XA9847301

ACTIVITIES AT THE ELECTRIC POWER RESEARCH INSTITUTE TO SUPPORT THE MODERNIZATION OF INSTRUMENTATION AND CONTROL SYSTEMS IN NUCLEAR POWER PLANTS IN THE UNITED STATES OF AMERICA

J. NASER
Electric Power Research Institute,
Palo Alto, California,
United States of America

Abstract

Most nuclear power plants in the United States are operating with a vast majority of their original analog instrumentation and control (I&C) equipment. Many of the I&C systems in the plants need to be modernized in a reliable and cost-effective manner to replace obsolete equipment, to reduce operating and maintenance (O&M) costs, to improve plant performance, and to maintain safety. The major drivers for the replacement of the safety, control, and information systems in nuclear power plants are the obsolescence of the existing hardware and the need for more cost-effective power production. Competition between power producers is dictating the need for more cost-effective power production. The increasing O&M costs to maintain systems experiencing obsolescence problems is counter to the needs for more cost-effective power production and improved competitiveness. Modern technology, especially digital systems, offers improved functionality, performance, and reliability; solutions to obsolescence of equipment; reduction in O&M costs; and the potential to enhance safety. Digital I&C systems with their inherent advantages will be implemented only if reliable and cost-effective implementation and licensing acceptance is achieved and if the modernized system supports reduced power production costs. Increasing competition will continue to be a major factor in the operation of nuclear power plants. It will continue to dictate the need for improved productivity and cost-effectiveness. EPRI and its member utilities are working together on an industry-wide Instrumentation and Control Program to address I&C issues and to develop cost-effective solutions.

1. INTRODUCTION

Operating nuclear power plants in the United States were designed 25 to 45 years ago with analog instrumentation and control (I&C) technology. Today, most plants continue to operate with much of their original I&C equipment and vintage digital I&C equipment. This equipment is approaching or exceeding its life expectancy, resulting in increasing maintenance efforts to sustain system performance. Decreasing availability of replacement parts, and the accelerating deterioration of the infrastructure of manufacturers that support analog technology, accentuate the obsolescence problems and cause operation and maintenance (O&M) cost increases.

I&C systems in nuclear power plants need to be developed and modernized in a reliable and cost-effective manner to replace obsolete equipment, to reduce O&M costs, to improve plant performance, and to maintain safety. The major drivers for the replacement of the safety, control, and information systems in nuclear power plants are the obsolescence of the existing hardware and the need for more cost-effective power production. Digital I&C systems need to play a major role in nuclear power plants to achieve real productivity improvements needed for increased competitiveness. The procurement of replacement modules and spares under current requirements, for hardware that is no longer fully supported by the original equipment manufacturer, is costly, time consuming and, in some cases, not even possible. Competition between power producers is dictating more cost-effective power production. The increasing O&M costs to maintain many of the analog systems is counter to the needs for more cost-effective power production and improved competitiveness. The reluctance to implement new digital I&C systems to address O&M cost concerns is also counter to the needs for more cost-effective power production and improved competitiveness.

Technological improvements, particularly the availability of digital systems and their supporting infrastructure, offer improved functionality, performance, and reliability; solutions to obsolescence of analog equipment; reduction in O&M costs; and the potential to enhance safety. Modern digital technology holds significant potential to improve cost-effectiveness and productivity in nuclear power plants. Modern systems have the potential for solving the utilities' current problems of growing equipment obsolescence; escalating O&M costs; lost generation due to system unavailability, spurious operation, and human error; and the inability to increase plant capacity due to equipment limitations. All of these problems contribute to reduced competitiveness with other power production sources and could lead to premature plant closures.

Reliance on custom designed systems coupled with new licensing and design issues have resulted in high implementation costs when digital upgrades have been performed in nuclear power plants. There is a need for a systematic approach leading to the identification, prioritization, and implementation of I&C solutions in nuclear power plants. Viable alternatives range from extending the useful life of existing equipment to the complete replacement of systems in a cost-effective manner when vulnerability to obsolescence or the need for increased productivity so dictates. The use of commercially available equipment for safety systems is desirable to reduce costs and to provide a high likelihood of continuing vendor support.

