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USE OF ARTIFICIAL INTELLIGENCE TO ENHANCE THE SAFETY OF NUCLEAR POWER PLANTS

Robert E. Uhrig
Oak Ridge National Laboratory*

ABSTRACT

In the operation of a nuclear power plant, the sheer magnitude of the number of process parameters and systems interactions poses difficulties for the operators, particularly during abnormal or emergency situations. Recovery from an upset situation depends upon the facility with which the available raw data can be converted into and assimilated as meaningful knowledge. Plant personnel are sometimes affected by stress and emotion, which may have varying degrees of influence on their performance. Expert systems can take some of the uncertainty and guesswork out of their decisions by providing expert advice and rapid access to a large information base. Application of artificial intelligence technologies, particularly expert systems, to control room activities in a nuclear power plant has the potential to reduce operator error and improve power plant safety and reliability.

Artificial intelligence (AI) burst on the scientific scene about 30 years ago with much fanfare and promise. Recognition that computer symbols could represent characteristics of the real world, and that computer programs could relate these features, provided the means by which computers could be used to simulate certain important aspects of intelligence and provided an information-processing model of the human mind. It is ironic that as progress floundered in the use of AI to increase the intellectual understanding of the workings of the human mind, certain practical applications of this information-processing model spawned whole new technologies that promise to revolutionize the way both business and industrial organizations operate. Expert systems (see Appendix A), probably the most commercially successful product of AI research, can be used to improve engineering, management, and operation of nuclear power plants in the United States.[1,2]

In the operation of a nuclear power plant, great quantities of numeric, symbolic, and quantitative information are handled by the reactor operators even during routine operation. The sheer magnitude of the number of process parameters and systems interactions poses difficulties for the operators, particularly during abnormal or emergency situations. Recovery from an upset situation depends upon the facility with which the available raw data can be converted into and assimilated as meaningful knowledge. Plant personnel are sometimes affected by stress and emotion which may have varying degrees of influence on their performance. Expert systems can take some of the

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uncertainty and guesswork out of their decisions by rapidly providing expert advice and access to a large information base. The application of AI technologies, particularly expert systems, to control room activities in a nuclear power plant can reduce operator error and improve plant safety and reliability. Furthermore, there are a large number of nonoperating activities (e.g., testing, routine maintenance, outage planning, equipment diagnostics, fuel management, etc.) in which expert systems can increase the efficiency and effectiveness of overall plant operation.

In the United States, development of expert systems in the nuclear power field is being carried out by a wide spectrum of organizations including nuclear equipment vendors, architect-engineer firms, universities, national laboratories, federal agencies, the electric power utility industry, and small entrepreneurial groups. The examples of application of expert systems in the nuclear power field cited here are typical of those being developed in the United States. They constitute only a small fraction of those being developed, although few systems are actually in use in nuclear plants today.

The most coherent of these efforts is the program undertaken in 1983 by the Electric Power Research Institute (EPRI) to demonstrate the usefulness of AI in a number of areas including augmenting plant automation activities. EPRI also has a program to transfer the technology of NASA's multiyear "AI Core Technology in Systems Automation" to the nuclear power industry.

One of the first EPRI projects in expert systems was REALM (Reactor Emergency Alarm Level Monitor), which was developed by Technology Applications, Inc.[3] The NRC has about 20 pages of guidance on classifying an emergency as an unusual event, an alert, a site area emergency, or a general emergency. Each level of emergency has a specific set of responses that the utility must undertake. The decision as to the level of the emergency must be made rapidly, 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 required for proper interpretation in such situations, and REALM is designed to operate in a real-time process environment. It incorporates what might be called a "first-level" diagnostic system that readily identifies the cause of the emergency based on comparison of the symptoms observed and the events that are possible in a nuclear power plant. In addition, REALM provides a rationale as to why it recommends a particular classification. It then carries out a "vulnerability analysis," telling the operators which events would lead to a higher emergency level and what needs to be done to get to the next lower level. REALM was developed for Indian Point-2 in cooperation with Consolidated Edison of New York, and it performed well when operated in parallel with normal plant operating procedures during the two most recent plant emergency drills.

EPRI is also developing a computerized tracking system for emergency operating procedures.[4] This expert system is co-resident on the safety parameter display system computer and is presently being tested on 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 requiring no input from the operators, and explanations for its conclusions are available to the operators.

Westinghouse Hanford Company has developed two expert systems that are "clones" of human experts at the Hanford Engineering Development Laboratory (HEDL) and the Fast Flux Test Facility reactor (FFTF).[5] 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 capable of generating a list of necessary refueling moves in less than 30 s, given the present and future core configuration of the FFTF. CRAW (Clone of Rawley, an expert in diagnosing fuel cladding failures in FFTF), interprets indications of fuel failure (i.e., tag gas detection). Rapid expert diagnosis shortly after detection is required 24 hours a day; this expert system is an effective substitute when the resident expert is not available.

