ELECTRIC POWER
RESEARCH INSTITUTE

Instrumentation and Control Strategies for Plant-Wide and Fleet-Wide Cost Reduction

Interim Guideline – Abridged Version

Interim Report

Instrumentation and Control Strategies for Plant-Wide and Fleet-Wide Cost Reduction

Interim Guideline – Abridged Version

1013482

Interim Report, May 2006

EPRI Project Manager
R. Torok

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1395 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Electric Power Research Institute (EPRI)

Randall May, Consultant

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

CITATIONS

This report was prepared by

Randall May, Consultant
119 Puesta Del Sol
Los Gatos, CA 95032

Principal Investigator
R. May

Electric Power Research Institute
3420 Hillview Avenue
Palo Alto, CA 94304

Principal Investigator
R. Torok

This report describes research sponsored by the EPRI.

The report is a corporate document that should be cited in the literature in the following manner:

Instrumentation and Control Strategies for Plant-Wide and Fleet-Wide Cost Reduction: Interim Guideline – Abridged Version. EPRI, Palo Alto, CA: 2006. 1013482.

PRODUCT DESCRIPTION

This report describes both progress to date and future directions of the EPRI initiative on "I&C Strategies for Plant-Wide and Fleet-Wide Cost Reduction." In contrast to the established practice of system-by-system digital upgrades, integrated modernization involves qualitative improvements to shared communications and computing infrastructure, plant processes, and organization that offer new benefits for the plant as a whole, not only for the instrumentation and control (I&C) systems. The report highlights three key aspects of I&C modernization planning: the potential benefits associated with reducing operations and maintenance (O&M) costs, an endpoint vision that describes functions and features needed to achieve the benefits, and a high level architectural concept that suggests how a cost-effective solution might be achieved. Two different strategies are contrasted: an aggressive approach intended to capture all the potential benefits and a constrained approach that attempts to maximize benefits within budget limitations.

Results & Findings

The task analysis results show that comprehensive I&C modernization can generate as much as a 18% reduction in O&M staff, which would represent about $11,000,000 in recurring yearly savings for a typical plant. Full realization of the O&M cost reductions, as well as additional benefits associated with improved equipment reliability and plant margins, would require a substantial investment of more than $120M in infrastructure, software, and integration, assuming current approaches.

Challenges & Objectives

Utility design engineers, strategic planners, and executives need a comprehensive approach for managing the obsolescence of aging I&C as nuclear plants look forward to license extension and decades of future operation. Cost-effective modernization strategies that maximize the benefits of implementing new technology have proven elusive. For utility executives and planners, this report provides an overview of the potential benefits and business case issues associated with modernization. It also clarifies why the narrowly focused "point-solution" digital upgrade approach practiced by most nuclear utilities captures only a small fraction of the potential benefits offered by the new technology. For the design engineer, the report offers examples of an architectural approach to I&C modernization that can be used as a starting point for designing plant-specific solutions.

Applications, Values & Use

A more compelling business case will be needed if aggressive modernization programs are to become the norm. Regardless of the returns, such a large investment presents a challenging hurdle for most utilities and also an opportunity in the sense that even partial improvements can generate significant savings. Thus, the most significant barriers to realizing the benefits of I&C modernization are reducing investment cost to a more manageable level and selecting a project scope that yields an optimal—and competitive—project rate of return. Future project tasks will address these issues and identify new approaches that might be used by utilities to significantly improve the cost-benefit picture.

EPRI Perspective

This project is part of a multi-year EPRI initiative to help utilities design, implement, and license digital I&C upgrades in nuclear power plants. This guideline is particularly significant in that it addresses planning and cost-benefit issues that have hindered modernization efforts for several years. The approach is unique in that it draws upon industry resources and takes the point of view of the utility, rather than that of the vendor. While it does not solve all the problems, the report highlights key issues and identifies areas that need more attention in the future.

The industry has long recognized the need to manage I&C obsolescence. However, systematic approaches and defensible cost-benefit assessments have proven elusive. With the great majority of plants now anticipating license renewal and decades of continued operation, the need to replace aging I&C systems has become more apparent and acute. This abridged interim guideline is intended to provide the broadest possible distribution of summary results and conclusions from EPRI 1010041, *Instrumentation and Control Strategies for Plant-Wide and Fleet-Wide Cost Reduction*, to technology vendors, system integrators and others who can contribute to ideas, products and solutions for cost-effective modernization of nuclear power plants. This abridged version is nearly identical to the full report, with the sole exception that the contents of three appendices have been deleted.

Approach

The goal of the report is to provide practical guidance that will help utilities develop plant-specific I&C modernization strategies that maximize benefits of the new technology within their schedule and resource constraints. An EPRI working group comprised of utility and industry representatives guided the project to ensure that the utility perspective was accurately reflected and that the resulting guidance would be useful and practical.

Keywords

Instrumentation and control
I&C modernization
Digital upgrade

ACKNOWLEDGMENTS

The utility working group on I&C Integrated Modernization has provided general direction for this project as well many insights and specific information about current nuclear power plant practices, issues and trends. We acknowledge valuable contributions from Mr. Darrell Cooksey of Ameren Energy, Mr. Kevin Lyall of Duke Energy, Mr. Patrick Salaun of Électricité de France (EdF), Mr. William Kurth of Exelon Corporation, Mr. Andrej Petrenko of Entergy North, Mr. Joseph Ruether of Nuclear Management Corporation, and Mr. David Hooten of Progress Energy.

This project has greatly benefited from the extensive knowledge and exceptional personal commitment of Mr. Ken Scarola of Nuclear Automation LLC. Mr. Scarola not only performed and documented the Task Analysis, upon which this report has drawn extensively, but also played a key role in conceiving and refining the aggressive endpoint vision, and in documenting an architectural approach that can realize it.

Mr. Bob Fink of CDF Services, Inc. has provided many helpful review comments as well as early information from the ongoing EPRI study on Control Room Human Factors.

Mr. Nguyen Thuy of EdF – currently assigned to EPRI in Palo Alto – has provided valuable insights regarding digital architectures and issues in general, as well as background information about EdF experience with their digital systems and their future directions with advanced plants.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 EXECUTIVE SUMMARY

This interim report describes both progress to date and future directions of the EPRI initiative on "I&C Strategies for Plant-Wide and Fleet-Wide Cost Reduction." In contrast to the established practice of digital system upgrades, integrated modernization strategies involve qualitative improvements to shared communications and computing infrastructure, plant processes and organization that offer new benefits for the plant as a whole, not only for the instrumentation and control (I&C) systems themselves.

Resulting capabilities such as on-line condition-based maintenance and wireless-based paperless work environment yield a wide range of benefits. These include reduction of threats to equipment reliability, plant availability and safety; lower operations and maintenance (O&M) costs primarily through staff reduction; and improved plant operating margins that allow increased power output.

A detailed task analysis performed at two operating plants determined that capabilities enabled by a comprehensive I&C modernization can generate as much as an 18% reduction in O&M staff, which would represent about $11,000,000 in recurring yearly savings for a typical plant. The task analysis is the benefit-centric part of a three-sided approach to modernization planning. It is accompanied by a high level endpoint vision that describes functions and features needed to achieve the benefits, and by a high level architectural concept that suggests how a cost-effective solution can be based upon a non-safety distributed control system, in conjunction with appropriate safety equipment and systems.

For utilities whose capital resources are too constrained to contemplate such a major step, an alternative slower-paced vision provides flexibility to accommodate shifting priorities to reduce imminent threats such as obsolescence and degraded reliability of equipment. By providing consistency and shared resources across multiple system solutions, a utility can reduce its costs of plant-wide infrastructure, spare parts, I&C maintenance and training.

To fully realize the $11,000,000 per year in O&M cost reductions, not to mention additional benefits associated with improved equipment reliability and plant margins, requires aggressive changes to plant process and organization and an investment of over $120M in infrastructure, software and integration. Even considering only the O&M cost savings, internal rates of return in the high single digits can be achieved for plants having extended licenses. However, such returns must be improved if the business case is to be made more compelling. Regardless of the returns, such a large investment presents a challenging hurdle for most utilities and must be reduced in absolute terms.

Thus, the most significant barriers to realizing these significant benefits are reducing investment cost to a more manageable level, and selecting a project scope that yields an optimal – and competitive – project rate of return. These themes are the principal drivers for 2006 project activities that will emphasize:

- Inclusion of other quantifiable benefits such as improvements to equipment reliability and plant availability.
- Reduction of required investment by providing example(s) of endpoint vision and integrated architecture that can help engage and guide I&C vendors, and by using utility internal teams to leverage experience across projects.
- Reduction of required investment by learning from more cost-effective non-nuclear industry practices where they are applicable, in view of the fact that full scope fossil plant modernizations are 10-15 times less expensive than those of a nuclear plant.
- Improved cost-benefit analysis methods to help each utility make the choice of scope and implementation method best suited to its own technical and business environment. By properly prioritizing and valuing activities, a utility may choose to stop short of a full modernization if the bulk of quantifiable benefits are achievable with a smaller investment.
- Continued development of concrete solutions – such as examples of endpoint visions and architecture concepts – that give utilities a baseline starting point for plant-specific planning and implementation.

2 BACKGROUND

2.1 Scope & Motivation

Although the project addresses strategic modernization of Instrumentation and Control (I&C) systems, it goes beyond the scope of traditional I&C boundaries to identify strategies and solutions that cost-effectively exploit I&C and information technologies to:

- Reduce equipment lifetime costs by simplifying plant I&C architecture.
- Reduce staffing requirements for plant operations and maintenance organizations.
- Reduce overall maintenance costs while improving reliability.

A further goal is to recognize economies of scale afforded by operation of multiple plants within a generating company fleet.

This project departs from the well-established practice of tactical digital upgrades[1], which are individual component or system replacements that create minimal disturbance to existing rack layouts, staff practices and organization. In contrast, integrated modernization involves qualitative changes to infrastructure and organization that offer new benefits to the plant as a whole, not just to the I&C systems themselves.

Research to date demonstrates that an aggressive approach to plant-wide integrated modernization yields substantial benefits through Operations and Maintenance (O&M) cost savings. The core of this report (e.g., Section 3) is devoted to the potential gains that can be obtained by an ambitious scope and significant investment for modernization.

However, it is also recognized that the investment required to realize the full benefits may lie beyond the resources of some utilities, so the project also seeks to define a capital-constrained approaches that yield partial benefits. By making limited investments in a shared infrastructure, settling on standard technologies and product lines across the plant and fleet, and developing internal project expertise, a utility can limit the costs of its acquisition and ongoing I&C maintenance compared to a purely tactical approach.

[1] Also referred later in this report as point solutions.

Business Impact of I&C Strategic Modernization

Integrated I&C Modernization can have significant positive impact on business performance through several classes of quantifiable benefits:

- **Threat Reduction**. The integrated approach addresses the major issues of obsolescence and equipment reliability, with goals of improving or preserving plant availability, and of extending the life of key plant assets and thus the productive lifetime of the plant itself.
- **Reduced Operations and Maintenance Costs.** Maintenance staff – both I&C, electrical, mechanical and administrative -- can be reduced by fully or partially automating labor intensive tasks, better aligning maintenance resources to focus on critical needs identified by remote monitoring and analysis, and generally reducing the number of components and interfaces. This integrated approach consolidates or eliminates activities that have been based upon arbitrary schedules or required for legacy point-to-point I&C architectures. The size of each operations shift staff can be reduced by improving the ability of control room operators to evaluate and respond to abnormal plant conditions and by consolidating remote operations within the main control room.
- **Improved Plant Productivity**. More comprehensive and frequent data collection and more accurate instrumentation reduce uncertainties and allow tighter operating margins that can increase revenue.

In addition, there are intangible benefits including:

- **Reduced concerns over workforce aging and retirement**. Required skills can be kept more in line with those skills available in today's marketplace. Dependence on expertise on aging or obsolete legacy equipment is alleviated.

Technical Advantages of I&C Strategic Modernization

These business benefits are achieved by exploiting various technical advantages provided by integrated modernization:

- **Tactical Benefits** include resolution of obsolescence problems, reduced cost of instrumentation, self-diagnostic and calibration features, and improved reliability. Although the industry is already familiar with these benefits, they have not been fully exploited, e.g., through streamlined test and maintenance procedures or through reduced spare inventories of highly reliable digital components.
- **Vertical flow of information**. Networked I&C technology facilitates the upward flow of data and processed information from plant equipment to plant and corporate information networks, where it can be archived and mined to support high level technical and business decisions, such as action in anticipation of component failure, or deferral of unnecessary maintenance.

- **Opportunities for Simplification**. Increased functionality of digital devices can reduce the need for distinct rack-mounted components to perform A/D conversion, signal conditioning, and similar functions. Intelligent digital field devices such as transmitters, valve positioners and motor starters, combined with bus-based communications and wireless solutions, can reduce wiring and signal conditioning needs.
- **On-line Asset Management and Condition-Based Maintenance** provide benefits for management not only for I&C field devices, but also for network infrastructure and underlying mechanical components.
- **Hierarchical Management** software can facilitate event monitoring and workflow automation across technologically diverse plant systems, as well as geographically distributed plants within a power generation company.
- **Improved Human Performance.** Information displays and electronic procedures can guide personnel to sound success paths. Full automation can be employed for repetitive, burdensome or challenging operating tasks.
- **Exploit experiences of related industries.** By centering I&C solutions around mainstream digital control product lines, the nuclear power industry can leverage applicable solutions devised by other industries such as oil, gas & chemicals, and can exploit lower cost and more powerful products that enjoy economies of scale across larger industries.

