CONF-890811--1

DISCLAIMER

CONF-890899--1

DE89 015064

USE OF EXPERT SYSTEMS IN NUCLEAR POWER PLANTS

ROBERT E. UHRIG

Oak Ridge National Laboratory,* Oak Ridge, TN 37831-6009
and
University of Tennessee, Knoxville, TN 37996-2300

To be Presented
at the
JOINT KOREA--UNITED STATES SEMINAR
on
EXPERT SYSTEMS FOR ELECTRIC POWER SYSTEMS

Sponsored by the

KOREA SCIENCE AND ENGINEERING FOUNDATION
and the
UNITED STATES NATIONAL SCIENCE FOUNDATION

August 13-18, 1989

SEOUL, KOREA

*Research sponsored by Nuclear Regulatory Commission, Human Factors Branch, U.S. Nuclear Regulatory Commission under Interagency Agreement 1886-8085-2B with the U.S. Department of Energy under Contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

EXPERT SYSTEMS AND THEIR USE IN NUCLEAR POWER PLANTS

ROBERT E. UHRIG*

I. INTRODUCTION

The application of   technologies, particularly expert systems, to the control room activities in a nuclear power plant has the potential to reduce operator error and increase plant safety, reliability, and efficiency. Furthermore, there are a large number of nonoperating activities (testing, routine maintenance, outage planning, equipment diagnostics, and fuel management) in which expert systems can increase the efficiency and effectiveness of overall plant and corporate operations.[1, 2, 3, 4, 5] Table 1 presents a number of potential applications of expert systems in the nuclear power field.

A recent study by Bernard and Washio [6] identified 287 expert systems for use in the commercial electric power industry, of which 145 are in the United States, 71 are in Japan, 29 are in France, and 42 elsewhere. Decision support systems constituted the largest fraction (20.6%) of the potential applications, followed by real-time diagnostic systems (15.0%), maintenance applications (12.2%), plant management (10.1%), control (8.7%), engineering tools (7.3%) and plant design (7.3%). Other

*The views and perceptions presented in this paper are those of the author and not necessarily those of his employers or the U.S. Nuclear Regulatory Commission.

applications include capturing human expertise, plant design, emergency response, and cognitive model development.

Although most of the potential applications described in the study (e.g., decision support systems, real-time diagnostic systems, and control) are intended to assist operators, most of the expert systems in operation today, particularly in the United States, are used outside the control room or by personnel other than the reactor operators. Such tasks as establishing fuel handling sequences, assuring compliance with technical specifications and limiting conditions of operation, monitoring tagout status, monitoring and diagnosing operation and maintenance of components and equipment, fuel leak detection, outage planning, welding advisers, and training constitute most of the applications today. Only a few expert systems actually interact with plant operators or deal with control room procedures. Generally, these applications are more complex and difficult to implement and may interact with safety systems. However, it is essential that these types of applications be pursued if the favorable potential impact of expert systems on safety is to be achieved.

II. USE OF EXPERT SYSTEMS

There are many situations in which expert systems offer unique advantages over conventional programs. Most applications of expert systems today can be classified into the following six categories: (1) monitoring systems, (2) control systems, (3) configuring systems, (4) planning systems, (5) scheduling systems, and (6) diagnostic systems.

Monitoring expert systems are dedicated to data collection and analysis over a period of time. The collected values are compared against expected performance, and if discrepancies are identified the expert system generates recommendations and/or notifies the operator.

Control expert systems are monitoring expert systems in which action (e.g., opening a valve, turning on a heater, etc.) is taken as a result of the discrepancy identified.

Configuring expert systems address problems in which a finite set of components is to be arranged in one of many possible patterns. The classical example in this category is XCON, an expert system used by a large computer manufacturer to configure its equipment in an optimal configuration consistent with user specifications.

Scheduling and planning expert systems coordinate the capabilities or components within an organization to optimize production and/or increase efficiency. The difference between planning and scheduling systems is that the components for a task are not always known in planning systems.

Diagnostic expert systems analyze and observe data and map the analysis results to a set of problems. Once the problems have been identified, the system recommends a solution based on facts in its knowledge base and on the other information it can acquire.

