scope of the CA is expanded to incorporate additional plant systems. As a result of this work, some problems with the performance of the integrated system may be addressed before it is connected to the Perry Nuclear Power Plant simulator. Certain findings have already been made regarding knowledge implementation and required monitoring frequency as a result of this testing project.

Projected Implementation Schedule

The performance of this simulation is ongoing at the time of this writing. Results are appearing gradually since more is observed with every run performed. Completion of this project will occur before the end of September, 1989.

There is no limit to the number of scenarios which may be run in this manner, provided one can acquire data from the Perry Nuclear Power Plant for the original malfunction, and provided the Operator Advisor contains the required knowledge to act upon the transient data. There are no plans, however, to pursue more of these scenario tests because an infinite number of scenarios can be examined once connection to the reference simulator succeeds.

1.3.7 Database Conversion

Background

Real-time application of large databases requires an efficient DataBase Management Systems (DBMS). Commercial databases provide sophisticated DBMSs which are not available in object oriented programming environments.

The primary objective is to provide an intelligent database working on-line with the simulator. The expert system will be residing in Common Lisp (CL) on top of the SUN UNIX working environment. The sub-systems will access the database through a query language.

The commercial package chosen for this purpose should be UNIX compatible, have standard query language, window, and screen features.

Current Plan

Informix-SQL has been selected the database engine for use in rebuilding the entire Intelligent Database. Informix-SQL is a relational database management system based on the standard IBM Structured Query Language (SQL). The access query language will be written on top of the database, to answer queries from the expert modules in CL. Informix-ESQL-C will allow us to embed SQL statements in the C-code. The entire system will reside inside the C-shell in the UNIX operating system.

Currently, we are finalizing the order with Informix. The plan is to install the packages on a SUN 4/260 in the Department of Computer and Information Sciences (CIS). This will be done strictly for learning purposes to make the programmers conversant with the SQL statements and development tools.

Current work also includes browsing through the manuals, and getting inputs from other research groups using commercial database packages for similar purposes.

Justification of the Current Plan

As Loops is unable to provide the necessary functions for the maintenance of a real-time database, it became necessary to consider commercial DBMS software. The present database does not have the data manipulation routines required for on-line update of sensor data.

Informix has emerged as the market leader in the UNIX DBMS market, having 43% of the market share. In a recent study conducted by the OSU CIS Department for a relational database system, it was shown that Informix's adherence to the ANSI standard is better than its competitors. Informix provides a complete line of application development tools that run on a full spectrum of SUN computers.

Informix-SQL will provide all of the tools necessary to build database applications, create and alter databases, as well as to retrieve and modify data.

The Simulator Interface Program (See Section 1.3.4) will be written in C language. Embedding ANSI-Standard SQL syntax into the C environment will greatly reduce the programming time by reducing the amount of code necessary for file or database access and manipulation. Using short, simple, English-like SQL statements complex data manipulation tasks can be performed.

The Intelligent Database is a commercial package that will be written for the future OA in CL environment. Present OA in the Medley environment does not have the necessary communication ability to access the C-codes.

Projected Implementation Schedule

Informix software is scheduled to arrive in July, 1989. Assuming CIS provides the necessary computer time, and disk storage, the database will be installed on a SUN 4/260 within a week following receipt. The software for development purposes will be developed when SPARC workstations arrive.

The development of the entire database in Informix will take about 3 months from the installation on SPARC stations. The testing will take another 3 months.

2.0 PROPOSED EFFORT FOR SECOND YEAR

2.1 Introduction and Revised Goals for Year 2

The goals stated in the original proposal for the second year of this project remain unchanged except for the addition of two new goals. The second year goals are:

1. Continue to expand the Operator Advisor to handle additional systems and malfunctions.
2. Evaluate the response of the plant and operators with and without the Operator Advisor.
3. Modify and improve the Operator Advisor and man-machine interface in accordance with findings from the V&V process, operator evaluations, and response evaluations in Objective 2.
4. Begin the testing and regulatory reviews for the installation of the AI Operator Advisor on an actual plant.
5. Begin conversion of the Operator Advisor to Common LISP.
6. Complete work on tasks identified for Year One that may not be complete at the end of September.

The first four are from the original proposal. These four and goal 5 were discussed in Section 1.2.2 of this proposal. Goal 6 is a logical addition to the set.

The remainder of Section 2.0 will discuss the specific tasks necessary for accomplishing the goals we have established.

2.2 Knowledge Base Expansion

The knowledge base will continue to be expanded to handle malfunctions in additional plant systems. A Task Committee has the responsibility to set the priorities for knowledge expansion and to develop the knowledge expansion process.

The priorities should be in place before the end of the first project year. Knowledge expansion will then continue throughout Year Two. Though knowledge base expansion will begin in accordance with the established priorities, it is anticipated that the priorities may change as testing is done on the simulator.

The process for knowledge expansion will be established as the procedures required by the specifications are completed. These procedures should all be implemented prior to the end of Year One, and will be in full use during Year Two. As experience is gained with them, we anticipate they will require changes

and updates. These procedures are extremely important to the success of the Operator Advisor. They will also be important once testing is started on the simulator because it may be necessary to modify the knowledge base on the fly as testing identifies missing knowledge or data.

2.3 Installation at the Perry Simulator

This task remains to be completed from the current year's efforts.

Three other tasks need to be completed before this task can be completed. All three should be complete before the end of the current project year. These tasks, in order of their required completions, are:

1. Conversion of the software environment to Medley.
2. Installation of the Operator Advisor on the Sun workstation.
3. Completion of the serial interface between the Sun workstation and the simulator computer.

All three of these tasks are expected to be complete before the end of September, 1989. Installation of the Operator Advisor at Perry can begin immediately thereafter. We expect this task to be complete by the end of calendar year 1989.

2.4 Evaluation of Operator Interaction

The objective of this task is to evaluate the reactor operator's response to plant transients with and without use of the Operator Advisor. Data obtained and the reactor operators' experiences with the Operator Advisor will then be used to help in improving the system. We expect that this will be especially helpful in improving the man-machine interface.

A set of simulator scenarios will be developed that will include challenges to the plant leading to entry conditions for both abnormal and emergency procedures. The scenarios will be run on the simulator by the development staff to assure that the Operator Advisor responds correctly.

Then two independent operating crews, neither of which knows the scenario, will each be run through the scenario. One crew will use the Operator Advisor, and one crew will not. Several scenarios will be used so that each crew will have the opportunity to run scenarios with and without the Operator Advisor. Several crews will be used for these tests. Since Perry is on a six-shift rotation, up to six crews might be available for running each scenario.

The response time of the crews to the plant malfunctions, the accuracy of their responses, and their performance in following procedures will be evaluated using objective criteria.