Reliable, integrated information is a critical element for protecting the utility's capital investment and increasing availability and reliability. Integrated systems with integrated information can perform more effectively to increase productivity, to enhance safety, and to reduce O&M costs. A plant communications and computing architecture is the infrastructure needed to allow the implementation of I&C systems in an integrated manner. Current technology for distributed digital systems, plant process computers, and plant communications and computing networks support the integration of systems and information. The test for future digital I&C system modernization will be whether they are cost beneficial to the plant and if they can offer a payback to the utility in an acceptable time period.

2. EPRI INSTRUMENTATION AND CONTROL PROGRAMME

Nuclear utilities are confronted by a growing equipment obsolescence problem which is a significant contributing factor to increasing costs for plant operation and maintenance. Plant age combined with the rapid pace of evolution of electronic technology is a significant factor in equipment obsolescence. The flexibility and performance advantages of modern digital technology can be used as the basis for modernizing obsolete equipment in a cost-effective manner in nuclear power plants. The realization of the benefits of digital technology is currently restrained by the relatively high cost of initial applications of new technology for the nuclear power industry in a highly regulated environment. Work is needed to establish reliable and cost-effective approaches for the design, qualification, and implementation of digital systems in nuclear power plants. This work should utilize, as much as possible, relevant information and experience from other process industries where digital systems are commonly used. Commercially available digital systems have proven reliable in other process industries, including safety related applications. Cost-effective approaches are needed to implement and qualify commercially available hardware and software for nuclear power plant applications. To address these issues and facilitate the modernization of I&C systems in nuclear power plants, the Electric Power Research Institute (EPRI), working together with its member utilities, developed an industry-wide I&C Programme. This programme is documented in the Integrated Instrumentation and Control Upgrade Plan (1).

The I&C Programme consists of research and development (R&D) and utility demonstration plant activities. R&D activities support the development and implementation of modern technology systems and also provide a technical basis for qualification and licensing of them. The R&D and demonstration activities provide the bases for the requirements, planning and evaluation methodologies, and implementation guidelines needed to plan, design, develop, qualify, implement, operate, and maintain modern digital systems. The demonstration plant activities identify utility needs, provide a test bed for, and feedback on, the methodologies and guidelines, and modern technology applications.

The EPRI I&C Programme has developed a life-cycle management approach for I&C systems. Life-cycle management involves the optimization of maintenance, monitoring, and capital resources to sustain safety and performance throughout the plant life. The main EPRI product used in life-cycle management of I&C systems is a set of methodologies and guidelines that, as part of the utility's overall life-cycle management effort, will enable nuclear power plants to fully address I&C cost and performance issues. They will assist utilities in identifying, prioritizing, and implementing I&C solutions more effectively. These methodologies and guidelines will assist the utilities in applying integrated I&C systems in the most timely and cost-effective manner possible.

3. PLANNING AND EVALUATION METHODOLOGIES

Four strategic planning and evaluation methodologies have been developed under the I&C Programme. The first, the Life-Cycle Management Plan (LCMP) methodology, is for developing a long term strategic plan for manageing a power plant's I&C systems over the planning period selected by the utility. The LCMP Methodology (2) guides the user through a comparison of I&C life-cycle management (LCM) strategies and through existing and planned LCM programme activities to identify interfaces and the integration of upgrade and maintenance options. The LCMP includes the identification of systems and components to be included in the programme; the development of bases for upgrade or long term maintenance options; the initial cost and performance improvement estimates, prioritization for detailed upgrade evaluation, and deferred-upgrade maintenance planning; and the identification of related programmes and organizational interfaces including key personnel and responsibilities. The methodology is accompanied by a workbook which contains various outlines, worksheets, and generic interview questions and topics that aid in the development of a LCMP. The methodology document also explains the overall process for planning and implementing the various elements of I&C life-cycle management, and the relationship of the other EPRI planning and evaluation methodologies and guidelines. This life-cycle approach is appropriate at the beginning of, and during, plant life.

The Plant Communications and Computing Architecture Plan (PCCAP) Methodology (3,4) provides utilities with a detailed set of instructions for preparing a PCCAP that will allow them to upgrade their I&C systems in a logical, cost-effective, and non-disruptive fashion. The PCCAP Methodology provides all of the information necessary for utilities to develop their strategic architecture plans in the most cost-effective manner possible. It guides the user through an assessment of the existing plant data network architecture, corporate communications architecture LCM plans, and I&C LCM implementation guidelines with respect to the communications architecture. The PCCAP addresses a characterization of the existing network; a characterization of the future network in terms of a network model and communication standards for connectivity and interoperability of network elements; a set of network architecture requirements regarding the physical configuration, network access, network add-on provisions, network performance monitoring, and I&C equipment communications interfacing; and a set of consistent human–machine interface requirements for I&C systems.

