Risk-Informed Asset Management (RIAM) Development Plan

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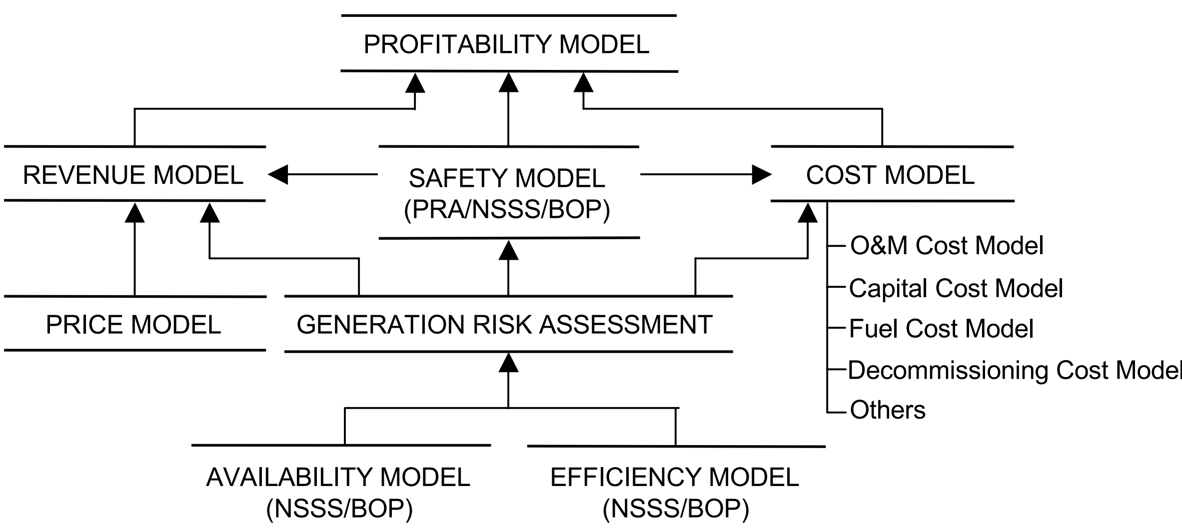

Risk-Informed Asset Management (RIAM) Development Plan

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REPORT SUMMARY

This report describes a methodology and software development plans for Risk-Informed Asset Management (RIAM), a decision-analysis, risk-based, plant-level asset and project evaluator tool appropriate for use in a market-driven industry. RIAM will provide plant operators with a project prioritization and life cycle management planning tool for making long-term maintenance plans, guiding plant budgeting, and determining the sensitivity of a plant's economic risk to the reliability and availability of systems, structures, and components, as well as other technical and economic parameters.

Background

Historically, the economically regulated nuclear power industry developed and used many physical and financial asset management tools. Life cycle management (LCM) and business planning was and is being done at all commercial nuclear power plants. Previously, LCM focused on reliability improvement and cost reduction. In this competitive era of electricity generation, plant operating and investment decisions must also improve plant profitability and manage performance while continuing to focus on reliability and safety. Currently, plant improvement projects are generally evaluated using best-estimate, point-value technical (safety and reliability) and economic (net present value) methods. Although risk-based methods are conventionally used for probabalistic safety analyses (PRA) and, of late, as a basis for NRC requirements, risk-based methods and tools for supporting plant operation and investment decisions are not widely employed. The EPRI development described in this report is intended to fill this need.

Objectives

- To formulate and describe a RIAM methodology for managing physical and financial plant assets
- To identify the benefits of RIAM over existing asset management and LCM processes, and show how beneficial features of existing methods and tools can be incorporated into RIAM
- To provide EPRI and its member utilities with a development plan for RIAM software tools.

Approach

Researchers reviewed and summarized the pioneering risk-informed asset management work of the South Texas Project Nuclear Operating Company. With that work as a starting point, they formulated a generic EPRI RIAM method and developed a plan for a RIAM software tool.

Results

This phase of the envisioned program provides a description of the RIAM methodology, identifies its great potential benefits to the electricity generating industry (to nuclear power by 2003 and perhaps to other generating technologies thereafter), and proposes a detailed plan for developing production-grade-quality RIAM software.

EPRI Perspective

The type of risk-informed asset management tool developed in this project can be used to support the full continuum of generating station decisions involving prioritization of corporate assets and investment. It will also serve the valuable function of enhancing LCM planning and budget optimization now being done on individual systems and components by allowing LCM planning at the plant level, taking into account system interactions and the constraints of budget limits. Eventually, the RIAM software can be integrated with other EPRI software such as the Nuclear Asset and Project Evaluator (NAPE) and LCM Planning Tools (LcmPLATO and LcmVALUE) to identify the capital improvement and O&M budget/investment levels that maximize plant value and profitability. This project was supported by the EPRI Nuclear Power Sector Core Program.

Keywords

Life cycle management
Nuclear asset management
Nuclear power
Probabilistic risk assessment
Probabilistic safety assessment
Risk-informed applications
Risk management

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RIAM Method Summary

The general concept of RIAM is to develop a rigorous systematic risk-informed approach to assessing, analyzing, predicting, and monitoring power plant economic (i.e., financial) performance while maintaining high confidence that NRC-established safety limits will not be breached. The RIAM process involves the modeling and probabilistic quantification of decision support performance indicators to aid plant decision-makers in determining not only which plant improvement investment options should be implemented, but also how to prioritize plant resources for their implementation based on their predicted levels of profitability. Key decision support indicators include, but are not limited to:

- Net Present Value
- Projected Earnings (sometimes referred to as “profitability” in RIAM)
- Projected Costs
- Nuclear Safety (core damage frequency, etc.)
- Power Production (availability, capacity factor, etc.)
- Efficiency (heat rate)
- Regulatory Compliance

RIAM uses a risk-informed approach to project these kinds of performance indicators. Unlike most conventional asset management approaches, RIAM includes the contribution of low-frequency, high-consequence events that can occur over the long term, as well as shorter-term “expected” events, activities, and conditions, into its performance indicator prediction process. Thus, using the RIAM approach, these performance indicators incorporate predicted cost aversion issues as well as the more conventional direct operations and maintenance (O&M) and capital cost issues. In this way, the RIAM performance indicators are effectively “risk-informed” and can be applied in evaluating cost aversion and revenue-impacting issues as well as conventional cost savings issues.

RIAM generates predictions probabilistically so that performance indicator information can be supplied to managers in terms of probability distributions as well as point estimates. This enables managers and other decision-makers to apply the concept of “confidence levels” in their critical decision-making processes.

In addition to primary economic performance indicators, the RIAM methodology provides safety performance indicators, like core damage frequency and large early release frequency, that give the decision-makers high confidence that investment implementation will not breach

NRC-established safety criteria for the plant (i.e., core damage frequency or core damage probability limits). In this way, decisions can be made to implement investments with positive impact on long-term profitability and reliability, while also providing for associated beneficial or negligible impact on plant safety. RIAM can also supply intermediate performance indicators, like projected plant trip frequency or projected generation loss (in MWH), to characterize the predicted impact of recommended investments on plant reliability. Experience has shown that a structured evaluation of these quantitative decision support performance indicators not only provides valuable relative prioritization information to the decision-makers, but also "injects" a more rigorous, systematic approach into the overall decision-making process than might otherwise be applied without their consideration. This report provides general introductory guidance on the development and application of quantitative decision support performance indicators and the analysis of our uncertainty in them at various stages of the plant improvement investment option development and implementation process. This process has been applied to LCM decisions evaluated by the STP Nuclear Operating Company (STPNOC) and described in this report.

