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

Interim Guideline

Technical Report

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Interim Report, December 2005

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PRODUCT DESCRIPTION

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 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. EPRI anticipates that this guideline on I&C modernization strategies will help utilities make the most informed decisions possible as they move forward.

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

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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.

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:

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

- **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.

<u>Shared infrastructure</u> 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.

<u>Architectural homogeneity</u> 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.

<u>Simplification</u>. 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]

<u>Restructured plant organization</u> 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.

<u>Cyber security</u> 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.

<u>Smart instrumentation</u> 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	A large Plant Overview Display, visible to the entire operator crew,

[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.

Feature Class (Benefit Classes[3])	**Description**
(QUAL, O&M)	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.
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.

Feature Class (Benefit Classes[3])	**Description**
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.
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

Feature Class (Benefit Classes[3])	Description
	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.
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.

Feature Class (Benefit Classes[3])	**Description**
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.
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.

Feature Class (Benefit Classes[3])	**Description**
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.
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.

Feature Class (Benefit Classes[3])	Description
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.

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.

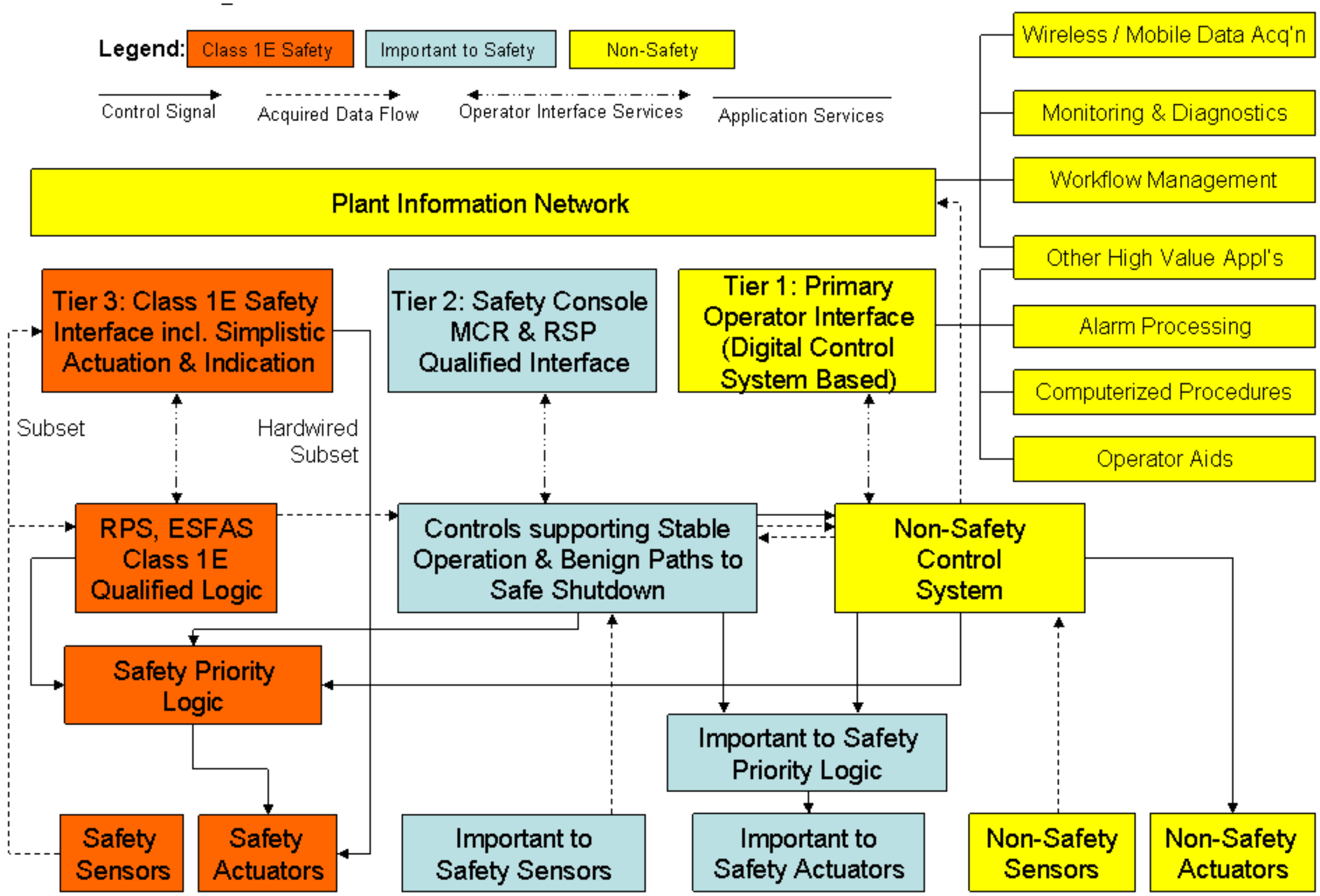

Figure 3-1
Functional Architecture

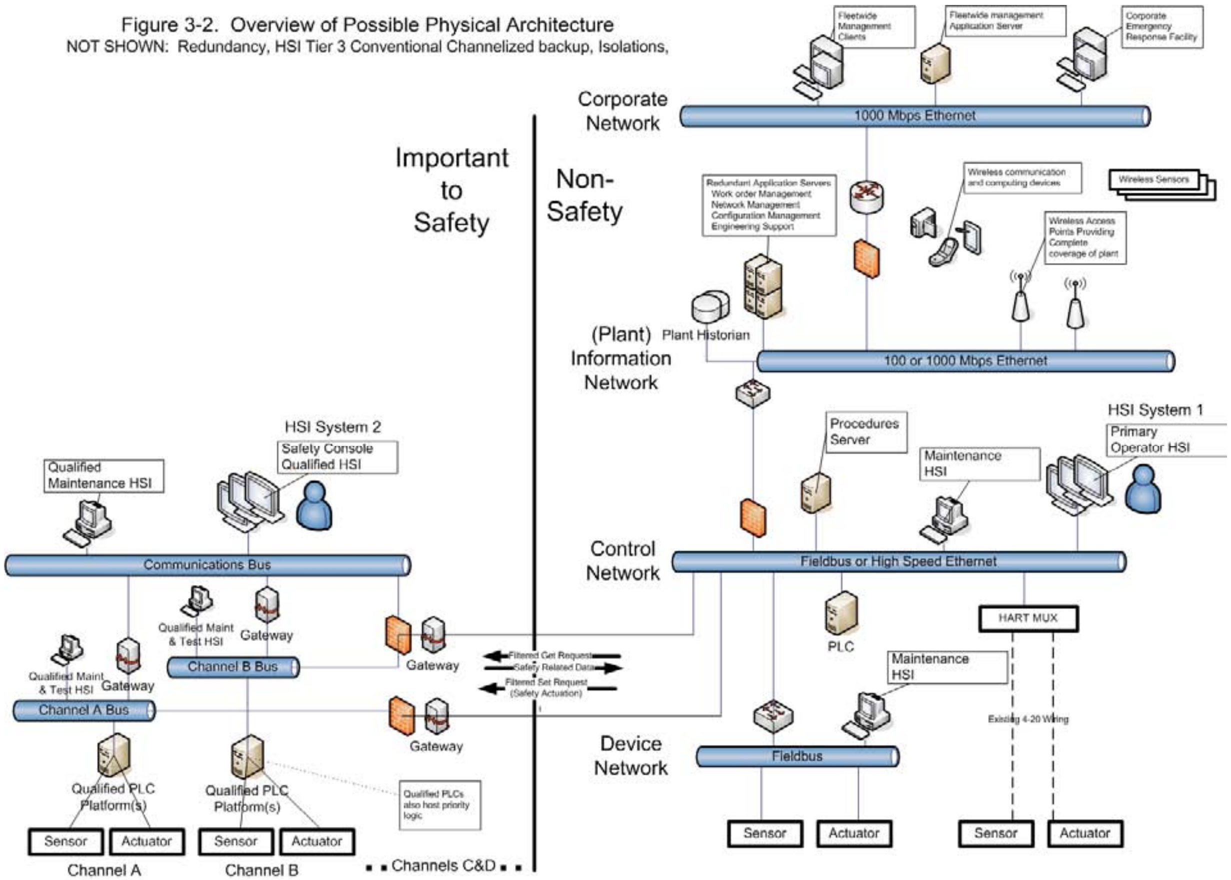

Figure 3-2
Overview of Possible Physical Architecture

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[4]. 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.

[4] 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[5], 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.[6]

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.

[5] 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]"

[6] 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[7]	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.

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

	HSI Tier 1	HSI Tier 2	HSI Tier 3
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.

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[8] 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.

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.

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

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. In addition, 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[9])	**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 & 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.
Limited Soft	Point solutions[10] may provide soft controls through the operator VDUs

[9] 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.

Feature Class (Benefit Classes[9])	Description
Control Capability (QUAL)	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.

[10] 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.

Feature Class (Benefit Classes[9])	**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.

Feature Class (Benefit Classes[9])	**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.

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[11]	**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								

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

	Phase 1 Rod Control	Phase 2 Small Systems	Phase 3 BOP	Phase 4 NSSS	Phase 5 Safety & Diverse Act.	Phase 6 Multiple[11]	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%	

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]

Phase-In Time (yrs)	Remaining Plant Lifetime (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

Phase-In Time (yrs)	Remaining Plant Lifetime (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.

<u>Investment Cost Reduction</u> 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.

<u>Granular cost-benefit analysis</u> 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.

<u>Refinement of Endpoint Vision Example(s)</u>. 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.

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A
OVERVIEW OF PLANT TASK ANALYSES

A.1 Methodology

Reference 6 describes the results of “Task Evaluations for Nuclear Plant I&C Modernization Strategies,” a key element of the broader project that addresses I&C Integrated Strategies for Plant-Wide and Fleet-Wide Cost reduction. The task analysis takes a ground-up, plant-centric focus on cost savings realizable through O&M staff reduction, one of the main areas of modernization benefits discussed in section 2.1. The task analysis studies identify potential opportunities at two operating single-unit Pressurized Water Reactor Plants:

- The 900-MW Plant A is part of a 5-unit nuclear fleet at 4 sites. It had a complement of 587 staff on-site at the time of the study.
- The 1126-MW Plant B had 804 staff on-site at the time of the study.

The Plant A study was highly inclusive and covered the work activities of 99% of the plant staff. Because of limited availability of its plant staff for interviews, the Plant B study analyzed only a subset of plant tasks that engage about 39% of its staff. For this reason, we focus on the comprehensive picture presented by the Plant A study, and in section A.6 we summarily compare the aggregate results from the two plants as a qualitative validation of the Plant A study.

Both studies were led and documented by an industry consultant having extensive PWR and I&C experience. Over 47 interviews, ranging from 1-4 hours in length, were conducted with management and senior technical personnel. Information and insight gathered from these interviews are collected in a document [11] that:

- Lists current tasks and specific staff roles within each plant departments
- Estimates the Full Time Equivalent (FTE) staff numbers currently associated with each major task.
- Identifies potential solutions – whether technical, procedural or otherwise – having the potential to increase productivity and thereby reduce staff headcount. Only realizable reductions of at least one FTE within a department were credited as cost savings, and they were classified according to the type of solution (i.e., point[12] vs. integrated) and the plant area (i.e., Human Systems Interface, Controls, Sensors, Facilities, Components or Broad).

[12] 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.