The Systems Maintenance Plan (SMP) Methodology (5) addresses long-term maintenance planning for systems or components where initial screening in the LCMP indicates that detailed upgrade evaluation is not justified, over the planning period, by cost and performance potential. The SMP Methodology contains a process for developing a comprehensive SMP for each identified system. The SMP will present the most efficient approach for maintaining the operational goals and life expectancy of the system. The SMP Methodology will describe how to develop long range maintenance objectives, to baseline and analyse the existing maintenance process, to analyse failure rates, inventory practices, and obsolescence issues, and to implement maintenance related problem solving techniques.

The Upgrade Evaluation Methodology (UEM) (6) addresses a detailed evaluation of I&C system and components when upgrading is indicated by the LCMP. The UEM is used to analyse each candidate system to determine if the upgrade is justified from a cost benefit perspective. The UEM is used to produce an Upgrade Evaluation Report (UER) for each candidate upgrade. The UER describes high level system functionality, upgrade alternatives and associated cost benefit evaluations, and the recommended alternative. The upgrade evaluation process includes detailed cost and performance analysis; conceptual design options analysis; cost/benefit analysis; and upgrade recommendations. Analysis of the conceptual design options includes the consideration of digital design basis changes, associated technical specification changes, and equipment selection candidates. When an upgrade is to proceed, the UER is used as input to the Functional Requirements Specification.

4. IMPLEMENTATION GUIDELINES

Design and licensing issues have inhibited access to cost and performance improvements possible with digital technology. Examples of the areas of concern for digital systems in nuclear power plants are licensing, software verification and validation (V&V), hardware qualification including electromagnetic interference compatibility and seismic, reliability, performance, separation, redundancy, fault-tolerance, common-mode failures, diversity, human–machine interfaces, and integration of systems and information through communications networks. Use of commercially available digital systems is an approach for more cost-effective implementations that is of considerable interest to the nuclear utilities. The development of good functional specifications and bid specifications for digital systems is essential to assure that the system will behave as desired. The EPRI I&C Programme has developed a collection of guidelines to address many of these concerns.

The Guideline on Licensing Digital Upgrades (7) was developed to be consistent with the established 10 CFR 50.59 process in the United States. It helps utilities design and implement digital upgrades, perform 10 CFR 50.59 safety evaluations, and develop information to support licensing submittals. It suggests a failure analysis-based approach that encompasses digital-specific issues and other possible failure causes, addressing both according to their potential effects at the system level. Abnormal Conditions and Events (ACES) (8), as described in IEEE 7-4.3.2-1993 "Application Criteria for Programmable Digital Computer Systems in Safety Systems of Nuclear Power Generating Stations", play an integral role in this approach. The licensing guidelines and ACES guidance help identify what is required to license safety systems in nuclear power plants.

Guidance for electromagnetic interference (EMI) susceptibility testing of digital equipment (9) and a handbook for electromagnetic compatibility of digital equipment (10) have been developed. These reports integrate the current knowledge and understanding of the electromagnetic issues concerning the installation of digital equipment in power plants. They direct the utility toward practical and economical solutions for dealing with electromagnetic interference. The handbook also helps eliminate some misconceptions that questioned the reliability of digital equipment subjected to the electromagnetic environment of nuclear power plants.

Guidelines and a handbook for software V&V have been developed (11-13). These describe approaches to categorize the software systems in terms of criticality and consequences of failure. They then identify levels of V&V commiserate with these categorizations. The guidelines for V&V in reference 11 developed a set of 16 V&V guideline packages based on the system category, development phase, and software system component which is being tested. For V&V methods in the guidelines that do not have a good description elsewhere in literature on how to use them, 11 sets of procedures have also been developed. The report identifies 153 V&V methods for software systems which can be used on 52 identified software defects. The guidelines developed were based on the attempt to identify the methods which were most successful in finding various types of defects, on the attempt to assure that the different guidelines catered to the different needs of different systems, and on the attempt to emphasize the practicality and cost-effectiveness of the methods recommended.