2.2 Project Principles

Multidimensional Character

Reference 1 describes the research program and approach in detail. It is based upon the well-accepted premise that the full productivity benefits of improved technology are never achieved simply by dropping newer technology into an existing environment. The technology must reflect the demands of the environment, and the environment should evolve to most effectively leverage capabilities of the new technology.

The project view toward integrated modernization recognizes that the solution involves major dimensions such as: concept, technology, process, task and organization, as suggested by Table 2-1. A general *concept* such as remote monitoring spawns specific *technologies* that may be standards-based or proprietary. Similarly, major *processes* such as valve maintenance and configuration management govern the interaction of more specific day-to-day *tasks*, and determine the structure and level of the *organizations* needed to perform them. Reference 1 provides specific examples of these dimensions, and suggests a conceptual process for iterating to a consistent solution.

It is useful to further divide the technology dimension between functionality-specific products (e.g., an instrument or software module) and infrastructure (e.g., an application server, or fieldbus communications network) to recognize that the infrastructure investment can be amortized across many specific uses within the plant.

Table 2-1
Dimensions of I&C Modernization Decisions

Dimension	Examples	Typical Opportunities
Concept	Mechanical Asset Management Networked Instrumentation Condition-Based (Predictive) Maintenance Workflow automation Fleet-wide Remote Monitoring & Work management Standardization and open systems. Wireless Data Collection	Automation: Routine data gathering and information processing tasks may be automated. Simplification: Current I&C architecture can be simplified and number of components and racks reduced. In general: Improved abilities to access, consolidate and process information support condition-based maintenance.
Technology	*Infrastructure:* Foundation Fieldbus 4-20 ma Local Loop control SNMP Based Network Management. *Specific Products:* Cisco 2955 Industrial Ethernet Switch Foxboro 3051S Pressure Transmitter Remedy Action Request System EPRI PMBasis	Technologies that implement networked instrumentation – such as fieldbus, smart sensors and industrial ethernet – have been proved in other industries. Secure wireless communication based upon spread spectrum technologies may bypass the cost and difficulty of laying cable in certain circumstances.
Process	Configuration Management I&C Upgrade Planning Motor-Operated Valve Maintenance Condition-Based Maintenance of Motor-Generator Set	Automation of condition-based monitoring. Procedures can be modeled and executed using tools adopted from IT industry. Simplified I&C architectures can reduce the level of maintenance and staff required. Remote Data Collection reduces needs for route-based data collection.
Task	Instrument Calibration Valve Stroke Testing Initiation of Maintenance Request	Streamline, eliminate or automate tedious tasks and reduce error in complex tasks.
Organization	Structure System-oriented vs. functional organization Fleet-wide monitoring center. Staffing Specialized expertise shared across departments or plants. Reduced needs for route-based roles.	I&C technology can enable a smaller, simpler organization. Traditional hard boundaries between system engineers may evolve to a more fluid organizational structure. Some monitoring responsibilities can be centralized for companies operating multiple plants.

To ensure that project direction is grounded in real plant opportunities for improvement, rather than enthusiasm for any particular technology choice, this project started with detailed task analyses performed in two operating PWR plants. These task analyses -- which focused on operations and maintenance staff time because of its importance to recurring cost structure – identify areas of opportunity and potential benefits (through improved productivity and reduced staffing) that can be achieved by point (single-system) solutions as well as integrated I&C modernization.

General Guidance versus Specific Solutions

This project addresses the modernization needs of operating plants and thus must recognize the need to provide flexible guidance that can apply across different reactor types, business conditions and financial resources, cultures and vendor relationships.

However, general guidance is most effective when accompanied by concrete solutions – whether presented as examples or as potential industry standards. Beginning with the endpoint vision for plant modernization, this project strives to provide not only guidance (e.g., specification for end point vision of Appendix B), but also concrete examples developed to an appropriate level of detail. Individual utilities may choose to apply such examples directly, to use them as communications tools for clarifying requirements with vendors, or simply for supplementing the general guidance.

Although the modernization endpoint vision must be thought through by each plant, the project is developing two bounding cases, beginning with brief high level summaries. Section 3 presents an aggressive vision that, to achieve significant benefits in O&M cost reduction, implies a substantial investment and sweeping changes to the entire operations and data acquisition infrastructure. It is accompanied by a candidate architectural approach based on previous industry and EPRI work in both ALWR and operating plant contexts. Because the investment required may be out of reach for many utilities, we also include a more limited “Capital-Constrained” endpoint vision in Section 4, which describes some simpler practices that can improve cost-effectiveness compared to a system-by-system approach to upgrades.

Recognizing that utilities face a range of business conditions and technical environments, during 2006 the project will develop cost-benefit methods that will help utilities determine the appropriate level and priorities for modernization within their plants and fleets. Appendix C discusses these issues in very general, qualitative terms and points out the needs for a quantitative method or tool to provide utilities with choices and the means to select the most appropriate choice.

2.3 Relationship to Other EPRI Projects

The current project can draw upon previous and current EPRI work in related areas. References 3 through 6 are representative of EPRI efforts to define techniques for digital upgrades and to support qualification of commercial products to enable cost-effective means for doing so. In addition, the current project has extensively used results from the following two more recent projects.

Control Room Modernization Guidelines

Reference 7 is the culmination of a multi-year program – sometimes referred to as the “Hybrid Control Room Project” – that was sponsored jointly by EPRI and the U.S. Department of Energy. That project applies Human Factors Engineering (HFE) principles to address the modification and upgrading of existing control rooms, and thus differs from most HFE documents that are focused on design of a new control room for a new plant. The document also provides detailed methodologies that can be used by utility engineers to design their control room, encompasses a modification lifecycle from planning through follow-up of modifications, and explicitly interprets regulatory requirements.

The attention paid by Reference 7 to control room and operations-centric issues is far deeper than that of the current project, which covers a broader range of topics including maintenance, IT infrastructure and organizational change. To a large degree this project has deferred to the guidance of Reference 7 for HSI related issues related to operations, both in normal and abnormal conditions.

Of particular relevance to the current project is the guidance of Reference 7 on Control Room Modernization Planning, which had been previously published as a separate document in Reference 8. Recognizing that the migration from conventional to fully modernized control room (together with underlying infrastructure) may take multiple steps, that document emphasized the importance of an “Endpoint Vision” that defines a concrete target for concept of operation, Human System Interface (HSI) design concept and failure management. The endpoint vision is plant-specific and considers the plant’s goals, financial and organizational constraints, as well as overall I&C upgrade strategy.

To help utilities define their endpoint vision, Reference 7 provides worksheets (Tables 2-5 through 2-7 of reference 7) that specify the contents and scope of such a vision. Examples of worksheet entries appear in Table 2-2.

Table 2-2
Two Selected Items from Control Room Endpoint Vision Worksheets
("Existing Control Room" column omitted)

Category	Endpoint Vision	Basis/Discussion
Surveillance testing	*Describe significant changes expected in how major plant surveillance tests will be performed, operator roles, burden reduction, etc.*	*Provide basis for expected changes in testing and operator roles (e.g., describe what automation features will be expected to lead to intended reduction in operator time spent on testing).*
Overall concept and architecture for controls, including: • Degree of implementation of soft controls • Spatially dedicated controls • Diverse backup controls	*Describe concept for controls, including overall approach for soft versus hard controls, spatially dedicated controls, diverse backups, etc.*	

The same method of specifying a vision can be applied to overall plant modernization, whose scope is significantly broader and includes other categories such as Concept of Maintenance, Infrastructure Architecture, and Organizational Architecture. With this in mind, the endpoint vision worksheets from Reference 7 have been used verbatim as the control-centric starting point for defining an endpoint vision, but in Appendix B have been extended to represent the broader scope of the current project.

A complete endpoint vision defined by these worksheets would be quite detailed, so a higher level description is needed to convey ideas and achieve consensus. For the narrow control-room centric scope, Table 2-1 of Reference 7 also suggests a structure for describing a "high level" vision in terms of a few categories such as: Workstations, Large Display, Integrated Soft Control Capability, Computer-Based Procedures, Intelligent Processing, and Failure Management. This provides the starting point for the high level visions presented in sections 3 and 4 of this report.

An extension and update to the control room guidelines [9] adds several new topics, most notably "Safety Monitoring and Control in Modernized Control Rooms." Reference 9 delves more deeply into regulatory requirements and industry guidance, to help utilities determine the necessary scope and design options for safety qualified indications and displays. For example, it describes criteria for determining what information should be presented in HSIs distinct from those of the frontline non-safety distributed control system (DCS) and for deciding which information should be presented in spatially dedicated displays. It also explains how required HSI resources can be determined by analyzing plant emergency operating procedures and the success paths they support.

Summary results from a recent utility modernization study also enumerate the surprisingly large number of qualified conventional devices (meters, switches and lights as well as more complex components) that are needed to support safety functions. This reinforces the advantages of qualified flat panel displays for simplifying maintenance of safety HSI components.

30-Day Modernization Project

Recognizing the extensive potential benefits of a full-plant modernization, Reference 10 addressed the scheduling dilemma for implementation in an operating plant, which would normally require a single extended outage (with the resulting loss of revenue) or a series of shorter outages tied to the fuel cycle (with the complication of temporary interfaces and mixed technologies during a long transition period).

A research team consisting of an I&C system supplier, an architect engineer and a nuclear utility evaluated the feasibility of a single-outage full plant I&C modernization, using Byron Unit 1 as a reference plant.

Keys to fast and cost-effective introduction include: the use of a compact HSI concept that can fit within an existing control room space or adjacent room; reliance on non-safety distributed control system environment and communications bus for frontline control, monitoring and single-point data acquisition; minimal replacement of existing field wiring, and extensive use of remote I/O. This study excludes replacement of field instruments and actuators, so the full potential offered by smart instrumentation is not immediately realized.

One alternative considered provides a monolithic non-safety HSI – built upon the foundation of a commercial distributed control system -- to provide primary control of both non-safety and safety equipment. This architecture provides a seamless and powerful operator interface with computerized procedures and integrated alarm management. Regulatory issues are accommodated by providing a safety console employing two levels of backups – one based on qualified multi-channel soft controls and flat panel displays capable of performing all safety functions, with one-step access to Regulatory Guide 1.97 Category 1 parameters. The safety console also includes system-level hardwired controls for reactor trip and actuation of each engineered safety feature.

This study concluded that for most utilities, a full-plant I&C modernization under these assumptions would be feasible with a single outage of no more than 60 days, at an estimated[2] cost of $94M.

Recognizing that many utilities would still require a phased modernization despite the need for temporary states and delayed benefits, the study also considered a phased modernization that partitions the work into up to 6 phases: 1) Rod Control; 2) Small systems such as turbine and feedwater control; 3) Balance of Plant Control; 4) NSSS Control; 5) Reactor protection and Engineered Safety Feature Actuating System (ESFAS); and finally 6) Plant Computer, Main control and Simulator. The resulting investment is estimated to cost about $122M, higher than

[2] Reference 10 provided “point” estimates of cost and did not attempt to characterize uncertainties.

the single-outage estimate because of the need to provide and remove interim interfaces during the several-year period of phased introductions.

The current project uses this work in two main ways. In section 5, its cost estimate is used to draw conclusions about the current cost of achieving modernization benefits. In section 3.4 the high level architecture example is closely related to that assumed above for the 30 day modernization effort.

2.4 Utility Industry Participation

Reference 1 describes the multi-year research program to develop I&C modernization strategies, including the balance between the broad scope of integrated strategies, versus the need to identify "gaps" and pursue these in more depth to achieve resolution.

A key element of that program plan is the role of a utility working group to help set priorities and keep the project grounded in actual utility needs and current practice. During 2005, such a working group on I&C integrated modernization was formed with representation from the following EPRI member utilities:

- Ameren Energy
- Duke Energy
- Électricité de France
- Exelon Corporation
- Entergy Nuclear Northeast
- Nuclear Management Corporation
- Progress Energy

Most significantly, the group formulated several project tenets that substantively modified the original research plan described in Reference 1:

- In addition to providing general guidance, the project should produce one or more solutions, essentially examples, to an appropriate level.
- Both safety and non-safety systems should be considered from the outset of the project.
- Starting point should be the development of specific example(s) of an endpoint vision, which should seek to represent concrete implementable solution(s) to an appropriate level.
- Examples of endpoint visions should address both external behavior (e.g., functional requirements) and internal structure (i.e., high level architecture).
- While solutions should be licensable, they should not necessarily be constrained to current licensing practice.

The group also endorsed the notion that the current work should not only provide technical basis, but also be useful to decision makers at an executive level who are balancing modernization decisions against competing investments.

In addition, members of the committee provided both direct inputs to the research project and access to plant staff.

3
AGGRESSIVE VISION

3.1 Introduction

Section 3 presents a comprehensive high-level view of a modernization target that maximizes benefits across the operations, maintenance and administrative areas of a plant. Table 3-1 summarizes the status and interim results of this ongoing effort.