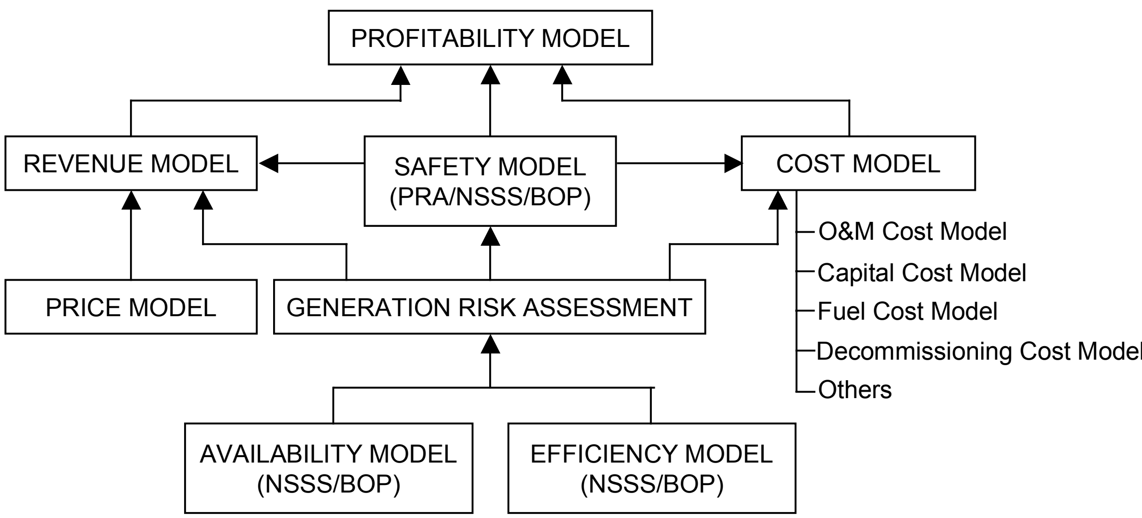

Figure E-1
RIAM Conceptual Model Overview Summary of Potential Benefits

Potential Benefits

Some benefits of the RIAM approach over a standard conventional plant economic analysis can be summarized as follows:

- Consistent, systematic, rigorous approach to major plant investment value-based decision making.
- Consistent treatment and integration of plant safety, reliability, efficiency, and cost factors in the decision-making process (i.e., "evens the playing field").
- Uncertainty analysis provides confidence levels for decision criteria related to change management, resource allocation, and staffing.

- Simultaneous treatment of safety, profitability, and budget constraints.
- Consistent framework for continuous monitoring and projection of station profitability and production performance.

Potential Applications

Potential applications of the RIAM method include:

- Refueling outage schedule and duration optimization
- Generating unit power uprate or upgrade
- Capital spares procurement analysis and prioritization
- Unit efficiency (i.e., heat rate) improvement
- Plant license renewal
- Treatment of risk from human errors
- O&M procedure improvement
- Operating/maintenance procedure training prioritization
- Trade-offs between on-line and off-line maintenance
- Quality assurance (QA) audit prioritization

Equipment Reliability and Life Cycle Management applications include:

- LCM planning at the plant level
- Equipment design modification optimization
- Major equipment refurbishment/replacement optimization
- Station major maintenance activity prioritization
- Component aging and aging management
- Component obsolescence management

Rough estimates put the initial cost of implementing RIAM at a plant at $100,000. On-going costs of RIAM are about $150,000 per year. Initial development of the RIAM approach and case study applications at STPNOC indicate that the potential for improvement of plant net present value ranges between roughly $1,000,000 and $200,000,000 per case study application. Consistent application of the RIAM method will support maximization of long-term profitability and maintaining of prudent safety, reliability, and efficiency standards with high levels of confidence.

1
INTRODUCTION

This report introduces the concept of using risk-informed asset management (RIAM) to help facilitate nuclear power plant LCM (optimizing plant operation and resource allocation for maximizing the value of plant physical assets and company financial assets over the remaining operational term of a plant or fleet of plants while maintaining safety). RIAM is a methodology, process, and (eventually) a software tool by which analysts review historical performance and develop predictive logic models and data analyses to provide plant managers and company decision-makers critical quantitative performance indicators. Examples of these indicators from Electric Power Research Institute (EPRI) and Nuclear Energy Institute (NEI) documents [91, 92, and 95] are:

- Net Present Value
- Projected Earnings
- Production Cost
- Nuclear Safety (WANO/NRC indices, core damage frequency, etc.)
- Power Production (output, capacity factor, availability, etc.)
- Efficiency (heat rate)
- Regulatory Compliance

RIAM estimates long-term projections of these and other performance indicators using a risk-informed approach. Unlike most conventional asset management approaches, RIAM incorporates low-frequency, high-consequence events that can occur over the long term, as well as shorter-term "expected" events, activities, and conditions, into its performance indicator prediction process. Also, RIAM generates predictions probabilistically, so that performance indicator information can be supplied to managers in terms of probability distributions as well as point estimates. This enables managers and other decision-makers to apply the concept of "confidence levels" in their critical decision-making processes. RIAM extends the historical use of risk concepts in assessing plant safety (via Probabilistic Risk Assessment [PRA], a.k.a. Probabilistic Safety Assessment [PSA]), and their more recent use in guiding the refinement and implementation of regulatory requirements, into the arena of comprehensive financial asset management.

1.1 Background

In the competitive era of nuclear power, the management of safety, production, and market/financial risk is crucial to all stakeholders. RIAM has been developed to take advantage of successful nuclear power industry applications of risk-informed technology, such as those performed by the STP Nuclear Operating Company's South Texas Project Electric Generating Station (STPEGS). From 1997 through 2001, a team of STPNOC and ABSG Consulting Inc. (ABSG) engineers and analysts made substantial progress in applying RIAM concepts to configuration management and financial asset management at STPEGS. The RIAM approach, envisioned to be developed by EPRI in collaboration with STPNOC, complements and integrates existing activities like PRA, PSA, equipment reliability assessments, plant maintenance optimization (PMO), life cycle management (LCM), and nuclear asset management (NAM). RIAM systematizes the asset management process and includes risk/uncertainty analysis.

There are many existing methods, requirements, and software tools that address asset, risk, and life-cycle management. In the following paragraphs we identify several of these and indicate how RIAM can complement, extend, and integrate them.

Safety Risk Management

Probabilistic Risk Assessment (PRA)

A foundation of the RIAM process is the conventional discipline of probabilistic risk assessment (PRA). Originally developed for the defense industry in the 1950s and 1960s, in the nuclear power industry, PRA is designed to model and predict the frequency of potential nuclear fuel damage and associated consequences associated with the operation of nuclear powered generating units. The key figure of merit in a conventional PRA is typically either core damage frequency (CDF) or frequency of radioactive release to the environment. PRAs are plant-specific analyses. PRA also applies many aspects of reliability, availability, and maintainability (RAM) analysis and reliability centered maintenance (RCM) technology developed to support commercial aircraft operations and maintenance management in the 1960s and 1970s.

Virtually all U. S. commercial nuclear power utilities have performed and continue to update PRAs for their plants. Some utilities developed their PRAs voluntarily while others developed them in response to the NRC requirements for Individual Plant Examinations (IPEs) [85 and 86]. RIAM applies the plant PRA in the safety analysis of RIAM's decision support process. As discussed later in this section, RIAM uses PRA techniques to examine availability and generation risk. The key figure of merit is power production.