III. APPLICATION OF EXPERT SYSTEMS IN NUCLEAR POWER PLANTS

This paper presents brief descriptions of several expert systems that are typical of those now in operation or under development in the United States or those with U.S. participation. (Comparable developments are under way in many other countries, notably Canada, France, Great Britain, Germany, Korea, Taiwan, Japan, and Sweden.) All of these applications are advisory in nature and, except for the expert system presenting emergency operating procedures deal with nonsafety-related systems. U.S. utilities appear to be reluctant to introduce expert systems that may interact with the safety-related systems of their nuclear plants until the various implementing issues are clarified.

Demands by the safety and environmental regulatory authorities for increased safety margins and lower environmental impacts and those by the economic regulatory authorities and the financial community for increased efficiency in operation (fewer trips, higher availability, greater plant investment protection) inevitably lead to more sophisticated plants with additional systems that must be controlled and/or automated. Hence, expert systems seem to be a natural addition to the control and instrumentation systems of the next generation of nuclear power plants. Indeed, integration of expert systems into the safety, control, and management systems of power plants is an integral part of the automation process that is evolving.

Applications presented here are typical of those in use or being developed in the United States today. These include:

REACTOR EMERGENCY ALARM LEVEL MONITOR. One of the first Electric Power Research Institute (EPRI) projects in expert systems was REALM (Reactor Emergency Alarm Level Monitor), developed by Technology Applications, Inc.[7] There are about 20 pages of guidance on classifying an emergency as an unusual event, an alert, a site area emergency or a general emergency. The decision as to the level of the emergency has to be made rapidly and sometimes in a time frame in which the true nature of the event is not yet clear. While many sensory and manual observations are available, certain needed data may be missing, ambiguous, or even conflicting. Judgment is therefore required for proper interpretation. REALM incorporates what might be called a real-time "first-level" diagnostic system that identifies the cause of the emergency on the basis of a comparison of the symptoms observed and the events possible in a nuclear power plant (which are stored in the knowledge base). REALM was developed for Indian Point-2 in cooperation with Consolidated Edison of New York and has performed well when operated in parallel with normal plant operations and for training.

COMPUTERIZED TRACKING SYSTEM FOR EMERGENCY OPERATING PROCEDURES. EPRI, with the assistance of General Electric Company and Taiwan Power Company, is developing a computerized tracking system for emergency operating procedures.[8] This expert system is co-resident on the safety parameter display system computer and is presently being tested in the Kuosheng Nuclear Power Plant, a BWR-6 nuclear reactor in Taiwan. The emergency operating procedures are written in about 250 rules that can be evaluated in less than 1 second. Conclusions as to the steps that should be taken are available within seconds after a parameter change. Its inference engine looks for pattern matches between the rule premises and the operating conditions, which then lead to the recommendation of action to be taken. It is an on-line system that requires no input from the operators, and explanations for its conclusions are available to the operators.

CLONES OF EXPERTS AT FFTF. Westinghouse Hanford Company has develcped two expert systems that are "clones" of experts at the Hanford Engineering Development Laboratory and the FFTF (Fast Flux Test Reactor).[9] Both expert systems have direct applicability to commercial nuclear power plants. CLEO (Clone of Leo, an expert on refueling the FFTF) is an expert system that, given the present and future core configuration of the FFTF, is able to generate a list of necessary refueling moves in less than 30 seconds as compared to days or weeks using conventional methods. CRAW (Clone of Rawlins, an expert in diagnosing fuel cladding failures in the FFTF) interprets indications of fuel failure (i.e., tag gas detection). Diagnosis by an expert is required within a short period of time after detection is required, 24 hours a day. This expert system is an effective substitute when the resident expert is not available.

INTELLIGENT EDDY CURRENT DATA ANALYZER. Westinghouse is also using its intelligent eddy current data analysis (IEDA) expert system to analyze the eddy current data of the 45 miles of tubing in a typical nuclear plant steam generator tube bundle.[10] The analysis typically requires 60,000 judgments, some extremely difficult. IEDA is based on a set of highly defined rules (developed from an "expert model data analyst") to which the eddy current data are compared. Incorporated into the system is a versatile and user-friendly operating mode that allows manual evaluations of those signals the computer cannot properly categorize.