Table 3-1
Status of Project Activities Related to Aggressive Vision

Completed in 2005	Identified Opportunities for O&M Savings (Section 3.3) High Level Description of Vision (Section 3.2) Example of High Level architecture (Section 3.4) Expanded Worksheets that specify what a detailed plant-specific endpoint vision entails (Appendix B)
Ongoing. **To be completed in 2006**	Details of Example EndPoint Vision(s) – from both external (functional) and internal (architecture) viewpoints. To be based upon considerations described in Appendix B worksheets.
Planned for 2006	Cost-Benefit Analysis to support utility decisions for plant-specific solutions and phasing Threat Reduction benefits associated with equipment reliability and plant availability. Cost Analysis of Example Solutions Phasing and Migration strategies

The following subsections summarize some of the work completed during 2005. Sections 3.2, 3.3 and 3.4 are closely interrelated and primarily concern functional requirements, end user requirements, and implementation approaches, respectively. Because each one influences the other two, they could be presented in any order.

To encourage top-down understanding and avoid premature commitment to prescriptive details, section 3.2 is a high-level summary that concentrates on the functional features for the target, but does refer to some enabling technologies where clarification is necessary. Work to expand this to a more detailed level is underway and will be completed in 2006, following a structure suggested by the worksheets in Appendix B. Readers who are familiar with EPRI Control Room Guidelines [7-9] will recognize that the control-centric parts of these worksheets are taken verbatim from that document; the worksheets have been extended to include topics of maintenance, architecture and organization in recognition that I&C modernization has a broader scope.

Endpoint modernization visions are plant-specific and dependent upon variables such as the culture, financial resources, type and vintage of the plant. The vision presented in this section should be regarded as a concrete example that can be adapted to suit plant-specific needs, not as a prescriptive solution that every plant must follow.

To date, the project has focused on identifying benefits as well as capabilities and feasible technical approaches to achieve those benefits. These approaches have taken into account regulatory requirements for solutions that cut across both non-safety and safety systems, but pursuing licensing precedents is outside the scope of the project as currently defined.

Section 5 points out that the barrier to achieving these benefits is investment cost rather than technology. During 2006, project emphasis will be on the cost side – not simply in determining the absolute costs of system acquisition and deployment, but in determining ways we may modify architecture, organization and project approach to reduce the cost multiplier of nuclear solutions compared to fossil and other industry applications.

3.2 Endpoint Vision

A high level summary of an aggressive endpoint modernization vision is presented in Table 3-2. This table is largely self-explanatory, but it is useful to summarize some of its main points.

Multidimensional change. As described in section 2.2, integrated modernization cuts across complementary dimensions of task, process, organization and technology. The full benefits of powerful technology are only realized when accepted as part of broader changes that cut across these dimensions.

Maintenance productivity and effectiveness is improved through use of general purpose workstations hosting software applications that support condition based maintenance, work flow management, and other analytical tasks. Wireless infrastructure is leveraged to monitor plant equipment while minimizing use of additional cable.

Operations productivity is achieved by presenting synthesized information at a higher level. This is made possible by commercial process control and system management software products that support hierarchical information access, integrated alarms, and computerized procedures with actions directly linked to control commands. The resulting productivity improvements enable the plant to be safely operated with the reduction of one control room and one auxiliary operator per crew, and allow most local control panels to be eliminated with their functionality shifted to the main control room.

Implementation costs of unnecessarily “gold-plating” designs can be contained by tailoring availability requirements to specific application needs, and by segmenting networks to bound failure impact rather than making indiscriminate use of redundancy.

Shared infrastructure provides uniform data communications (wired and wireless), storage, applications and other services while amortizing costs over multiple uses, minimizing the variety of systems to be maintained, and reducing spare parts inventories.

Architectural homogeneity is achieved by choosing a commercial distributed control system platform, as well as a qualified platform for safety applications. The non-safety platform preferably employs industry standard interfaces, so the utility can keep open the option to migrate to a compatible commercial platform in the future.

Simplification. By incorporating technology such as multifunction smart instruments, bus-based communications and direct digital I/O, the number of I&C interfaces and rack-mounted devices is reduced by a factor of 3-4 compared with legacy analog or like-for-like digital replacement architectures. [12]

Restructured plant organization reflects the ability for staff members to deal with a broader class of problems, when they are supported by modern data acquisition, communications and analysis technologies. Specialized services are supplied by fleet-wide organizations – whether central or virtual. Modernization projects are lead by a core technical team having expertise in the selected platforms, and team members should be given enough time in their positions to leverage cumulative experience across multiple projects.

Cyber security is designed into the architecture from the start, in recognition of security risks incurred when information flows more freely between low levels of the plant to upper levels of the corporation.

Smart instrumentation exploits capabilities for self-calibration, passive tracking of performance and active incremental testing to reduce the level of manual activities and staff required to perform them.

Table 3-2
Features of a Fully Modernized Nuclear Power Plant
Expanded from Table 2-1 of EPRI 1008122

Feature Class (Benefit Classes[3])	Description
Business Goals and Scope of Change	This endpoint vision aims to maximize investment rate-of-return over the full plant lifetime and across the entire fleet. Integrated changes to process, tasks and staffing, organizational structure, I&C and information architecture, and underlying technology are aggressively introduced to achieve optimal financial return through staff reductions and improvements to plant availability and reliability.
Operator Workstations (QUAL, O&M)	Compact, redundant operator workstations with computer-driven displays and soft control devices provide organized, hierarchical access to alarms, displays, controls and procedures. Each workstation has the capability to perform all main control room functions, with advanced navigation and automation features that enable a full complement of two control room operators to operate the plant under all conditions. Following a transfer to the Remote Shutdown Panel (RSP) all controls are fully isolated from the Main Control Room (MCR), so that cold shutdown can be achieved from full function workstations at the RSP without the need for Auxiliary Field Operators; this allows a reduction in the Auxiliary Operations staff. Additional workstations, typically with restricted capability are provided outside the main control room or operating area for others to access information without distracting the main control room operators. On a separate computer workstation, operators are provided with complete access to maintenance and management displays.
Maintenance & Management Workstations (QUAL, O&M, EAI)	Outside the control room, general purpose computer workstations with graphical displays, real-time access to monitored data, device configuration capabilities, and analytical tools support a wide variety of plant maintenance, workflow management and performance monitoring functions. Upon user login and authentication, each workstation session supports privileges and functionality tailored to the user's role and workstation location. With the exception of workstations in the control room, any sessions involving active control or configuration functions have an idle-time timeout requiring repeat login and authentication. Non-operator roles or locations have no privilege to perform real-time control actions on the plant. Non-operator roles may be privileged as appropriate with view-only access to operator control displays. For safety devices, qualified safety maintenance and test systems perform configuration functions.
Overview Displays (QUAL, O&M)	A large Plant Overview Display, visible to the entire operator crew, provides a spatially dedicated, fixed-format, continuously available overview of plant status including essential equipment status, values of key process variables, and high-level alarms visible throughout the main control room. Additional large format displays may incorporate selectable windows and specific displays such as closed-circuit video monitoring of critical plant areas and equipment. Outside the control room, specialized maintenance & management workstation sessions link to view-only overview status display(s) to provide system context where appropriate.

[3] Following are classes of Benefits:
EAI – Minimization of engineering, acquisition and installation costs
O&M – Operations & maintenance cost reduction
AI – Availability improvement
TR – Threat reduction – including heading off obsolescence, challenges to availability, etc.
QUAL – Qualitative improvements in staff performance quality and productivity.

Table 3-2 (continued)
Features of a Fully Modernized Nuclear Power Plant
Expanded from Table 2-1 of EPRI 1008122

Feature Class (Benefit Classes[4])	Description
Integrated Soft Control Capability (QUAL, O&M, EAI)	Non-safety soft controls at the operator workstations provide the principal mechanism for control of both safety-related and non-safety-related equipment using a single seamless Human-System Interface (HSI). Priority logic techniques are used to ensure that hardware or software faults cannot contradict signals that initiate safety functions, and that safety functions can be maintained even if non-safety controls fail.
Automation (O&M, QUAL)	Selected operations functions and tasks -- including sequential control actions associated with plant startup, shutdown, and testing and maintenance – are automated. Most automation is driven by computerized procedures that allow operators to release individual procedure steps or entire procedure sections for automatic execution. Operators control the pace and extent of this Procedures-Based Automation, with automatic holds at predefined steps or when process feedback indicates steps are not properly completed. Thus, the operator remains involved, aware of the status, and ready to back up the automation as necessary. Workflow automation in support of maintenance tasks – such as creation and approval of work orders, and data collection -- is performed with the aid of flexible scripts or graphical workflow models that can be configured without changes to product source code. Automation capabilities support collaborative workgroup activities, e.g., review cycles and electronic signatures, to eliminate the time and expense of paper processing. In addition, certain maintenance and management tasks are selected for full automation – which can execute autonomously without hold points -- based upon their degree of: Repetition and labor intensity Risk Susceptibility to human error (e.g., time pressure or complexity) Competition with other tasks for human attention.
Computer-Based Procedures (QUAL, O&M, TR)	Computer-based procedures provided at the workstations integrate process and equipment information and alarms with procedure steps, and are integrated with the automation features to provide efficient execution of tasks and ready access to information and controls. Text-document forms of the procedures are generated automatically and available as a consistent backup to computer-based procedures.
Intelligent Processing (QUAL, O&M, TR)	Correlated and prioritized smart alarms, intelligent processing of low-level data into directly interpretable information ,and operator aids that help the operators deal with instrument and signal failures, provide higher-level information to directly support operator tasks, and reduce nuisances and distractions associated with alarms. Access to more detailed information can be obtained by “drilling down” to the level needed. Software accessible from the maintenance & management workstation automatically discovers the current configuration and state of all I&C components and, to the degree possible, of the underlying mechanical components as well. Violations of operating constraints (e.g., Limiting Conditions of Operations) or discrepancies between as-designed and as-discovered configurations (e.g., switch states and availability of backup links) are alarmed and displayed. For non-instrumented equipment, the operator is prompted to confirm or update the system’s current understanding of equipment status.

[4] Following are classes of Benefits:
EAI – Minimization of engineering, acquisition and installation costs
O&M – Operations & maintenance cost reduction
AI – Availability improvement
TR – Threat reduction – including heading off obsolescence, challenges to availability, etc.
QUAL – Qualitative improvements in staff performance quality and productivity.

Table 3-2 (continued)
Features of a Fully Modernized Nuclear Power Plant
Expanded from Table 2-1 of EPRI 1008122

Feature Class (Benefit Classes[5])	Description
Failure & Availability Management (TR, EAI, AI)	Redundancy and other fault tolerance features including self-diagnostics, early fault detection, and associated indications and alarms that enable the operators to remain aware of the health of the I&C systems and deal with degraded conditions gracefully. Hot swap capabilities improve system availability by allowing component replacement and/or upgrade without interrupting operations. For maintenance functions, the requirements for system availability and reliability, scheduled maintenance intervals and downtime, and failover recovery time, are tailored to the particular function. Designs for individual solutions consider both safety and economic risks, so that capital dollars can be concentrated on critical areas. This risk-informed approach permits cost-effective commercial technology and solutions to provide the required level of performance while avoiding costly overdesign. Control & device networks are segmented to bound the impact of a single failure of PLC, intelligent field device or other component. Control & information networks achieve tolerance to single failures by using standard network design techniques such as redundant meshes with spanning tree algorithm enabled on switches, in conjunction with logic for re-intializing or re-synchronizing application software following restoration of communications. Where appropriate, device networks can implement failure tolerance and redundancy economically by deploying some control and monitoring functions to smart instruments within an architecture that supports field-based control. Notwithstanding these features for high availability and reliability of the non-safety distributed control system, for safety functions there are two additional levels of diverse backup functions capable of restoring critical functions following complete failure of the non-safety distributed control system. First, a safety-qualified HSI and deterministic computing platform underlie a limited-scope Safety Console, which provides all the functionality needed not only to actuate and monitor all safety functions, but also to achieve cold shutdown in an benign fashion that does not impact the plant investment. Second, for a limited number of core safety functions such as RPS , ESFAS and functions credited by the FSAR for manual actuation, hardwired controls and simple video panels are provided for actuation and indication, respectively. Priority logic techniques are used to ensure that a malfunctioning non-safety system cannot contradict signals that initiate safety functions.

[5] Following are classes of Benefits:
EAI – Minimization of engineering, acquisition and installation costs
O&M – Operations & maintenance cost reduction
AI – Availability improvement
TR – Threat reduction – including heading off obsolescence, challenges to availability, etc.
QUAL – Qualitative improvements in staff performance quality and productivity.