Middle South Utilities has developed TRIBES (Trip Buffer Expert System).[6] TRIBES analyzes trips caused by the core protection calculator and the control element assembly calculator, which monitor nuclear power plant parameters and control element assembly positions respectively. These core protection systems will initiate a trip to prevent violation of fuel design limits (i.e., kilowatts per foot, DNBR limits, rate of power increase, etc.). Analysis of the computer output is required to establish the cause of the trip before the plant can be restarted.

Stone and Webster Engineering Company has developed an expert system to analyze the limiting conditions of operation (LCOs) and technical specifications in a nuclear power plant.[7] These limitations are imposed by regulation, and violations can result in regulatory action that may include civil penalties as well as shutdown of the plant. One of the uses of this system is to assess the effect of both operational changes and the removal of equipment from service to determine whether either of these activities will lead to a violation of LCOs or technical specifications. The program has a "what if" mode that allows the operators to determine the impact of the proposed maintenance actions and operational changes before they are authorized. This mode is used to detect the subtle interactions that might otherwise go undetected and inadvertently cause a trip of the plant or a violation of the LCOs or technical specifications.

Southern California Edison has developed TAGS (Tagout Administration and Generation System) for their San Onofre nuclear power plant.[8] TAGS is a conventional computer program to administer the safety tagout process. It has been integrated with an expert system in the form of an intelligent work station using PLEXSYS (plant expert system), which was developed by EPRI. PLEXSYS will present piping and instrumentation drawings (P&IDs) and one-line electrical schematics for the systems of interest. When the components to be tested are selected, PLEXSYS and TAGS recommend a "safety tagout boundary" that allows maintenance to be performed without danger of tripping the plant.

Texas Utilities and Westinghouse jointly have developed GenAID™, an on-line generator diagnostic system,[9] to diagnose hundreds of conditions with damage potential to the electrical generator and to recommend corrective action for each condition. Special monitors are attached to the generators located in Texas and are coupled to computer terminals continuously linked via phone lines to the Westinghouse Diagnostics Center in Orlando, Florida. Diagnoses and recommendations are based on the knowledge of the best experts (designers, service engineers, field engineers, operators, etc.). GenAID is now in operation and has proven to be an effective tool in reducing the risks of error in human judgment, thereby improving plant productivity and availability.

Westinghouse is also using its Intelligent Eddy Current Data Analysis (IEDA) expert system[10] to analyze eddy current data from the 45 miles of tubing in a typical nuclear plant steam generator tube bundle. 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 signals the computer cannot categorize properly.

The Duane Arnold Energy Center and Iowa State University have initiated an advisory expert system called MOVES (Motor-Operated Valve Expert System) for valve maintenance planning.[11] The data base contains ~117 safety-related motor-operated valves. Maintenance encompasses diagnosis of operational symptoms, prescription of corrective maintenance, determination of procedural requirements, and identification of required postmaintenance testing. The importance of valve maintenance is indicated by industry estimates that valve-related problems cost U.S. utilities about $100 Million per year in lost plant availability and up to 30% of the industry's annual maintenance budget.

Other reported applications of expert systems in various stages of development include outage planning, heat rate improvement, alarm filtering, sequencing and suppression, diagnostics for instruments and equipment, welding rod selection advisor, generating welder procedure specifications that comply with regulatory codes, signal validation, disturbance analyses, condensate feedwater monitor, radwaste processing system advisor, bypass-inoperable status indicator system, sequencing 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.

The fundamental and synergistic relationship between training and expert systems offers a unique opportunity to improve the training of nuclear power plant personnel. One of the features that makes an expert system so compatible with diagnostics in nuclear plants is its ability to explain its reasoning and its conclusions for the postulated or real conditions given to it. All supporting evidence for machine opinions about systems or events can be cited for final evaluation and decision by human operators. As the operators work with an expert system, there is constant exposure to the bases, limits, and nature of system interrelations. Recent work at The University of Tennessee[12] has dealt with the symbiotic relationship between diagnostics and training. Indeed, the understanding gained in developing and encoding the knowledge base on the operation of a nuclear power plant into an expert system may be as important as (if not more important than) the use of that system in actual plant operation. This effort further enhances the quality of nuclear personnel training.