Risk-Informed Regulations

Another foundation and motivation for RIAM development and implementation is based, in part, on several historical developments and issues, largely involving the incorporation of risk management technologies into nuclear power station programs and regulations via application of the plant PRA and associated configuration risk management program (CRMP) [16]. Some of these are:

- "Risk-informed" regulatory requirements in 10 CFR 50 (see the internet web site: http://www.nrc.gov/NRC/REACTOR/RISK50/index.html).
- Implementation of risk-informed technical specifications applications [10], revisions, and refinements such as
- The Nuclear Energy Institute (NEI) Risk-Informed Technical Specification (RITS) Task Force work [13, 16, 18, 21, and 33]
- "Standard technical specifications" development [22 through 26]
- STPNOC initial efforts on risk-informed diesel generator allowed outage time implementation, configuration risk management program (CRMP) development [16]
- Development of a risk-informed integrated safety management specification (RIISMS) [33 and 99]).
- Other risk-informed performance-based probabilistic risk assessment (PRA) applications such as: Risk-Informed In-Service Inspection (RI-ISI) and Testing (RI-IST) Programs [13, 14, 17, 18, 19, and 20]
- Risk-Informed Graded Quality Assurance (GQA) Programs [28 and its reference list]
- PRA support of Risk-Informed Maintenance Rule (10 CFR 50.65, specifically 10 CFR 50.65(a)(4)) Implementation [12 and 27]
- "State-of-the-Art" Living PRA standards (e.g., current ASME and ANS PRA Standards), PRA quality assurance, PRA configuration control, and periodic PRA update efforts.

RIAM is designed to take advantage of aspects of these applications of risk-informed technology that have been previously developed, reviewed and approved by the NRC, and implemented by a number of nuclear power plants. To support risk-based decision making in a competitive industry, RIAM extends aspects of safety asset management into the areas of physical and financial asset management.

Generation Risk Management (Physical Asset Management)

Reliability-Centered Maintenance (RCM) & Preventive Maintenance Optimization (PMO)

The uninterrupted supply of electrical power depends on the integrity of physical assets. The integrity of physical assets depends in turn on equipment maintenance practices and policies. In 1978, Stanley Nowlan and Howard Heap, working for United Airlines and using the commercial airline industry as their model source, published a milestone report [87], commissioned by the U. S. Department of Defense. This report described a then-new framework for maintenance program development and management called reliability-centered maintenance (RCM).

RCM employs fundamental reliability engineering tools such as failure modes, effects, and criticality analysis (FMECA) and reliability data analysis to identify and prioritize planned maintenance activities for facility systems, structures, and components (SSCs). Originally, RCM-planned maintenance activity intervals were primarily time-based and were established using engineering judgement. Since the mid-1980s, however, RCM has employed increasingly sophisticated techniques such as predictive maintenance tools and processes, now frequently referred to as condition-based maintenance. In condition-based maintenance, on-line equipment monitoring tools are applied to establish parameter baselines and thresholds designed to guide maintenance staffs in scheduling planned maintenance, using a "just-in-time" maintenance philosophy. Over the past 20 years, RCM has been specifically applied to several power plant systems by EPRI (see, for example, [88]).

In recent years, competitive pressures have been placing challenging demands on electric power plant owners and operators to revolutionize maintenance practices to optimize plant availability and production costs. As follow-on to RCM practices, EPRI has established a plant maintenance optimization (PMO) process for nuclear power plants [89], and has performed projects and activities to develop associated tools and techniques. PMO is designed to aid plant staffs in developing well-balanced maintenance programs. PMO balances corrective, preventive (i.e., planned), predictive, and proactive maintenance activities along with equipment availability and maintenance cost considerations, with the ultimate goal of maximizing plant value. RIAM provides a framework for applying these tools and techniques as well, but broadens the scope from plant maintenance policies and practices to all aspects of plant asset management. Rather than optimizing on the basis of reliability, availability and *cost* as in the traditional economically regulated electricity, RIAM optimizes on the basis of *value* in a deregulated competitive industry. In a market-based industry, the net present value (NPV) of a physical asset is defined as the integral of cash flow (revenues less costs) over the remaining life of the plant. RIAM focuses on NPV as the main figure of merit for profitability.

Life Cycle Management (LCM)

A traditional process in cradle-to-grave (design, operation, and decommissioning management of heavy industrial facilities is "life cycle management." In its broadest definition, nuclear life cycle management (LCM) is the integration of nuclear power plant engineering, operations, maintenance, regulatory, environmental and economic planning that (1) manages plant condition (including aging and obsolescence), (2) optimizes operating life (including the options of early retirement and license renewal), and (3) maximizes plant value while maintaining safety. LCM benefits a plant whether it plans to operate over its original 40-year license term or plans to apply for license renewal to operate over a 60-year term. LCM is sometimes viewed in a narrower sense, limited to physical asset management including long-term treatment of equipment reliability, aging, and obsolescence of systems, structures, and components (SSCs). This meaning of LCM is synonymous with "long term equipment reliability." Currently, all commercial nuclear power plants are applying LCM.

In 1998 EPRI prepared an "LCM Implementation Guide" [35], which reintroduced the concepts/benefits of LCM to nuclear plant owners/operators and gave EPRI recommendations on how to organize and implement plant LCM programs. From 1998 to 2001, an EPRI LCM demonstration project developed an EPRI LCM process and software and showed how LCM can be implemented at operating nuclear power plants [2]. In parallel, EPRI, Duke Energy, Xcel Energy, South Carolina Electric & Gas, and Wolf Creek Nuclear Operating Company sponsored LCM applications to twelve types SSCs at four plants -- Oconee, Prairie Island, VC Summer, and Wolf Creek [2].

The LCM demonstration project addressed LCM planning at the SSC level. Typical of current commercial nuclear power plant LCM programs, the EPRI program used a point estimate (best estimate) approach to technical and economic evaluations of LCM plans.[1] RIAM does LCM planning at either the SSC or the plant level. Plant level planning is important because systems interactions, budget limitations, and potential double counting can be addressed in the optimization process. Based on extensive experience with projects and programs at nuclear power plants, managers know that inputs to their LCM decisions are generally highly uncertain. Uncertainty arises due to many factors, but mainly from the long time scales (usually on the order of decades) and equipment reliability estimates. Unlike almost all current nuclear power plant LCM programs, RIAM takes the valuable step of addressing uncertainties in plant performance and cost by means of probabilistic analysis. With RIAM, the NPV of various LCM plan management alternatives can be expressed in the form of risk curves (rather than point estimates) with potentially large, but heretofore unquantified uncertainty bands. RIAM accepts the same input parameters (e.g. costs, failure rates, and lost generation due to failures and maintenance) as current plant LCM programs and as LCM software such as EPRI's LcmPLATO and LcmVALUE. Using RIAM, one can input not only point values of these parameters, but also probabilistic ranges for more important plant value drivers such as O&M costs and lost generation. As discussed in Section 3, future RIAM software, which will do LCM plan optimization at the plant level, will incorporate appropriate features of the existing SSC-level LCM planning tools.

License Renewal

Increasingly more attention was placed on LCM during the two-decade industry effort to establish a stable license renewal process, which extends the operating term of US plants from 40 to 60 years. The process essentially ensures to operators and the NRC that long term aging degradation effects, not significantly present nor specifically addressed in the original design basis of a plant, are managed by means of monitoring, refurbishment, or replacement before they advance to the point of impacting safety. During the 1990s, the License Renewal Rule addressing aging management for license renewal was issued. The aging management required by the rule focuses on aging effects in SSCs (mainly passive SSCs) that may affect safety and are not in existing plant programs. The scope of equipment covered by the rule does not include SSCs that do not affect safety.