Table 3-2 (continued)
Features of a Fully Modernized Nuclear Power Plant
Expanded from Table 2-1 of EPRI 1008122

Feature Class (Benefit Classes[6])	Description
On-Line Condition Based Maintenance and Asset Management (O&M, TR, AI)	Equipment condition data such as vibration spectra, motor current traces, and valve-stroke force and position traces are gathered and archived automatically, and made available for analysis throughout the plant and company. Using current, historical and benchmark information, advanced algorithms – such as SmartSignal models -- evaluate performance, condition, and degradation trends for all monitored components. Significant deviations between actual and projected condition are alarmed well in advance of crisis situations, and responsible individuals are automatically notified and assigned action items. Continual reassessments of condition, priority maintenance actions, and time constraints for such actions are generated and displayed in response to both schedules and user requests. Priorities of such actions, as well as conflicts between them, are evaluated in terms of availability and safety risks to the plant, as well as financial risks to the parent company. For context, maintenance engineers can view the life cycle maintenance plan for each component or system, as well as its basis. Actual performance data is automatically factored into the procurement process and is used to track issues associated with equipment classes.
Fleet-Wide Monitoring and Workflow Management (O&M)	The system supports 24 X 7 shared services for fleetwide equipment monitoring, trending and troubleshooting across multiple sites. These shared services may be located at a common central location or may be distributed among multiple corporate sites – including individual plants – and coordinated virtually. The combination of automated trending and prompt review by shared specialists identifies equipment performance changes before they can be detected by operations.
Shared Infrastructure to support integrated solutions (EAI, O&M)	A basic shared infrastructure is provided to enable quick and cost-effective design and implementation of solutions throughout the plant. The plantwide infrastructure includes broadband communications to support real-time monitoring and control, run-time software environment, redundant host computers, data historian and mining applications, and software environments for development, maintenance and management of real-time applications. In keeping with the principle of single-point data acquisition, data acquired by the qualified safety platform is supplied to the non-safety HSI to complete a seamless view of the plant, and likewise the non-safety control system provides selected data to the qualified Safety Console to support certain functions needed to achieve cold shutdown. As individual system upgrades and problem solutions are identified and phased into the plant over time, their designs opportunistically leverage this shared infrastructure to achieve plantwide integrated solutions that can be built and maintained more cheaply than point solutions. Fieldbus device network cabling and control infrastructure is installed to allow maximum use of smart instrumentation capabilities for field-based control. Wireless technology is used to enable equipment monitoring functions – such as vibration monitoring -- while minimizing the amount of new cabling required and reducing rounds-based data collection. Other labor intensive activities such as instrument calibration and hot fire watch are streamlined by wireless support of data logging, field data communications and video surveillance.

[6] Following are classes of Benefits:
EAI – Minimization of engineering, acquisition and installation costs
O&M – Operations & maintenance cost reduction
AI – Availability improvement
TR – Threat reduction – including heading off obsolescence, challenges to availability, etc.
QUAL – Qualitative improvements in staff performance quality and productivity.

Table 3-2 (continued)
Features of a Fully Modernized Nuclear Power Plant
Expanded from Table 2-1 of EPRI 1008122

Feature Class (Benefit Classes[7])	Description
Architectural Homogeneity **(EAI, O&M)**	Utility management promotes designs, installations, and operational and maintenance practices that are homogeneous within each plant and across similar plants in its fleet. Common engineering designs and their costs are shared across similar units, as are common maintenance practices that enable sharing of technical resources and their training.
Commercial and Standards Based Systems **(EAI, O&M)**	Procurement policy for non-safety applications gives preference to standards-based interfaces and commercially available platforms having experience history in multiple industries. A preferred vendor platform may thus be selected while preserving the option to migrate to a competing platform in the future. Instruments, devices, communication infrastructure and application software have strict requirements for standardized interfaces, so that replacement parts and upgrades can be selected from multiple vendors, while considering both price and best-of-breed characteristics. A single qualified digital platform is selected for safety applications.
Cyber Security **(O&M, QUAL, TR)**	Configurable policies establish which roles and physical locations are privileged to perform the various classes of control, monitoring and management functions. These policies are enforced automatically as each individual or trusted client system is authenticated. Standards-based encryption protocols adopted from the network and process control industries are employed to take advantage of their extensive experience histories and exposure to thousands of varied potential threats over time. Legacy field devices incapable of supporting standard protocols are isolated by gateways that ensure validity of incoming requests. Interfaces between plant corporate networks are secured to facilitate upward flows of useful business information to corporate shared resources, while blocking downward requests or commands that might increase risk to the plant.
Architectural simplification **(EAI, O&M, AI)**	By incorporating technology such as multifunction smart instruments, bus-based communications and direct digital I/O, the number of I&C interfaces and rack-mounted devices is reduced by a factor of 3-4 compared with legacy analog or like-for-like digital replacement architectures. Legacy discrete function devices are eliminated, and strict adherence to single point acquisition and addressability of data eliminates any need for field signal splitting. The value of this simplification is realized in reduced I&C maintenance costs and staffing requirements, as well as minimized engineering, acquisition and installation costs.

[7] Following are classes of Benefits:
EAI – Minimization of engineering, acquisition and installation costs
O&M – Operations & maintenance cost reduction
AI – Availability improvement
TR – Threat reduction – including heading off obsolescence, challenges to availability, etc.
QUAL – Qualitative improvements in staff performance quality and productivity.

Table 3-2 (continued)
Features of a Fully Modernized Nuclear Power Plant
Expanded from Table 2-1 of EPRI 1008122

Feature Class (Benefit Classes[8])	Description
Exploitation of Smart Instrumentation **(EAI, O&M)**	Diagnostic and test functions previously performed manually by operators, or by host computers or PLCs, are deployed to smart instrumentation and intelligent actuators, where they can be executed locally with minimal effect on network bandwidth or time delays. These capabilities support a shift from outage testing to on-line testability, with corresponding reductions in labor costs and outage time. For example, smart valve positioners can passively collect and diagnose valve trace data during normal movement, or alternatively can incrementally stroke stationary valves to confirm performance within specifications. Such automatic operations increase component reliability while decreasing maintenance staff time. Backup control algorithms are deployed to certain other smart instruments, reducing the need for redundant PLCs, simplifying I&C architecture and reducing costs.
Streamlined plant organization **(O&M)**	On-line data acquisition, processing and display allows consolidation of specialized repetitive tasks and skills into more productive activities, allowing a more compact maintenance organization with fewer fragmented tasks. For example, smart instruments with self-calibration features substantially reduce manual calibration of individual instruments and loops. Network auto-discovery of livelist device addresses, configurations and states, provides a very detailed view of actual plant conditions and, used in conjunction with downloads to handheld computers, facilitates the time-consuming process of in-field equipment verification. Specialized skills are considered corporate resources to be shared among plants as appropriate. Recruiting concerns are eased, as the streamlined organization needs more workers with flexibility and up-to-date general technical skills, and fewer hard-to-find specialists dedicated to legacy equipment. Organizational structure and interfaces are simplified, as improved information flow and analysis capabilities enable individuals to deal with broader sets of problems. Diagnostic emphasis shifts from component level to system level.
Core technical team **(EAI)**	A small core technical team is staffed internally and trained to expert level with the infrastructure and its application to monitoring, control and work management applications. This team provides technical leadership to ensure a consistent and cost-effective approach to deploying and maintaining integrated solutions. This approach provides an alternative to purchasing turnkey or proprietary point solutions that are more expensive to integrate and maintain.

[8] Following are classes of Benefits:
EAI – Minimization of engineering, acquisition and installation costs
O&M – Operations & maintenance cost reduction
AI – Availability improvement
TR – Threat reduction – including heading off obsolescence, challenges to availability, etc.
QUAL – Qualitative improvements in staff performance quality and productivity.

3.3 Benefits of O&M Staff Reduction – Plant Task Analysis

Summary

Reference 11 describes the results of "Task Evaluations for Nuclear Plant I&C Modernization Strategies" which take a ground-up, plant-centric focus on cost savings realizable through O&M staff reductions, one of the benefit areas discussed in section 2.1. A very comprehensive study at one operating PWR ("Plant A") covering 99% of the plant tasks provides the basis for most of the conclusions, while a more limited study at a second operating PWR ("Plant B") provides some independent confirmation of the Plant A results. Each study centered around extensive interviews with plant management and senior technical staff.

Appendix A describes the task analysis methodology and scope, an expanded summary of two selected areas (i.e., I&C Maintenance and Plant Operators), and aggregate results.

Based on the discussion of changes to current work processes facilitated by modern integrated technologies, representatives from each plant estimated the staffing changes they believe are reasonably achievable. These estimates included staff reductions that can be realized by elimination of tasks or inefficiencies in current work processes, as well as certain staff additions needed to support the new technology. All proposed reductions are based on real people conducting actual tasks. Task efficiency improvements that resulted in less than a full person reduction were not included in the aggregate staff reduction results. At a department level, the staff reductions ranged from 0% to 70%, with the largest reductions coming from I&C Maintenance, Management Support Services and Operations. Table 3-3 summarizes the aggregate results for Plant A.

Table 3-3
Plant A Current Staff and Potential Modernization Reductions
(Identical to Table A-3 in appendix A)

Plant Organization		Current Staff	Reductions by Org	% of Current	% Total Reduction
Maintenance					
	I&C Maintenance	29	20	69%	19%
	Electrical Maintenance	8	2	25%	2%
	Mechanical Maintenance	25	6	24%	6%
	Facility Maintenance	57	6	11%	6%
	Maintenance Management	12	3	25%	3%
Operations					
	Plant Operators	66	13	20%	12%
	Off-Shift Operations	8	1	13%	1%
	Operations Support	14	1	7%	1%
Engineering					
	Systems Engineering	30	8	27%	7%
	Design Engineering	25	0	0%	0%
	Engineering Technical Services	23	4	17%	4%
Scheduling		15	3	20%	3%
Training					
	Technical Instructors Support	17	5	29%	5%
	Operations Instructors	15	3	20%	3%
	Managers	5	1	20%	1%
Radiation Protection		35	11	31%	10%
Chemistry		24	1	4%	1%
Management Support Systems		48	25	52%	23%
Corporate Shared Services (New)			-13		
Security		131	8	6%	7%
		587	108	18%	100%

Aggressive modernization could reduce the staffing by more than 18% overall at Plant A, resulting in yearly savings of about $11,000,000 based upon the utility's burdened cost structure. Although O&M staff reduction is only a part of potential gains, its substantial recurring savings provides very strong motivation to consider investing aggressively in modernization.

Table 3-3 shows a large reduction of on-site Management Support Systems, which includes functions of finance, licensing, emergency planning, quality assurance, nuclear assessment, document services, and information technology (IT). However, most of these on-site gains are achieved by shifting to centralized corporate services that would be shared across 5 units at 4 sites – so that the reduced headcount on-site must be balanced by an increase of 13 people at corporate level.

Advanced HSI and other capabilities allow reduction of one main control room operator and one auxiliary operator per shift.

Otherwise, inspecting the “% of current” columns shows that the most dramatic changes are in areas such as I&C Maintenance, Radiation Protection, and Systems Engineering.

On an absolute basis, the biggest potential for staff savings is in the maintenance area, partly because it has the second-highest number of current staff. The efficiency of Radiation Protection activities can be improved by used of modern fully digital system with automated calibration, surveillance testing and improved user interface. System Engineering activities in troubleshooting, corrective action and equipment monitoring can be made more efficicient by relying upon self-diagnostics, higher reliability equipment, and remote monitoring & trending capabilities, respectively.

Although security is the area of largest headcount and would seem to especially benefit from video surveillance, current regulatory rules prescribe a level of staffing commensurate with the conservative assumption that security systems fail or are knocked out. Therefore realizable savings in security staff are quite modest.

Although the scope of the Plant B study is more limited, covering tasks performed by only 39% of plant staff, the study provides a validation that the Plant A results are generally applicable. Plant B managers estimated an aggregate staff reduction of 28%. The higher percentage at Plant B is probably related to the its higher current staffing level (i.e., headcount of 804 compared with 587 at Plant A) and to the smaller sampling of plant tasks and bias toward evaluating tasks that may be most affected by plant modernization. It can reasonably concluded that Plant A numbers are conservative and meaningful beyond that one plant.

Relation to Aggressive Vision and Architecture Example

To completely achieve this high level of annual savings, plants must undertake dramatic functional changes similar to the aggressive vision of section 3.2. Key aspects of the integrated modernization vision that yield these savings include:

- A wireless information technology infrastructure that supports continuous on-line condition monitoring for electrical and mechanical process components, as well as wireless video surveillance, voice communications and mobile computing.
- A Main Control Room (MCR) with expanded functionality to allow elimination of local operations and local control rooms. This MCR Human Systems Interface is based largely on soft video controls, electronic procedures and procedure based automation, and paperless records and work order management.
- Plant-wide standardization on two common digital platforms (one for safety and one for non-safety).
- Integration of stand-alone I&C systems to minimize equipment.

- All new digital technology is “plug-and-play”, “run-to-failure”, “self-diagnosing” and highly standardized to minimize training and support burden. In essence, any new technology installed to reduce current labor, adds minimal labor burden itself. With few exceptions, everything is testable with the plant on-line. The methods used to test all new systems and functions are validated as an integral part of the design process.

Reference 11 ties potential staff reductions to features such as these, and section A.3 of this report has provided some examples of this linkage. While point solutions – typical of current digital upgrade practice – can resolve immediate obsolescence and reliability concerns with current analog systems, it is clear that over the long term, integrated solutions offer much more potential for significant O&M cost reduction For example, the total staff reduction attributed to point solutions at Plant A is only 14 people, whereas the total staff reduction attributed to integrated solutions is 92 people.

As one might expect, a substantial investment must be made to achieve this high level of integrated plant modernization. Sections 5 and 6 of this report introduce some issues of investment cost, as well as planned research activities to quantify and improve cost-benefit for strategic modernization in nuclear plants.