- Rolls up yearly cost savings to the level of the department level and plant level. The resulting aggregate annual saving is one contributor to the benefits of a comprehensive plant modernization, the scope of which is similar[13] to the endpoint vision discussed in section 3.2.

Of course, technical solutions do not appear out of thin air from requirements, so the project participants drew upon their previous knowledge of current I&C or IT technology, an emerging functional vision (section 3.2), and specific examples of architectural approaches (section 3.4) for realizing the vision. Thus, Sections 3.2, 3.3 and 3.4 are all evolving together. These sections are works in progress and will become more complete, detailed and mutually consistent over time.

A.2 Characterization of Organization and Tasks

Table A-1 shows the fine granularity sought in the interviews and in the associated staff reductions. Details of two tasks areas are included in Section A.4 to illustrate the nature of the interviews and of the process by which conclusions were reached.

Table A-1
Plant Organization and Tasks[14] considered in Task Analysis Interviews

Plant Organization		Task (or staff role)
Maintenance		
	I&C Maintenance	
		Transmitter Calibration
		Loop Calibration
		SSPS Actuation Logic & Master Relay Test
		Pneumatic Controls
		CRDM Coil Traces
		Radiation Monitoring
		Fire Detection System
		Radwaste and Water Treatment Controls
	Electrical Maintenance	
		6.9KV Breakers
		480V Breakers
		6.9kv Swing Bus Breaker
		480VAX Motor Control Center Breakers
		Protective Relays
		Auxiliary Control Relays
		Ammeters and Voltmeters in MCR
		Batteries for Station Busses
		Batteries for Emergency Lighting
		Motors

[13] The aggressive endpoint vision of section 3.2 does not explicitly list all point solutions, or all the task applications of the integrated solutions.
[14] In some cases, rather than describing small individual tasks, the interviewees focused on staff roles that covered multiple tasks.

Table A-1 (continued)
Plant Organization and Tasks considered in Task Analysis Interviews

	Mechanical Maintenance	
		Vibration Data Collection
		Valve Mechanical Maintenance
		Hot Work Fire Watch
	Facility Maintenance	
	Maintenance Management	
Operations		
	Plant Operators	
		MCR Staffing - Normal Operations
		MCR Staffing - Emergency Operations
		Auxiliary Operator - Regular Rounds
		Auxiliary Operator - Fire Brigade
		Auxiliary Operator - Emergency Communicator
		Auxiliary Operator - Radwaste Control Room
		Auxiliary Operator - Safe Shutdown Field Operator
		Equipment Clearances
		Channel checks & Other Daily MCR Logs
		Component Control Testing
		SSPS Slave Relay Testing
		ESF Response Time
		Diesel Loading
		Remote Shutdown
		MOV In-Service Testing
		Reactor Trip Breakers
		Roving Fire Watch
	Off-Shift Operations	
		Management & Specialists
		Water Treatment Operator
		SROs approving work clearances
	Operations Support	
		Fire Protection Surveillance Testing
		Safe Shutdown Analysis
		Procedure writers
		Data Management
		Administrative Assistant
		Contingency Training Instructor
		Unit Evaluator
		Human Performance Lead
Engineering		
	Systems Engineering	
		Mechanical Engineers
		Electrical Engineers
		I&C Engineers
		Managers
		Rod Control System Preventative Testing

Table A-1 (continued)
Plant Organization and Tasks considered in Task Analysis Interviews

		Vibration Monitoring
		MOV Performance Testing
		AOV Performance Testing
	Design Engineering	
	Engineering Technical Services	Specialized Programs:
		Flow Accelerated Corrosions
		Valve Programs
		Component Performance Monitoring
		Leak Rate
		Vibration
		Thermography, Lube Oil, Snubbers, Welding etc
Scheduling		
		On-Line Scheduling
		Outage Scheduling
Training		
		Technical Instructors & Support
		Operations Instructors
		Managers
Radiation Protection		
		Shift Technicians (assigned to operations teams)
		ALARA Planning
		ALARA Job Coverage
		Radwaste
		Support
		Spent Fuel
Chemistry		
		Shift Technicians
		Technicians
		Specialists
Management Support Systems		
	Finance	
	Licensing	
	Emergency Planning	
	Quality Assurance	
	Nuclear Assessment	
	Document Services	
	Information Technology	
	Manager	
Security		
		Improved central surveillance
		Other technological capabilities improving security (without staff reduction)
Corporate Shared Services (New)		Assume shared across 4 plants (5 units)

A.3 Types of Technical Solutions Considered

As described in Reference 11, the task analysis considered a range of technical solutions – both integrated and point solutions – as well as efficiency improvements due to pure process improvement independent of technology. The following classification is used:

- I&C Point Solution is a stand-alone I&C system upgrade that is specified, procured and installed as a separate project. Examples include radiation monitoring or fire protection systems. Different I&C Point Solutions do not share a common computing platform, communications infrastructure or HSI. Typically, each point solution preserves the existing interfaces of the current architecture, which may be quite complex as a legacy of the original analog technology.
- I&C Integrated Solution deploys a common digital control system as the foundation of all applications. The digital control system facilitates integration among peer systems, single point data acquisition, and consistent HSI behavior. Elimination of loop calibrations is a good example of a task area addressed primarily by I&C Integrated Solutions. The tighter integration enables single point data acquisition[15] so that numerous single-function analog modules can be replaced by software functions hosted on more flexible digital devices.
- IT Point Solution typically refers to software used for offline functions such as analysis, workflow management, etc. Computer application software to improve the ALARA planning efficiency is a good example of an IT Point Solution.
- IT Integrated Wireless Infrastructure provides a flexible communications medium that supports on-line monitoring instrumentation, mobile computing, and video and voice applications. On-line condition monitoring for mechanical plant components can be enabled by an IT Integrated Wireless Infrastructure without the need for pulling extensive new cabling.
- I&C/IT Integrated Solutions combine features from the I&C Integrated Solution and the IT Integrated Wireless Infrastructure. For example, most staff reductions in Operations fall into this category, since efficiency gains not only require advanced HSI (a feature of I&C Integrated Solutions) but also the paperless work environment and workflow automation enabled by an Integrated Wireless Infrastructure.
- Process or Organizational Improvement can bring about efficiency gains simply by improving day-to-day work methods, without the need for new technology. Examples include greater reliance on thermography, and organization improvements that consolidate plant-by-plant management of specialized technical programs as part of shared corporate services.

[15] Single point data acquisition is the simple principle that each measured input can and should be collected only once, and made available by broadcast or addressing for other purposes. It contrasts with analog style signal splitting, and with distinct (not just redundant) instruments measuring for safety and non-safety use.

A.4 Examples / Excerpts from Analysis of Plant A

Sections A.1 – A.3 describe a fairly general process for task analysis process. To make it more concrete, we provide examples from two selected areas:

- I&C Maintenance: Tasks can be clearly separated and gains associated with specific new functions.
- Plant Operators: Gains are achieved by leveraging I&C/IT Integrated Solutions that raise individual productivity, thus allowing operators to take on more duties such as pulling local control functions into the MCR.

See reference 11 for more detailed discussions of these particular areas, as well as the full set of task areas and departments described in Table A-1.

A.4.1 I&C Maintenance

Because I&C maintenance is the area most directly associated with I&C improvements, it is not surprising to see a 70% staff reduction through modernization. The general approach to reduce staff associated with I&C maintenance is to move to a purely digital control system for which

- Various periodic tasks can be eliminated, automated or more easily managed.
- There are fewer components and component types to be maintained.
- Individual components are more reliable, plug-and-play, and run-to-failure.

Table A-2 lists 8 categories of tasks, together with associated staff reduction benefits due to modernization changes described below. Note that some of the improvements described may require changes to the plant Technical Specifications.

Transmitter Calibration

Workload associated with calibration of transmitters can be reduced by leveraging a variety of I&C and IT capabilities.

Calibration intervals (normally once per outage) can be extended[16] significantly by continuous on-line monitoring of transmitters, including cross-channel checking, and by deploying smart transmitters with self-diagnostic features.

Manual calibration teams can be reduced from two to one person, by using Radiofrequency Identification (RFID) tags or video surveillance combined with wireless communications, to remotely perform independent verification that is normally handled by a second person in the field. The need to coordinate people at multiple field locations simultaneously can be satisfied by using wireless voice over IP to, for example, request the MCR operator to put a channel into test mode using soft video controls from an advanced operator HSI. Also, a digital control

[16] This may require regulatory approval of changes to technical specifications.

system could put channels in bypass mode (rather than trip mode), thus permitting many transmitter calibrations to be done on-line.

Result of these technical capabilities and process changes is to reduce I&C maintenance staff by one FTE.

Loop calibrations

Loop calibrations are currently performed by checking the inputs and outputs of every module in a complete instrument loop. With a plant-wide digital control system relying upon digital devices and serial communications, all loop calibrations can be eliminated with the exception of the input module, which can be quickly checked during transmitter calibration. Furthermore, loop calibrations associated with control board meters are eliminated by using video displays.

Because loop calibrations currently require about 20,000 person-hours per cycle at Plant A, their elimination would release the equivalent of 10 staff positions, one of the most significant productivity gains to be uncovered.

Protection System Actuation Logic and Master Relay Tests

Actuation Logic Tests can be eliminated with a plant-wide digital control system, which is capable of continuously checking configuration against requirements. Furthermore, components such as master relays are no longer necessary.

However, because this testing entails less than a full-time person today, it does not result in a realizable staff reduction.

Pneumatic controls

The frequent performance issues arising from pneumatic controls, which are most prevalent in heating ventilation and air-conditioning (HVAC) systems, consume more than 6000 maintenance and calibration labor hours per cycle. Replacing them with digital controls can reduce this number by 2/3. The use of smart sensors and actuators in conjunction with a fieldbus (or remote I/O) allows digital replacement with a minimum of new cabling.

Replacement of pneumatics with digital controls would allow the current staff of three people to be reduced to one.

Control Rod Drive Mechanism (CRDM) Coil Traces

At each refueling outage, technicians record coil currents to check CRDM performance. The need to collect and analyze coil traces can be eliminated by introducing a fully digital system that can adjust control settings and optimize CRDM performance dynamically. While such a change can incrementally improve maintenance efficiency, it is not large enough to credit staff reduction.

Radiation Monitoring

The existing system of 126 monitors (or which 30 fall under plant technical specifications) requires monthly surveillance by a team of two full-time I&C technicians for one shift every day. By introducing an improved digital radiation monitoring system (an example of an I&C Point Solution), its self-calibration and monitoring capabilities are expected to reduce this labor burden by 80%, for a savings of 5 FTE staff.

Fire Detection

Annually testing the 2500 fire detectors is a very labor intensive activity that consumes about 3 man-months per cycle of grappling with ladders, safety belts, and scaffolding. New digital detectors can continually self-test for degraded sensitivity, but manual tests would still be required to confirm that their smoke vents remain open and unblocked. Furthermore, a new digital fire detection system could also identify the location of a fire much more precisely, and safety issues with climbing around the plant could be alleviated.

Because less than one full time equivalent person is involved, there is no credited staff reduction.

Radwaste and Water Treatment Controls

Currently, maintenance associated with analog and relay-based Radwaste and Water Treatment Control panels consumes about 8000 person-hours per cycle.

From a technical point of view, these local control panels (and associated maintenance and manning requirements) can be completely eliminated by moving these controls into the main control panel, resulting in a staff reduction from four to two people needed to support these systems.