With an adequate level of safety during an extended term having been ensured by the License Renewal Rule, LCM focuses on all SSCs important to availability, production, and profitability. The scope of SSCs that warrant LCM planning is established by one of the first steps in the EPRI LCM process [2]. RIAM treats the impact of all LCM-important SSCs on plant value while performing an economic evaluation that optimizes LCM plan alternatives at the plant level. It also uses PRA to ensure that the optimum LCM plan for each important SSC does not compromise safety.

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[1] An LCM plan is a long-range plan for preventive maintenance, replacement, refurbishment and/or redesign of an SSC important to safety and reliability that optimizes the SSC's contribution to plant value.

INPO Equipment Reliability Process

INPO has provided the nuclear industry with a detailed technical process for identifying maintenance activities to maintain or improve the reliability of equipment important to safety and/or economics. Recently, INPO AP-913, the INPO document describing the equipment reliability process [39], was revised. One of the purposes of the revision was to enhance the process by increasing its attention to long-term planning and LCM. The INPO process calls for ensuring that near- and long-term maintenance activities are included in a plant's business plan. Currently, the EPRI LCM process and planning software are identified as tools that can be used to assist in the implementation of AP-913. When available, RIAM, with its treatment of risk and plant-level life-cycle equipment reliability will be a more comprehensive tool to assist utilities in implementing the AP-913 process.

Nuclear Asset Management (Financial Asset Management)

RIAM is an updated and upgraded specialization of conventional strategic financial asset management and associated decision analysis techniques applied to electric utility management. It is designed to integrate systems analysis and uncertainty analysis techniques into the conventional decision analysis framework to optimize financial decisions. RIAM is a logical extension of current nuclear asset management (NAM) techniques developed and deployed by EPRI. Two such techniques are described briefly in the following paragraphs.

Strategic Asset Management (SAM)

The heart of risk-informed asset management is the conventional decision analysis technique, which uses random sampling or decision trees to treat uncertainty in the decision-making process. Sensitivity analysis, tornado diagrams, decision trees, and random sampling simulation have been incorporated into EPRI products over the last three decades. In the 1990s, EPRI pioneered the application of decision analysis in the electricity generating industry in an asset management framework called "Strategic Asset Management" (SAM) for improving business decisions and better aligning investments and resource allocations with corporate goals (see EPRI TR-102730 and TR-104917). SAM uses uncertainty analysis to translate corporate objectives into meaningful value measures to guide operational decisions and suggests a process for quantifying the uncertainties, risks, and returns of decision alternatives. This strategic decision process was applied in an asset management case study of license renewal at Calvert Cliffs. It also was the forerunner of the Nuclear Options Model (NOM) for plant valuation. In 2001, NOM was upgraded to NAPE, the Nuclear Asset and Project Evaluation model described briefly below.

Nuclear Asset & Project Evaluator (NAPE)

As did NOM, the Nuclear Asset and Project Evaluator tool uses the state-of-art options pricing method for discounted cash flow (DCF) calculations of plant NPV that guide operating life decisions. It also calculates NPV without and with a specified plant project investment, which is then used to prioritize plant O&M and capital projects. The NAPE code is stand-alone, but can also be a module of the EPRI Energy Book System, which manages risk at the corporate level of a generating company. NAPE can be viewed as a high-level NPV calculator that uses options DCF in contrast to the conventional DCF method currently envisioned for the developmental stage of RIAM. As discussed in Section 3, the planned production-grade version of RIAM will include the options value of an investment in plant improvement.

1.2 Motivations for Improving Risk Management Methods and Tools

Some issues providing motivation to nuclear utility companies for development and application of RIAM are:

- Electricity industry transition to a deregulated environment -- financial asset management changing from cost-based to value-based
- Movement in the industry to risk-inform operations, regulations, and physical/financial asset management
- Increasing pressure to decrease incremental generation costs and increase long-term profitability at the generating station level of the energy business
- Increasing electricity pricing competition with other (non-nuclear) generation sources
- General corporate pressures to reduce costs and increase productivity
- Current surge in interest in the international business world in enterprise risk management and associated tools and techniques.

Clearly, one of the strongest motivations for nuclear utility companies to implement a NAM process via RIAM at their plants is to optimize plant investment in operations, maintenance, and capital improvements, thereby enhancing business enterprise profitability and competitiveness.

1.3 Objectives

The general objective of this EPRI project is to provide electricity generation companies and plants with a methodology and software for implementing effective and efficient risk-informed physical and financial asset management.

The complete RIAM project will be carried out in phases. This report covers the planning phase with the following objectives.

1. Formulate and describe a RIAM methodology for managing physical and financial plant assets.

2. Identify the benefits of RIAM over existing asset management and LCM processes and how features of existing methods and tools can be incorporated into RIAM.

3. Provide EPRI and its member utilities with a development plan for RIAM software tools.

Depending on the industry level of interest and funding for future work, follow-on phases of the RIAM project will include software development, pilot plant applications, an implementation guide, and training workshops.

1.4 Approach

The general approach applied in this initial phase of RIAM methodology development and communication is as follows:

- Consolidate lessons learned at STPNOC over the last three years of RIAM-related work into a concise refined RIAM methodology for the U. S. nuclear power industry (see Section 2.4 and Appendix C).
- Review and incorporate mutually supporting synergistic aspects of current ABSG/STPNOC RIAM methods and related EPRI, INPO, NEI NAM/LCM/Equipment Reliability processes, methods, and tools.
- Communicate the RIAM method and associated existing and proposed tools and techniques to power plant operating companies and other key industry organizations (i.e., EPRI, INPO, NEI, NRC, ASME, ANS, Owners Groups, etc.).
- Incorporate industry feedback into an integrated EPRI-industry plan for future RIAM methods and tools development, pilot plant case studies, and follow-on industry applications.

The approach herein incorporates aspects of the EPRI PSA Applications Guide [9] prepared in 1995, buts goes far beyond conventional probabilistic safety analysis. This approach has been developed to take advantage of successful applications of risk-informed technology, such as those previously approved for application by STPNOC. RIAM complements and integrates, rather than duplicates, existing probabilistic safety assessment (PSA), probabilistic risk assessment (PRA), life cycle management (LCM), and nuclear asset management (NAM) methodologies, such as those covered briefly above.

Some of the guiding principles recommended for RIAM process development are as follows:

- Nuclear safety requirements remain as mandatory operating “constraints” on managing improvements at nuclear power plants (i.e., nuclear safety is the foremost requirement).
- Nuclear safety, plant reliability, and long term profitability are assessed, analyzed, predicted, monitored, and managed in an integrated (as opposed to a rigid organizationally structured) fashion at nuclear power stations.
- Decision analysis, probabilistic risk assessment modeling, and data analysis concepts previously used for safety assessment are applied to address productivity and financial uncertainties as well, and enhance information provided currently by point value models and data analysis.
- RIAM methodology development needs to be consistent and integrated with existing LCM and NAM activities of all industry organizations.
- RIAM process development should be coordinated with other current industry risk-informed technology application efforts such as GQA programs, RI-Equipment Categorization

(i.e., Option 2), RI-ISI/IST programs, RITS (or RIISMS) programs, risk-informed maintenance rule administration, etc.

- Important terms are defined to be consistent with the large body of literature on related areas, such as PSA, LCM, NAM, SSC aging, and maintenance.