3.4 Example of a Conceptual Architecture

The endpoint vision of section 3.2 describes the functionality and behavior needed to achieve the potential benefits of O&M staff reductions identified in section 3.3. A practical question is whether this functionality can be provided within acceptable technical risk and project cost.

Section 2.4 discussed the Utility Working Group and several challenging tenets including:

- To seek licensable integrated solutions that apply across both non-safety and safety systems, thus providing major plant-wide benefits
- To not be constrained by established licensing practice and/or architectural approaches.
- To define implementable solutions rather than general guidance alone.

To acknowledge these goals and to provide confidence in the technical feasibility of achieving the type of functionality identified in earlier sections, this section briefly describes an architectural direction whose implementation can largely be based upon commercial products. Such an example can provide a starting point for discussions with vendors to determine their capabilities and practices, and for cost analysis and cost-benefit analysis.

The architectural direction is not novel, but rather has roots in several programs such as: Evolutionary Advanced Light Water Reactor (ALWR) programs such as CE System 80+; EdF/Framatome's experience with N4 plants, which pioneered the use of sit-down, digital compact operator stations; EdF directions and contributions toward a European Power Reactor (EPR); and Passive ALWR Plant designs such as AP 1000. It is also closely related to one alternative proposed for the 30-day modernization effort [10], as mentioned in Section 2.3. The motivating ideas include:

- A monolithic operator interface based upon a commercial distributed control system provides the primary means for controlling the entire plant, including both safety and non-safety systems under both normal and emergency conditions.
- Supplementary safety systems – both digital and conventional – provide high integrity control and indication that satisfy regulatory requirements, even following a postulated complete failure of the entire primary operator interface and/or its underlying control system.
- Single point data acquisition simplifies architecture and system maintenance.
- Secure information exchange is provided for data flows from sensors and mobile staff entries up to plant and corporate level application software. These applications support day-to-day actions and long-term business decisions within the plant and company.

Primary reliance on a full-function distributed control system leads to increased maintenance and management productivity through capabilities such as those described in the task analysis (Section 3.3 and Appendix A). Similarly, operations productivity gains allow shift operations staff reductions through features such as: functional view of plant state, with drill-downs to detail; system level actuation; and computerized procedures, including direct linkage to control actions to provide procedure based automation.

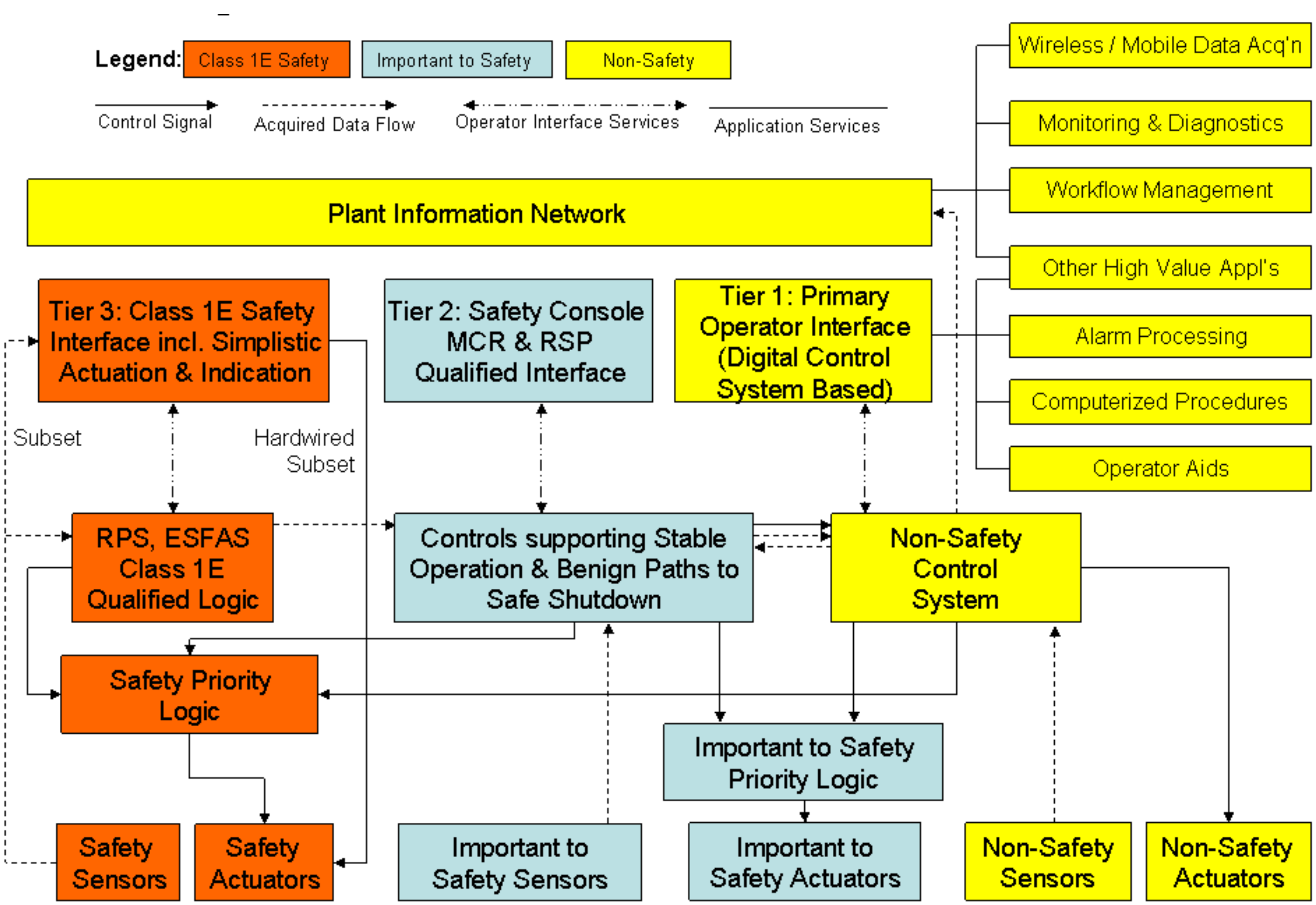

Figure 3-1
Functional Architecture

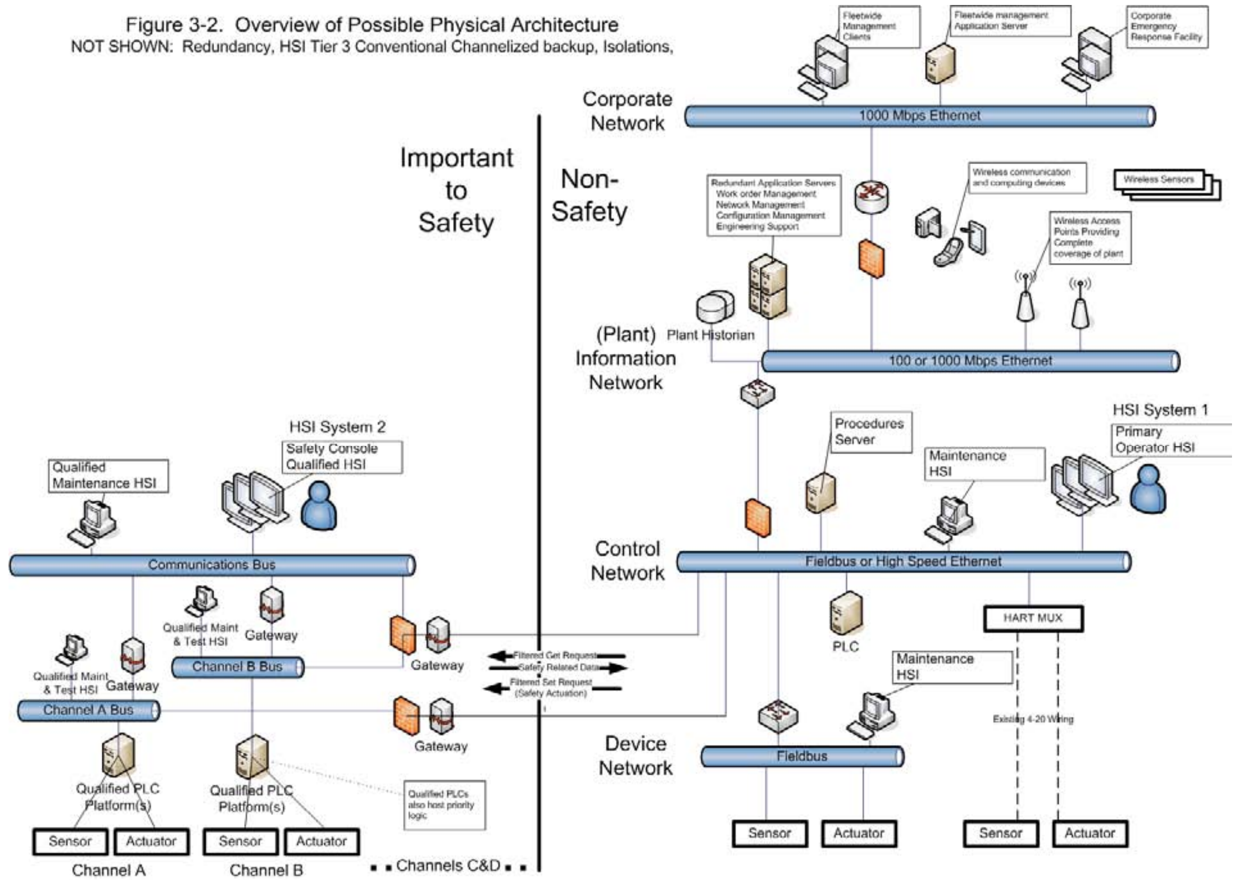

Figure 3-2
Overview of Possible Physical Architecture

Figure 3-1 presents a functional view of a 3-Tier architecture concept. Note that each tier involves not only the operator's Human System Interface (HSI), but also underlying control logic & automation, and field instruments.

Tier 1 employs a commercial non-safety distributed control system -- together with underlying services such as data acquisition and storage as well as complementary applications such as valve stroke analysis and sophisticated alarm processing -- as the lynchpin for the entire architecture. Under all normal and emergency operating conditions, Tier 1 provides the primary operator interface covering the full range of functions.

Tier 2 relies upon a diverse qualified platform to provide backup following a major failure of Tier 1, such as a failure of the Primary Operator Interface or a major element of its underlying non-safety distributed control system. Tier 2 includes qualified displays that can be used to perform the complete range of safety functions, as well as additional functions needed to achieve a stable state or safe shutdown, without relying upon undesirable success paths[9]. Tier 2 HSI is deployed both in the Main Control Room (MCR) in a separate location as a Remote Shutdown Panel (RSP).

Tier 3 provides Class 1E capabilities to provide indication and control for critical safety functions. Tier 3 is channelized with independence and single failure compliance equivalent to that of the reactor protection system. A qualified display (which may be of the same type as Tier 2) provides safety indication using data passed by the channel network, or alternatively by using a signal split off upstream (for one channel only) which bypasses the network and logic to satisfy simplicity requirements of BTP-19 Point 4 [14]. Similarly, manual actuation signals are initiated by conventional devices such as hardwired pushbuttons. Note that the underlying control logic of Tier 3 may be deployed to the same type of qualified platform used in Tier 2.

In the main control room, the HSIs from Tiers 2 and 3 are placed close together to form the operator's safety console.

By exchanging data between the Tiers, single point data acquisition can be achieved with only one exception, the above-mentioned splitting of a few safety signals to provide the simplistic indication required by BTP-19 Point 4. Single point data acquisition drastically simplifies I&C designs compared to traditional approaches that measure the same variable using both safety and non-safety sensors, or that split individual signals. Note also that non-realtime monitoring and workflow applications can be applied across all three tiers, ensuring that O&M efficiency gains can be achieved for the whole range of systems, both non-safety and safety.

For two reasons, it is necessary that Tier 2 be classified Important to Safety rather than Class 1E, and thus that graded licensing precedents be established for operating plants. First, to deal with both safety and non-safety data while adhering to single point data acquisition, Tier 2 may rely upon a communications network that does not meet all the IEEE 384 independence criteria.

---

[9] Tier 2 provides capabilities for achieving safe shutdown without using undesirable success paths that involve atmospheric venting, containment flooding or contamination, safety injection or reactor coolant pump trip. To avoid these in favor of "benign" success paths requires incorporation of non-safety data, and Tier 2 control signals must be passed to both safety and non-safety actuators.

Second, to smooth the operators' transition to Tier 2 following a failure of Tier 1, and to avoid additional training burdens, Tier 2 must include some functions of intermediate complexity – such as scaled-down alarm management. Such functions would be difficult to implement within restrictive Class 1E requirements. The licensing rationale for this intermediate level of quality is to be based upon the diversity and redundancy provided by the non-safety Tier 1, and by elements of the Class 1E Tier 3 system that provide safety critical functions.

Achieving monolithic control requires the non-safety distributed control system to send control signals that actuate safety components. This requires a departure from current practice that restricts data flows to a unidirectional flow only from safety to non-safety systems. The Class 1E Priority logic must detect any conflicts between such commands originating from Tier 1 and qualified requests originating from Tier 2 or Tier 3, and must resolve any conflicts in favor of the senior Tier. This safety qualified Priority Logic can be hosted in several ways: one approach is to use a separate class 1E component, and another (common practice in non-nuclear safety applications) is to host it on a safety qualified platform that inherently defaults to a safe state.