DIAGNOSIS OF MULTIPLE ALARMS. An expert system called Diagnosis of Multiple Alarms (DMA) has been used successfully for several years by the Du Pont Company[11] at the Savannah River Production Reactors in Aiken, S.C. The system is connected to the 235 plant alarm annunciators and uses an event-tree analysis to identify patterns of alarms associated with specific plant conditions. Alarm patterns were developed for process malfunctions using logic trees. Primary diagnosis usually involves a single logic tree, while higher order diagnoses involve combinations of decisions and provides more information. Any diagnosis of an abnormal condition is displayed to the operators, and the corrective procedure to be followed is designated. This display is automatically superseded if a higher priority diagnosis is made. This system is integrated with operator training and emergency procedures.

IMPROVING NUCLEAR EMERGENCY RESPONSE WITH AN EXPERT SYSTEM. A prototype expert system to help coordinate overall management during emergency conditions at a nuclear power plant has been developed at Rensselaer Polytechnic Institute.[12] Its knowledge base consists of the New York State (NYS) Procedures for Emergency Classification, the NYS Radiological Emergency Preparedness Plan, and knowledge of experts in the NYS Radiological Emergency Preparedness Group and the Office of Radiological Health and Chemistry of the New York Power Authority. It is portable, modular, and can interact with external programs and interrogate data bases. Future planned capabilities include directly accessing data from the safety parameter display systems of nuclear power plants in the state of New York.

REACTOR SAFETY ASSESSMENT SYSTEM. The reactor safety assessment system is an expert system under development by Idaho National Engineering Laboratory for the Nuclear Regulatory Commission.[13] It is designed for use at the NRC Operations Center in Bethesda, Maryland, in the event of a serious incident at a licensed nuclear power plant. This expert system provides a situation assessment that uses plant parametric data to generate conclusions for potential use by the NRC Reactor Safety Team. It uses multiple rule bases and plant-specific data files to be applicable to several licensed U.S. plants. It currently covers several generic reactor categories and multiple plants within each category, but plant specific data are available only for the

Calvert Cliffs Nuclear Plant today. Undue reliance on this expert system is handled by having the operator of this system as only one input in the discussions around the table where decisions about an accident are made.

RESIDUAL HEAT REMOVAL EXPERT SYSTEM. Odetics, Inc. has developed a residual heat removal (RHR) expert system for use during shutdown under DOE Small Business Innovation Research (SBIR) awards.[14] A prototype system has been constructed that provides a functional demonstration of its ability to (a) monitor data from plant sensors, (b) provide early diagnoses of abnormal conditions in the system, and (c) provide an explanation of the underlying root cause of system failure as well as the corrective action needed. Since 65% of all RHR system failures involve human factors (inadequate procedures and/or operator/technician error), this system has the potential to reduce significantly the risk associated with RHR system problems. A demonstration unit was tested on the Zion Nuclear Power Simulator in 1988.

HANDLING POTENTIALLY INVALID SENSOR DATA. Recent work at Ohio State University Laboratory of Artificial Intelligence Research and the Nuclear Engineering program has concentrated on the problem of diagnostic expert system performance and its applicability to the nuclear power plant domain.[15] It is concerned about the diagnostic expert system performance when using potentially invalid sensor data. The expert system developed can perform diagnostic problem-solving despite the existence of some conflicting data in the domain.

HALDEN REACTOR PROJECT EXPERT SYSTEMS. Through the NRC, the United States is participating in the Halden Reactor Project,[16] which includes development of the following three expert systems:

DISKETT - a rule-based diagnosis system to aid operators in analysis of plant disturbances. It is an expert system designed for process control of dynamic phenomena and uses symbolic descriptions of dynamic behavior in which characteristic changes of important parameters during a transient are stored as "fingerprints" in a knowledge base.

EARLY FAULT DETECTION - a computer-based operator aid designed to assist operators in diagnosis of feedwater system faults. It is a computerized operator support system designed to detect faults before the traditional alarm limits are reached. Small changes in process parameters are detected, measured as deviations between calculated reference measurements from mathematical models and actual plant values, and discriminated as being normal or abnormal.