The utilities are introducing expert systems into nuclear power plants very slowly, possibly because they are reluctant to submit this new technology involving uncertainties to regulatory review until they are convinced that the benefits gained will warrant the effort required. Perhaps regulators' principal concern with expert systems is the ability to encode expertise properly, particularly the fine nuances and shades of meaning, into the knowledge base of an expert system so that it can emulate human expertise with fidelity. Another major concern is the narrow scope of the expertise and the associated limited area of applicability of expert systems. Two of the consequences of these limitations are the inability of an expert system to exhibit common sense and its limited ability to recognize when it is operating outside its field of knowledge. Researchers have sought to minimize the impact of these limitations by building "robustness" into expert systems (i.e., the ability to fail gradually and predictably when it gets outside its operating regime). These limitations, as well as the lower confidence associated with answers when data are missing or have low certainty factors, may be of concern to regulators when expert systems are introduced into the safety-related systems of nuclear power plants.

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 (e.g., fewer trips, higher availability, plant investment protection, etc.) inevitably lead to more sophisticated plants with additional systems that must be controlled and/or automated. Digital systems inevitably will totally dominate the control systems of the next generation of nuclear power plants unless they are specifically forbidden by regulatory authorities. Indeed, the integration of expert systems into the safety, control, and management systems of power plants is an integral part of the automation process.

In summary, a nuclear power plant is too complex a system to be managed or operated by anyone's "gut feeling." An expert system can be the ever alert, knowledgeable assistant to the operators as well as a valuable tool for plant management. Demands for increased safety margins, lower environmental impacts, increased performance, and greater investment protection will inevitably lead to automation of most functions of nuclear power plants. In turn, automation will be paced by the ability to develop efficiently the needed software through the use of modern computer science brought about by AI programming techniques. The regulators and the public must be assured that these plants are properly designed, properly built, properly operated, and properly maintained. Artificial intelligence and expert systems can and must play a major role in providing this assurance.

REFERENCES

1. Proceedings, ANS Topical Meeting, "Artificial Intelligence and Other Innovative Computer Applications in the Nuclear Industry," Snowbird, Utah (August 31-September 2, 1987).
2. Seminar Notebook: "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).
3. R. Touchton, A. Gunter, and D. Cain, "Reactor Emergency Action Monitor: An Expert System for Classifying Emergencies," included in Ref. 2.
4. W. Petrick, C. Stewart, and K. Ng, "A Production System for Computerized Emergency Procedures Tracking," included in Ref. 2.
5. S. E. Seeman, private communication, "Application of Artificial Intelligence at Hanford," DOE/ANL Training Course on "The Potential Safety Impact of New and Emerging Technologies on the Operation of DOE Nuclear Facilities", Knoxville, Tenn. (August 18-20, 1987).
6. R. Lang, "TRIBES-A CPC/CEAC Trip Buffer Expert System," included in Ref. 2.
7. G. Finn, F. Whittum, and R. Bone, "An Expert System for Technical Specifications," included in Ref. 2.
8. J. Munchausen and K. Glazer, "An Expert System Technology for Work Authorization Information System," included in Ref. 2.
9. J. Carson and M. Coffman, "TU Electric Experience with On-Line Generator Monitoring and Diagnostics," included in Ref. 2.
10. J. L. Gallagher, Westinghouse Nuclear Technology Systems Division, private communication (August 1987).
11. 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).
12. R. E. Uhrig and M. T. Buenaflor, "Artificial Intelligence and Training of Nuclear Reactor Personnel," International OECD-CNSI Specialist Meeting on Training of Nuclear Reactor Personnel, Orlando, Fla., (April 21-24, 1987).

APPENDIX A
WHAT ARE EXPERT SYSTEMS?

Expert systems can be defined as "computerized processes or programs that attempt to emulate the human thought processes associated with the application of expertise to problems." As expert systems have evolved over the past decade, they have typically consisted of two separate components, an "inference engine" (i.e., an information processor) and a knowledge base. The inference engine gathers the information needed, guides the search process in accordance with the strategy programmed into it, uses rules of logic to draw inferences about the processes involved, and presents conclusions (when warranted) along with an explanation of the bases for the conclusions. The inference engine may use either "forward chaining" (i.e., forward reasoning), in which it starts with the given data and proceeds toward a solution, or "backward chaining," in which it assumes a conclusion and then looks for evidence to support that conclusion. Since the inference engine and the knowledge base are entirely separate, changes in the knowledge base can be made easily without any influence on the inference engine.

Generally, the knowledge base of the expert systems relies on the expertise of experts or expert knowledge that has been codified in publications, books, or regulations to provide advice under a wide variety of conditions. When the data and/or information in the knowledge base are specific and precise, expert systems give results that are unambiguous. However, when the needed information is imprecise or "fuzzy," incomplete, missing, or even conflicting, expert systems can still reach a rational conclusion or solution through the use of confidence factors or probabilities. Under these conditions, an expert system will give the "most probable" solution or the "best" solution in a statistical sense. For this reason expert systems usually identify alternative or less probable solutions along with the associated probabilities or confidence factors. This characteristic of expert systems is one of their greatest advantages, although it may be of concern to regulatory authorities when these systems are installed in nuclear power plants.