Although the NRC has acknowledged similar approaches[10], there is no direct and complete precedent for operating plants in the US, so it represents a licensing challenge to be evaluated further in 2006.[11]

For consistency and completeness, the diagram shows a intermediate class of sensors and actuators categorized as Important to Safety. Because such actuators might receive commands from either Tier 1 or Tier 2, conflicting commands would need to be mediated by priority logic qualified to the senior level (Important to Safety). [Note that in some designs, all sensors and actuators may be classified as either safety or non-safety and acquired/activated by the qualified platform or non-safety distributed control system respectively.]

From a control room-centric point of view, Table 3-4 clarifies important attributes of these three Tiers. Except for the roles of the commercial distributed control and qualified platform, Table 3-4 and Figure 3-1 do not imply a particular physical implementation.

[10] In reference 13, the NRC reviewed the general concept of multi-channel workstations (i.e., Tier 2) as a credited backup to a non-safety primary interface, and "finds the conceptual approach ... may be used for guidance ...., but the evaluation of each forthcoming design remains a PSAI. [Plant Specific Application Issue]"

[11] An alternative position would be to compromise the monolithic interface concept and instead require all manual safety actuations to be performed from Tiers 2 or 3 HSIs, eliminating the need to send commands from the Tier 1 system to safety systems. This would still allow the non-safety distributed control system to provide a monolithic display of the entire plant state, but would require the operator to use only qualified HSIs to actuate safety function under all conditions.

Table 3-4
Summary of Layered Operator Interfaces and Platforms

	HSI Tier 1	HSI Tier 2	HSI Tier 3
Purpose	Principal operator interface at all times – normal, upset and accident. Monolithic. Use commercial software to achieve productivity improvements for both operations and maintenance.	Provide diverse backup with respect to Tier 1. Achieve stable state or safe shutdown in orderly fashion, following failure of Tier 1.	Regulatory compliance, including BTP-19 diversity requirements, minimum inventory simplicity, and credited manual actions. Provide diverse manual backup to Tiers 1 and 2.
Safety Classification[12]	Non-Safety	Important to Safety (relies on some non-safety data)	Safety Critical (Class 1E)
Location(s)	Main Control Room (MCR)	MCR Safety Console; Remote Shutdown Panel (activated via manual Master Transfer Switch)	MCR Safety Console
Mechanism for Control	Soft	Soft	Hard (Conventional)
Mechanism for Indication	General purpose computer workstation	Qualified Display Panels (VDU)	Qualified Display Panels (VDU)
Overview Display	Large format, viewable throughout MCR. Highly processed informa- tion to determine plant state.	Qualified Overview Display (small format) Processes information, primarily from safety data.	None.
Underlying Platform	Non-safety, full function distributed control system.	Qualified computing platform, with bidirectional way gateway to Tier 1. Control conflicts mediated by priority logic.	Conventional hardware for actuation. Qualified HSI computing platform for display.
Data Inputs	All safety & non-safety	Safety and some non-safety inputs required to achieve purpose	Safety.
When Used	Always, if available	Following global failure of HSI Tier 1.	Diverse complement to digital systems (1 & 2)
System Scope	All safety and non-safety controls. Subsumes current local control panels.	Safety & non-safety control for accident management, and to reach benign cold shutdown.	RPS, ESF, TT manual actuation, RG 1.97 , and credited manual actions.
Functionality	Full, including computerized procedures with direct linkage to control functions.	Subset of System 1: Reduced alarm & data No computerized procedures Simplified navigation.	Train level (simplistic) actuation and indication for RG 1.97 Type A (2 channels) and BTP-19 Point 4 (1 channel).
Control level	System & component level	System & component level	System level.
Complexity supported	Utilize full flexibility of distributed control system, allied communication systems and applications	Intermediate complexity within scope of qualified platform.	Extremely simple. Similar to conventional RPS or ESFAS initiation.

[12] Similar to ALWR licensing precedents and IEC 880.

Figure 3-2 goes one step further by presenting a conceptual example of a physical architecture for Tiers 1 and 2. Note that Tier 3 is not included in this diagram. Some points to note include:

- Data acquired by the distributed control system – both real-time and archival – is freely available at the plant and corporate levels, thus allowing both plant-wide and fleet-wide equipment monitoring.
- Wireless access points linked to the plant information network support mobile data transfer by roving maintenance personnel, as well as wireless data acquisition for condition based maintenance that minimizes the expense of new cabling.
- For instruments already having 4-20 ma cabling in place, HART technology offers a way to introduce smart digital instruments without the need for pulling new cable. For new instruments (e.g., digital replacements for pneumatics), fieldbus communications minimizes the need for new cabling.
- To maintain independence among the 4 safety channels (denoted A, B, C, D), field instruments and associated local controllers communicate across channel-level busses. The Tier 2 qualified displays (sometimes characterized as multi-channel) pull together data from all four channels to present a system-wide view, which also allows selectable information and control action for the individual channels.
- Vertical flow of information over networks introduces security risks that must be dealt with in the architecture. Firewalls and gateways are generally needed between vertical levels, with the exception of control and device networks that may be assumed to be physically secure. A defense-in-depth approach to security must be balanced against requirements for system performance and user accessibility.
- The Primary Operator HSI is pictured as tied to the control network. In practice, some vendors further partition this level, separating out a "Terminal Bus" (i.e., dedicated HSI network) because the more variable bandwidth demands of the HSI and its supporting applications have potential to compromise network performance and reliability.
- The safety system may broadcast data to the non-safety system, but doing so indiscriminately can unnecessarily add traffic to the control networks. The non-safety system can send two types of messages[13] to the safety side, each of which are strictly filtered by a firewall: "Get-requests" can be submitted for reply during dedicated periods of the safety systems clock cycle – this is a common technique used in non-nuclear safety applications to avoid unnecessary broadcast burden. Similarly, "Set-requests" can be used to change state – i.e., perform actuations – for safety related components; such requests are further analyzed by the priority logic for consistency with other instructions to ensure that any conflicts lead to a safe resolution.

[13] Note that this approach presumes that the safety qualified platform exposes services of this type.

While Figure 3-2 is very general and lacking much detail needed for a design, examples such as this can be presented to vendors to explore their own approaches to implementing mixed safety/non-safety systems. Because achieving a cost-effective implementation depends upon not only leveraging established commercial products but also allowing multiple choices of vendors, architecture descriptions should provide enough flexibility to adapt commercial practices, without compromising essential requirements. [Note that specialized safety solutions such as Tier 3 will probably lie outside the purview of a commercial process control vendor.]

3.5 Summary of Aggressive Endpoint Vision

Sections 3.2, 3.3 and 3.4 have a summarized high level endpoint visions of required functionality, benefits of O&M cost reduction, and one architectural approach to realize the benefits of an aggressive approach to plant-wide modernization.

During 2006, the architectural approach will be developed in more detail, accompanied by an evaluation of licensing status and risk, and compared with alternative approaches that have different mixes of financial investment, licensing and technical risk, and overall benefit. In addition, the high-level aggressive endpoint vision will be fleshed out and documented to a level of detail similar to that specified in the worksheets of Appendix B.

4
CAPITAL-CONSTRAINED VISION

Section 3 has described an example of a comprehensive vision for full modernization of control room, operations, maintenance, and associated administrative procedures. Such aggressive modernization was seen to yield substantial benefits, but at the cost of a very large investment to realize them.

In reality, business conditions and financing resources vary from utility to utility, and irrespective of compelling net benefits, some plants are constrained to live within strict constraints on available investment capital. Common practice under these conditions has been to evaluate and plan each digital upgrade project in isolation as a point solution that may have little in common technically with its neighboring point solutions. Under these limitations, long-term planning decisions may also need to be compromised against management flexibility to make opportunistic decisions and priority adjustments to focus on threats. However, by having a limited plant-wide vision in mind to coordinate decisions for a sequence of projects, the utility can plan and acquire systems in a more coordinated fashion to achieve some benefits of integrated modernization. Principles include:

- Plan and justify a full set of projects over a 5-8 year time horizon, rather than project-by-project.
- Seek I&C architectural homogeneity, by limiting the number of platform vendors, ideally to a single safety platform and a single standards-based non-safety distributed control system vendor.
- Identify and prioritize threats to plant availability and profitability over the 5-8 year time horizon. Eliminate single points of failure for critical systems.
- Preserve the overall layout of the existing main control room, while dealing with obsolescence issues by replacing control board instruments with more easily maintained video display units (VDUs).
- Invest in shared infrastructure for plant-wide wired and wireless communications, as well as application servers that can host functionality needed by system solutions.
- Leverage these investments to introduce or expand on-line condition-based maintenance, including automated trending and analysis.
- Use HART communications to introduce smart instruments while minimizing the need to replace existing cabling.
- Staff a small core technical team to prepare bid specifications, perform technical review and vendor management. Stabilize this team’s staff to provide continuity across multiple projects.

In general, these steps will help lead to a consistent and cost-effective approach to deploying and maintaining solutions that facilitate interoperability and cost-effective maintainability. Additionally, the following specific types of savings should be achieved:

- The inventory of spare parts types and numbers is reduced.
- Reduced cost of individual applications as infrastructure is shared over multiple applications.
- Procurement, integration, and installation of replacement systems is simplified.
- As a side benefit, some headcount reduction of maintenance staff may be achieved through the benefits of on-line asset management, less dilution of technical expertise, fewer components and component types, and reduction of calibration tasks no longer needed for smart instruments.

Table 4-1 describes an overall picture of a gradually-reached endpoint vision applicable to a capital-constrained business environment.

Table 4-1
High Level Features for a Capital-Constrained Endpoint Vision Structure expanded from Table 2-1 of EPRI 1008122

Feature Class (Benefit Classes[14])	Description
Business Goals and Scope of Change	The goal is to extend the profitable life of an individual plant, while keeping capital investment within strict constraints. Emphasis is on avoiding challenges to plant availability due to aging and obsolescence. Costs are justified and optimized individually for each project, but shared infrastructure costs may be amortized across multiple committed projects. System and component changes are incremental and focused on priority issues that most threaten plant profitability over a rolling 5-year time horizon. Overall I&C system architecture and organizational structure are generally preserved. As a side benefit, labor intensive tasks will be streamlined or eliminated to reduce O&M costs where possible, but there is minimal change to plant processes.
Operator Workstations **(QUAL, EAI)**	The traditional control board continues to serve as the main control room operator interface. When necessitated by obsolescence, groups of individual meters and controls are replaced by Video Display Units (VDUs) that emulate their behavior. Alarms remain as separate annunciator windows, although conventional light boxes may be replaced by VDU emulation. General purpose workstations independently provide supplementary operator aids to support specific functions such as monitoring real-time streaming video from fixed cameras and/or portable wireless cameras. On a separate computer workstation, operators are provided with complete view-only access to maintenance and management displays.
Maintenance and Management Workstations **(QUAL, O&M)**	Outside the control room, computer workstations support a variety of plant maintenance, workflow management and performance monitoring functions. Access to a maintenance & management session depends upon authentication of an appropriate user role and location.
Large Displays **(QUAL)**	Although no plant overview display is provided, a large display panel, visible to the entire crew, may be activated to display the current session of any of the supplementary operator workstations or maintenance & management workstations.

[14] Following are classes of Benefits:
EAI – Minimization of engineering, acquisition and installation costs
O&M – Operations & maintenance cost reduction
AI – Availability improvement
TR – Threat reduction – including heading off obsolescence, challenges to availability, etc.
QUAL – Qualitative improvements in staff performance quality and productivity.

Table 4-1 (continued)
High Level Features for a Capital-Constrained Endpoint Vision
Structure expanded from Table 2-1 of EPRI 1008122

Feature Class (Benefit Classes[15])	Description
Limited Soft Control Capability (QUAL)	Point solutions[16] may provide soft controls through the operator VDUs described above. Soft controls may be non-safety or safety related, depending upon the application. Non-safety digital controllers and VDUs are diverse from safety controllers and VDUs. The non-safety controllers and VDUs provide diverse backup manual controls and supporting indications to satisfy requirements for coping with safety system common mode failure. Sufficient conventional controls are maintained to meet the requirements of Regulatory Guide 1.62, BTP19 Point 4, and FSAR-credited manual operator actions.
Automation **(O&M)**	Automation is not a principal goal, but it is introduced where short term O&M cost reductions can be achieved with minimal investment.
Computer-Based Procedures **(QUAL, TR)**	Computerization of procedures is not an explicit goal, although it may be introduced as a supplementary operator aid. Any such procedures only display information and do not interface directly to control functions.
Intelligent Processing **(QUAL, TR)**	Upgraded instruments, components or systems provide high level diagnostics to the operators as supplementary features, but procedures continue to point to traditional lower-level information available through main control board.
Failure & Availability Management **(TR, EAI, AI)**	Upgrades to digital systems take advantage of hot swap capabilities to improve system availability by allowing component replacement and/or upgrade without interrupting operations. Single points of failure are eliminated for critical systems. Requirements for system availability and reliability, scheduled maintenance intervals and downtime, and failover recover time, are tailored to the economic and safety risks of the particular function.
On-Line Condition-Based Maintenance and Asset Management **(O&M, TR, AI)**	Condition-based maintenance (CBM) is introduced for monitoring and trending mechanical components that are principal contributors to corrective maintenance costs or to plant unavailability. Normally, portable or installed data acquisition devices are employed in rounds-based data gathering and upload to an historian application for offline analysis. Wireless monitoring of equipment is used to acquire data from components in hazardous areas, and in specific applications where high O&M costs justify the infrastructure investment.