2.5 Design of Man-Machine Interface

This task refers specifically to the interface between the Operator Advisor and the human reactor operator. The task discussed in the next section refers to the interface between the Operator Advisor and the staff either developing or maintaining the Operator Advisor.

Design of the man-machine interface depends heavily on the capabilities of the Medley system and the Sun workstations. Since we know little about these at this time, it is difficult to project how quickly this task will be completed.

However, an interface currently exists that will allow the reactor operator to be presented with procedural steps, and that will enable the reactor operator to query the Operator Advisor concerning its diagnosis of off-normal conditions. This will allow us to begin working with plant crews as soon as the Operator Advisor is installed on the simulator. Reactor operator input can then be obtained to help in developing specifications for the eventual man-machine interface.

2.6 Design of Maintenance Facility

Two maintenance tasks are of concern. The first is that of adding knowledge and data to the Operator Advisor. The second is maintaining this information.

Data will be maintained in the database in the form of objects. A user-friendly facility for adding and modifying this data needs to be specified and designed.

Knowledge includes the rules and objects in the three expert systems that analyze plant conditions and provide guidance to the reactor operators. The interfaces for adding this knowledge will be similar to that for entering data. In addition, it should also include automated rule generators that will force the syntax to remain consistent and understandable by all three expert systems.

2.7 Implementation of the V&V Program

The formal V&V Program will be implemented incrementally as procedures and testing methods are completed. The specifications and V&V Plan will be completed by the end of the current project year. Also, procedures for data and knowledge input will be complete before the end of the current project year.

Needing development in Year Two are procedures for exhaustive testing of the rules and objects, inference testing, and testing of reactor operators' response to plant off-normal conditions with and without the Operator Advisor.

2.8 Begin Regulatory Reviews

The V&V Plan is critical to receiving regulatory approval. It must include an effective testing program at the plant site.

Additionally, we must begin a dialogue with NRC personnel who will have responsibility for reviewing and approving installation of the Operator Advisor on the power plant. We intend to begin this process working through both the research and regulation sides of the Commission.

One approach that will be used is to invite the on-site inspectors to participate in the simulator testing of the Operator Advisor.

3.0 PERSONNEL AND MANAGEMENT PLAN

3.1 Project Organization

Brian K. Hajek will continue to serve as overall project manager and Principal Investigator. Mr. Hajek is a Research Scientist in the Nuclear Engineering Program and has served as Principal Investigator for the previous research programs sponsored by DOE, and Co-Principal investigator on the current and past NSF grants addressing theoretical aspects of Artificial Intelligence. Mr. Hajek has also been a Certified BWR Operator Licensing Examiner with the U.S. Nuclear Regulatory Commission.

Dr. Don W. Miller will continue to serve as associate project manager and Co-Principal Investigator. Dr. Miller is the Principal Investigator for the current and past NSF AI Grants and the coordinator of The Ohio State University Applied AI in Engineering Program.

Dr. B. Chandrasekaran will serve as Co-Principal Investigator and consultant on the theoretical and practical aspects of Artificial Intelligence. Dr. Chandrasekaran is also a Co-Principal Investigator on the NSF AI Grants and past DOE Grant, and a member of The Ohio State University Applied AI in Engineering Program Committee.

Mr. Jeff Maresh, a private consultant, is responsible for the hardware and software interface between the AI system and the Perry Plant Simulator. Mr. Maresh, who holds a B.S. and M.S. in Aeronautical Engineering from The Ohio State University, has extensive hardware and software design experience with emphasis on microcomputer data acquisition and flight simulation.

In Section 3.2, a more detailed description of the three faculty personnel has been included.

In Section 3.3, a description of the Task Committee organization is presented. This discussion also provides insight into the organization of the entire research team, including the graduate students. A discussion of graduate student qualifications and their involvement in the research program is found in Section 1.2.4.

3.2 Faculty

This section provides a description of each of the principal investigators designated to play key roles in the proposed research program. The descriptions highlight the respective investigators' areas of interest, experience, and qualifications of specific relevance to the proposed research.

Brian K. Hajek

Mr. Hajek is a Research Scientist in Nuclear Engineering. He was Associate Director and Operations Manager of the Ohio State Nuclear Reactor Laboratory

for twelve years. In this position he held a Senior Reactor Operator's License and his responsibilities involved all aspects of reactor operations, including reactor and radiation safety, liaison with the Nuclear Regulatory Commission and government agencies, and coordination of research and training programs.

He has completed simulator training courses for engineers on both PWR and BWR simulators. He has taught courses at Ohio State in reactor operations, nuclear instrumentation, thermal hydraulics and measurements, applied AI in engineering, and in PWR and BWR plant operation, which included operating experience on the respective plant simulators.

Mr. Hajek was the Principal Investigator and project manager for the Department of Energy research program (September 1986-June 1988) entitled "Application of Artificial Intelligence to the Operation of Nuclear Power Plants". He is a Co-Principal Investigator on NSF funded research grants which have and continue to address theoretical issues relating to the application of AI to complex engineering systems such as nuclear power plants. Finally, he is a Co-Principal Investigator and member of the Applied AI in Engineering Program Coordinating Committee (one of five) at The Ohio State University. This program, under Ohio State University sponsorship, is developing AI tools and protocols for introducing AI into engineering problem solving. Ultimately, the goal is to form a Center of Excellence.

He has taught operations oriented courses at both PWR and BWR plant sites on reactor physics and fluid flow. He has done research in neutron radiography, neutron activation analysis, BWR boiling profiles, core flux mapping, and the application of artificial intelligence techniques to nuclear power plant operations and instruction manuals.

Mr. Hajek has been actively involved in managing and developing training programs for nuclear power plant personnel since 1979. Particular programs related to nuclear power plant systems for which Mr. Hajek has had management responsibility include a Technical Specifications Training Program, a Plant Thermal Sciences Training Program, and a System Description Manual Training Program.

Mr. Hajek was a consultant examiner with the Nuclear Regulatory Commission Operator Licensing Branch (OLB) from 1978 through 1988. In this position he held an appointment with the OLB branch at Region 1 and is a Certified BWR Operator Licensing Examiner.

Professor Hajek is also President of Nuclear Education and Training Services, Inc. In this capacity, he has managed the development of software descriptions for the General Electric process computer replacement and SPDS system known as GEPAC Plus.

Mr. Hajek is active in several professional associations. He has been a member of the technical program committee for The Symposium on Training of Nuclear Facility Personnel for the past five symposia. He has been a member of the

executive committee of the American Nuclear Society Reactor Operations Division and was recently elected as Secretary, and has served on several committees for the ANS Education and Training Division.