The key enabler of such a change is to improve productivity of the control room operators by providing them with advanced HSI and automation features, so that their workload can expand to accommodate new responsibilities such as radwaste control. This is a good example of the integrated approach to modernization, where technological improvements may have broad impact on the plant, provided process and/or organizational structure is modified to fully leverage them.

Summary for I&C Maintenance

Table A-2 summarizes staff reductions in this one area – I&C Maintenance – enabled by investment in an aggressive plant modernization. The current staff of 29 FTEs can be reduced to 9, while providing components and systems with improved reliability compared to the present.

The task-by-task discussions also show identify various smaller efficiency gains and automated checks that are not reflected in the staff reduction benefits.

Table A-2
Breakout of reductions for I&C Maintenance Tasks

Plant Organization	Task	Current Total	Staff Reduction
I&C Maintenance		29	
	Transmitter Calibration		1
	Loop Calibration		10
	SSPS Actuation Logic & Master Relay Test		0
	Pneumatic Controls		2
	CRDM Coil Traces		0
	Radiation Monitoring		5
	Fire Detection System		0
	Radwaste and Water Treatment Controls		2
		Total:	20

A.4.2 Plant Operators

Plant A currently has 66 operators organized into 5 operating crews, each having 12-14 people. The high cost of 7 X 24 shift operations makes plant operations an attractive target for cost reductions, because one fewer person per shift can result in a reduction of 5-6 FTEs. Reference 11 describes an exhaustive analysis of the duties of each crew member at Plant A and proposes how duties can be rearranged and expanded given a complete plant modernization. [The scope of these operator duties is shown in Table A-1 under the operations category.] The conclusion of this analysis is that by implementing an aggressive modernization vision:

- Main control room (MCR) operators can be reduced[17] from 5 to 4 per shift, and
- Auxiliary operators can be reduced from 5 to 4 per shift, and
- Overall operations staff can be reduced from 66 to 53 FTEs.

Furthermore, even with one fewer MCR operator, the use of advanced Human Systems Interface (HSI), diagnostics and procedure based automation features improves efficiency so much that the MCR operators (e.g., radwaste control discussed in section A.4.1) can take on responsibilities formerly associated with local control rooms. Basis for these conclusions with respect to Plant A can be found in Reference 11 and is summarized below.

[17] Note that any reduction in main control room operators would require NRC approval.

Main Control Room (MCR) Operators

Before delving into particular tasks, it is useful to review some of the features from the aggressive vision that improve operator performance:

Advanced HSIs provide a functional view of plant state, with unnecessary detail hidden until needed, at which time the operator can easily drill-down to get it. Alarms provide a substantially richer picture of plant state, because they are associated with robust process variables and equipment status rather than individual instruments, and an equipment status hierarchy (e.g., relations between component, system and plant function) allows higher level alarms to be automatically derived (using a model of the hierarchy) and displayed.

Software logic enables system level actuation using simple soft commands. Most computerized procedures are directly linked to the soft control actions through procedure based automation, for which steps can be held and released by an operator who is always kept aware and in the loop. As a result, a procedure can always be executed by a single operator, although peer checking and release by a control room supervisor can be performed through his soft screen. Furthermore, the capability also exists for a single operator to monitor and execute multiple procedures simultaneously.

Plant A's operations staff believe that about a 50% efficiency improvement can be expected in about 50% of the MCR operator's daily tasks. This productivity improvement allows the MCR operator to take on additional tasks from the Radwaste Control Room and Water Treatment Control Panel, which are to be eliminated and subsumed within the digital control system. Procedure Based Automation for these BOP systems would allow MCR operators to take on supervisory responsibility for these systems without additional manual task burden. On this basis, it is reasonable to expect that the daily MCR staffing need could be reduced by ½ person. To eliminate a complete person in the MCR the remaining 1/2 – FTE tasks for this person would need to be distributed to the STA (now expected to be a licensed operator) who will assume a partial role in normal operations. Under these assumptions, the task analysis concludes that the number of MCR operators can be reduced by one person per shift.

Auxiliary Operators

Auxiliary operators play a variety of roles during normal and emergency operations. At Plant A, principal assigned roles of the five auxiliary operators include: Regular Rounds; Fire Brigade Team Leader; Emergency Communicator; Radwaste Control Room; and Safe Shutdown Field Operator. Furthermore, the fire brigade also includes two of the other (non-licensed) auxiliary operators on an ad-hoc basis.

The Radwaste control room auxiliary operator position can be eliminated if that local control room is brought under the supervisory umbrella of MCR operators, which as discussed above, becomes possible with a soft control environment, for which advanced HSI technology greatly improves MCR operator efficiency.

Furthermore, fiber optic communications and soft HSI used in a modernized plant will allow all local controls credited for safe shutdown to be remotely controlled from the MCR. For MCR fire evacuation, Master Transfer switches initiate software disconnect of all signals originating from the MCR when control is transferred to the Auxiliary Shutdown Panel. These two modernization features would allow the Safe Shutdown ERO position to be eliminated. Eliminating this position for emergency operations and eliminating the Radwaste Control Room operator for normal operations would allow the reduction of one Auxiliary Operator from each shift.

Other Plant Operators

Additional plant operations shift staff perform a variety of specific functions, as described in reference 11 and listed in Table A-1, and the extra people (beyond 10 per shift) are needed to accommodate vacations, sick time, training etc. Reducing the entire 66-person staff by 20% (in proportion to the 2 of 10 operators per shift) leads to an overall reduction of 13 plant operators.

A.5 Aggregate Results for Plant A

Section A.4 has illustrated the process used to build up O&M staff reduction benefits by analyzing down to the level of individual roles and tasks, and re-evaluating needs under the assumption of an aggressive investment in plant modernization. Applying this process to the extensive list in Table A-1 systematically assembles potential reductions for the entire plant.

Summary results are shown in Table A-3. Based upon the task evaluation, aggressive plant modernization could reduce the staffing by over 18%, resulting in overall yearly savings of about $11M.

Note that there is a large reduction of on-site Management Support Systems, which includes functions of finance, licensing, emergency planning, quality assurance, nuclear assessment, document services, and IT. However, most of these on-site gains are achieved by shifting to centralized corporate services that are shared across 5 units at 4 sites – so that the on-site headcount of 25 FTEs must be netted against an increase of 13 people at corporate level.

As described in Section A.4, advanced HSI and other capabilities allow reduction of one main control room operator and one auxiliary operator per shift.

Table A-3
Plant A Current Staff and Potential Modernization Reductions

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 of 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%

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

On an absolute basis, the biggest potential for staff savings is in the maintenance area, not surprisingly because it has the second-highest number of current staff. The efficiency of radiation protection activities can be improved by use of a modern digital control system with automated calibration, surveillance testing and improved user interface. System Engineering activities in troubleshooting, corrective action and equipment monitoring can be streamlined due to 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.

Table A-4 categorizes these savings according to the types of solutions described in Section A.3. Evidently, staff reductions are primarily facilitated by integrated solutions, whether I&C, IT or combined in scope. Point solutions can effect a reduction of 14 FTEs (i.e., 11 plus 3), compared with 94 FTEs that can be enabled by integrated solutions.

Table A-4
Staff Reductions by Technology Category

Technology Category	Current	Reduction	% Current	% of Total Reduction
I&C Point solution		11	55%	10%
I&C Integrated solution	85	29	34%	27%
IT Point Solution	5	3	60%	3%
IT- Integrated Wireless Infrastructure	208	35	17%	32%
I&C/IT Integrated Solution	128	28	22%	26%
Process Improvement Only	7	2	29%	2%
No solution identified	134	0	0%	0%
Totals	587	108	18%	100%

Table A-5 shows the Plant Area categorization results for which the following Plant Area terms are defined:

- HSI – Human System Interface related: Instrumentation and controls used by MCR operators or operators at local panels and local control rooms.
- Controls – Equipment inside I&C System cabinets.
- Sensor – Field mounted instrumentation.
- Component – Controlled plant equipment such as pumps, valves, breakers, etc.
- Broad – Changes involving a complete cross section from HSI to plant equipment.

Table A-5
Staff Reductions by Plant Area

Plant Area	Current	Reduction	% Current	% of Total Reduction
HSI	15	3	20%	3%
Controls	13	10	77%	9%
Sensor	10	6	60%	6%
Component	173	31	18%	29%
Broad	198	49	25%	45%
Facilities	178	9	5%	8%
Totals	587	108	18%	100%

This table suggests that a large portion of staff reductions arise from modernization that affects a broad cross section of plant areas, from HSI to plant components.

A.6 Cross-Check of Results Against Plant B Task Analysis

A similar study was carried out at Plant B, using the same methodology described in section A.1. However, because of limitations on staff availability, only a subset of the plant tasks could be analyzed. The evaluation encompassed 315 of the 804 people at Plant B – thus providing about 39% coverage. This sample provides a valuable independent assessment to confirm that results from the Plant A study are applicable beyond a single plant.

Of further interest is that Plant B had previously performed its own internal staff reduction surveys:

- A general evaluation of the potential benefits of I&C modernization, which estimated a 10-20% overall staff reduction
- An internal assessment of cost reductions achievable from modernization (using a distributed control system) of six non-safety I&C systems.
- An internal assessment of cost reductions achievable from modernization (using a Common Q platform [5]) of 12 systems having safety significance.

The current study could draw on these results as a complement to new interviews and analysis. The key assumptions of a fully modernized plant were similar to those of Plant A, i.e., all digital I&C, with smart transmitters and actuators, and single point data acquisition. The specific conclusions included:

- From an operations staff of 116 people, included 6 shift crews, Plant B concluded that 1 MCR operator and 2 auxiliary operators could be eliminated from each crew, leading to a reduction of 38 people, or 33%.

- I&C Maintenance staff (both technical and administrative) can be reduced from 55 to 31 people, or 44%
- Mechanical Maintenance staff can be reduced by approximately 22%, primarily because valve maintenance is greatly improved by smart instrumentation that allows extended preventative maintenance intervals.
- Electrical maintenance can be reduced by 25% due to the doubling of maintenance intervals.

Table A-6 summarizes selected results for comparison to the Plant A study (Table A- 4). Based on the limited sample, Plant B predicts a 28% reduction in plant staff compared to Plant A's 18%. However, this may be partly because Plant B's staff is currently significantly larger[18], and partly because the sample is biased toward areas where I&C modernization offers the most promise. Nevertheless, Plant B's aggregate results are significantly higher, so it seems quite reasonable to conclude that the Plant A results are validated to be "conservative" estimates.

Table A-6
Plant B Categorization of Staff Reductions by Technology Category

	Current	Reduction	% Current	% of Total Reduction
Technology Category				
I&C Point solution	0	0	0%	0%
I&C Integrated solution	83	29	35%	33%
IT Point Solution	16	3	19%	3%
IT Integrated Wireless Infrastructure	50	11	22%	13%
I&C/IT Integrated Solution	131	45	34%	51%
Process Improvement Only	0	0	0%	0%
No solution identified	35	0	0%	0%
Totals	315	88	28%	100%

This table also backs up an important conclusion from the Plant A study -- that most staff reductions are facilitated by either integrated I&C solutions or integrated IT solutions.

A.7 Summary & Conclusions for Task Analyses

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

[18] Staffing numbers for Plant B had been increased approximately, 12% above normal levels, in preparation for an anticipated swell in retirement.

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% of the current staff, with the largest reductions coming from I&C Maintenance, Management Support Services and Operations.