This introduction has described the background and objectives of the report. Section 2 presents an overview of the RIAM methodology. Section 3 summarizes the recommended scope of work for future RIAM development, including associated software development. Section 4 presents a discussion of the potential cost-benefit of implementing RIAM. Section 5 presents a comprehensive list of references and information sources supporting this report. Also, appendices are provided to present examples of RIAM application. These appendices also include a glossary of key terms and a list of acronyms.

2
RIAM METHODOLOGY

The general concept of RIAM is to develop a rigorous systematic risk-informed approach to assessing, analyzing, predicting, and monitoring power plant economic (i.e., financial) performance while maintaining high confidence that NRC-established safety limits will not be breached. The basic concepts of the RIAM methodology and some examples of RIAM applications are presented in the RIAM concept presentation provided in Appendix D. In general, the RIAM process involves the modeling and probabilistic quantification of decision support performance indicators to aid plant decision-makers in determining not only which plant improvement investment options should be implemented, but also how to prioritize plant resources for their implementation based on their predicted levels of profitability. As stated in Section 1, key decision support indicators include, but are not limited to, the following:

- Net Present Value
- Projected Earnings (sometimes referred to as "profitability" in RIAM)
- Projected Costs
- Nuclear Safety (core damage frequency, etc.)
- Power Production (availability, capacity factor, etc.)
- Efficiency (heat rate)
- Regulatory Compliance

References [91], [92], and [95] identify and describe the types of performance indicators that will be supported by RIAM. However, in RIAM, future projections of these performance indicators are determined using a risk-informed approach. Unlike most conventional asset management approaches, RIAM includes the contribution of low-frequency, high-consequence events that can occur over the long term, as well as shorter-term "expected" events, activities, and conditions, into its performance indicator prediction process. Thus, using the RIAM approach, these performance indicators incorporate predicted cost aversion issues as well as the more conventional direct operations and maintenance (O&M) and capital cost issues. In this way, the RIAM performance indicators are effectively "risk-informed" and can be applied in evaluating cost aversion and revenue-impacting issues as well as conventional cost savings issues. Also, RIAM can generate predictions probabilistically so that performance indicator information can be supplied to managers in terms of probability distributions as well as point estimates. This enables managers and other decision-makers to apply the concept of "confidence levels" in their critical decision-making processes.

In addition to primary economic performance indicators, the RIAM methodology provides safety performance indicators, like core damage frequency and large early release frequency, that give the decision-makers high confidence that investment implementation will not breach NRC-established safety criteria for the plant (i.e., core damage frequency or core damage probability limits). In this way, decisions can be made to implement investments with positive impact on long-term profitability and reliability, while also providing for associated beneficial or negligible impact on plant safety. RIAM can also supply intermediate performance indicators, like projected plant trip frequency or projected generation loss (in MWH), to characterize the predicted impact of recommended investments on plant reliability. Experience has shown that a structured evaluation of these quantitative decision support performance indicators not only provides valuable relative prioritization information to the decision-makers, but also "injects" a more rigorous, systematic approach into the overall decision-making process than might otherwise be applied without their consideration. This report provides general introductory guidance on the development and application of quantitative decision support performance indicators and the analysis of our uncertainty in them at various stages of the plant improvement investment option development and implementation process. This process has been applied to "real" LCM decisions evaluated by STPNOC (See Appendices C and D).

While most nuclear power station LCM programs have established processes that address portions of the financial asset management/profitability prediction process, most do not have a comprehensive top-down integrated focused approach. The envisioned RIAM methodology incorporates the ability to predict important decision support performance indicators at the station or corporate level, while maintaining the capability of displaying, in an integrated fashion, useful breakdowns of contributors to the major decision support performance indicators. The ability to perform "risk decomposition" and "risk roll-up" comparative analyses within the RIAM methodology has proven to be valuable in the decision-making and decision-implementation process at STPNOC.

In order to appreciate the top-down integrated approach applied in the RIAM method, it is first important to understand the relationships among the important LCM-related elements of power plant operation maintenance, and management, and how they impact station value. Figure 2-1 displays a linked power station value map showing a conceptual overview of these relationships.

In its ultimate form of development and application, RIAM encompasses the consideration of all historical (i.e., experienced) and potential future cost-impacting and revenue-impacting events, activities, and conditions at the target nuclear power station(s). The scope of a fully-developed RIAM process includes assessment, prediction, and monitoring of all significant factors impacting station costs and revenues, including spot market prices for electricity and associated electricity sales contracts. However, the primary focus of a practical RIAM process is generally on the factors that can be controlled or significantly influenced by station or corporate management and support staffs. These factors include, but are not limited to, the following:

- Planned outage (i.e., refueling outage) frequency and duration
- Nuclear safety (i.e., reactor fuel damage frequency, large early release of radioactivity frequency, frequency and magnitude of unplanned radiation exposure to the general public, etc.)
- Reactor trip frequency
- Station reliability and availability performance (i.e., control of generation (MWH) losses)

- Unit thermal efficiency (i.e., heat rate) performance
- Frequency and magnitude of lost-time industrial safety incidents
- Frequency and magnitude of liability lawsuits
- Staffing levels
- Direct O&M and capital costs
- Short and long-term electricity sales contracting arrangements, etc.

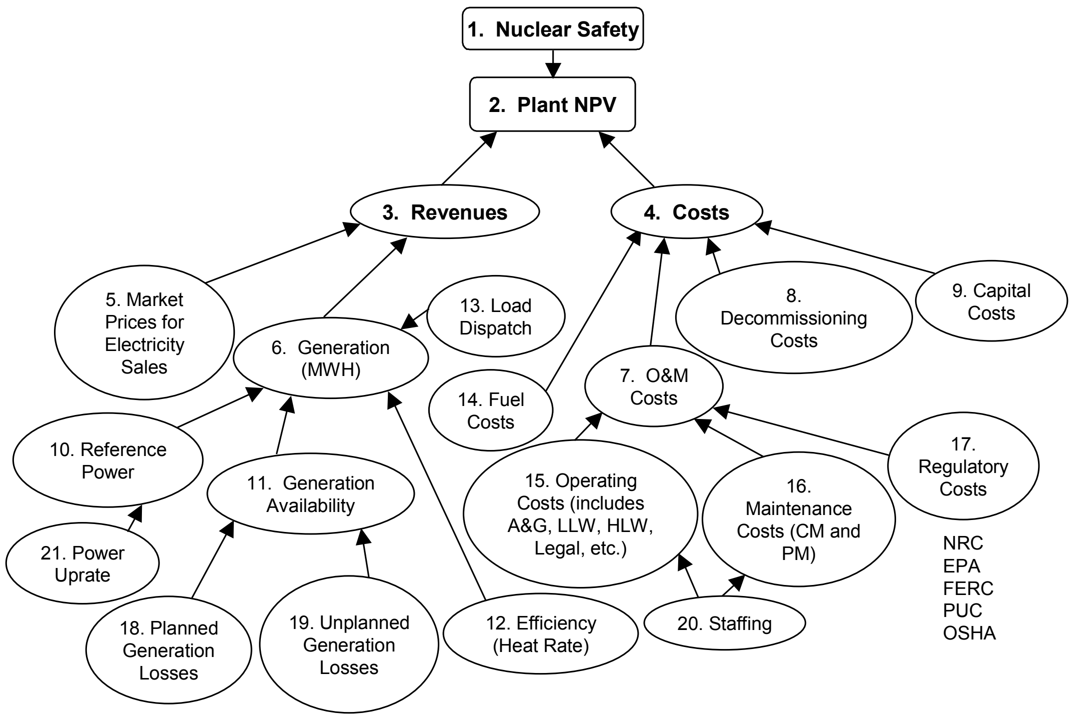

Figure 2-1
Nuclear Station Value Map

All this information is generally available within the existing scope of LCM activities at nuclear power stations. The RIAM approach utilizes a top-down logical approach to identify and analyze cost and revenue impacting factors (or parameters) that make the most significant contributions to station or company long-term profitability and value, and therefore, likely present the most significant opportunities for financially sound plant improvement investments. Thus, RIAM can serve as an effective strategic decision-support tool.