Experience with digital upgrades in nuclear plants has shown that there is significant room for improvement in predicting modernization costs and in anticipating the types of technical problems that will be encountered. Often the problems can be traced to deficiencies in the specifications that govern the design, development, installation and testing activities that must be done properly to ensure success. While proper specification of requirements has always been an area where plant modernization projects are vulnerable, the introduction of digital technology has exacerbated the situation through its need for new types of requirements with which utility engineers and operators typically have limited experience and expertise. A methodology (14) is being developed to help utilities create better requirements specifications for digital systems. It addresses nuclear-specific issues as well as typical problems encountered in digital specifications. The methodology uses an iterative approach that maintains a focus on the areas of highest risk to the project and incorporates various requirements analysis techniques. Its intent is to help utilities realize a predictable and successful upgrade process, producing more reliable systems, avoiding cost overruns and project delays, and thereby reducing overall project costs.

The use of commercially available digital equipment in nuclear safety applications continues to be a controversial issue. A process for the commercial-grade dedication of hardware was developed several years ago (15, 16) and has proven very successful. The basic concepts of this process were used as the starting point to formulate an approach for evaluation and acceptance of commercially available microprocessor-based equipment. EPRI worked with a group of utility industry representatives to develop industry consensus guidelines (17, 18). These guidelines will help the utility engineer determine what activities to undertake to establish adequate assurance that a commercially available digital device used in a safety-related system will perform its safety function. The approach will extend the traditional commercial dedication process to include digital-specific issues, such as software configuration management, unanticipated functions and failure modes, and the software development process. Guidance will be provided to help determine appropriate technical and quality requirements and to help confirm that such requirements have been met. EPRI is continuing to work with the group of utility representatives to develop a second tier document which will provide more details and examples showing how the guidance is implemented.

5. PRODUCTIVITY ENHANCEMENT SYSTEMS

The requirements on nuclear power plant personnel to improve availability, reliability, and productivity and to reduce safety challenges to the plant have been increasing. These personnel are working with more complex systems, and responding to increasing operational, regulatory, and productivity demands. As tasks become more complex, involving large numbers of subsystem interrelationships, the potential for human errors increases. Therefore; reliable, integrated information is a critical element for protecting the utility's capital investment and increasing availability and reliability. Integrated systems with integrated information access can help personnel perform more effectively to increase productivity and enhance safety.

Traditionally systems have been implemented in a stand-alone manner which has resulted in increased O&M costs. This approach has also reduced the effectiveness, and in some cases the possibility, of new and upgraded systems. An integrated approach is essential to maximize the effectiveness of new and upgrades systems. The modern technology available for distributed digital systems, plant process computers, and plant communications and computing networks is fully capable of supporting integration of systems and information. This capability and its effectiveness has been proven in other process industries.

Modern digital technology can support increased power output from nuclear power plants. The improved accuracy of digital systems and the associated reductions in uncertainties can allow the utility to increase its plant's power rating. Digital systems also have the potential to support faster startups for increased power output. They can also facilitate determination of the root causes of plant events. At the same time, they can support the faster evaluation of the performance of the equipment and systems during the event. Both of these will allow a faster return to power after an unanticipated trip and; therefore, allow more power to be produced by the plant. The abilities of modern digital systems offer many ways to reduce O&M costs. Besides improved reliability and availability, ways to reduce O&M costs can be derived from the continuous monitoring, trending and reporting capabilities, as well as the archival capabilities, of digital systems.

The technological advances of the last few years have made it possible to develop sophisticated personnel support systems, which can not only process and present information, but can also give advice to the human. With appropriately implemented personnel support systems, humans can be augmented substantially in their capacity to monitor, process, interpret, and apply information; thus reducing errors and increasing reliability and availability. These personnel support systems will increase productivity by eliminating routine labor-intensive efforts such as recording, collecting, integrating, and evaluating data; and by assisting in monitoring and control activities. These systems can improve the consistency and completeness of decision-making activities by performing the role of diagnostic and decision-support advisors. Personnel support systems can assist in reducing safety challenges to the plant by presenting more complete, integrated, and reliable information to plant staff to better cope with operating and emergency conditions. Reducing safety challenges leads directly to improved reliability and availability and hence productivity. It can also reduce the maintenance activities, which would have been required, for equipment that would have been unnecessarily challenged. Functional requirements (19) for an environment that would support these capabilities have been developed.