Dr. Don W. Miller

Professor Miller is currently Chairman of the Nuclear Engineering Program and Director of the Ohio State Nuclear Reactor Laboratory. He specializes in nuclear and reactor instrumentation, reactor system control, reactor kinetics and dynamics, nuclear power plant operations, and AI applied to process control engineering. Professor Miller's recent research has included evaluation of surveillance methods for plant nuclear instrumentation, development and analysis of position sensitive fission chambers and neutron noise analysis. His current research includes scintillating fiber optics, digital radiography, and development of artificial intelligence methods for plant operations and design.

Dr. Miller has conducted research in nuclear instrumentation at several operating nuclear power plants. This research has included monitoring of neutron sensor performance and availability using high frequency detection noise analysis, and root cause evaluation of startup channel faults in PWRs. In addition, he has conducted research in the use of in-core fission chambers to detect reactor water level in BWRs under simulated accidental conditions, and the development of an in-core position sensing fission chamber for neutron flux profile measurements in nuclear power reactors.

Professor Miller has managed research in artificial intelligence for the past five years. He has and continues to be the Principal Investigator of the NSF Grants to address theoretical issues of AI applied to complex engineering systems. He is Co-Principal Investigator of the DOE Grant, and Principal Investigator for The Ohio State University Applied AI in Engineering Program.

At Ohio State Dr. Miller teaches courses in reactor laboratory, nuclear instrumentation, reactor kinetics, plant dynamics, and plant control systems. He also has taught similar courses to plant engineering and operations technical personnel.

Dr. Miller, in his position as Director of the OSU Nuclear Reactor Laboratory (OSU NRL), has provided leadership and technical direction for a comprehensive upgrade of the OSU NRL. The upgrade has included design, construction, and testing of a solid state control and safety instrumentation, conversion to Low Enriched Uranium (LEU) (criticality attained December 15, 1988) and increase in power to 500 kW (to be completed in 1990).

Professionally he has served as Chairman of the Nuclear Engineering Department Heads Organization (NEDHO), and is Chair of The American Nuclear Society Education and Training Division 1987/88. He was recently elected to the ANS Board of Directors.

B. Chandrasekaran

Professor Chandrasekaran is Director of the Laboratory for Artificial Intelligence Research at The Ohio State University. He is a world recognized expert in the development and applications of artificial intelligence techniques. He specializes in the development of methods to handle large bodies of knowledge and thought processes, in particular, developing framework for reasoning systems which perform diagnosis, information retrieval, and planning or design.

Professor Chandrasekaran's research has been supported by grants from the National Science Foundation, the Air Force Office of Scientific Research, and the Defense Advanced Research Projects Agency. He has served as a Co-Principal Investigator with Mr. Hajek and Dr. Miller in their DOE and NSF Grants. He is also a Co-Principal Investigator and a member of The Ohio State University Applied AI in Engineering Program Committee.

Dr. Chandrasekaran has given numerous invited lectures addressing many aspects of artificial intelligence and applications to engineering problem solving. Recently he was the luncheon keynote speaker at the EPRI Expert Systems Conference in Boston (May, 1987), gave a keynote lecture at the AI in Engineering Conference, also in Boston (August, 1987), was an invited lecturer at the Texas Instruments Artificial Intelligence Center (August, 1987), and was an invited speaker at the 1987 International Joint Conference on Artificial Intelligence in Milan, Italy (August, 1987). During the past five years, Dr. Chandrasekaran has been a Principal Investigator or Co-Principal Investigator on eighteen funded research programs, and has published more than fifty papers on artificial intelligence and its applications.

He is professionally active as a journal editor and member of editorial boards, on technical committees, and is a Fellow of the Institute of Electrical and Electronics Engineers. Professor Chandrasekaran was recently named one of 13 recipients of the Ohio State Alumni Award for Distinguished Teaching.

3.3 Task Committees - Graduate Student Participation

The research program described in this report is directed to a broad and complex array of tasks, all of which are interactive and require in most cases synergistic solutions. To facilitate an effective approach to these problems, four task committees have been identified. These committees in effect comprise research teams with specific areas of responsibility and goals consistent with the goals of the overall research program. The Task Committees are listed below followed by a brief outline of their respective goals and tasks (*denotes Committee Chair).

(1) Conversion to Common Lisp:

Hari Narayanan *
Loay Khartabil
Jae-Joo Ha
Jim McDowell(Chemical Engineering)

(2) Knowledge Organization and System Expansion

Chuck Hardy *
Rajiv Bhatnagar
Scott Haggerty
Jae-Joo Ha
Greg Manning
Brian Hajek
Don Miller

(3) Hardware/Software Interface-Installation and Human Factors

Prabal Acharyya *
Greg Manning
Jeff Maresh
Scott Haggerty

(4) Operator Advisor Specification and V&V

Brian Hajek *
Chuck Hardy
Scott Haggerty
Rajiv Bhatnagar
Tom Jakubowski

Bhatnagar, Jakubowski, and Manning will be completing their degrees and leaving for employment by the end of August

The objective of Task Committee (1) is to convert all the OA files from the current environment of Interlisp-D and Loops to Common Lisp. A complete discussion of the rationale for this conversion can be found in Section 1.3.2. This is a major and unexpected effort dictated by the current direction of AI technology. As described in Section 1.3.2 it is estimated that this effort will require a major commitment of two graduate students for one year. Hari Narayanan will be taking the lead with Loay Khartabil assisting. It is expected that a procedure will be developed which will hopefully permit undergraduate students to become involved thus, relieving the graduate students of this somewhat tedious task.

The goal of Task Committee (2) is to evaluate improved methods for knowledge organization and incorporation into the OA (See Section 1.3.5.). This will facilitate more rapid and accurate knowledge acquisition which in turn will result in better maintainability and easier verification. In addition this committee will develop a plan and a methodology for effective expansion of the OA to incorporate additional plant systems. This is a very important task and if successful will save considerable time and effort as the OA is expanded and modified to accommodate new plant systems and changes.

The initial objective of Task Committee (3) has been to specify the hardware and software for the AI workstation and its interface with the plant simulator. This task has also included specifying the software for incorporation of a commercial database into the OA.

Following completion of this task, this committee will have the task of installation and initial testing of the OA on the Perry simulator. This committee is also responsible for developing an evaluation program using the plant simulator. This activity will include considerable involvement and interaction with the plant operations staff. During this phase of the program, the man-machine interface design will be initiated.

Initially a committee was assigned the task of developing a detailed specification of the OA as a first step in a Verification and Validation program. Following completion of this task a second committee completed a detailed critique of this specification. The result is a comprehensive design specification for the OA; a specification by which performance can be measured.

Task Committee (4) consists of members of both the committees which developed the OA specification. Task Committee (4) will update the specification as needed and also continue the development of the V&V program. This effort will include designing an evaluation of the OA by the Perry Plant operations staff. This latter activity will require considerable interaction with Task Committee (3).