COPMA - a computer-based procedure system for use by plant operators. It is an online system for computerization of procedures, aimed at handling and presenting procedure information in a way compatible with present-day written procedures. It assists the operator in identifying the relevant procedures as well as monitoring plant response.

These expert systems are part of the Halden Program, which grew out of the 1984 Halden Workshop Meeting on "Computerization of Procedures and Information Presentations."[16]

OTHER EXPERT SYSTEMS. Literally hundreds of expert systems are being developed for applications to various aspects of nuclear power plant operation. Several systems being developed in the U.S. are listed in Table 2 to indicate the breadth of the scope of applications.

Other reported applications of expert systems in various stages of development include outage planning, heat rate improvement, diagnostics for instruments and equipment, welding rod selection advisor, generating welder procedures that comply with regulatory codes, signal validation, disturbance analysis, condensate feedwater monitor, radwaste processing system advisor, bypass-inoperable status indicator system, sequencing boiling water reactor (BWR) control rods after maneuvering, water chemistry control, pressure-temperature control during startup (to avoid pressurized thermal shock problems), real-time emergency evacuation planning, and real-time radiation exposure management.

IV. POTENTIAL IMPLEMENTATION ISSUES FOR EXPERT SYSTEMS

Potential problems in implementing expert systems in nuclear power plants can be projected from past experience with the introduction of new and innovative systems.

A number of issues regarding the implementation of expert systems in nuclear power plants need to be addressed. These include, but are not limited to, the following:

Quantitative and Objective Performance Guidelines for Expert Systems. The introduction of expert systems into nuclear plant operations has the promise of significant contributions to improved operation and safety. These applications may occur naturally with plant upgrades, system obsolescence, and perhaps with plant life extension. Alternately, the introduction may be driven by the productivity concerns of the utilities.

The primary concern about the introduction of any new system into a nuclear power plant would appear to be the potential impact it can have on a safety system when something goes wrong. The ultimate question in judging any new system must be "Can the failure of the system lead to a challenge of the existing safety systems?" Above all, replacement of an existing system with an expert system must not introduce new unresolved issues (i.e., new unreviewed safety hazards).

Introduction of a new system must not lead to confusion of operators or other plant personnel. New tools, including objective criteria that are quantitative in nature, may be needed to evaluate and measure the performance of expert systems and the impact of these systems on human performance.

Validation and Verification (V&V). In conventional software programming, verification and validation have well-established meanings; verification is a determination that software has been developed in a formally correct manner in accordance with a specified software engineering methodology, and validation means demonstrating that the completed program performs the functions within the requirements specifications and is usable for the intended purposes. However, expert systems go beyond the procedures of conventional software engineering. Expert systems, especially those operating under uncertainty or with incomplete data, may have so many states as to make exhaustive testing and other V&V methods unfeasible. Hence, new approaches to V&V are needed for expert systems. A major issue in the use of expert systems in nuclear power plants undoubtedly will be the adequacy of the validation and verification provided.

User Acceptance. A primary human factors concern is that the expert system should present information to the user in a way that is comprehensible and understandable. Information must mesh well with the perspectives of the users, and the way in which the information is displayed should correspond to their mental models of the plant.

Another concern is user reaction to the expert system. Will they accept the system and use it when needed? Above all, will they trust and have confidence in the information presented by the expert system? Alternatively, will the user become too dependent upon the guidance of an expert system and ignore other indications that might not agree with the conclusion of an expert system. These are important questions that need to be addressed.

The function allocation and division of responsibility between the expert system and the user is another important issue. Humans should be assigned only those functions that they are most capable of performing and that utilize their abilities.

Expert systems should relieve some of the physical and cognitive workload on users and not overload them. The system should make human jobs more efficient. Clearly users should be involved in this analysis.

4. Accident Management. One of the major potential applications of expert systems is accident management, especially those extremely rare accidents that involve an unusual combination of events and could have severe consequences. They could provide the expertise of the world's experts on severe accidents to an isolated plant at any time.