2.1 RIAM Conceptual Model

Figure 2-2 presents a general overview of the asset management approach applied in RIAM.

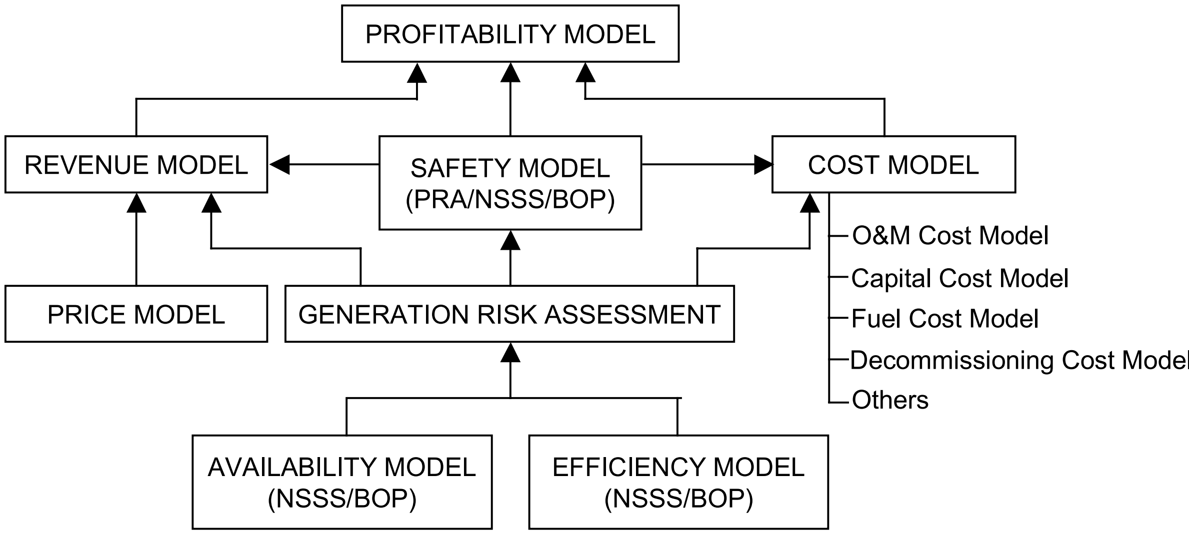

Figure 2-2
RIAM Conceptual Model Overview

Table 2-1 relates RIAM model elements in Figure 2-2 with the nuclear station value map elements in Figure 2-1. In practice, these model elements are, of course, intricately interrelated and interdependent in their impact on generating station profitability and value.

Table 2-1
RIAM Model Relationship to Nuclear Station Value Map Elements

RIAM Model Element (See Figure 2-2)	Nuclear Station Value Map Element (See Figure 2-1)
Profitability Model	1, 2, 3, and 4
Safety Model	1
Generation Model	6, 10, 11, 12, 13, 18, 19, and 21
Availability Model	11, 18, and 19
Efficiency Model	12
Cost Model	7, 8, 9, 14, 15, 16, 17, and 20
Market Price Model	5

Figure 2-3 displays the relationships of a preliminary set of RIAM performance indicators with the RIAM model in Figure 2-2.

The performance indicators identified in Figure 2-3 are defined and described in detail in [91], [92], and [95]. In RIAM applications at specific reactor plants, a subset of these performance measures is usually selected for decision support, and these selected performance measures are validated by the plant staff.

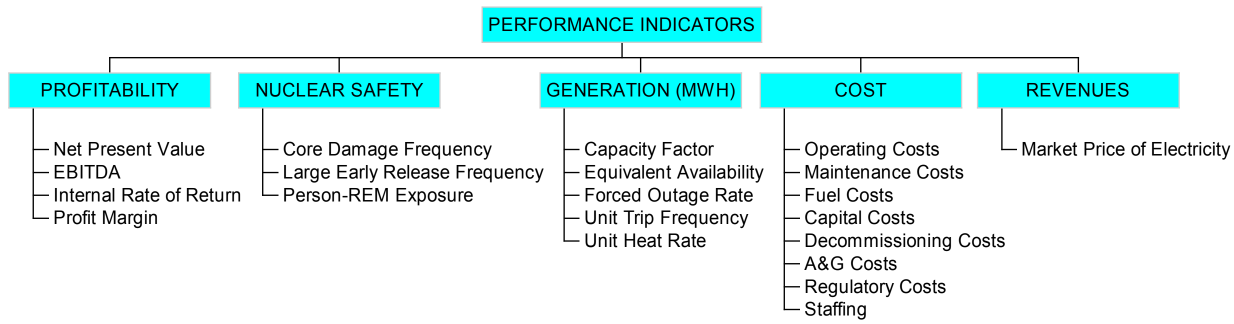

Figure 2-3
Preliminary RIAM Performance Indicators

The RIAM method includes the explicit treatment of uncertainty and time-dependence within the calculation processes for the decision support performance indicators. Experience has shown that the capability of displaying, quantitatively, our uncertainty about key decision performance indicators, and their predicted variation over time, provides decision-makers with a valuable tool. For example, choosing a specific proposed plant improvement option may show, through a RIAM analysis case study, that, based on point estimate or mean values, there would be a significant increase in predicted value of the station over its expected life. However, the same RIAM analysis may show that there is, for the same decision performance indicator, a significant cumulative probability of negative impact on station value (see Figure 2-4). Given such results, the decision-maker may choose to commission additional research and analyses to reduce the existing uncertainty bounds around the key decision performance indicator before making a final decision. Conversely, if the RIAM case study shows a relatively narrow band of uncertainty about a prediction of significant net benefit associated with a specific improvement option, the decision-maker will likely choose to move forward with the implementation of the proposed improvement option. In a fully-developed RIAM process, specific decision criteria, including consideration of both mean values and uncertainty bounds of multiple decision support performance indicators, are clearly defined for supporting the decision-maker in the complete spectrum of likely decision-requirement situations or scenarios.

The ability to incorporate confidence intervals in decision criteria is a significant advantage of RIAM over conventional "point estimate only" supported decision-making. Figure 2-4 presents an example showing probability density distributions of projected investment net present value (NPV) for two different investment options, both with the same predicted mean (or point estimate) net present value performance indicators ($300,000 in this case). However, to most plant managers, Investment Option 2 would be preferable, and would likely be recommended over Option 1 in the RIAM process, because the outcome is more certain, and because there is a much lower chance of a negative payback result with Investment Option 2. There are many realistic examples of decision-making processes in which the assessment of uncertainty significantly alters the outcome of the decision identification and selection, when compared with a "point-estimate-only" decision-making approach. In RIAM, decision criteria (i.e., investment option selection criteria) can be applied based on uncertainty distribution characteristics as well as point estimates.