In summary, we believe the task committee approach is the most effective means of addressing the research issues and tasks necessary to develop and evaluate an Operator Advisor on a plant referenced simulator. Communication among all members of the research team and specifically the task committees is maintained through weekly project meetings.

*Budget request,
ds*

APPENDIX A

Specifications for the Operator Advisor

Rev. 0.1

May 2, 1989

SPECIFICATIONS FOR THE OPERATOR ADVISOR

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1.0 INTRODUCTION

The committee leaves this section open to incorporate appropriate areas of this document into the introduction.

It is recommended this be performed by a new group composed of members of each of the original groups.

2.0 DEFINITIONS AND ACRONYMS

2.1 Definitions

Abnormal Condition

Conformation

Critical Safety Function

Data

Data Security

Diagnosis

Identification

Knowledge

Performance Specification

Root cause Diagnosis

Safety Function

Safety Function Maintenance

Sample Plan

Sensor Data

Standard

Success Path

Validation ¹

The process of confirming external correctness or desired outputs by measuring system performance.

Verification

The process of confirming the presence or absence of internal errors such as distortions in converting requirements to design specifications or errors in coding the database exactly.

2.1 Acronyms

AOP- Abnormal Operating Procedure
ARP- Alarm Response Procedure
DFMS- Dynamic Procedure Management System
DVS- Diagnostic and Sensor Validation System
EOP- Emergency Operating Procedure
PSMS- Plant Status Monitoring System
RO- Reactor Operator
SRO- Senior Reactor Operator

¹ The definition of validation and verification should reflect the OSU recommendations to EPPI.

3.0 OVERVIEW

3.1 Categories of Specifications

3.2 Top Level Specification for the Overall System

3.3 Sub-System Interactions

3.0 OVERVIEW

3.1 Categories of Specifications

Specifications for the Operator Advisor fall into the following categories:

- 3.1.1 Top level specifications are for the overall system design and relate the Operator Advisor to the tasks and actions performed by a reactor operator.
- 3.1.2 Sub-system interaction specifications define the relationships of the various sub-systems of the Operator Advisor. They define the flow of information from one sub-system to another, and the control actions taken by each sub-system.
- 3.1.3 Sub-system specifications define the internal functions, actions, knowledge representation, and operational requirements for each sub-system.
- 3.1.4 Data/knowledge input specifications detail the procedures for verifying:
 - o Data before it is input to any part of the Operator Advisor,
 - o That data is input properly,
 - o That the data is internally (among all sub-systems) consistent,
 - o That expected (as defined by human experts and confirmed by Perry referenced simulator operation) results are achieved after data has been entered.
- 3.1.5 Computer specifications include the requirements for both the development and delivery environments, including interface and data transfer requirements among different computers. These specifications discuss the languages to be used, the developer interfaces, multi-tasking requirements, and the human interface with the delivered system.

3.2 Top Level Specifications for the Overall System

The Operator Advisor is an aid to the Reactor Operators (ROs) and Senior Reactor Operators (SROs) in the Control Room. It performs the mental

functions normally performed by the operators, provides information to the Operators in a clear and concise format for use in decision making, and monitors the effects of control actions taken by the Operators.

The Operator Advisor is not intended to perform these functions in lieu of the Operators performing them, but act as a supplementary resource for assisting with decision making in the Control Room. The Operator Advisor does not take any control actions.

The Operator Advisor is safety function dominant, and fails gracefully² when unable to complete a diagnosis or provide a procedure to be followed. The Operator Advisor normally implements³ the plant Emergency Operating Procedures (EOPs) whenever an entry condition to these procedures is detected. When such an entry condition is not present, the Operator Advisor identifies an Abnormal Operating Procedure (AOP) or Alarm Response Procedure (ARP) to be followed.

3.2.1 In performing Control Room duties, Operators:

1. Monitor and comprehend the state of the plant,
2. Identify normal and abnormal plant conditions,
3. Diagnose abnormal conditions,
4. Predict plant response to specific control actions taken in response to the identified or diagnosed abnormal conditions,
5. Select and implement the best available control action to mitigate the abnormal condition, monitor the results of that action, and
6. Determine alternate control actions in the event of a failure of the initial control action.

3.2.2 To emulate the activities and actions of the ROs and SROs, the Operator Advisor:

² We were unclear as to the meaning and actual system response to a failure.

³ The original word "defaults" did not seem correct in that default implies no other path available. When an entry condition to an EOP occurs, a very clear option is available.

1. Monitors the state of the reactor,
2. Detects deviations from normal operations, including those conditions that threaten the safety of the plant, operating crew, and general public,
3. Identifies* the abnormal conditions in accordance with the following:
 - o Conditions that threaten safety goals as defined by the entry conditions to the Emergency Operating Procedures (EOPs),
 - o Conditions which have been previously identified as Abnormal Events, and that can be defined by their entry conditions to the Abnormal Operating Procedures (AOPs),
 - o Conditions that are identified in the Alarm Response Procedures (ARPs),
 - o Conditions that represent potential for abnormal conditions as defined above.
4. Provides the Operators with a procedure to mitigate the consequences of the abnormality,
5. Monitors the performance of the procedure by continuing to monitor plant data,
6. Provides an alternate procedure when initial procedural actions fail.

3.2.3 To accomplish the Performance Specifications, the Operator Advisor consists of four primary sub-systems:

1. An Intelligent Database

The Database is the link between the Operator Advisor and the power plant. It collects data from the plant and formats the data for use by the other sub-systems. The Database is accessible by all Operator Advisor sub-systems.

* We have replace "diagnoses" with "identifies". We felt the system did not diagnose at this point.

Database data includes raw or processed parameter data, such as pressures and flows, component state data such as whether a pump is on or off, and certain response data such as if a pump trips, the standby pump (if available) will start on low discharge header pressure.

2. Plant Status Monitoring System

The Plant Status Monitoring System (PSMS) is the control unit between the Database and the other Operator Advisor sub-systems. The PSMS monitors data in the Database, identifies abnormal conditions, and initiates the activities of the other two sub-systems.

3. Dynamic Procedure Management System⁵

The Dynamic Procedure Management System (DPMS) is initiated by PSMS when PSMS identifies a specific procedure to be followed. This procedure can be an EOP, an AOP, or an ARP. The identification of these procedures is by simple pattern matching of entry conditions.

DPMS provides a procedure for the Operator to follow, monitors the Operator's success and progress in completing the procedural steps, and provides alternate procedures should the initial procedure fail.

4. Diagnostic and Sensor Validation System

The Diagnostic and Sensor Validation System (DVS) is initiated by PSMS to diagnose the cause of the abnormal event or the deviation from normality. The initiation of DVS however, is conditional in the case of detection of abnormal event by PSMS. DVS is initiated only after the need for diagnosis has been identified. In the case of detection of just deviations from normality, DVS is initiated immediately and used to predict the malfunction before the alarm conditions.