While the current staffing levels at the two plants are quite different, the evaluations showed surprising similarity in the potential efficiencies anticipated and the resulting estimates for staff reductions. The managers interviewed at Plant A and Plant B estimated an aggregate staff reductions of 18% and 28% staff reduction, respectively. The higher percentage at Plant B is likely related to the higher current staffing starting point and to the smaller sampling of plant tasks and bias toward evaluating those tasks that may be most affected by plant modernization. Applying burdened labor rates in 2005 dollars, the reductions estimated can yield significant annual savings of about $11,000,000 and $12,000,000, respectively.

To completely achieve this high level of annual savings, plants must undertake dramatic functional changes similar to the aggressive vision described in 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 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.4 of this appendix provides 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, both studies demonstrate that over the long term, integrated solutions offer more potential for significant O&M cost reductions. For example, the total staff reduction attributed to point solutions at Plant A is 14 people, where as the total staff reduction attributed to integrated solutions is 92 people.

B
EXTENDED WORKSHEETS FOR CONSTRUCTING MODERNIZATION ENDPOINT VISION

(Note: Material in *Italics* is taken Verbatim from Appendix B of EPRI 1003569, or Tables 2-5, 2-6 and 2-7 of EPRI 1008122)

I. CONCEPT OF OPERATIONS

	Endpoint Vision Considerations	**Basis/Discussion**
Monitor the plant process and systems/equipment, including performance monitoring	*Describe briefly any intentions for significant changes in how operators will perform monitoring tasks. For example, will higher-level information be used as opposed to discrete parameter monitoring? High-level overviews (e.g., on top-level workstation display and/or wall panel display)? Is it a goal that more automated equipment monitoring and diagnostics will be done by the system, with alerts to the operator? What about plant performance monitoring?*	*Describe goals and objectives – reduce operator time spent collecting and digesting individual bits of data? Specific goals for certain types of monitoring? Or is the objective to simply maintain equivalent capability to what is provided now? Any goals related to equipment or plant performance monitoring? Any past problems to be corrected?*
Perform or participate in maintenance & testing	*Describe intentions for any significant changes in time spent supporting maintenance and testing (either due to I&C upgrades or related to HSI improvements such as automated test support).*	*Describe any goals in this regard – specific goals for reduction of time spent? Reduction in personnel errors? Any particular evolutions targeted as troublesome now and needing improvement? Describe basis for expecting improvements – where will they come from?*
Equipment switching and tagging		*Any objectives related to improvements here? Any intent to tie into limiting conditions of operation decision-making or support?*
Take readings and log information	*Will some of this be automated?*	*Specific objectives? Basis for elimination of manual logs? Will operators lose touch if they do not take manual readings? How will this be addressed?*
Accomplish shift turnovers	*Even if no change is intended, describe how change may occur due to the modernization – time spent reviewing displays at workstation, how this will be accommodated, etc.*	
On-shift training		
Startups and shutdowns	*Describe any significant changes planned for startup and shutdown evolutions, how the operators will accomplish them, what role the operators will play, and how many operators will be required. (Fewer manual control actions? More time to monitor and check for problems, or diagnose abnormal indications? Reduction in peak workloads?)*	*Describe basis for expected changes. Relate the proposed changes to any plant-level goals regarding startup and shutdown, outage time reduction, etc.*
Power level changes, including load following		
Surveillance testing	*Describe significant changes expected in how*	*Provide basis for expected changes in testing and*

	Endpoint Vision Considerations	**Basis/Discussion**
	major plant surveillance tests will be performed, operator roles, burden reduction, etc.	*operator roles (e.g., describe what automation features will be expected to lead to intended reduction in operator time spent on testing).*
Identify and respond to plant equipment failures and other situations requiring operator action	*Describe any changes planned in the operators' use of alarms, expected use of overview displays, and other significant changes in how the operators detect problems and determine actions. Worksheet 2 will describe the alarm system and its features – this is the place to describe the operational implications of planned changes – for example, is it expected that the operators will use alarms during plant upsets? Will greater intelligence in alarm processing allow this, and also allow operators to be given higher-level alerts to developing problems, not just individual parameter alarms? Will this change how the operators monitor or respond to abnormal conditions?*	
Diagnose and troubleshoot problems with the plant process, systems and equipment	*Is it intended that operators will use specific displays or aids to assist them in diagnosis or troubleshooting? Any automation that will allow operators to work at a higher level, not having to deal with low-level information?*	
Respond to plant transients and upsets		
Respond to accidents using emergency operating procedures	*Describe any differences in how emergency operations will be conducted, and EOPs will be used.*	*Provide a description of the basis for the changes including any improvements that are intended and why they can be expected.*
Maintain situation awareness	*Describe concepts regarding how operators will maintain situation awareness in the modernized control room, and how this will differ from the current control room.*	*Discuss the basis for the planned concept and how situation awareness will be maintained or improved (describe goals for improvement). Address the potential drawbacks of computer-based systems and seated workstations regarding impact on situation awareness and how this is addressed.*
Handle compliance with tech spec conditions		
Monitor and control the plant under conditions of degraded or failed I&C/HIS	See Worksheet 3	See Worksheet 3
Monitor and control the plant when the main control room must be evacuated	*Note any planned changes in use of the remote or auxiliary shutdown panel.*	
Plant systems and functions for which direct monitoring and control responsibility is in MCR	*Describe any plans related to centralizing functions, bringing some responsibilities into the*	*Discuss basis for the planned change and objectives that are to be met. Discuss potential for*

	Endpoint Vision Considerations	**Basis/Discussion**
	MCR that presently reside outside. Discuss impact on operators in various plant operating modes.	*increased burden on MCR operators, and potential loss of information and awareness due to not having as much presence out in the plant – discuss how this is addressed.*
Plant systems and functions given oversight in MCR but controlled outside the MCR	*Describe any changes in level of automation for these functions and the impact on operations.*	*Discuss basis for the change – what goal is to be achieved.*
MCR operator involvement in I&C/HSI system diagnosis, troubleshooting and repair		
Number of reactor operators, senior reactor operators, and auxiliary or equipment operators on shift	*Note any planned changes here.*	*Describe basis for making the change (what is to be accomplished and why), and basis for acceptability (e.g., address burden on the remaining crew members if staffing is to be reduced).*
Skills, education and training of reactor operators, senior reactor operators, and auxiliary or equipment operators		
Division of responsibility among crew members	*Describe how this is expected to change in the modernized control room, considering roles of automation, more efficient HSIs, etc.*	
Crew communication and coordination		*Address the potential for crew communication and coordination to be degraded if a compact workstation design is used in the endpoint, and how this will be addressed.*
Crew supervision		
Interaction between MCR operators and AO's	*Describe any intentions regarding use of new information systems to share information between MCR and outside operators.*	
Interaction between MCR operators and maintenance		
Interaction between MCR operators and engineering		

	Endpoint Vision Considerations	**Basis/Discussion**
Maintenance personnel are alerted to I&C/HSI problems, diagnose them, generate work orders, etc.	*Describe intentions for handling low-level diagnostic alarms, fault indications, etc. from the new digital systems. Will these be sent directly to a maintenance work order system? Will operators be alerted to these and be expected to take any action?*	
System engineers monitor their systems' performance, diagnose problems, etc.	*Any improvements planned related to the Maintenance Rule?*	
I&C engineers perform configuration changes and modifications to I&C/HSI		*Describe basis for the chosen approach. Address minimization of errors at the interface and potential for such errors to cause system failures.*
Managers obtain plant data and monitor performance		
Corporate Emergency Response	Who will own post-accident management and emergency response -- the plant personnel or a corporate team? Will Emergency Response Facility(ies) be shared across multiple plants? Will ERF technical expertise be pulled from multiple sites? What communications and problem solving infrastructure is needed to support this strategy?	Provide the philosophy for dealing with significant events while and after they occur. Define the criteria and procedures for transitioning responsibilities from plant shift staff to a post-accident team.
Fire Protection	What will be the split between roving fire watch and remote video fire surveillance? What video display, sensor measurements and workflow management capabilities are needed? What staff will be required to effect transfer of control to a Remote Shutdown Panel? What facilities and staffing are necessary for monitoring?	Determine what areas of the plant can be cost-effectively covered by remote video surveillance. Is staff reduction a goal of replacing some roving fire watch and rounds by video surveillance?

IA. CONCEPT OF MAINTENANCE

	Endpoint Vision Considerations	**Basis/Discussion**
Maintenance management		
Degree of shift toward on-line condition based maintenance (CBM)	What role will on-line equipment monitoring and predictive analysis play in equipment and system maintenance? How will condition based maintenance be coordinated between equipment that has on-line data acquisition and that for which manual sampling is required? What infrastructure is needed to support these activities?	Describe the goals for any such shift toward CBM – e.g., to reduce staff time involved, to improve quality and timeliness of condition assessments, or simply to maintain equivalent capability at present levels? Describe frequency at which CBM data (of various kinds) needs to be gathered.
Balance between corrective, preventive and predictive maintenance.	What are the technical criteria for addressing a problem via corrective vs preventive vs predictive maintenance, or a blend of each? Is there a critical need to identify incipient failures earlier than is currently done? If so, can such a capability be valued quantitatively?	Describe the plant maintenance philosophy and its targets for the next 5-10 years. Describe the management approach to making technology investments that may reduce staff levels and/or allow earlier detection of incipient failures. Are there particular areas where existing practice has fallen short of expectations?
Operator awareness of maintenance activities and equipment condition	How will operators be kept aware of current equipment and system condition, and of anticipated and in-progress maintenance activities that may have impact on operations? How should this information be communicated, e.g., by daily status reports, change reports, on-line views, informal communications etc? How often does this information need to be updated? Will this information be integrated into the operator interface normally used for monitoring plant systems and equipment – if so, how?	
Role and responsibility of operators in maintenance	What is the role and responsibility of MCR operators in identifying equipment problems and identifying maintenance actions? To what extent, and with what priority, do operators support maintenance activities performed during day shift and otherwise? For what types of actions must maintenance staff obtain clearance from operations? When should alarms indicating equipment problems be communicated directly to maintenance personnel without operator involvement? When should operators be involved?	
I&C Maintenance Management		

	Endpoint Vision Considerations	**Basis/Discussion**
Configuration Management	What will be the criteria for upgrading device firmware as per manufacturer's advice? How will mutual compatibility of devices be ensured, for example when replacement devices are acquired and configured for an existing system? How will consistency be maintained between documented ("as-designed") and deployed ("as-built") configurations? Will configuration management tools be relied upon for this purpose?	There is a tradeoff between sticking with a stable but outdated (or buggy) device configuration, versus upgrading to a recent firmware configuration that has full support and attention of the manufacturer, but less operating history. Describe the approach for achieving the appropriate balance.
Spare Parts & Supply Chain management	What will be the criteria for storing spare parts for in-production and out-of-production devices? Will spare parts devices be shared among plants? How will essential requirements for spare parts be identified to allow maximum flexibility for procurement?	Describe the strategy for reducing spare parts inventory across plant and fleet. Will more expensive multi-function devices be used to reduce spare parts inventories? Describe strategy with respect to single-vendor partnership versus multi-vendor competitive sources.
Performance tracking	Will there be a data historian available for archiving equipment data? At what frequency will each type of equipment data be sampled? What client applications will be available to automatically analyze performance trends? To whom will any alerts or alarms resulting from these analyses be routed? Engineering? Maintenance? Operations?	Ability to trend long term data and compare it against baseline data is important for optimally timing predictive maintenance and anticipating failures or degradation.
Redundant hot-swappable modules	Will the operator be notified when a hot swap occurs for functionally equivalent modules? Will this notification be sent to an I&C maintenance workstation? Will a maintenance work order be generated automatically?	What are the criteria for allowing redundant modules to be swapped out of safety and non-safety systems, for replacement or testing during normal operations? What are the criteria for shifting to a backup module at run-time? Will redundant modules be designed into the system expressly for the purpose of allowing hot swap?
Calibration		
Instrument Calibration	Describe your general approach (i.e.,for all sensor types) for optimizing the effort associated with sensor and actuator calibrations. Do you intend to extend fixed calibration intervals specified by current tech specs? On what basis? Will the calibration approaches differ between safety and non-safety sensors? Will you employ on-line monitoring of redundant or correlated instrument channels to detect discrepancies?	Smart instrumentation can provide self-diagnostic functionality that provides limited self-calibration and extends calibration intervals.