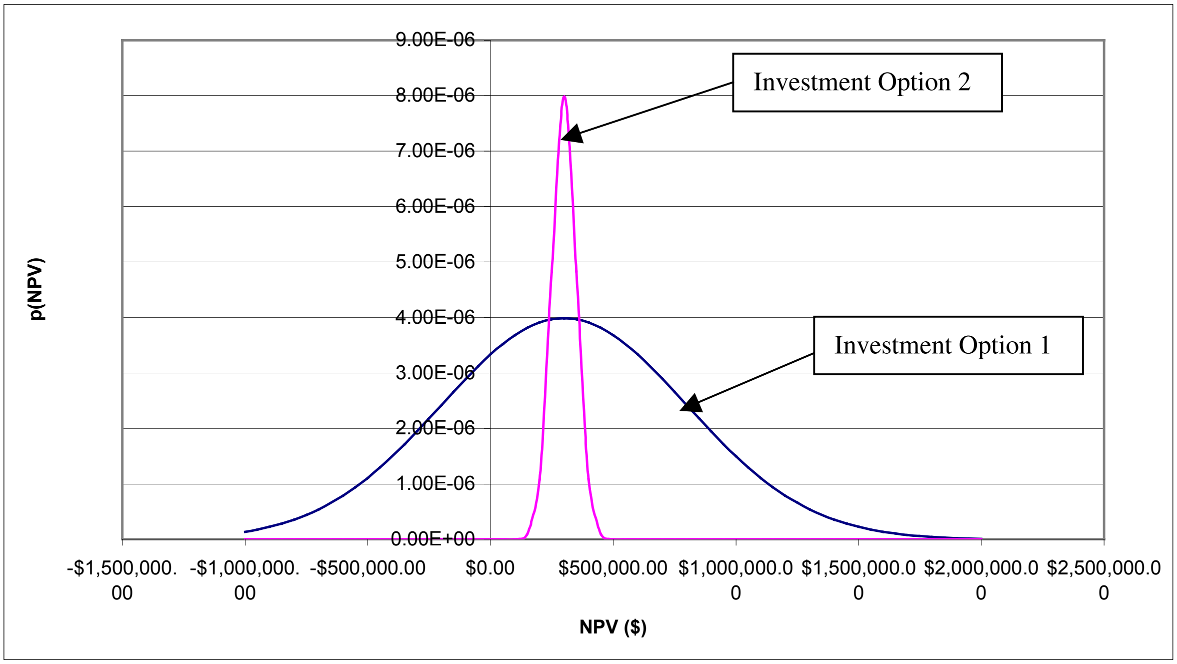

Figure 2-4
Example Application of Confidence Levels in RIAM

RIAM includes both monitoring and trending of historical performance as well as prediction of future performance. After the baseline RIAM process is developed for a specific power station or company, it can be applied in the station asset management process. There can be many differing sources of motivation for plant investment. Investment can be motivated internally at the station via monitoring, trending, and analysis of selected plant performance indicators. In this process, the analysis of performance indicators includes peer group comparative analyses and benchmarking analyses to aid in the identification of potential investment or improvement options and strategies. Investment can also be motivated from outside sources such as regulatory agencies or owner/stockholder groups.

The RIAM model can be used to predict both baseline (i.e., “base case”) performance and performance under an “investment case,” often referred to as a “delta case” in the plant decision support framework. This process is similar to the base case and “alternative LCM plans” analyses described in the EPRI LCM process [2]. A general representation of the RIAM process flow is provided in Figure 2-5.

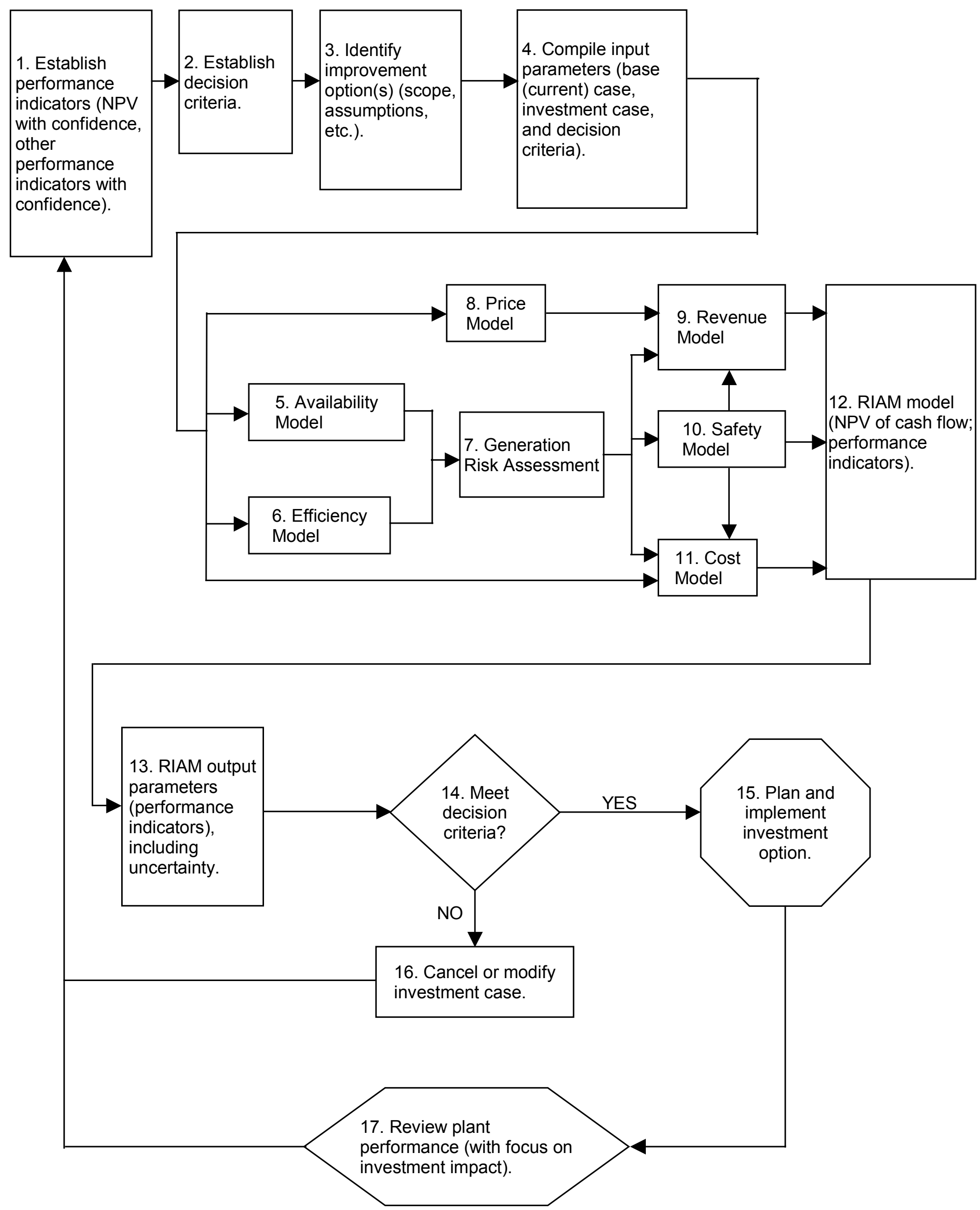

Figure 2-5
RIAM Process Flow Chart

The first step of the process is the establishment of appropriate performance criteria to support the types of decisions being considered at the plant. Typically, these decisions involve assessment of various plant investment options designed to improve some aspect of the station (i.e., operations, maintenance, etc.) or mandated changes required by regulating authorities. The key performance indicators usually include net present value (NPV) and other decision support metrics identified in Section 1. In RIAM, these performance indicators include both point estimate and confidence interval parameters.