⁵

Section 3.2.4 was replaced entirely to clarify and minimize mention of changing data. It is not felt that the system should actually change data.

3.3 Sub-System Interactions

Information flow among the Operator Advisor sub-systems is defined by Figure 1.

3.3.1 Information Flow

PSMS, DVS, and DPMS have access to the Database to perform their functions. PSMS also initiates DVS if required to determine the cause of entry into an EOP, ADP, or ARP.

3.3.2 Control Operations

1. PSMS initiates DPMS when an EOP, ADP, or ARP required action is identified.
2. If PSMS identifies a deviation from normality that does not map to an EOP, ADP, or ARP, PSMS initiates DVS for determination of the abnormality.
3. Once DVS determines the cause of an abnormality, DVS notifies DPMS of its findings.
4. If DVS determines that the diagnosis of PSMS was based on invalid sensor data, then DVS informs PSMS of its findings.

Figure 1

Architecture of the Operator Advisor

To be provided at the appropriate time

4.0 DATABASE

4.1 Purpose

4.2 Overall Specifications

4.3 Input Requirements

4.4 Actions and Interactions

4.5 Knowledge Representation

4.6 Testing Requirements

4.0 DATABASE

4.1 Purpose

The Intelligent database collects data from the plant and formats the data for use by other subsystems. It also provides the link between the plant computer and the Operator Advisor system. The database utilizes features from the data which are of importance to the Operator Advisor, such as the flow rate of steam through the main steam lines or the state of a particular component.

The database provides a suitable environment from which the other Operator Advisor components can acquire information. The database contains the knowledge a human operator would use to answer high level questions about the states of systems or components. As an example, if in a particular flow line all flowrate sensors indicate low flow, and the pressure sensors indicate below normal pressure, the database determines that a pump trip has occurred in that line. The database transforms the raw data available from sensors into meaningful knowledge. Averaging techniques or other logical techniques are used by the database to detect abnormal states and perform diagnoses.

4.2 Overall Specifications

The operator advisor uses a large amount of data to make its decisions. The database has sufficient capacity to store the data required by the Operator Advisor and process the data in real time.

The content of the database is equivalent to the sensor data used in the power plant and the knowledge which a human operator has gained through experience and training. The specific knowledge employed by the operator and contained in the database includes the following:

1. The criteria to determine what value to use when more than one sensor is measuring a specific physical parameter.
2. The relationship of particular system and component states to plant conditions.
3. The data range(s) which define a value as being normal, high, low, etc. The numerous types of sensors employed by a plant necessitate the presence of knowledge about sensor normality for each type.

4. Temporal information to determine how long some data have been within a predetermined range and at what rate the values are changing.

4.3 Input Requirements

All plant sensor data are required by the intelligent database. Analysis and inferential methods contained within the database are utilized only after data are transferred to the database.

Data in the database is updated to store the present value, previous value, and time. If the DVS subsystem detects and diagnoses a faulty sensor, this information is transferred to the database.⁶

4.4 Actions and Interactions⁷

The analytical and inferential methods associated with the database are the following:

1. Normality Analysis -- If the external interface can not accomplish normality analysis prior to database entrance, the analysis is performed by the database. Results of the method indicate whether the sensor reading is very high, high, normal, low, or very low.
2. Trend Analysis -- Used to study the trend of an individual physical variable -- increasing or decreasing, or increasing or decreasing rapidly. A trend is a linear regression analysis in terms of database values for the most recent data points of physical variables.
3. Redundancy Checking -- This method is used to provide one representative value in the event that more than one sensor exists for a particular physical variable measurement. The choices for a representative value include the maximum, minimum, or average of a set of physical variables.

⁶ The original wording referred to the "incorporating" of data. This could create a misunderstanding as data is used by the methods, but not contained within.

⁷ Refer to "An intelligent Database for Process Plant Expert Systems" By Rajiv et. al. pg. 5 (Data Analysis Methods)

4. Historical Analysis -- The determination of changes in values of physical variables or system states with respect to an external measure, i.e. another physical variable reading or system state.

In order to prevent DVS from arbitrarily changing the database when it identifies inconsistent physical variables, special storage locations are reserved for validated data. Established rules are followed to determine when validated physical variables are to be trusted or rejected. The database contains both the validated and raw data from the buffer. All three expert subsystems are able to query the database for this data.

4.5 Knowledge Representation

The data and inference knowledge will be represented according to the format and query language grammar provided by Database formulation. Any data represented in the Database must be classified as a member of three classes. The three classes of data in the Operator Advisor are SENSORDATA, COMPONENTSTATES, and ALARMS.

The class SENSORDATA contains only actual process plant parameters. This includes temperatures, pressures, levels, and flow rates as they apply to plant systems. Actual plant parameters are of several major types: feedwater, recirculation, and main steam line systems have similar monitoring parameters such as pressure, temperature, and flowrate.

The hierarchical structure of plant parameters provide an opportunity to utilize the inheritance features provided by object oriented programming⁸. Subclasses are created for each parameter type such as PRESSUREDB, FLOWRATEDB, TEMPERATUREDB, and WATERLEVELDB. When variables such as limits and ranges are specified in these subclasses, the variables are automatically passed to instances of each subclass when that instance is created. Programming efficiency is increased because when an instance is added to a subclass, only the numerical values of its limits, ranges, etc. must be entered.

⁸ Programming efficiency and details provided in Section 4.5 may not be relevant to this document. The information is retained for future use in a more specific document.

⁹ References to actual language features should be minimized.

The class COMPONENTSTATES contains information concerning power plant system components such as pumps, turbines, and breakers. It also contains information on system components which are not directly responsible for power production. Examples are the components of the Low Pressure Coolant Injection System and the Residual Heat Removal System.

The class ALARMS contains information on all bistable components such as actual plant alarms. Examples are the SRV OPEN and the SRV LEAKAGE alarms. The class ALARMS also contains bistable components which are not actual alarms such as switch and relay positions.

The class of COMPONENTSTATES has a structure which resembles the structure of both ALARMS and SENSORDATA. Components such as turbines and pumps are be grouped into appropriate subclasses to promote full use of object oriented programming and to provide the programmer with observational transparency. Other balance of plant systems such as the Residual Heat Removal System are grouped together in subclasses.

4.6 Testing Requirements

The specifications presented in this section may be tested through database inspection or by performing a set of relevant scenarios. Raw data buffer and the intelligent database should be transparent to each other. A testing dataset containing many types of data groups will be used as an input to the data buffer. The consistency of the buffer and database are verified by checking the output.