	Endpoint Vision Considerations	**Basis/Discussion**
Loop Calibration	Will all analog signal processing devices be eliminated, with exception of analog input modules directly associated with sensors? What capabilities and resource requirements, if any, must be retained to support loop calibration? What technology choices will they emphasize for the long term?	Analog data acquisition systems entail extensive effort for loop calibration of each analog device in the chain. When such analog chains are replaced by a digital system with serial communication, loop calibration can be eliminated except for the analog input module, which can be calibrated along with its associated sensor.
Mechanical maintenance & monitoring		
On-line condition-based maintenance	At what level will you gather, trend and act on component data in a uniform way – i.e., by system, component type, globally? Will you invest in a plant-wide asset management system for use across all equipment types?	
Valve maintenance (AOV & MOV)	What is the strategy for corrective, scheduled/preventive and predictive valve maintenance? Will infrastructure be introduced to support passive trending and archiving of valve stroke data? What about on-demand active incremental stroking for troubleshooting or trending of normally stationary valves?	With HART or fieldbus communications, valve position and force trace data can be captured and analyzed during normal operation, and/or during incremental on-demand tests. Corrective and scheduled maintenance can give way to predictive maintenance.
Vibration monitoring	What types of faults – and which equipment types – will be represented in vibration signature analysis? Will you introduce tools for automatic analysis of spectra, or rely upon manual interpretation? In which cases will sensors be permanently mounted? How will information be transmitted and stored? How will this be integrated or coordinated with conventional vibration alarms and trips? How will the information be integrated into maintenance and operations information displays?	

	Endpoint Vision Considerations	**Basis/Discussion**
Electrical Maintenance & monitoring		
Breakers and Switchgear	Will load distribution breakers be controlled and/or monitored using fieldbus or HART communications? What diagnostic software capabilities will be supported, and what low level data and high level interpretation will be provided to maintenance and operations staffs?	Equipment vendors supplying switchgear components, such as 480 VAC load distribution breakers, now support fieldbus interfaces for control and in some cases provide Field Device Tool (FDT) element managers that support maintenance data acquisition and diagnostics.
Motor current signature analysis	What types of faults – and for which equipment types -- will you seek to monitor using motor current signature analysis? Will you introduce tools for automatic analysis of spectra, or rely upon manual inspection? In which cases will sensors be permanently mounted? How will information be transmitted and stored? How will it be integrated into maintenance and operations information displays and alarms?	
Fleetwide Centralized Monitoring & Diagnostics		
Roles and responsibilities	What is the role of fleetwide monitoring and diagnostics activities and how does it support plant needs? Will this be a 24x7 or single shift resource?	
HSI and communication infrastructure requirements	What communications architecture is needed to tie fleetwide monitoring facility to plant data? What workgroup collaboration capabilities are needed to support problem identification and resolution between plant and fleetwide staff at different locations?	Describe requirements for technology to acquire, analyze and display data to support fleetwide monitoring, diagnostic and workflow management activities.
Fleetwide standardization of processes and procedures	To what extent will plant procedures and processes be derived from fleetwide standards, vs. developed and maintained independently in each plant? Will this standardization be used to facilitate portability of O&M staff between plants, and/or to reduce staff needed to maintain plant-level processes? To what extent will procedure and process changes be coordinated with strategic technology choices for I&C and IT?	Technology advancements result in improved productivity and staff reduction only if processes and procedures are upgraded to take full advantage of them. Describe any goals to define and maintain standardized procedures and processes that are applicable to all or many plants in the fleet.

II. HSI Design Concepts for Endpoint Vision

	Endpoint Vision Considerations	**Basis/Discussion**
Architecture/arrangement and types of information displays provided, including: • *Degree of conversion of discrete indicators and meters to computer-based information displays* • *Method of displaying trend information* • *Recording of historical data* • *Plant/process overview information display* • *Display of detailed data on systems and equipment including individual sensors*	*Describe overall concept for information display and degree of modernization planned, including:* • *Any fundamental changes in the type and structure of information displays (e.g., functional displays, system-oriented displays similar to P&IDs, task-based displays, higher-level information displays)* • *Provision of spatially-dedicated indications and displays, in addition to computer-driven displays* • *How information presently displayed on recorders will be handled (trends, historical data)* • *Overview displays (e.g., large display panel, overview displays on workstations?)* • *Access to detailed information*	
Method of handling safety system status indication (W) and bypassed and inoperable status indication (BISI)		
Architecture of alarm information presentation, including: • *Different levels of alarm information (e.g., plant level, system level, component level)* • *Different priorities of alarms* • *Groupings of alarm information (e.g., by system, function, operator areas of responsibility)* • *Display of diagnostic or other information to support responding to alarms, including alarm response procedures*	*Describe overall alarm presentation concept, including how and where different levels of alarm information will be presented, how alarm priorities will be handled, and presentation/automation of alarm response procedures.*	

	Endpoint Vision Considerations	**Basis/Discussion**
Alarm processing, including: • *Level of integration of data to form higher-level alarms* • *Alarm logic, filtering, suppression, reduction*	*Describe any changes in overall alarm processing concepts.*	*Describe goals and basis for alarm processing concept (e.g., goals for alarm reduction during upsets, fewer alarms active during shutdown)*
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.*	
Degree to which control actions are automated (e.g., sequences of control actions automated, startup sequences, system line-ups, etc.)	*Describe control automation approach.*	*Discuss basis for automation – objectives, basis for deciding what to automate, etc.*
Degree to which safety related and non-safety related controls are integrated (e.g., ability to control safety related equipment using the same non-safety workstations that are used for normal operation)		
Degree of implementation of computer-based procedures, and method of presentation and use	*Describe overall approach to procedures – access, presentation, use, and any associated automation.*	
Degree to which COSS are implemented in control room		
Level of integration of displays, controls, alarms, and procedures	*Describe overall approach regarding degree of integration. Does the concept include presentation of alarm information on process/system monitoring displays? Integration of live information display with procedures? Access to controls from procedures?*	
Degree of consolidation of monitoring and control capability at one or more locations (e.g., workstations) in the control room	*Describe approach regarding work areas or workstations. Will desks be converted to seated workstations? Retain benchboards, vertical panels? Create work areas at panels rather than seated workstations?*	

	Endpoint Vision Considerations	Basis/Discussion
Degree to which control room HSI equipment (user interface including hardware and software) is made consistent or standardized		
Degree of support provided for maintenance personnel		
Degree of support provided for system engineers to monitor system and equipment performance, diagnose problems, etc.		
Support for I&C engineers to perform configuration changes and modifications to I&C/HSI		
Degree of support for managers to obtain plant data and monitor performance		

IIA. Technical Architecture

	Endpoint Vision Considerations	**Basis/Discussion**
Overall Network Architecture	How will plant networks communicate with fleetwide monitoring facilities, emergency response facilities and corporate IT? What are the preferred architecture(s) for networking and real-time process control solutions at the device and controller levels, and how will heterogeneity at these levels be accommodated? How will these low level networks aggregate and transform data into higher level information needed at the plant and corporate levels?	Define the architecture for providing data, information and control flows at the levels of device, control, plant information, fleet and corporate networks. Identify key issues – especially regarding security and impact of failure – associated with integration of these levels. What is the appropriate level of integration to balance these issues against the benefits of enhanced information flow.
Shared Infrastructure to support integrated solutions	Define the infrastructure set that will provide shared resources to support integrated solutions. What is the scope of these resources – i.e., whole plant, BOP systems, etc. Are there any limitations to the type of systems (e.g., safety vs non-safety) that can rely upon this infrastructure?	Introducing shared infrastructure – such as communications backbone, application servers and archival storage – can facilitate integrated solutions that can be more cost-effectively installed and maintained, in comparison to point solutions.
Security Architecture		
User Privilege Policies	Define the various roles for a user, as well as the classes of functions that each such role is allowed to perform. Should some of these roles also be conditioned on the workstation and/or its location? [For example, can a maintenance engineer request an incremental valve stroke from any workstation, or only from a particular workstation in a controlled area.] Privileges can be applied for trusted client systems as well as to human users.	Privileges to perform various software functions should depend upon both the role (e.g., operator vs maintenance engineer) and location (e.g., control room vs. corporate diagnostic center) of the user. The probability and impact of an intrusion or inappropriate action can be limited by rigorously bounding user actions. Of course, this must be balanced against the need to provide users with enough flexibility to do their jobs efficiently.
Authentication	What criteria will be sufficient to authenticate the identity of a human user – e.g., ID & password, biometrics, etc. Will criteria depend upon the user's role and sensitivity of its privileged functions? What approach will be used to authenticate a trusted client system that is attempting to establish communications from within the plant or corporate network?	When sensitive services (e.g., write functions involved in device configuration or system control) are privileged for a role, the human user or trusted client system's identity must be authenticated before enabling access to such services.
Protocol & encryption standards	What standard protocols will be used for encryption and communications security? What resource and feature requirements does this choice imply for acquisition of instruments, and monitoring &	Selection of security protocols must consider not only the level of security provided, but also availability of resources (memory and processor cycles) and impact on system performance.

	Endpoint Vision Considerations	**Basis/Discussion**
	control systems?	
Role of physical security	How (if at all) will physical security methods such as locking up devices, providing remote surveillance, etc. be used to complement cyber security of control systems?	Techniques for cyber security (e.g., encryption, authentication, role based privileges) and physical security (e.g., keeping critical workstations in restricted areas) can be combined for best effect.
Heterogeneous and legacy components	How will you ensure that no "back doors" exist that may allow unauthorized access of critical functions? How will deviations from preferred protocols be handled (e.g., inability for a smart device or PLC to support local encryption because of resource limitations)? How can secure gateways be used to isolate legacy devices lacking security capabilities?	Describe how heterogeneities in the plant I&C and IT architectures can be accommodated from a security point of view. Such issues may be caused by presence of legacy control systems or instruments, or of products reflecting multiple protocols and vendors. Another concern is undocumented technical support access (e.g., by modem) provided by some process control vendors.
Long term product life cycle strategies		
Explicit end-of-life strategy for devices & infrastructure.	How will you ensure that modernization decisions will cost-effectively endure for the required period? If you expect I&C/IT obsolescence prior to end of power plant life, how will you prepare for another cost-effective transition that will maintain plant availability as long as required?	I&C and IT product lines have significantly shorter lifespans than do mechanical and electrical components. Upgrades and modernizations should anticipate end-of-life decisions by vendors and provide a strategy for dealing with them. For each solution, infrastructure element and product line, describe its anticipated life until obsolescence, and the dependability of vendor(s) existence and promised support.
Criteria for spare parts warehousing	What criteria will be used to determine spare parts inventories for mass market components? … for limited production components still supported? … for custom or end-of-life components? What will be the approach to accommodate a change in a component's status? How are risks to plant availability and system reliability, as well as cost factored into these criteria.	Spare parts inventory level depends upon the phase in its product life cycle and the confidence that it will remain available over time.
Degree of commitment to open standards vs vendor-specific systems	What vendor relationships and commitments are necessary to ensure long-term support? What is your level of confidence that these commitments will be honored for sufficient time? What financial commitment are you willing to make to a vendor to sustain such a relationship? To what degree will you identify and support open vendor-neutral standards that have potential for outliving	It is expected – but not guaranteed – that industry-wide open standards have a longer lifetime than individual commercial product lines. Describe the relative emphasis on vendor-neutral standards-based systems, as opposed to long-term partnership agreements with vendors to ensure their continued support.