Advances in technological and human engineering offer the promise of helping nuclear power plant staff to reduce errors, improve productivity, and minimize the risk to plant and personnel. A plant-wide infrastructure for coordinated personnel support systems should be created to enhance these systems and to reduce their implementation costs. This infrastructure will include information communication capabilities, database and knowledge base managers, and a unified human–machine interface. This infrastructure, which is the plant communications and computing architecture discussed above, will permit incremental additions of I&C systems in all domains.

6. DEVELOPMENT OF MODERN I&C SYSTEMS

Through strategic alliances with industry, three diverse modern forms of I&C technologies are being applied to safety systems in nuclear power plants. All three of the technologies are suitable for control systems as well. The first is commercially available programmable logic controller (PLC) technology (20,21). PLCs with appropriate qualification programmes are ideally suited for a large number of nuclear power plant applications including safety applications. PLCs have proven highly reliable in many industrial applications and can be used to enhance safety, improve operation and productivity, and reduce O&M costs. Areas that must receive careful attention when adopting commercially available PLCs include software verification and validation (V&V), hardware qualification, and regulatory acceptance. Standardized designs of PLC-based systems for safety system applications offer the opportunity for increased cost-effectiveness in plant implementations. A generic qualification and functional requirements specification for commercially available PLCs for safety applications has been developed (22) and sent to the United States Nuclear Regulatory Commission (NRC) for review. The first generic qualification of a commercially available PLC platform is to be completed by the middle of 1998.

Application specific integrated circuit (ASIC) technology is being adapted for reactor applications. Due to the stringent and, from past history, costly requirements for licensing digital systems for reactor protection systems (RPS), cost and regulatory risk are major concerns. To satisfactorily ensure that a microprocessor-based RPS will perform as desired, be highly reliable, and not have unintended functions is very costly. A potentially cost-effective alternative is to develop an ASIC-based RPS. In this case, the ASIC is designed to perform only the needed functionality of the RPS. This reduces the effort required to assure the RPS's performance in safety critical functions. This same technology will be very useful for other plant systems. ASIC technology represents a good diverse technology from microprocessor and analog systems that can be used when diverse systems are required. Currently an ASIC-based RPS is being designed to replace 7300, 7100, and H-Line modules in the Westinghouse RPS. The ASIC chip has been designed and prototypes have been fabricated and tested. The motherboard, controller, and personality modules have been designed and are currently being fabricated. The chip and controller have been designed to be generic so that they can be used for other safety and control applications. All of the components will undergo extensive testing programmes. ASIC-based modules to replace 7300 modules will be implemented in 1998. The ASIC-based modules can be used for other applications which currently use 7300, 7100, and H-Line modules.

The third modern approach uses the dynamic safety system (DSS) technology. Unlike key safety systems in most nuclear power plants that use analog technology operating in a static mode, the DSS technology operates with insertions and processing of test signals for continuous verification of both hardware and software components. Although DSS is computer-based, the final checking of signal patterns is performed by a solid state hardware component. Thus, the DSS offers the benefits of computer-based functionality and reliability while avoiding concerns about undetected software problems. The DSS technology, which was developed and applied in the United Kingdom for advanced gas cooled reactor (AGR) plants, has now been demonstrated feasible for processing LWR safety system algorithms. It was installed in a spare RPS channel at a U.S. operating nuclear plant for demonstration and evaluation of performance. The DSS equipment operated on-line, in a flawless manner, with no maintenance, for a one year demonstration period. The DSS technology could potentially eliminate all surveillance and testing of safety channels, and permit revisions to the safety analyses that would permit increasing plant performance.

7. DEMONSTRATION PLANT PROJECTS

The utility demonstration plants essentially are the laboratories where I&C cost and improvement options are being researched and developed. There are six utility demonstration plant projects in progress which are providing the primary inputs, as well as testing, validation and refinement activities for the methodology and guideline development under the I&C Programme.

Activities at each of the six demonstration plants may include the preparation of I&C life-cycle management plans and plant computing and control architecture plans; system screening, deferred-upgrade maintenance planning, and detailed upgrade evaluations; testing, validation, and refinement of various plant-specific methodologies and guidelines; and development of options and plans for integration of I&C cost and performance improvement activities with related life-cycle management efforts. The activities at these demonstration plants, as well as at other nuclear power plants, include implementations of new and upgraded systems.