5.0 PLANT STATUS MONITORING SYSTEM

5.1 Purpose

5.2 Overall Specifications

5.3 Input Requirements

5.4 Actions and Interactions

5.5 Knowledge Representation

5.6 Testing Requirements

5.0 PLANT STATUS MONITORING SYSTEM

5.1 Purpose

The Plant Status Monitoring System (PSMS) monitors plant data to detect any abnormal plant behavior that might degrade plant operation or threaten reactor safety.

5.2 Overall Specification

1. PSMS continuously monitors plant data to detect any threats to plant safety and/or abnormal plant behavior.
2. PSMS directs DFMS to initiate the procedures defined to control the detected plant malfunction.
3. PSMS directs DVS to initiate plant diagnosis whenever an abnormal state is detected.
4. PSMS directs control to and receive messages from DVS and/or DFMS.

5.3 Input Requirements

1. PSMS accesses data from the Database.
2. PSMS receives messages from DVS and DFMS.

5.4 Actions and Interactions

1. First, PSMS scans the safety function hierarchy.
2. If a threat to a safety function is established, then PSMS directs DFMS to initiate the relevant procedure.
3. PSMS directs DVS to start plant diagnosis.
4. PSMS looks at the first event in the abnormal event list.
5. If after looking at all the entry conditions an event is established, PSMS initiates DFMS and DVS.

6. DPMS acknowledges that it has received a message from PSMS, and a message from DVS (to inform PSMS of the validity of its conclusion).

5.5 Knowledge Representation

Three groups of knowledge are represented in the Plant Status Monitoring System:

1. Safety Functions

The safety functions are organized in a hierarchial form based on analysis of Critical Safety Functions. Each higher level parent node covers the safety of its children nodes. If the safety of a child node cannot be maintained at some level, the safety of the parent node will be maintained. Each node contains the entry conditions necessary to establish a threat to safety.

2. Abnormal Events

Abnormal events are predefined abnormal states, events, and alarms of the system. Each event contains the entry conditions needed to establish it as an abnormal event and is augmented with the safety function expected to be threatened if the procedure associated with that abnormal event should fail.

3. Deviations from Normality of Relevant Plant Parameters

Deviations from normality of relevant plant parameters are abnormal conditions that do not map to either a threat to a safety function or an abnormal event. These conditions consists of unstable trends.

5.6 Testing Requirements

1. Verification of the entry conditions of the Safety Functions and Abnormal Events.
2. Testing the PSMS response to a selected set of well defined plant scenarios based on the actions and reactions specifications.

6.0 DYNAMIC PROCEDURE MONITORING SYSTEM

6.1 Purpose

6.2 Overall Specification

6.3 Input Requirements

6.4 Actions and Interactions

6.5 Knowledge Representation

6.6 Testing Requirements

6.0 DYNAMIC PROCEDURE MONITORING SYSTEM

6.1 Purpose

The Dynamic Procedure Monitoring System (DPMS) assists the Reactor Operator in the execution of plant procedures to mitigate the consequences of an off normal condition. An off normal condition is defined as any deviation from normal operating conditions. These conditions are normally found in plant Alarm Response Procedures (ARPs), Abnormal Operating Procedures (AOPs), and Emergency Operating Procedures (EOPs).

6.2 Overall Specifications

- 6.2.1 DPMS provides the Reactor Operator with the sequence of actions required to mitigate the consequences of a malfunction or safety threat when given a malfunction or safety threat determination from PSMS or DVS.
- 6.2.2 DPMS resolves conflicts among indicated procedural requirements by utilizing an integrated event/symptom oriented approach to procedure management. In this approach, the alarm and event procedures are indexed to the safety (symptom) procedure that would be threatened should the alarm or event procedure fail to be executed.
- 6.2.3 DPMS has the capability to manage requirements to perform multiple procedures simultaneously.
 - o Multiple procedures may need to be run when multiple alarms are initiated, requiring one procedure to be run for each alarm.

During multiple alarms, the Reactor Operator cannot respond to all alarms simultaneously, but may be able to respond to several at one time. DPMS determines the necessary priority for procedure performance and provides the necessary procedures to the Reactor Operator in the correct order.

DFMS notifies the Reactor Operator when required actions cannot be monitored by plant sensors, and is capable of accepting operator input under these circumstances.¹⁰

- o Multiple procedures may need to be executed when inputs to multiple EOPs occur.

- 6.2.4 DFMS monitors the performance of each procedure, and provides an alternative success path whenever a primary success path cannot be completed.
- 6.2.5 DFMS defaults to the next level of threat whenever a procedure and its alternatives fail. That is, if an ARP and its alternatives fail, the AOP is executed. When an AOP and its alternatives fail, the indexed EOP is executed.
- 6.2.6 DFMS displays the expected default path to the Reactor Operator whenever a lower level threat is being managed. This permits the Reactor Operator to anticipate possible future actions.
- 6.2.7 DFMS informs the Reactor Operator when manual input of data is required.¹¹ A facility is provided for the Reactor Operator to input this data with a minimum of interaction with the terminal keyboard. For instance, if information regarding whether a component has been checked is required, a YES and NO box could be displayed on a touch screen.¹²

6.3 Input Requirements

- o DFMS is capable of querying the Database to obtain information about changes in component status and plant status to determine the success or failure of procedural steps.

¹⁰ This statement on operator input is repeated several times. It should be evaluated to determine the most appropriate location to avoid redundancy.

¹¹ Second repeat of input statement.

¹² The last sentence in Section 6.2.7 may belong in Section 10.0, Man-Machine Interface.

- o DFMS is capable of receiving Reactor Operator input from the Operator Advisor terminal when it is requested. ¹³

6.4 Actions and Interactions

- o DFMS accepts input from PSMS and DVS to initiate procedure management, or to change the management path when DVS determines by further diagnosis that an incorrect or unnecessary procedure has been requested by PSMS.
- o DFMS monitors the performance of each success path and provides an alternative success path when required.
- o When available primary and alternative success paths fail, DFMS transfers control to the next level of safety function maintenance.
- o DFMS informs the Reactor Operator when manual input of data is required.

6.5 Knowledge Representation

6.5.1 The knowledge base for DFMS is embodied in two distinct constructs.

1. The more critical construct is the hierarchy that establishes the relationship among the various malfunction states from individual alarm, to event procedures, to safety function maintenance procedures (EOPs).
2. The second construct is the set of objects that contain the knowledge of the interrelationships among the various procedures and procedure steps.

6.5.2 The construct interrelationships is determined by analysis and verified by a panel of domain experts.

6.5.3 Three agents are employed.

1. The SPECIALIST is the object (agent) containing the knowledge relating the various threat levels to one another.

¹³ Third repeat of input statement.

2. The PLAN is the overall procedure to be followed. It contains references to procedural steps.
3. PROCEDURES are the sub plans. They contain references to the PLANS that call them.