	Endpoint Vision Considerations	**Basis/Discussion**
	individual products and vendors?	
Management of heterogeneity		
Multiple digital standards and product lines	What communications or applications standards are regarded as inviolate across the plant? When will you allow multiple standards with the capabilities to interoperate? Will you enter strategic partnership with preferred vendor(s) of control, communications, instrumentation or other products?	For infrastructure and integrated solutions, there are two basic approaches: you can select preferred vendor(s) and work with them toward integrated solutions; or you can remain vendor-neutral and select multi-vendor standards. The latter approach is well-established in networking, but less viable in process control.
Migration from legacy digital to advanced digital systems	What is the strategy for ensuring long-term compatibility with legacy digital systems and components? To what degree are these systems independent, and to what degree do they need to interoperate with other plant systems or corporate systems? Will you extend their lives indefinitely, or plan a migration to plant-standard solutions?	Identify digital systems that have already been installed in the plant, and estimate their lifetimes. Identify external interfaces, spare parts and skills needed to support these systems.

IIB. Simplification Concepts

	Endpoint Vision Considerations	**Basis/Discussion**
Smart Instrumentation		Within bus-based architectures, smart instrumentation can support functions that previously required PLCs or multiple instruments. Fully utilizing these capabilities can reduce the number of components and simplify architectures.
Multivariable instruments	Will your architecture allow multiple process variables to be measured by the same smart instrument? If so, will this be restricted to non-safety applications? How will this capability be reconciled with diversity and defense-in-depth principles? How will you assess any system reliability / availability issues with this simplification?	Smart instruments may be capable of monitoring multiple process variables. A typical example measures differential, absolute, or gage pressure, as well as process temperature.
Self-diagnostic capabilities	For each type of smart sensor or actuator, what types of self-diagnostic processing is to be performed locally on the device? What information should be alarmed or uploaded to the control network, and how frequently?	When device diagnostics are deployed to the device itself, only higher level information or exceptions, rather than frequent detailed data, need be uploaded to the system. This reduces bandwidth requirements and system complexity.
Field Control	Will you support Foundation Fieldbus or a similar architecture that supports field control? If so,…. Will you allow field control for non-safety systems? Will you utilize field control to provide: - primary control function? - backup control functions, thereby reducing the need for dual redundant PLCs? - autonomous local control to track a constant target state following the failure of demand signal? In each case, what types of applications are suitable?	Many smart instruments support Foundation Fieldbus functions blocks that implement control logic. These blocks may be deployed either to host controllers (e.g., PLCs) to provide "distributed control" or to the devices themselves to provide "field control."
Communications infrastructure		
Bus-based communications (monitoring & control)	What is the strategy for field level communications for monitoring and control. Will this strategy be applied plantwide, or incrementally as needed for systems within the planning horizon?	For newly introduced systems, fieldbus architectures provide high bandwidth multidrop communications with a minimum of new cabling. In contrast, for replacements to legacy analog systems, HART architectures re-use existing analog cabling runs. Although HART supports multidrop communications, each cable is usually limited to a

	Endpoint Vision Considerations	**Basis/Discussion**
		single variable because of bandwidth limitations
Wireless communications (monitoring)	Will you provide wireless backbone infrastructure – i.e., local access points, fast or gigabit Ethernet backbone and network management – to support wireless monitoring? What types of plant applications will be supported?	In-plant wireless strategies provide flexibility to introduce new monitoring applications with minimal or no local wiring.
Risk Informed Design Approach	Describe how quantitative (PRA) or qualitative (cut sets, FMEA) risk information can be used to establish requirements such as reliability, diversity, redundancy, etc. [Pointing to reference documents should suffice.]	Except for some safety systems for which design criteria are mandated, reliability and availability requirements should be appropriate for the degree of safety and financial risk.
Hardware reduction strategies		
Elimination / reduction of cabinet control logic	What is the approach to control and monitoring architecture that promotes consolidation of devices and cabinets?	Taking a strategy of preserving I&C system interfaces, rather than existing cabinet interfaces, allows fully digital data stream and processing, eliminating the need for signal conditioning and other elements of I/O subsystem, as well as single function devices. Further consolidation can be achieved by consolidating across I&C systems to a process oriented architecture.
Field control	See entry under Smart Instrumentation	Deploying primary and/or backup control logic blocks to smart instruments, can eliminate the need for PLCs to perform these functions. Sensors may communicate directly with actuators without the need for intervening control devices.

III. HSI Failure Management Concepts

	Endpoint Vision Considerations	**Basis/Discussion**
	[Note: For each Failure Management topic, the utility should answer the following questions: • *How detected?* • *How handled?* • *Need procedure?* Section IIIA describes some additional topics with particular issues that may be relevant	
Instrument/sensor failures		
Multiplexer/communication link failures		
Data storage/database failures or corruption		
Display device failures including individual meters, indicators, CRTs, panel displays		
Recording/logging device failures (including historian)		
Control device failures including individual control switches, controllers, manual/auto stations, and dedicated soft control panels		
Workstation failures including processor, overall workstation failure		
Alarm/annunciator system failures including gross failure, failure to update (lock-up), display failure, audible failure		
Monitoring and display system failures		
Large-scale failure of component control		

	Endpoint Vision Considerations	**Basis/Discussion**
capability		
Large-scale integrated system failures affecting multiple workstations, display and control capability		
Failures of process control automation		
Failures of sequential control action automation (e.g., automated startup sequences, etc.)		
Failure of other automatic features the operators may rely on (e.g., automatic thermal limits monitoring, automated tech spec condition monitoring, other operator aids)		

IIIA. Additional Failure Management Issues

	Endpoint Vision Considerations	**Basis/Discussion**
	General: Consistent with worksheet 3 of 1008122, each item in IIIA should answer the questions: "How detected? How handled? Need Procedure?" In addition, special considerations for these issues are discussed below.	
Network element failures		
Communications Bus Failure	Will redundant communications bus be supported? If so, confirm that it is compatible with the bus architecture selected, and describe the concept for failure detection and recovery.	Failure of bus or communications medium is generally an infrequent event.
Switch Failure	Is every Ethernet switch and connectivity path provided with a redundant alternative? Will all data packets be reliable TCP? Will spanning tree be the mechanism for failing over to backup paths? If not, what is the alternative approach? What are failover times required? If redundancy is not provided, what will be the procedure (including recovery time requirements) for detecting failure and recovering manually? Following restoration of communications, what protocol is required to reinitialize and/or resynchronize interacting	Adequately designed and configured redundant mesh Ethernet networks are self-healing in the sense that the spanning tree algorithm automatically reconverges to a backup configuration. However, once low-level communications are restored, high-level applications must be brought back to a stable state.

	Endpoint Vision Considerations	Basis/Discussion
	applications?	
Router failure or degradation	When are redundant routers and links required? For redundant and non-redundant routers, what are the recovery times required, respectively? Must low level data be archived locally during this recovery time, or is it permissible to discard data which is not uploaded?	Routers provide scalability of information networks and govern access to the public internet. They are typically not found at the low level of device network and its controller. Encrypting routers are generally limited by encryption capacity rather than raw bandwidth, so their effective throughput can be degraded compared to theoretical bandwidth.
Gateway failure	How must the device network behave if a gateway with its supervising control network fails? …. E.g., must it continue to operate assuming constant demand, revert to a safe state, etc. What are reliability and recovery time requirements?	Failure of a gateway (also known as a protocol converter) has a similar effect to loss of connectivity. Gateways typically allow networks at different levels (e.g., fieldbus device network and Ethernet control network) to interoperate.
Failure of stateful smart instrument	In general, how will stateful devices be re-initialized upon failure of function or interruption of input stream? Are there specific devices that must be handled differently?	Smart instrument functionality may be "stateful", i.e., involve storage of state variables over multiple time steps. [Examples may include PID control logic, and short-term trending.] Even brief failure of stateful devices (or their input streams) may require a re-initialization. Appropriate action depends upon details such as: whether state is stored in volatile or non-volatile memory; whether the device is configured to re-initialize to last good value or startup value; whether the device fails high, low or as-is; and whether state timestamps are saved.
I&C component failures		
Device network segmentation	Describe criteria for segmenting the device network.	In foundation fieldbus architectures, device networks are limited to a few control loops, including at most one critical loop, to limit the impact of a failure within the specific network.
Failure of link active scheduler (or equivalent)	If applicable, what is the general strategy for designating priority and backup link active schedulers to nodes?	In foundation fieldbus architectures, each device network has a link active scheduler (LAS) that manages real-time behavior. The LAS function can be deployed to a PLC or to an end device (smart sensor or actuator) having sufficient computing resources.
Failure of centralized controller (PLC); control network segmentation	What is the maximum scope of control hosted by a single PLC or redundant pair of PLCs? What are the criteria for device and control network	A single PLC may host several control loops, so the failure of a PLC without redundant backup can have significant impact on plant systems and the

	Endpoint Vision Considerations	**Basis/Discussion**
	segmentation to limit the impact of a PLC failure? What are the criteria for requiring redundant PLCs with automatic failover to backup? What common cause failures need to be considered when redundancy is used?	ability of the operators to deal with the ensuing transient.
I&C System Failures		
Impact on maintenance and non-real-time operations activities.	What maintenance functions are dependent upon continued control system data acquisition or processing functions? Could there be any impact on functions expected to provide backup to control automation failure?	Integrated solutions may have dependencies of maintenance and management automation on control functions such as data acquisition.
Availability and recovery time requirements for monitoring & maintenance systems.	What are the goals for availability and downtime for each monitoring & maintenance system. Given such a failure, how will users adapt to disabled function or missing data for these time periods.	For maintenance & management systems it is unnecessary and prohibitively costly to match availability and recovery time goals of control systems.
Automation Failures – additional items		
Failure of smart instrument control function	If applicable, describe criteria for providing backup control and automatic failover following failure of smart instrument control. What recovery time is required?	Failure of control function deployed to a smart instrument has similar effect as PLC failure, except that the impact is limited to one (or at most very few) control loops.
Failover to distributed control function / reversion to normal operating state.	Describe the behavior expected – including allowable time delays and discontinuities in response rate – when control is transferred from primary to backup control and back again.	