Demonstration project activities which are using the full life-cycle management approach are presently being pursued at the Tennessee Valley Authority's Browns Ferry Unit 2, Baltimore Gas and Electric Company's Calvert Cliffs Units 1 and 2, Northern States Power Company's Prairie Island Units 1 and 2, Energy Company's Arkansas Nuclear One Units 1 and 2, Omaha Public Power District's Fort Calhoun, Taiwan Power Company's Chinshan Units 1 and 2, and Korea Electric Power Company's Kori Unit 2.

EPRI and several utilities, including some of the above mentioned ones, are working together on modernization projects. These projects in some cases are the result of the life-cycle management planning while others were determined opportunistically from obvious needs at the plant. The projects include those on the three modern I&C technologies described above as well as several other modernization activities.

8. CONCLUSIONS

The implementation and integration of modern digital I&C systems enhance the ability of the utility to achieve the goals of improved availability and reliability, enhanced safety, reduced O&M costs, and improved productivity in nuclear power plants. The planning and evaluation methodologies provide the basis for plant specific strategies and approaches that are most effective for the plant in the design and operational phases of the plant. The modern technology of distributed digital systems, plant process computers, and plant communications and computing networks have proven their ability to achieve these goals in other process industries. The use of this modern, proven technology is a key contributor to improved competitiveness in nuclear power plants. EPRI has established an I&C Programme to support its member nuclear utilities in developing methodologies, guidelines, and digital applications to take advantage of this modern technology to improve nuclear power plant competitiveness. Strategic alliances are an important approach to reduce the costs and risks of first-of-a-kind development, implementation, and licensing.

REFERENCES

[1] "Integrated Instrumentation and Control Upgrade Plan, EPRI NP-7343 Revision 3, December 1992.

[2] "Instrumentation and Control Life-cycle Management Plan Methodology", EPRI TR-105555, Vols. 1&2, August, 1995.

[3] "Plant Communications and Computing Architecture Plan Methodology", EPRI TR-102306, Vols. 1&2, November 1993.

[4] "Plant Communications and Computing Architecture Plan Methodology Revision 1", EPRI TR-104129, Vols. 1&2, December 1994.

[5] "Instrumentation and Control Systems Maintenance Plan Methodology", EPRI TR-106029, Vols. 1&2, December 1996.

[6] "Instrumentation and Control Upgrade Evaluation Methodology", EPRI TR-104963, Vols. 1&2, July 1996.

[7] "Guideline on Licensing Digital Upgrades", EPRI TR-102348, December 1993.

[8] "Abnormal Conditions and Events Analysis for Instrumentation and Control Systems", EPRI TR-104595, Vols. 1&2, January, 1996.

[9] "Guidelines for Electromagnetic Interference Testing in Power Plants", EPRI TR-102323-R1, December 1996.

[10] "Handbook for Electromagnetic Compatibility of Digital Equipment in Power Plants", EPRI TR-102400, Vols. 1&2, June 1994.

[11] "Guidelines for the Verification and Validation of Expert System Software and Conventional Software", EPRI TR-103331, Vols. 1-8, April 1995.

[12] "Verification and Validation Guidelines for High Integrity Systems", EPRI TR-103916, Vols. 1&2, December 1995.

[13] "Handbook of Verification and Validation for Digital Systems", EPRI TR-103291, Vols. 1-3, December 1994.

[14] "Requirements Engineering for Digital Upgrades", EPRI TR-108831, December 1997.

[15] "Guideline for the Utilization of Commercial Grade Items in Nuclear Safety Related Applications (NCIG-07)", EPRI NP-5652, June 1988.

[16] "Supplemental Guidance for the Application of EPRI NP-5652 on the Utilization of Commercial Grade Items", EPRI TR-102260, March 1994.

[17] "Guideline on Evaluation and Acceptance of Commercial Grade Digital Equipment for Nuclear Safety Applications", EPRI TR-106439, October 1996.

[18] "Evaluating Commercial Digital Equipment for High-Integrity Applications: A Supplement to EPRI Report TR-106439", EPRI TR-107339, December 1997.

[19] "Programmable Logic Controller Qualification Guidelines for Nuclear Applications", EPRI TR-103699, Vols. 1&2, October 1994.

[20] "Programmable Logic Controller Requirements and Evaluation Guidelines for BWRs", EPRI TR-103734, November 1994.

[21] "Generic Requirements Specification for Qualifying a Commercially Available PLC for Safety-Related Applications in Nuclear Power Plants", EPRI TR-107330, December 1996.