[15] Following are classes of Benefits:
EAI – Minimization of engineering, acquisition and installation costs
O&M – Operations & maintenance cost reduction
AI – Availability improvement
TR – Threat reduction – including heading off obsolescence, challenges to availability, etc.
QUAL – Qualitative improvements in staff performance quality and productivity.
[16] Point solutions are stand-alone digital upgrades focused on individual systems, and they do not depend upon extensive shared infrastructure. In contrast, integrated solutions share a common infrastructure and architectural approach across many plant applications, and across the task, process, equipment and organizational views of the problem.

Table 4-1 (continued)
High Level Features for a Capital-Constrained Endpoint Vision
Structure expanded from Table 2-1 of EPRI 1008122

Feature Class (Benefit Classes[17])	Description
Fleet-Wide Monitoring and Workflow Management **(O&M)**	Not an explicit goal. Monitoring and diagnostic services continue to be performed within individual plant organizations, consistent with the goal of preserving the existing organizational structure.
Shared Infrastructure to Support Integrated Solutions **(EAI, O&M)**	Shared infrastructure is limited to computing facilities and software applications that can be used by point solutions or easily integrated with them. Minimal infrastructure includes a data historian; dual redundant servers to support real-time monitoring, trending and display of selected real-time data for equipment diagnostics. A basic wireless infrastructure -- including area wireless access points linked to the plant information network, and supporting network management – can be leveraged for equipment monitoring applications. Plantwide bus-based communication infrastructure at the device level is not included. As digital point solutions are phased in, existing home-run cabling and/or remote I/O are used to support HART-compatible replacement instruments. Plantwide shared network communication infrastructure at the control or HSI levels is not included. Point solutions drive individual VDUs on the Main Control Panel, and point solutions interface critical control signals via point-to-point communications with appropriate signal distribution and channel isolation devices. To the degree these point solutions are mutually independent, the need for backup systems to cope with large scale control or HSI failures is reduced or eliminated.
Architectural Homogeneity **(EAI, O&M)**	Point solution procurement strives to limit the number of vendors and types of spare parts, subject to the constraint of optimizing total discounted acquisition costs over the set of committed projects. Ideally, a single non-safety distributed control system would be used as the foundation for non-safety applications.
Commercial and Standards Based Systems **(EAI, O&M)**	Procurement policy for non-safety applications gives preference to standards-based interfaces and commercially available platforms, subject to the constraint of optimizing total discounted acquisition costs over the set of committed projects. A single qualified digital platform is selected for safety applications.
Cyber Security **(O&M, QUAL, TR)**	Point solutions support standards-based encryption and authentication protocols. Legacy field devices incapable of supporting standard protocols are isolated by gateways that ensure validity of incoming requests. Interfaces between plant corporate networks are secured to facilitate upward flows of useful business information to corporate shared resources, while blocking downward requests or commands that might increase risk to the plant.

[17] Following are classes of Benefits:
EAI – Minimization of engineering, acquisition and installation costs
O&M – Operations & maintenance cost reduction
AI – Availability improvement
TR – Threat reduction – including heading off obsolescence, challenges to availability, etc.
QUAL – Qualitative improvements in staff performance quality and productivity.

Table 4-1 (continued)
High Level Features for a Capital-Constrained Endpoint Vision
Structure expanded from Table 2-1 of EPRI 1008122

Feature Class **(Benefit Classes[18])**	**Description**
Architectural Simplification **(EAI, O&M)**	Goal is to minimize the impact to current architecture and to preserve its internal system interfaces. Generally, cabinet interfaces are preserved unless a vendor-supplied turnkey solution is available that consolidates cabinets.
Exploitation of Smart Instrumentation **(EAI, O&M)**	Self-diagnostic functions provided by individual smart instruments are exploited within the constraints of low bandwidth HART communications. Fieldbus-based products are limited to replacement of pneumatic controls and other situations where minimization of new wiring is a significant issue.
Streamlined Plant Organization **(O&M)**	Through elimination or automation of individual tasks, the reduction of individual staff positions is a side benefit. Fundamental restructuring of organization or processes is avoided as disruptive.
Core Technical Team **(EAI)**	A small core technical team is staffed internally to prepare bid specifications, perform technical review and vendor management. The team seeks a consistent and cost-effective approach to deploying and maintaining solutions that facilitate interoperability and cost-effective maintainability.

[18] Following are classes of Benefits:
EAI – Minimization of engineering, acquisition and installation costs
O&M – Operations & maintenance cost reduction
AI – Availability improvement
TR – Threat reduction – including heading off obsolescence, challenges to availability, etc.
QUAL – Qualitative improvements in staff performance quality and productivity.

5 COST ISSUES FOR AN AGGRESSIVE APPROACH

5.1 Cost implications of 30-day Modernization Study

Section 2.3 alluded to EPRI's project on "Full Plant I&C Modernization in 30 Days or less" [10]. One of its architecture alternatives helps motivate our architecture example in section 3.4, and this study also provides a rare source of cost data that is applicable to a nuclear plant modernization of extensive scope.

Reference 10 provided two cost estimates. An intense single-outage modernization is estimated to cost about $94M and take 30 – 60 days. Alternatively, a more cautious utility could instead break the modernization into up to 6 phases: 1) rod control, 2) small systems (e.g., turbine control), 3) BOP, 4) NSSS, 5) safety systems, and finally wrapping up with6) plant network and computer, main control room and simulator upgrades. Such a phased approach can be argued to reduce project risk, but at the cost of generating inefficiencies due to temporary states and rework, so the estimate rises to about $122M.

The rest of this section confines itself to the phased approach as being more realistic in view of the conservative financial environment faced today by almost all utilities.

Table 5-1
Comparison of Selected Scope Items

	Aggressive Vision (Section 3.2, 3.4)	30-Day Modernization (Reference 10)
Architecture concept	3 Tiers: non-safety primary, important-to-safety shutdown, and safety critical simplistic actuations & indications	Similar approach. DCS based primary, with safety console
Smart Instruments	HART and/or Fieldbus	Not included
Plant computer functions	Included	Included
Safety / Non-Safety Interface	Bi-directional	Bi-directional or unidirectional (no distinction in cost estimates)
Plant Wireless Infrastructure	Plant wide	Not included
Workflow applications and integration	Extensive software applications and integration with procedures	Not included
Control room and HSI	See section 3.2 and Tables 3-2 and 3-4	Similar conceptual basis with Compact workstations. Similar display hierarchy and objects and navigation features.
Procedures	Procedures based automation	Computerized procedures
New automation logic	Selected functions	None
Alarms	Directly linked to procedures. High level processing of hierarchical alarms.	Procedures link not included. Otherwise similar scope.
Fleet-wide monitoring capability	Included	Not considered

Table 5-2
Cost Breakdown For 30-Day Modernization Study – Phased Case
(condensed from Table 6-2 of Reference 10)

	Phase 1 Rod Control	Phase 2 Small Systems	Phase 3 BOP	Phase 4 NSSS	Phase 5 Safety & Diverse Act.	Phase 6 Multiple[19]	All Phases Total	% Total
I&C Vendor Scope	$4,494,000	$1,244,000	$13,532,000	$13,480,000	$26,604,000	$25,002,000	$84,356,000	69%
Utility Scope	$778,000	$338,000	$2,014,000	$2,007,000	$4,509,000	$4,481,000	$14,127,000	12%
Project Management								
Schedule&Planning								
Work Packages								
Engineering								
Operations								
Information Tech.								
Simulator Work								
Licensing								
T&L								
Installation Scope	$763,000	$3,185,000	$1,803,000	$1,799,000	$3,390,000	$2,727,000	$13,667,000	11%
Elec Commodities								
Installation Support								
Structural Work								
Indirect Support								
Construction Tests								
Disposal								
Other								

[19] Plant network and computer; main control room; simulator

Table 5-2 (continued)
Cost Breakdown For 30-Day Modernization Study – Phased Case
(condensed from Table 6-2 of Reference 10)

	Phase 1 Rod Control	Phase 2 Small Systems	Phase 3 BOP	Phase 4 NSSS	Phase 5 Safety & Diverse Act.	Phase 6 Multiple[20]	All Phases Total	% Total
Architect-Engineer Scope	$387,600	$387,600	$1,550,400	$1,550,400	$1,938,000	$3,702,600	$9,516,600	8%
Checklists								
Install Instructions								
Test Requirements								
Procedure Change								
Drawings								
Equip Data Sheets								
Installation Support								
50.59 Evaluation								
Calculations								
Phase totals	$6,422,600	$5,154,600	$18,899,400	$18,836,400	$36,441,000	$35,912,600	$121,666,600	100%
% by Phase	5%	4%	16%	15%	30%	30%	100%	

[20] Plant network and computer; main control room; simulator

Table 5-1 compares some scope elements between the two projects. Evidently, the scope of the 30-Day Modernization project is narrower in several important areas – not surprisingly so since its primary focus was rapid introduction, rather than optimizing O&M cost reduction. To accommodate this scope difference, we arbitrarily boost the cost estimate upward by about 10%, to a nominal estimate of $135M.

Table 5-2 is taken directly from the more detailed data of Reference 10's Table 6-2. From this table, one can make some observations:

- Non-Transparency of Vendor Cost. Although the I&C vendor cost represents about the lion's share – about 69% -- of the total estimate, it is presented as a single line item with no hint of its breakdown. Such a lack of transparency is thought to be typical of vendor estimates. It is difficult to look for improvements without additional detail that can point to dominant areas, opportunities for synergy, and inefficiencies.
- Highly specialized systems. Together, rod control and safety systems represent about 35% of the total cost. We speculate that this number will be hard to reduce significantly, because it cannot easily be delegated to a wider selection of competitive process control suppliers.
- Utility internal effort represents only about 12%. The visions of both sections 3 and 4 each suggest the importance for a utility to sustain a centralized technical group that can drive a series of such projects from both a management and technical viewpoint. To do this, the utility scope would expected to increase both on an absolute and a percentage basis, and its effort would have to enable significant cost reductions from vendor contributions. For example, the internal team may drive design and integration associated with highly specialized nuclear issues such as diverse safety function, thereby opening more possibilities for non-nuclear I&C vendors to cover the more conventional elements.
- Differential returns from operations and maintenance changes. Note that Phase 6 --which represents 30% of changes -- is largely operational in nature, e.g., including main control room and simulator upgrade. Note also that the aggressive vision scope of section 3 proposes extensive functional improvements to the Human Systems Interface (HSI), raising this percentage still higher. For a major modernization, operational changes are best introduced in final phase(s) to minimize the need for operations staff to accommodate heterogeneities or transition periods in their operations environment. Thus, to some degree operational changes can be separated out functionally from maintenance and infrastructure improvements. Likewise, differential benefits associated with control room HSI improvements – which we see from Table 3-3 are about 15-20% -- should be evaluated in view of associated investments to ensure that their rate of return is comparable with other elements of the investment. Such a more granular cost-benefit assessment is a subject for further study in 2006.

Returning to the aggregate numbers, we can estimate some internal rate of return numbers by making some simplifying assumptions:

- Assume that all materials, services and O&M costs escalate at the same inflation rate. Then we can deal with current dollars only and compute a meaningful real internal rate of return.
- Assume a $135M investment for our vision, based upon the Reference 10 phased approach plus 10% for its increased scope.
- Assume that the investment is spread evenly over N years of phase-in time
- Conservatively assume that no O&M benefits are achieved until the phase-in time is complete. Then we begin to realize $11,000,000 per year O&M Staff Reduction benefits, in 2005 dollars.

With these assumptions, Table 5-3 computes internal real rate of return (i.e., essentially Return on Investment, or ROI) for the combination of two key parameters: the phase-in time, and the remaining plant lifetime.

Table 5-3
Real Return on Investment (ROI) for a Full Plant Modernization
[Given Above Stated Assumptions]

	Remaining Plant Lifetime (yrs)						
Phase-In Time (yrs)	10	15	20	25	30	35	40
1	-5.8%	1.8%	4.8%	6.2%	7.0%	7.4%	7.7%
2	-7.9%	0.8%	4.1%	5.7%	6.6%	7.0%	7.3%
3	-10.3%	-0.3%	3.5%	5.2%	6.1%	6.7%	7.0%
4		-1.4%	2.8%	4.7%	5.7%	6.3%	6.7%
5		-2.7%	2.1%	4.2%	5.3%	6.0%	6.3%
6		-4.0%	1.3%	3.7%	4.9%	5.6%	6.0%
7			0.6%	3.2%	4.5%	5.3%	5.8%
8			-0.2%	2.7%	4.2%	5.0%	5.5%
9				2.2%	3.8%	4.7%	5.2%
10				1.6%	3.4%	4.4%	5.0%
11				1.1%	3.0%	4.1%	4.7%
12					2.6%	3.8%	4.5%

Note that for remaining plant lifetimes of less than 20 years, the return (based on O&M cost reduction alone) on a modernization investment is either negative or distinctly unattractive. A plant life extension that stretches remaining plant lifetime to at least 30 – 40 years is needed to realize a reasonable ROI for extensive modernization on this basis.