IV. Organizational Architecture

	Endpoint Vision Considerations	**Basis/Discussion**
Streamlined Plant Organization		
Broadened department responsibilities and reduced organizational interfaces	Is organizational simplification (as distinct from staff reduction) a goal of your company? If so, over what time horizon? Will plant organizations be tailored to each plant or made uniform across the company? Describe current plant operations and maintenance organizations and job roles, and indicate how this structure can be simplified to reduce the number of day-to-day interfaces.	Integration of technology for remote monitoring, data analysis and automation enables staff to deal with broader, less fragmented problems. This in turn allows a shift of emphasis from component to system engineering.
Workflow and process revisions	To what degree do you wish to realign workflows and processes achieve productivity gains? Will you support a major procedure rewrite?.... or rewrite of specific procedures to take full advantage of technology upgrades.	
Fleetwide Shared Services	In addition to fleetwide monitoring and diagnostics (if applicable) what other services will be shared across multiple plants? What will be the protocol for plants to obtain these shared services, and who will be accountable for supporting plants adequately? How will priorities for fulfilling service requests be established?	
Organizational models and responsibilities	What part(s) of the organization are accountable for equipment, system and plant availability? Does the plant continue to be fully accountable, with fleet monitoring in support?	Describe your fleet of plants and their key similarities and differences – technically, organizationally and culturally. Describe how plant staff works with corporate engineering in support of availability goals set by corporate. What is the appropriate level of plant autonomy in this area? Describe strategy and limitations for introducing fleetwide monitoring technology and personnel.
Staff experience & skill characteristics	What level and types of equipment expertise will reside within fleetwide shared resources? Expertise in specific equipment classes such as pumps and valves? General expertise in equipment modeling, monitoring and diagnostics? Will staff be drawn from corporate engineering, plant O&M, or other sources? Is plant experience required?	A wide range of skills – covering the mechanical equipment, diagnostic techniques and supporting technologies – is needed at some level to support the plant needs. Describe the strategy for covering these skills and where they should be distributed or concentrated.
Interaction with plant staff & organization	Will fleetwide shared resources proactively attempt to anticipate incipient failures, or reactively respond	Describe cultural or organizational issues that must be addressed to ensure a constructive working

	Endpoint Vision Considerations	**Basis/Discussion**
	to plant requests for support? Will fleetwide resources participate in planning or executing problem solutions as well as diagnostics?	relationship between plant and fleetwide staff, toward goal of improved equipment reliability.
Skills and Organizational Requirements		
Integration / interaction between plant I&C and IT organizations	To what degree will traditional I&C and IT organizations be kept distinct? If they are to be pulled closer together, how will the culture accommodate both the rigor required of I&C activities and the flexibility required of IT activities	Traditionally, there has been a dramatic distinction between skills and functions required of "I&C" and "IT" organizations.. However, as instrumentation and devices become universally digital and network based, and as process control systems share more and more characteristics with networks and their distributed software, this clear distinction fades.
Relationship to corporate IT organization	What will be the relationship between the corporate IT organization and the plant I&C/IT organization(s)?	Interoperability and security are the key competing considerations here. Factoring plant operations and maintenance data into corporate procurement and financial decisions requires the ability to upload plant data to corporate information network. However, corporate IT networks have many functions and connections to the public internet that raise security concerns.
Core technical team – Integrated Solutions	To what degree will the utility take responsibility from vendors for specifying, designing, installing, and/or maintaining I&C solutions? Will a dedicated team be staffed internally and trained to expert level? How long will team members be expected to remain with the team, and how can they be induced to so?	Some utilities are questioning the traditional approach of purchasing turnkey or proprietary point solutions that are expensive to integrate and maintain.
Recruiting and Skill Issues	To what extent will specialized skills be considered corporate resources to be shared among plants?	Recruiting concerns can be eased, as a streamlined organization needs more workers with flexibility and up-to-date technical skills, and fewer hard-to-find specialists dedicated to legacy equipment.

C
QUALITATIVE MODEL FOR MODERNIZATION INVESTMENT DECISIONS

A very simple conceptual model of costs and benefits is useful for:

- Understanding the business distinction between the capital-constrained and aggressive visions,
- Visualizing the nature of decisions that will be made by utilities and
- Defining needs for quantitative and qualitative methods to support plant-specific decisions.

The following discussion ignores important questions such as prioritization and phasing of modernization activities, in favor of a simplistic parameter "% Plant Modernization" that ranges from 0 to 100%. We implicitly assume that Plant Modernization proceeds in an orderly sequence starting with highest priority systems or support activities. Furthermore, all the curves shown here are conceptual and speculative only – it remains for work in 2006 to generate quantitative results and/or methods that utilities can use to help arrive at solid business decisions for specific plants.

C.1 Basic Qualitative Model

Figure C-1a) depicts the cumulative benefits arising from modernization efforts. Low levels of modernization (A) give rise to only modest benefits – due mainly to threat reduction (obsolescence and reliability) but possibly with side benefits due to enhanced productivity of I&C maintenance. As consistent modernization is applied across an increasing fraction of the plant (B), the incremental benefits become more attractive because O&M staff positions can be eliminated as the levels of labor-intensive activities – e.g., loop calibration and mechanical maintenance – are increasingly automated. Improved on-line asset management also yields benefits both in labor productivity and equipment availability. At some point (C), diminishing returns take over after we complete the scope having largest potential benefits, but when all legacy systems are eliminated by complete modernization (D), we might expect an additional burst of benefits, since some legacy expertise is no longer required. As part of this curve, we might also expect a breakpoint (E) at the threshold where economies of scale begin to be realized.

Figure C-1b) conceptually depicts a corresponding investment profile. For zero modernization, there is still a baseline (F) investment to maintain the legacy equipment and adequate spare parts inventory. Incremental investment costs are likely to be initially high (G), until sufficient systems are introduced to adequately amortize these shared investments. Finally, as more experience is gained and investment is shared across the whole plant, we expect incremental costs to fall off (H). Naturally, this profile glosses over many details such as the high cost of specialized, high-risk safety systems.

Figure C-1c) conceptually depicts a cumulative Return on Investment (ROI). Again, note that this is purely qualitative and not directly derived from figures C-1a) and C-1b). Initially, we might expect a negative ROI (I) because of the small benefits associated with isolated upgrades, followed by a breakeven point (J) and improving ROI as economies of scale are realized. Whether the ROI continues to increase or tail off depends, of course, upon the details of cost and benefit programs, but for sake of argument we assume that the ROI has a peak (K), beyond which the incremental costs and benefits of remaining modernization activities are less compelling.

The main point of the qualitative model is to suggest the need for a quantitative model that would:

- *Provide a rational way of prioritizing and ordering activities*
- *Provide a rational way of phasing groups of activities in time for best return*
- *Deal correctly with time value of money, for both investment and benefit sides*
- *Identify data or data inputs needed on both investment and benefit sides*
- *Explicitly relate capabilities (benefit-side) with requisite features and resources (cost-side)*

C.2 Capital Constrained Case

Despite the many motivations to go ahead with an aggressive plant-wide or fleet-wide modernization effort, a utility may be tightly constrained for capital budget either throughout the life of the effort, or on a year-by-year basis.

Figure C-2 illustrates how a capital constraint naturally limits what can done. For simplicity, assume a single Capital Constraint (L) as a single present value over the life of the project (rather than yearly constraints), and assume that projects have been prioritized (ordered) appropriately. In Figure C-2b) the intersection of the cost curve with the capital constraint determines the level of modernization (M) that can be accommodated. This is a common resolution among many utilities, even in cases such as this where additional benefits must be "left on the table." Note that in such cases, the actual ROI may be far less than the optimum ROI obtainable in the absence of the capital constraint.

Any practical method or tool for cost-benefit analysis must support decisions about scope and phasing at an appropriate level of granularity (e.g., making year-by-year choices considering capital constraints), must be flexible enough to accommodate improvements and changes to the ordering of projects, and must support comparison of alternative plans.

C.3 Required ROI with no Capital Constraint: Competing Projects

As indicated in section 3, the other important case of an aggressive vision for full-plant modernization is a strategic decision that may require large one-time commitments of capital far beyond typical year-to-year constraints. However, even in such a case which is not explicitly constrained, there still may be competition for capital across alternative projects, such as steam generator replacement. Another way of determining the right level of commitment is to impose a required cumulative[19] ROI – usually in comparison to competing projects under consideration by utility management.

Assume the peaked ROI profile postulated earlier, and consider three cases shown:

- Case 1: Low or no minimum ROI requirement. As shown, performing all activities in the full integrated modernization would cumulatively win out over any competing projects. Of course, this assumes that full-scope benefits are sufficiently compelling.
- Case 2: Very high ROI requirement. In this case, it would be impossible to justify any degree of integrated modernization, simply because the entire capital stock would be diverted to competing projects. In practice, purely tactical upgrades would be introduced as point solutions to address individual components or systems posing imminent threats to plant availability.
- Case 3: Intermediate ROI requirement. Here you would want to perform a modernization up the level shown by vertical line (N). Beyond this level, it would be hard to justify further modernization in competition with other investment needs within the utility.

C.4 Performing Economic Analysis of Modernization in the Real World

The discussion in this appendix is very qualitative and speculative, but it does illustrate the types of decisions that must be made in real business environments – and hence the need for "constrained" visions that may fall short of our unfettered technical ambitions.

Studies[20] of full plant modernizations have generally concluded that, given the decision to fully modernize a plant, the effort can be done at least cost by completing it as fast as possible, preferably within a single extended outage. The reasoning is based on avoiding intermediate states and temporary interfaces that must be changed in subsequent phases.

In contrast, decision-making and planning for a partial modernization is actually more challenging, because:

- There are more alternatives to analyze.
- When benefits are considered, the best ordering of projects and infrastructure support activities may not be obvious.

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[19] This is not the only way to pose this problem. A very demanding criterion might insist that every element of I&C modernization (not just the cumulative result) be competitive with other projects.

[20] J. Hasenkopf, S. Kawanago and W. Kurth, Full Plant I&C Modernization in 30 days or Less: A Feasibility Study" EPRI 1009611, December 2004

- Dependencies of phased projects may dictate lead-times for shared infrastructure. Delays in introducing digital infrastructure usually have advantages for actual and discounted costs, but their benefits are not realized until all functional dependencies are satisfied.
- Capital constraints and competing project ROIs change from year to year.
- In reality, the project list and its priorities may change with new threats to availability and with shifts in management emphasis. There must be flexibility to accommodate such changes, with the understanding that each change compromises the effectiveness of the overall plan.

A utility will make plant specific decisions (e.g., functional scope, preferred vendor(s), etc) in the course of defining its plant-specific vision according to Appendix B. Given these choices for its endpoint vision, the utility still needs to make decisions about scope (what elements from the endpoint vision to actually commit to) and phasing (when to implement them). There is a need for an analytical method and/or software tools to help organize basic cost and benefit data, evaluate various scenarios of scope and phasing, and arrive at decisions that are defensible from a business point of view. Such analytical needs are in addition to a reference design that can aid communication with vendors in support of cost evaluation, as well as basic data (e.g., task analysis, equipment reliability impacts) that help identify opportunities for cost reduction and that quantify their benefits.

These issues will be addressed during the cost evaluation activities planned for 2006.