An expert system could also be very helpful under severe accident conditions. It is reasonable to expect reactor operators to handle all sorts of upset conditions, but it may not be reasonable to expect them to handle all sorts of "beyond design basis" accidents that are beyond the scope of most operator training. Expert systems could be the preferred method of preparing for low-probability, high-damage events. For instance, an expert system might be used for containment assessment--there presently are only a limited number of experts in the entire nation who are capable of assessing the status of a containment under accident conditions.

V. USE OF NEURAL NETWORKS IN NUCLEAR POWER PLANTS

When a nuclear power plant is operating safely, the outputs of the hundreds, or even thousands, of sensors or instruments form a pattern (or unique set) of readings that represent a "safe" state of the plant. When a disturbance occurs, the sensor outputs or instrument readings undergo a transient and form a different pattern that represents a different state of the plant, which may be safe or unsafe, depending upon the nature of the disturbance. The fact that the pattern of sensor outputs or instrument readings change or are different for any given condition is sufficient to provide a basis for identifying the state of the plant at any given time. To implement a diagnostic tool based on this principle that is useful in the operation of nuclear power plants requires a real-time method of pattern recognition. Networks of artificial neurons, a concept involving a non-algorithmic approach to information processing, can provide this capability.

A network of artificial neurons (usually called a neural network) is a data processing system consisting of a number of simple, highly interconnected processing elements in an architecture inspired by the structure of the cerebral cortex portion of the brain. Hence, neural networks are often capable of doing things which humans or animals do well but which conventional computers often do poorly. Neural networks exhibit characteristics and capabilities not provided by any other technology.

Neural networks may be designed so as to classify an input pattern as one of several predefined types (e.g., the various fault or transient states of a power plant) or to create, as needed, categories or classes of system states which can be interpreted by a human operator. Neural networks have the ability to respond in real-time to the changing system state descriptions provided by continuous sensor inputs. For complex systems involving many sensors and possible fault types (such as nuclear power plants), real-time response is a difficult challenge to both human operators and expert systems. However, once a neural network has been trained to recognize the various conditions or states of a complex system, it only takes one cycle of the neural network to detect a specific condition or state.

Neural networks have the ability to recognize patterns, even when the information comprising these patterns is noisy, sparse, or incomplete. Unlike most computer programs, neural network implementations in hardware are very fault tolerant; i.e. neural network systems can operate even when some individual nodes in the network are damaged. The reduction in system performance is about proportional to the amount of the network that is damaged. Thus, systems of artificial neural networks show great promise for use in environments in which robust, fault-tolerant pattern recognition is necessary in a real-time mode, and in which the incoming data may be distorted or noisy.

Recent work at the University of Tennessee[35, 36] has demonstrated the feasibility of using neural networks to identify six different transients introduced into the simulation of a steam generator of a nuclear power plant. The number of sensor outputs monitored ranged from 2 to 4, the number of training cycles from 500 to 1500, and the random noise introduced into the sensor output from 0 to 90% of the mean amplitude. As the number of training cycles increased, the number of sensor signals processed increased, or the amount of noise decreased, the performance of the neural network improved. An index of performance based on the average error in the six transients studied showed that there is a trade-off between the number of variables, the number of training cycles and the amount of noise in the sensor signals.

ACKNOWLEDGEMENT

The review of expert systems that resulted in this paper was supported, in part, by the Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, under Interagency Agency Agreement 1886-8085-2B, NRC FIN No. B0852. This support is gratefully acknowledged. The views and opinions expressed here are those of the author and do not necessarily reflect the criteria, requirements, or guidelines of the NRC.

REFERENCES

1. Conference Notebook of the EPRI Conference on "Expert Systems Applications for the Electric Power Industry," Orlando, FL, June 5-8, 1989.

2. R. E. Uhrig, "Applications of Artificial Intelligence in Nuclear Power Plants," POWER Magazine, McGraw-Hill Energy Systems, June 1988.

3. J. I. Sackett (ed.), Proc. ANS Topical Meeting on Artificial Intelligence and Other Innovative Computer Applications in the Nuclear Industry, Snowbird, Utah, August 31-September 2, 1987.