It is fair to say that these returns are interesting, but probably not impressive enough to by themselves justify a major risky project investment in the plant. To become competitive with competing projects, the plan and business case for extensive integrated modernization need to be improved by:

- Analyzing Full Scope of benefits. Table 5-3 considers only benefits due to O&M staff reduction. We need to quantify threat reduction benefits associated with equipment reliability, and plant availability.
- Reducing Investment cost. A per-plant investment of $135M is simply beyond the resources of many utilities, irrespective of more detailed arguments. A capital-constrained vision (section 4) is one approach, but it leaves many potential gains on the table. A standardized solution for architecture offers one possibility, but at the cost of reduced choices for individual utilities. Restructuring of modernization projects may help with investment cost limitation, for example by modifying the role split between utility and vendor(s).
- Optimizing scope of modernization. An objective approach should be taken to partitioning the project and considering cost-benefit on a more granular level. It may be that some technically attractive elements of a “full” plant modernization are simply not competitive in terms of their concrete benefits, and may need to be jettisoned or deferred to raise the overall return of a smaller project. Note that this approach is to some degree in conflict with the notion of a standardized solution mentioned above.
- Considering Non-quantifiable benefits. If benefits are strategic and compelling enough (e.g., reduced risk to public safety through improved operator behavior, or reduced equipment failure), they may trump the high barriers imposed by purely economic considerations.

5.2 Applicability of Fossil Plant Cost Experiences

During 2006, one focus of this project will be to formally acquire and document project scope, cost and organizational approach of full-plant I&C modernization in non-nuclear environments, to include fossil plants especially but also other industry applications (e.g., petrochemical) that deal with both non-safety and safety functions.

Direct comparison of fossil and nuclear modernization efforts is always tenuous, but as a minimum it must consider scale of project (e.g., I/O point count), functional scope (e.g., complexity of HSI and underlying applications), operational and maintenance concepts and degree of heterogeneity and integration challenges. Of course, the nuclear industry has unique safety and regulatory requirements (e.g., BTP-19 [14]) and highly specialized systems (e.g., rod control), but most monitoring and control functions are not fundamentally unique and in nuclear plants may be overdesigned (e.g., with unnecessary redundancy) and burdened with over-documentation and inflexibility in design process.

Typical anecdotal information was obtained from Électricité de France (EdF) for full modernization of two 250 MWe plants. Complete modernization of each plant with new instrumentation, control room and distributed control system architecture cost about $5.8M for each plant (61 million French francs total for two plants), divided on a per plant basis as follows:

- Principal I&C Vendor $3.4M (58%)
- Control Room Vendor $0.4M (7%)
- EdF Scope (Engineering, Planning, Vendor Support) $2.0M (35%)

The I&C vendor took the lead role as integrator for these efforts, with the utility providing direct support for their team, as well as requirements specifications and review. Although soft controls were included in the scope, no advanced features (e.g., procedures automation, alarm processing, etc.) were designed into the operator interface. These numbers are representative of anecdotal information from domestic fossil power plants, where full plant modernizations are thought to involve investments in the $5-$10M range, with the upper end at $14M for a large plant that involved some non-I&C work such as control valve replacement.

At this point, such anecdotal broad-brush numbers should not be taken too literally because they are not accompanied by descriptions of scale and scope. The important point to notice is that integrated nuclear plant modernization is a factor of 10 to 15 higher than that of fossil plants. This ratio is quite eye-catching and cannot be accounted for only by special safety and specialized issues -- which according to Table 5-1 represent only about 35% of the total. Even assuming that this 35% is largely immutable, we need to seek changes in architecture, implementation and project management that shave the remaining factor significantly.

For example, if we can remove 35% from the budget (equivalent to reducing the ratio of 10-15 to only about 6 – 9, i.e., about halving the non-specialized parts) Internal rates of return (ROIs) improve to those shown in Table 5-4. Achieving a 35% cost reduction is both hypothetical and challenging, but the huge premium demanded by nuclear compared to fossil plant modernization motivates the search for opportunities to do so.

Table 5-4
Revised Return on Investment (ROI) when Required Investment is hypothetically reduced by 35% to $88M

	Remaining Plant Lifetime (yrs)						
Phase-In Time (yrs)	10	15	20	25	30	35	40
1	2.5%	8.6%	10.7%	11.6%	12.1%	12.3%	12.4%
2	0.1%	7.2%	9.7%	10.8%	11.3%	11.5%	11.7%
3	-2.6%	5.9%	8.7%	10.0%	10.5%	10.9%	11.0%
4	-5.5%	4.5%	7.8%	9.2%	9.9%	10.2%	10.4%
5	-8.9%	3.1%	6.9%	8.5%	9.3%	9.7%	9.9%
6		1.6%	6.0%	7.8%	8.7%	9.2%	9.4%
7		0.0%	5.1%	7.2%	8.2%	8.7%	9.0%
8		-1.7%	4.2%	6.6%	7.7%	8.2%	8.6%
9			3.3	5.9%	7.2%	7.8%	8.2%
10			2.3	5.3%	6.7%	7.4%	7.8%
11			1.2	4.7%	6.2%	7.0%	7.5%
12				4.0%	5.7%	6.6%	7.1%

6 CONCLUSIONS AND DIRECTIONS

This report has reviewed the advantages and principles of integrated I&C modernization. To support modernization planning, it has identified a 3-pronged approach based upon a task analysis, a functional (external) endpoint vision, and an architectural concept (internal vision). High level examples of these three elements are presented for a aggressive approach that involves significant capital investment and process change, and a brief endpoint vision is also summarized for capital-constrained business environments.

Task analyses performed for operating PWR plants have identified operations and maintenance (O&M) activities for which improvements to I&C, information technology (IT) and/or work processes can lead to significant staff reductions and thus O&M cost savings. The task analysis demonstrates that a comprehensive I&C modernization can significantly improve efficiency across the full range of operations, maintenance and administrative activities. For one plant, these efficiency gains lead to more than an 18% reduction in O&M staff, representing over $11,000,000 in recurring yearly savings.

However, fully achieving such significant benefits in O&M cost reduction implies a substantial investment in data acquisition and communications infrastructure, as well as willingness to adapt process and organization to fully exploit the potential. Even applying forward-looking, cost-conscious I&C architectures based on a commercial distributed control system in conjunction with a safety qualified platform result in investment costs of over $120M per plant, assuming phased introduction of capabilities. For plants with remaining lifetimes of 30 years or more, such investments generate positive rates of return even ignoring other benefits such as improved equipment reliability and plant availability. However, the returns are not compelling enough to make a strong business case given the tight environments of most utilities.

Thus, the critical issues do not revolve around technical feasibility or around the potential for O&M cost savings – we already have confidence in these areas. Rather, the most significant barriers are reducing investment cost to a manageable level, and selecting a project scope that yields an optimal – and competitive – project rate of return. These themes will be the principal drivers for project activities planned for 2006:

<u>Broader coverage of benefits</u>. We need to establish direct and quantitative linkages between I&C modernization elements and others benefits, primarily arising from equipment reliability and ultimately plant availability. EPRI’s ongoing program in Risk Informed Asset Management provides a framework and starting point.

Investment Cost Reduction will be approached from three specific directions, but common to each is the need to gain a more explicit understanding of why costs are so high under current practice, e.g., to better understand the 70% of costs currently associated with the vendor. The three directions are:

- Architecture and Project based. Both traditional (e.g., NSSS vendors) and non-traditional (i.e., non-nuclear commercial) I&C suppliers will be engaged to obtain a better understanding of how their products can be best integrated and deployed to support all or part of the endpoint vision. Architectural concepts such as the example described in Section 3.4 will be expanded to a level of detail sufficient to help guide vendors and utilities toward cost-effective solutions.
- Organizationally Based. We will work with proactive utilities to determine whether and how a dedicated utility team can assume responsibility – and project risk – for technical and management organizations traditionally performed externally, with the goal of lowering overall costs.
- Non-nuclear experiences. We need a clearer and more quantitative understanding of why fossil and other non-nuclear plant modernizations incur less than 10% of nuclear costs, which nuclear plant activities (e.g., regulatory-driven functions) are immutable for the nuclear industry, and which elements can be recast more cheaply in view of non-nuclear practices.

Granular cost-benefit analysis to support utility-specific decisions for improving investment rate of return. Central to this is a model that clearly and explicitly relates specific technical capabilities with specific quantifiable benefits, and identifies dependencies between specific capabilities (e.g., features) and the underlying infrastructure elements that indirectly contribute to multiple benefits. Cost-benefit analysis must allow some granularity for plant-specific decisions that prioritize applications areas (e.g., shift operations vs. equipment maintenance) according to potential returns. In addition, it must be recognized that some benefits are intangible (e.g., safety and staff retention) and must also be incorporated into the decisions.

Refinement of Endpoint Vision Example(s). In support of all these activities is further elaboration of the example visions such as those in Sections 3 and 4, to a level of detail similar to the worksheets of Appendix B. Together with expanded examples of architectural concepts, these can provide templates and starting points for utilities engaged in plant-specific planning and implementation.

7 REFERENCES

1 EPRI 1009617, I&C Modernization for Plant-wide and Fleet-wide Cost Reduction, Technical Update December 2004

2 R. May, K. Scarola & R. Torok, Integrated Approach to I&C Strategic Modernization, Presented at ANS Winter Meeting, Washington DC, November 2005

3 EPRI TR-104963, Instrumentation and Control Upgrade Evaluation Methodology, Vol. 1: Manual, Vol. 2: Workbook, July 1996

4 EPRI TR-1002835, Guideline for Performing Defense-in-Depth and Diversity Assessments for Digital I&C Upgrades: Applying Risk-Informed and Deterministic Methods," December 2004 (In press)

5 EPRI 1003566 Generic Qualification of the Westinghouse Common Qualified PLC-Based Platform for Safety-Related Applications – Revision to EPRI TR-110045, July 2002

6 EPRI TR-114017, Qualification of Siemens Power Corporation TELEPERM XS Safety System: Compliance with EPRI TR-107330 "Generic Requirements Specification for Qualifying a Commercially Available PLC for Safety-Related Applications in Nuclear Power Plants", December 1999

7 EPRI 1008122, R. Fink, D. Hill and J. O'Hara, "Human Factors Guidance for Control Room and Digital Human-System Interface Design and Modification: Guidelines for Planning, Specification, Design, Licensing, Implementation, Training, and Maintenance," November 2004

8 EPRI 1003569, Nuclear Power Plant Control Room Modernization Planning, October 2002

9 EPRI 1010042, R. Fink, D. Hill and J. O'Hara, "Human Factors Guidance for Control Room and Digital Human-System Interface Design and Modification: Guidelines for Planning, Specification, Design, Licensing, Implementation, Training, and Maintenance: Revision to EPRI 1008122," December 2005

10. EPRI 1009611, J. Hasenkopf, S. Kawanago & W. Kurth, Full-Plant Modernization in 30 Days or Less: A Feasibility Study, December 2004

11 EPRI 1011934, K. Scarola, Task Evaluations for Nuclear Plant I&C Modernization **S**trategies, November 2005.

12 J. Ruether, L. Link, D. Owen & K. Bently, " Simplification Strategy for Nuclear Power Plant Digital Upgrades: The Prairie Island Scoping Study," 13th Annual Joint ISA POWID/EPRI Controls & Instrumentation Conference, June 2003

13 US NRC TAC No. MB0780, June 22, 2001, "Safety Evaluation for the Closeout of Several of the Common Qualified Platform Category 1 Open Items Related to Reports CENPD-396-P, Revision 1, and CE-CES-195, Revision 1"

14 Branch Technical Position HICB-19, Guidance for Evaluation of Defense-in-Depth and Diversity in Digital Computer-Based Instrumentation and Control Systems, excerpted from Chapter 7-A of: USNRC Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants (NUREG-0800)

A
OVERVIEW OF PLANT TASK ANALYSES

[Contents of this appendix have been deleted from this abridged version and can be found in the full report EPRI 1010041.]

B
EXTENDED WORKSHEETS FOR CONSTRUCTING MODERNIZATION ENDPOINT VISION

[Contents of this appendix have been deleted from this abridged version and can be found in the full report EPRI 1010041.]

C
QUALITATIVE MODEL FOR MODERNIZATION INVESTMENT DECISIONS

[Contents of this appendix have been deleted from this abridged version and can be found in the full report EPRI 1010041.]

Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case-by-case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

The Electric Power Research Institute (EPRI)

The Electric Power Research Institute (EPRI), with major locations in Palo Alto, California, and Charlotte, North Carolina, was established in 1973 as an independent, nonprofit center for public interest energy and environmental research. EPRI brings together members, participants, the Institute's scientists and engineers, and other leading experts to work collaboratively on solutions to the challenges of electric power. These solutions span nearly every area of electricity generation, delivery, and use, including health, safety, and environment. EPRI's members represent over 90% of the electricity generated in the United States. International participation represents nearly 15% of EPRI's total research, development, and demonstration program.

Together...Shaping the Future of Electricity

Program:
Nuclear Power

1013482

Printed on recycled paper in the United States of America

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1395 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com