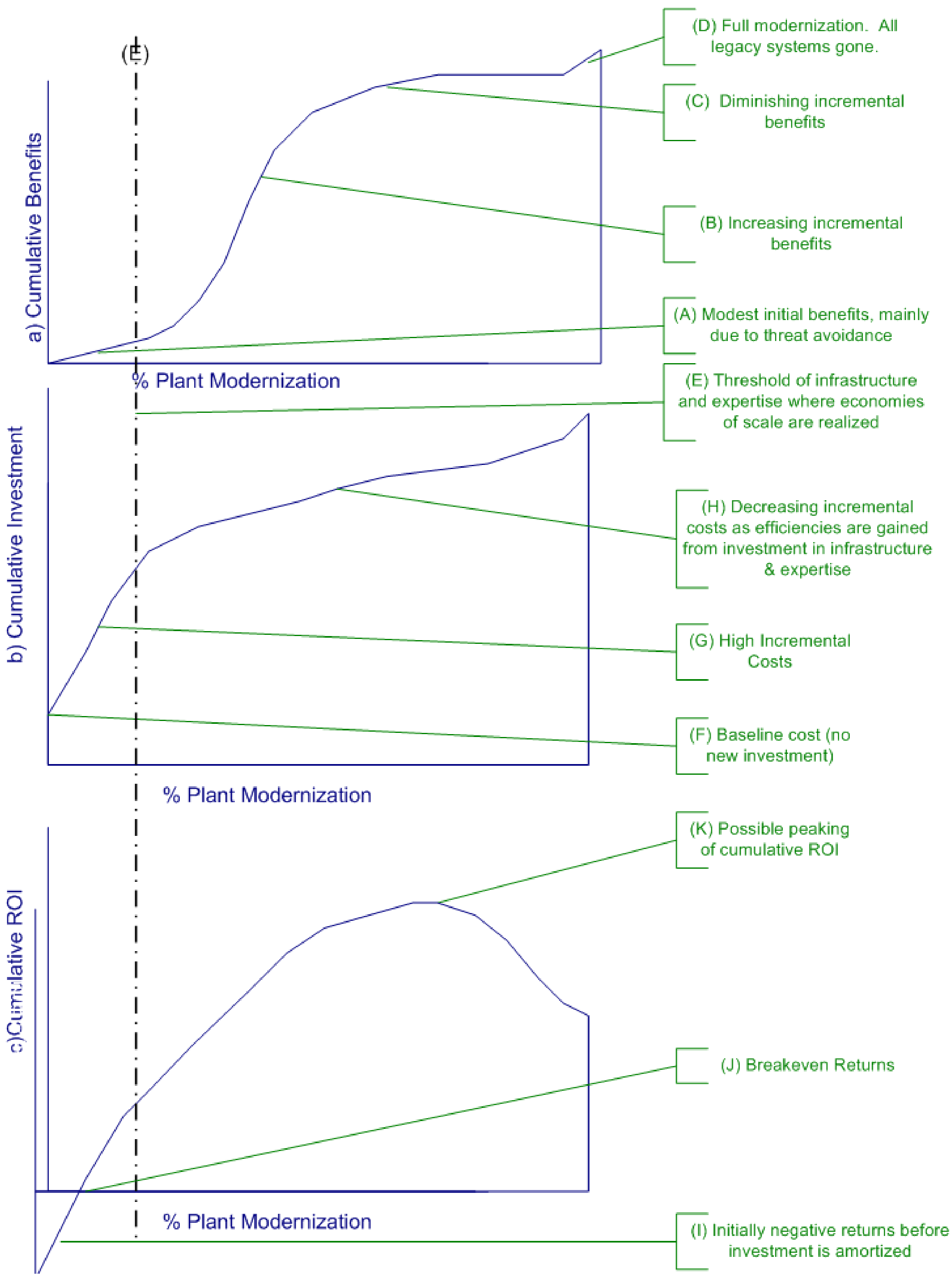

Figure C-1
Qualitative Conceptual Model for Costs, Benefits and ROI

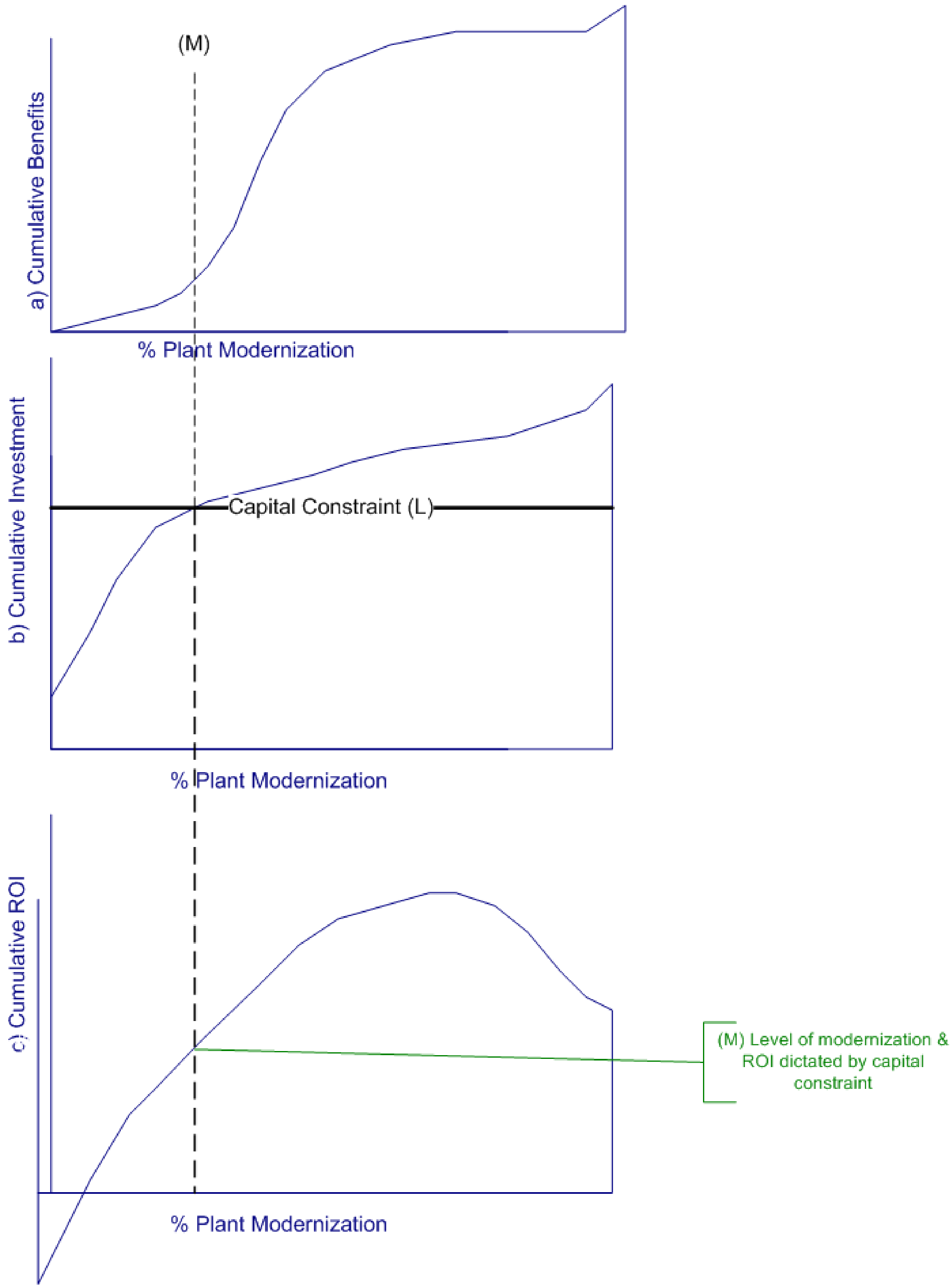

Figure C-2
Modernization Scope Decision under One-Time Capital Constraint

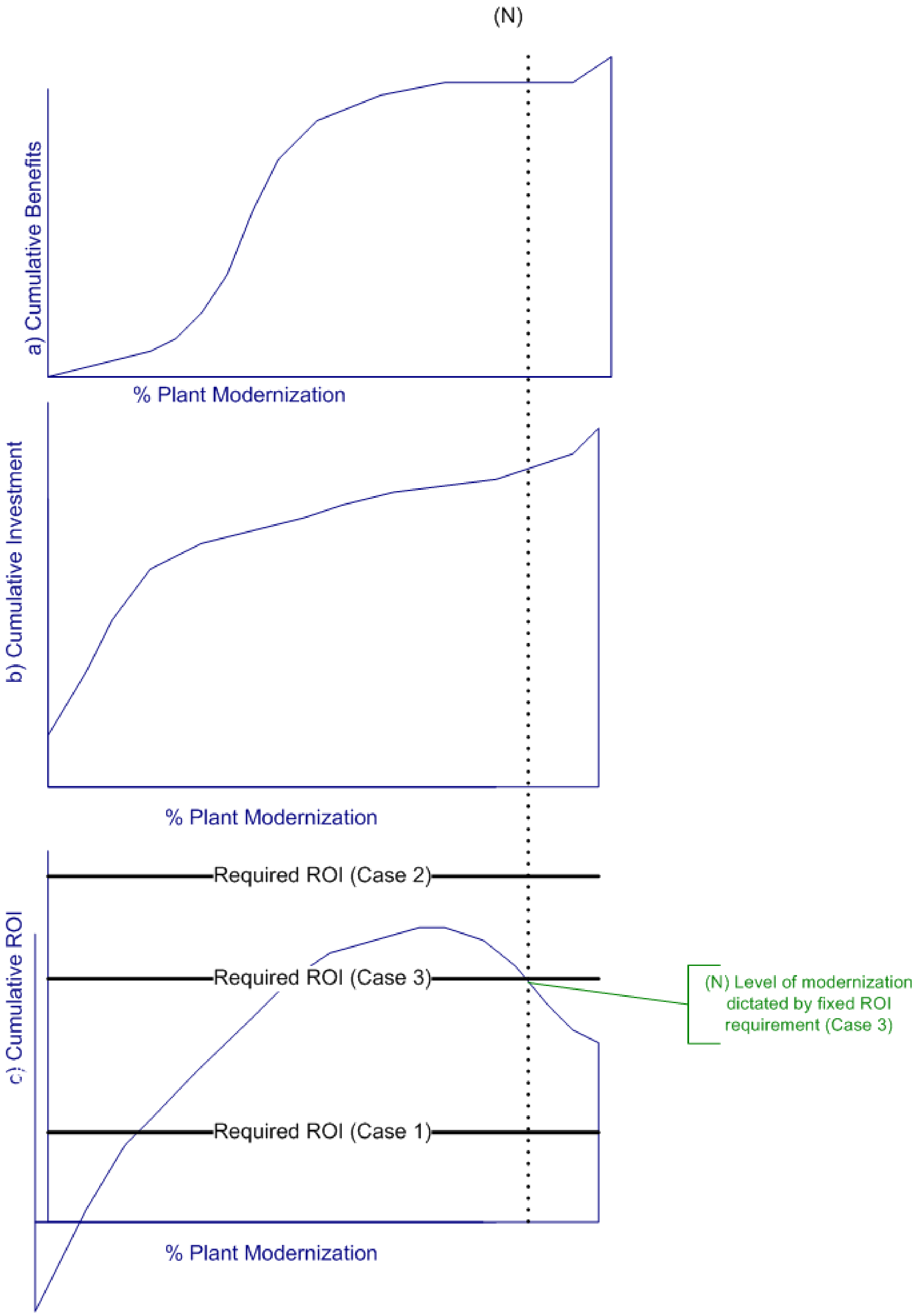

Figure C-3
Modernization Decision against Competing Projects (Required ROI)

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