4. R. E. Uhrig, "Application of Artificial Intelligence in the U.S. Nuclear Industry" (see ref. 3).

5. Seminar Notebook of Seminar: "Expert Systems Applications in Power Plants" (prepared by Expert-EASE Systems, Inc., for the Electric Power Research Institute, Palo Alto, Calif.); Boston, Mass., May 27-29, 1987.

6. J. A. Bernard and T. Washio, "The Utilization of Expert Systems within the Nuclear Industry," (see ref. 1).

7. R. Touchton, A. Gunter, and D. Cain, "Reactor Emergency Action Monitor: An Expert System for Classifying Emergencies" (see ref. 5).

8. W. Petrick, C. Stewart, and K. Ng, "A Production System for Computerized Emergency Procedures Tracking" (see ref. 5).

9. S. E. Seeman, Private communication, "Application of Artificial Intelligence at Hanford," DOE/ANL Training Course The Potential Safety Impact of New and Emerging Technologies on the Operation of DOE Nuclear Facilities, Knoxville, Tenn., August 18-20, 1987.

10. J. L. Gallagher, Westinghouse Nuclear Technology Systems Division, Private communication, August 1987.

11. K. L. Gimmy, "Automatic Diagnosis of Multiple Alarms for Reactor Control Rooms," Trans. Am. Nucl. Soc. **41**, 520 (1982).

12. A. Salame-Alfie, G. C. Goldbogen, R. M. Ryan, W. A. Wallace, and M. L. Yeater, "An Expert System for Improving Nuclear Emergency Response" (see ref. 3).

13. D. E. Sebo, M. A. Bray, and M. A. King, "Reactor Safety Assessment System" (see ref. 3).

14. G. B. Westram, "Artificial Intelligence Expert System for Nuclear Power Plant Control and Maintenance" (see ref. 3).

15. S. Hashemi, B. K. Hejek, and D. W. Miller, "An Expert System for Sensor Data Validation and Malfunction Detection" (see ref. 3).

16. K. Haugset, "The Development of an Advanced Computerized Control Room," Post-Graduate Seminar on Computers in Nuclear Power Stations, Winterthur, Switzerland, November 28-30, 1988.

17. R. Lang, TRIBES - A CPC/CEAC Trip Buffer Expert System (see ref. 5).

18. G. Finn, F. Whittum, and F. Bone, "An Expert System for Technical Specifications" (see ref. 5).

19. R. A. Danofsky, B. Spinrad, and K. Howard, "MOVES: A Knowledge-Based System for Maintenance Planning for Motor-Operated Valves," Trans. Am. Nucl. Soc. 55, 66-67 (1987).

20. J. T. Robinson and P. J. Otaduy, "An Expert System for Alarm Diagnosis and Filtering" (see ref. 3).

21. D. R. Corsberg and L. Johnson, "A Nuclear Reactor Alarm Display System Utilizing A Techniques for Alarm Filtering" (see ref. 3).

22. J. M. Gross, S. A. Birrer, and D. R. Corsberg, "Applying A Techniques to Improve Alarm Display Effectiveness" (see ref. 3, p. 135).

23. K. Y. Kim, P. Y. C. Chen, and D. Okrent, "An Expert System for Spare Parts Inventory Control" (see ref. 3).

24. W. A. Prather and G. A. Sly, "Plant Status Monitor System Description" (see ref. 3).

25. A. H. Robinson, J. O. Heaberlin, and G. L. Wang, "An Automated Search Procedure for Fuel Shuffling in PWRs Including Rotation Effects" (see ref. 3).

26. R. S. Reynolds, "A BWR Fuel Channel Tracking System" (see ref. 3).

27. R. K. Fink, R. A. Callow, T. K. Larson, and V. H. Ransom, "ATHENA Aide - An Expert System for ATHENA Code Input Model Preparations" (see ref. 3).

28. O. J. M. Peixoto, "An Expert System for Operational Control of PWR Cores" (see ref. 3).

29. T. Kessler, G. Liu, B. Frogner, D. Gloski, P. Wallace, and D. Shieh, "INSPECTR: A Power Plant Performance Diagnostic Expert System Using Evidential and Model-Based Reasoning" (see ref. 3).