6.6 Testing Requirements

- 6.6.1 The approval path for the DFMS hierarchies shall be documented. This shall satisfy the requirement for approval of the agents in the affected SPECIALIST.
- 6.6.2 The content of each PLAN and PROCEDURE shall be checked and verified by an independent expert. DFMS shall contain documentation of the revision number and date of each procedure being used.
- 6.6.2 Scenarios based on expected plant responses shall be written and run to test the interaction and performance of each agent.
- 6.6.3 Requirements for data shall be checked for the availability of data in the Database or for the requirement to request additional data input.
- 6.6.4 Initiation of DFMS by either PSMS or DVS shall be verified.
- 6.6.5 Proper transfer of control from low level threats (ARPs or AOPs) to higher level threats (AOPs or EOPs) shall be verified for changing plant conditions.

7.0 DIAGNOSTIC AND SENSOR VALIDATION SYSTEM

7.1 Purpose

7.2 Overall Specifications

7.3 Input Requirements

7.4 Actions and Interactions

7.5 Knowledge Representation

7.6 Testing Requirements

7.0 DIAGNOSTIC AND SENSOR VALIDATION SYSTEM

7.1 Purpose

The purpose of the Diagnostic Sensor and Validation System is to diagnose the cause of abnormal plant conditions. This includes diagnosing "abnormal" conditions which are actually the result of faulty sensor data. In the event of slowly developing plant problems or abnormalities, DVS provides warning to operators before the problem would normally be detected.

The diagnosis made by DVS is used by PSMS for two purposes:

- o To establish that the abnormal event/safety threat established by PSMS was correctly identified, or
- o To determine the root cause of plant abnormalities which cannot be identified by PSMS.

DVS detects data which appears to be questionable based on expectations of data patterns for particular plant conditions. When the existence of faulty data is confirmed, DVS provides "corrected" values to the database.

7.2 Overall DVS Specification

DVS is capable of performing the following tasks: ¹⁴

- o Confirming the preliminary diagnosis made by PSMS when plant conditions match one or more of the abnormal events or safety threats recognized by PSMS.
- o Diagnosing the cause of an abnormal plant condition which does not match any of the abnormal events or safety threats recognized by PSMS.
- o Detecting and informing PSMS when faulty or missing data has caused PSMS to incorrectly identify an abnormal event or safety threat.
- o Transferring "correct" values to the database when faulty sensor data is detected.

¹⁴

The * items are not currently available.

- o Correctly diagnosing the plant state in the presence of faulty or missing data.
- * o Explaining a diagnosis to the operator upon request.
- * o Recognizing when a correct diagnosis cannot be made based upon available information.
- * o Predicting plant problems based on data trends.

7.3 Input Requirements

DVS receives a signal to start from PSMS.

DVS is capable of querying the database.

7.4 Actions and Interactions

DVS is capable of receiving a message from PSMS. This message indicates the type of diagnosis to be performed.

When PSMS requests a "diagnosis," DVS commences diagnosis at the top node in the general malfunction tree.

When PSMS requests a "confirmation," DVS commences diagnosis at the malfunction node corresponding to the abnormal event identified by PSMS.

DVS is capable of sending a message to PSMS containing the results of its diagnosis.

DVS is capable of transferring validated data to the Database.

7.5 Knowledge Representation

Knowledge in DVS is represented in a hierarchical form as shown in Figure 2.

This knowledge must be input correctly to ensure the proper operation of DVS. In particular, the structure of a malfunction hierarchy and the manner of querying the database require special attention. The following guidelines are to be used when adding malfunction hierarchies to DVS:

1. The Database can answer queries from DVS if the queries are worded exactly as contained in the Database. There are a finite number of queries in which the database is capable of answering.
2. The final node in any branch should reach a useful conclusion. For example, "Feed Pump Flow Low" is not an adequate conclusion. In general, the conclusion should point to a problem at the component level such as "Feed Pump Discharge Valve Closed".
3. The structure of the tree moves from "symptom oriented" to "component oriented" traveling from left to right along the knowledge tree.
4. Since PSMS requests confirmation of certain events/threats, the malfunction tree contains a node corresponding to each abnormal event. Therefore, when adding a malfunction hierarchy for a system which have abnormal events associated with it, there must be a node corresponding to each event.

7.6 Testing Requirements

The testing requirements of the Diagnostic and Sensor Validation System include the following:

1. Verification that DVS recognizes ALL of the abnormal events and critical safety function threats recognized by PSMS.
2. Verification that DVS arrives at a correct and useful diagnosis when the plant is in an abnormal condition not recognized by PSMS.
3. Verification that DVS returns a "negative confirmation" diagnosis to PSMS in time to prevent problems caused by performing the incorrect procedure.
4. Verification that DVS transfers "correct" data to the database when faulty data is detected. This includes verifying that DVS does not alter the database to the extent that a large portion of the database is "validated data".
5. Verification that the process of transferring data to the database does not interfere with the other processes (procedure management, process monitoring, etc.) running simultaneously in the expert system.
6. Verification that DVS correctly queries the database.

7. Verification that DVS provides a useful explanation of its diagnoses upon request.
8. Verification that DVS recognizes and correctly responds to situations where it is unable to diagnose the plant state.
9. Verification that DVS predicts plant problems before an abnormal condition occurs. This prediction must occur early enough to allow operators to take corrective action.

Figure 2

Hierarchical knowledge representation in DVS

This information will be added to the specification at the appropriate time.

8.0 DATA/KNOWLEDGE AND CODE INPUT AND MODIFICATIONS

8.1 Purpose

8.2 Definition of Data and Knowledge

8.3 Modifications of the Data/Knowledge Base

8.4 Modifications to Computer Code and Calculations

8.5 Reporting Requirements

8.6 Comments in the Code

8.0 DATA/KNOWLEDGE AND CODE INPUT AND MODIFICATIONS

8.1 Purpose

The Operator Advisor will evolve as plant changes are made, as the Operator Advisor is expanded, and as a greater understanding of the operation and behavior of the nuclear power plant is obtained.

The purpose of Data/knowledge Input Specifications is to detail the procedures for verifying:

- 8.1.1 Knowledge/data before it is input to any part of the Operator Advisor,
- 8.1.2 That data is input properly,
- 8.1.3 That the data is internally (among all sub systems) consistent,
- 8.1.4 That expected (as defined by human experts and confirmed by Perry referenced simulator operation) results are achieved after data has been entered.

8.2 Definition of Data and Knowledge

- 8.2.1 DATA is any well defined plant parameter related item required by the Operator Advisor.
- 8.2.2 DATA is of two types.
 - 1. STATIC DATA consists of items that usually do not change with plant operating history (time related changes) or with plant operating conditions (transient related conditions). STATIC DATA does not require reasoning to obtain it, but may require calculation to alter it for effective use.
 - 2. DYNAMIC DATA changes as a function of time and plant conditions.
- 8.2.3 DATA is normally derived from plant printed information, from sensors in real time, and from plant computers.