30. M. Ragheb, M. Abdelhai, and J. Cook, "Production-Rule Analysis System for Nuclear Plant Technical Specifications Tracking" (see ref. 3).

31. S. Kaplan, M. S. Frank, D. C. Bley, and D. G. Lindsay, "Outline of COPILOT, Expert System for Reactor Operational Assistance Using a Bayesian Diagnostic Module," Proc. International Post SMiRT-9 Seminar on Accident Sequence

Modeling: Human Actions, System Response Intelligent Decision Support, Munich, August 24-25, 1987.

32. R. E. Uhrig, "Use of Probabilistic Risk Assessment (PRA) in Expert Systems to Advise Nuclear Plant Operators and Managers," Proc. SPIE-The International Society for Optical Engineering, "IV: Applications of Artificial Intelligence" 937, Orlando, Florida, April 4-6, 1988.

33. A. D. Gunter and R. A. Touchton, "Accident Diagnosis and Prognosis Aide (ADPA)" (see ref. 3).

34. I. S. Kim and M. Modarres, "MOAS: A Real-Time Operator Advisory System" (see ref. 3).

35. R. E. Uhrig, "Use of Neural Networks in Nuclear Power Plant Diagnostics," Proceedings of the "International Conference on Availability Improvements in Nuclear Power Plants," Madrid, Spain, April 10-14, 1989.

36. R. E. Uhrig and Z. Guo, "Use of Neural Networks in Expert Systems for Nuclear Power Plant Diagnostics," Proceedings of "Applications of Artificial Intelligence VII," SPIE Technical Symposium on Aerospace Sensing, Orlando, Florida, March 28-30, 1989.

Table 1. Potential Utility Applications of Expert Systems in the Nuclear Power Field

Field	Function of Expert System
Diagnostics and surveillance	Monitoring plant behavior Predicting incipient failure of components Monitoring for long-term gradual deterioration Diagnosing equipment malfunctions
Outage planning	Optimal sequencing of refueling activities Optimal fuel handling Minimizing radiation exposure
Compliance with specification	Complying with technical specifications Complying with limiting conditions of operation Proper classification of emergencies Resolving ambiguous situations
Operational advisor	Analyzing plant "trips" Tracking emergency procedures Guiding and monitoring plant maneuvers Ensuring the ability to remove residual heat Monitoring "bypassed/inoperable" equipment Data logging and interpretation Emergency management
Nuclear training	Intelligent computer-aided instruction
Mitigation of accident consequences	Real-time management of evacuation Fast-time prediction of plume travel Minimization of radiation exposure
Reactor safety assessment system	Gives "big picture" to NRC safety team Monitors and projects core conditions, containment conditions, and fission product barriers
Reviewer aid	Provides a consistent framework and interactive process for reviewing licensing applications submitted by power plant licensees

Table 2. Expert Systems Being Developed in the U.S.

Expert System	Developer
Trip Buffer Expert System[17]	Middle South Utilities
Technical Specification Monitor[18]	Stone and Webster
Motor-Operated Valve Expert System[19]	Arnold Energy Center & Iowa State University
Alarm Diagnosis and Filtering[20]	Oak Ridge National Lab.
Alarm Filtering[21, 22]	Idaho National Engr. Lab.
Spare Parts Inventory Control[23]	University of California
Plant Status Monitor System[24]	E.I. Services
Search Procedure for Fuel Shuffler[25]	Oregon State University
BWR Fuel Channel Tracking System[26]	Mississippi State Univ.
ATHENA Code Input Model Preparation [27]	Idaho National Engr. Lab.
Operational Control of PWR Cores[28]	Stanford Univ, Expert EASE
Diagnostics Using Model Base Reasoning[29]	Expert EASE, Inc.
Nuclear Plant Technical Specification Tracking[30]	University of Illinois
Fault Tree Analysis in EXPERT SYS.[31]	Expert EASE, Inc.
Use of PRA in Expert Systems[32]	Oak Ridge National Lab.
Accident Diagnosis and Prognosis Aide [33]	Technical Applications,
MOAS: A Real-Time Operator Advisory System[34]	University of Maryland
COPILOT: An Expert System for Reactor Operation[35]	Pickard, Lowe & Garrick