- 8.2.4 DATA is normally located in the Database of the Operator Advisor, and may be accessed¹⁵ by PSMS, DVS, or DPMS.
- 8.2.5 KNOWLEDGE is the information, commands, procedural steps, required actions, conflict resolution determinations, strategies, expert opinions, results of analyses, and like information that is derived from human determinations or from inferring done by the Operator Advisor.
- 8.2.6 KNOWLEDGE is incorporated in the PSMS, DVS, and DPMS subsystems.

8.3 Modifications of the Data/Knowledge Base

- 8.3.1 User friendly tools will be used to add Data and Knowledge to the Operator Advisor.
- 8.3.2 All additions or changes to the Data/Knowledge Base shall be reviewed and approved by at least one domain expert other than the person entering the Data/Knowledge. This review shall occur both before and after the additions or changes are made.
- 8.3.3 All additions or changes shall be documented as to the source of the information used, the date it was input, and the approvals and reviews performed.
 - o This documentation shall consist of a paper-based record keeping system during initial stages of the project.
 - o An automated record-keeping system shall be developed for on-line support of these records. Consideration shall be given to incorporating revision information among the instances of each rule, object, or node.
- 8.3.4 An on-line facility shall be provided to check the syntax and internal consistency of all changes. Warnings shall be provided if errors are made.

8.4 Modifications to Computer Code and Calculations

¹⁵ The reference to "embedding" of knowledge was changed to avoid confusion.

- 8.4.1 All modifications to the code shall be pre-approved as to their purpose and expected effect.
- 8.4.2 A facility shall be developed to check and automatically record the results of every code change.
- 8.4.3 Prior to AND following each approved code change, a scenario shall be run that specifically checks and verifies the change. The results of these runs shall be retained.

8.5 Reporting Requirements

- 8.5.1 On-demand reports in tabular or graphical form, either on screen or in hard copy, shall be available for checking and recording all changes made to the Operator Advisor.
- 8.5.2 These reports shall be automatically generated by a reporting facility. Requests for specific reports and their format shall be from a menu system.
- 8.5.3 These maintenance reports shall be available through the same menu system that would supply reports for normal operations of the Operator Advisor.

8.6 Comments in the Code

- 8.6.1 The code written for the Operator Advisor shall be commented to explain the purpose of each section of code, the decisions being made, the use of rules and objects, and the expected paths for decisions.
- 8.6.2 A Code Comments Standard shall be written and followed for all comments.
- 8.6.3 Comments in the code shall be verified to conform with the Standard.

9.0 HARDWARE

9.1 Main Computer

9.2 Data Source

9.3 Terminals

9.4 Communications Links

9.0 HARDWARE

9.1 Main Computer

9.1.1 The Operator Advisor is written to run on a computer system that may be readily interfaced with the types of plant computers normally used at Nuclear Power Plants.

9.1.2 The Operator Advisor Computer performs all the data processing required for diagnosis and resolution of plant conditions.

9.2 Data Source

9.2.1 The data source for the Operator Advisor is the plant Process Computer and the plant Safety Parameter Display System.

9.2.2 For the testing phase, the data source may be the plant full function simulator computer.

9.2.3 The data source shall not be perturbed by the presence of the Operator Advisor computer.

9.3 Terminals

9.3.1 The output of the Operator Advisor main computer is available to the Control Room operators on multiple terminal displays. These terminals display the rationale the required actions for the findings of the Operator Advisor.

9.3.2 The output of the Operator Advisor main computer also is available to remote terminals as determined to be required by plant staff. It is anticipated that at least three additional sites may be interested in observing Operator Advisor outputs. These include the Technical Support Center, the Emergency Operations Facility, and an engineering facility or off-site location such as a Utility main office.

9.3.3 Remote terminals are provided that permit the Operator Advisor to be run in test and training modes without affecting the operation of the main program. These terminals may be used for maintaining the Operator Advisor, or for using the Operator Advisor for training operators by running scenarios of simulated data on the system. If while running simulated data, a real event should

occur, the operations of the Remote Terminals are automatically switched to an on-line monitor mode.

9.4 Communications Links

- 9.4.1 The interface between the Operator Advisor computer and the plant computers takes maximum advantage of existing hardware and software.
- 9.4.2 The interface assures the security of the data and processes running on the plant computers.
- 9.4.3 Updated plant information shall be provided periodically to the Operator Advisor according to a Sample Plan.
- 9.4.4 The initial interface links the Operator Advisor computer to the Perry plant referenced simulator.

10.0 Man-Machine Interface

To be written.

Possible reference for human engineering guidelines is EPRI NP-3701,
Computer-Generated Display System Guidelines.

11.0 Other Considerations

The following have not yet been considered. They could be added to the above material or placed in sections of their own. Accuracy and reliability criteria should definitely be included. The other items are possible enhancements that could be considered for later development or thesis topics.

11.1 Accuracy

11.2 Reliability

11.3 Training Mode

11.4 What-if or Vulnerability Modes

APPENDIX B

Papers Written During Current Project Year

1. "A Modular Real-Time Operator Advisor Expert System for Installation on a Full Function Nuclear Power Plant Simulator," by B. K. Hajek, D. W. Miller, and R. Bhatnagar. Proceedings of the Seventh Power Plant Dynamics, Control, and Testing Symposium, Knoxville, Tennessee, May, 1989 (Invited) (Complete Paper Published).
2. "A V & V Program for a Real Time Operator Advisor Expert System," by B. K. Hajek, C. R. Hardy, D. W. Miller, and R. Bhatnagar, Proceedings of the Expert Systems Applications for the Electric Power Industry Conference, sponsored by the Electric Power Research Institute, Orlando, Florida, June 5 - 8, 1989.
3. "The Knowledge-Based Framework for a Nuclear Power Plant Operator Advisor," by D. W. Miller and B. K. Hajek. Proceedings of the American Nuclear Society Annual Meeting, Atlanta, GA, June, 1989.
4. "Transient Simulation for a Real-Time Operator Advisor Expert System," by T. Jakubowski, B. K. Hajek, D. W. Miller, and R. Bhatnagar. Accepted for presentation at the Specialist's Meeting on Artificial Intelligence in Nuclear Power Plants, Helsinki, Finland, October 10 - 12, 1989.
5. "An Integrated Operator Advisor System for Plant Monitoring, Procedure Management and Diagnosis," by R. Bhatnagar, D. W. Miller, B. K. Hajek, and J. E. Stassenko. Submitted for publication in Nuclear Technology, February, 1989. Accepted for publication and currently being revised. Not included in Appendix.

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added separately.
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