The second step is to establish decision criteria associated with the selected performance indicators. This generally involve establishing desired confidence levels for performance indicator decision limits (i.e., having at least 95 percent confidence that the projected NPV of a selected investment option is above some pre-established positive value). This will help guide which portions of the remaining RIAM process will need to be exercised in the overall decision support process. Decision criteria generally include the projected impact of the investment option of interest on selected plant-level performance indicators, such as net present value (NPV), earnings (i.e., EBITDA as defined in [92]), and internal rate of return (IRR) (see [92] for industry definitions of these performance indicators). This projected change in plant NPV, accounting for the implementation of the investment option, is known as the NPV of the investment option (often referred to as the "net benefit" of the investment option). Investment option decision criteria also include the benefit-to-cost ratio, payback period, return-on-investment (ROI) of the investment option. The benefit-to-cost ratio is typically defined as the projected gross benefit of the investment at the end of plant life, using discounted cash flow accounting, divided by the total implementation and investment "maintenance" costs over the same time period. The payback period is typically defined as the time between initial implementation of the investment and the time at which the projected value of that investment, using discounted cash flow accounting, is zero (i.e., the time at which the investment value passes through zero from negative to positive). The ROI of an investment option can be calculated in a number of ways, but the recommended definition of investment ROI for RIAM decision support is as follows: ROI is the equivalent "risk-free" rate of return on the investment over the investment life (i.e., the equivalent annual percentage rate (APR) on a secure "certificate-of-deposit" type investment instrument with a principal value equal to the investment cost and an "end-of-life" value equal to the projected NPV of the investment). In addition to financial performance indicator decision criteria, other "constraint" performance indicator decision criteria can and should be applied. For nuclear power plants, the key constraint performance indicator is nuclear safety, most frequently defined as the projected core damage frequency (CDF) for the plant. Other nuclear safety performance indicators include large early release-of-radioactivity frequency (LERF) and projected public radiation dose (in person-REM per year) associated with projected core damage events. References [9] and [33] provide definitions of typical nuclear safety performance indicators. These criteria can also include other performance indicators supported by RIAM as defined in [91], [92], and [95]. In addition to projected values of selected performance indicators and projected changes in these performance indicators associated with investment option implementation, the concept of confidence levels can be applied in the selected set of decision criteria. For example, the decision-makers may desire to have a confidence level of no less than 60% that the NPV of a selected investment option is greater than a particular value. Similarly, they may desire to have a confidence level no less than 90% that the NPV of a selected investment option is positive (i.e., the chance that the investment will at least pay itself back over plant life). Conversely, we can view this criterion as having no more than a 10% chance of loosing money on the investment over plant life. These confidence level criteria can be applied to one or several performance indicators in the RIAM process.

The third block of the process includes the identification of candidate improvement investment options, including the description of improvement option scope and associated bases and assumptions. This candidate improvement investment option identification process is supported, in practice, via the monitoring of historical and projected performance indicator parameters and trends, and comparison of these parameters and trends to associated performance goals. For example, if we note that plant value is trending down, and that this is related to an increasing trend in forced outage rate (increased unplanned generation (MWH) loss), we investigate the component cause category(ies) associated with this trend, and compare this performance with that of our previous unit history, entire industry group history, and/or a “peer group” of similar plants, if available. We use this information to help identify potential investment options (i.e., design improvements, preventive maintenance program revisions, spare parts procurement/inventory status, etc.) that might cost-effectively reduce the projected forced outage rate. In practice, this initial step of the RIAM process is one of its most important elements.

The fourth step in the RIAM process is to compile base case and investment option case input parameters and enter them in the appropriate models in RIAM. In most cases, these input parameters include, at a minimum, basic component failure rate, exposure time for associated failure modes, and failure recovery (or repair) time parameters, as well as investment cost and associated projected expenditure timing parameters. In most cases, the RIAM model can be constructed to accept investment case parameters in terms of absolute values or percentage changes in baseline values.

In steps five through eleven of the RIAM process, the appropriate RIAM “component” models and/or databases are exercised to provide performance indicator results and to provide follow-on input data for the RIAM NPV model. In most cases, at a minimum, the plant availability and plant safety models must be exercised, at some level, to adequately evaluate any particular investment option. It is important to note that exercising these two models includes not only component failure mode data analysis, but also, very importantly, human error mode data analysis. In the phased or tiered approach for RIAM defined later in this section, exercising these models can frequently be accomplished at high (i.e., less detailed) levels to perform screening evaluations of selected investment options. In this portion of the RIAM process, the analyst may need to also exercise the plant efficiency (i.e., heat rate) model to calculate follow-on input parameters for the RIAM NPV model.

In the twelfth step of RIAM, the analyst exercises the RIAM cash flow model to calculate projected financial performance indicators necessary for supporting the investment option implementation decision. In step thirteen, these financial performance indicators, including, for example, net present value (NPV) of the investment option (sometimes referred to as the “net benefit” of the investment option), benefit-to-cost ratio, payback period, and ROI of the investment option, must be evaluated and compared to the decision criteria selected for the associated investment option implementation decision. For multiple investment options, ranked lists of the options are constructed in step eight of this process based on key performance indicators and parameters, including investment option NPV, projected investment implementation cost, ROI, and CDF impact, to help the decision-makers develop investment implementation “go-no go” and timing recommendations. This evaluation then supports the final steps (i.e., steps 14 through17 of Figure 2-5) of the RIAM process. If the decision criteria are deemed to be met, the investment option can be recommended, based on RIAM, and the investment option planning, development, and implementation process is recommended to proceed. If the decision criteria are not met, the RIAM analyst will recommend that the investment option, as defined, not be pursued until revised or refined such that the decision criteria are met. If the decision criteria are met, and the investment option of interest is implemented, then plant performance indicators are monitored with specific focus on the impact of the investment option on plant performance indicator trends, so that investment option implementation effectiveness can be evaluated over plant life. In practice, the RIAM process can be repeated at any desired stage of investment option development as associated new or refined data and input parameters are identified, defined, and quantified.

The general types of RIAM NPV model input parameters are listed in Table 2-2.

Table 2-2
Types of RIAM NPV Model Input Parameters

Model Parameter Type	Units
Outage Frequency	Refueling Outages/Year/Unit
Planned Refueling Outage Duration	Days/Outage (by Case)
Base Case Unit Average Service Factor	% Time On-Line
Average Net Power Rating	MWe (by Unit)
Average At-Power Cost of Power Production (Direct Costs)	$/Month at Power/Unit
Average Lost-Time/Liability Incident Rate	Events/Year
Average Lost-Time/Liability Incident Cost per Event	$/Event
Fraction of Average Lost-Time/Liability Incident Rate Dependent on Outage Duration	Unitless Fraction
Operational CDF - Base Case	Events/Calendar Year/Unit
Outage CDF	Events/Outage Hour/Unit
Fraction of Outage CDF Dependent on Outage Duration	Unitless Fraction
Average Integrated Public Dose in Person-Rem per CDF Event	Person-Rem/Event
Average Risk-Related Dose Cost per Person-Rem	$/Person-Rem
Average Risk-Related Site Cost per CDF Event	$/CDF Event
Direct Cost Outage Duration Dependence Factor	Unitless Fraction
Average Fuel Expenses	$/Year
Average Capital Costs	$/Year
Average Decommissioning Expenses	$/Year
Average Administrative and General Costs	$/Year
Average Sales Price of Electricity	$/MWH
Selected Component Failure Rates (by Failure Mode)	Events/Hour or Events/Demand
Selected Component Failure Mode Exposure Parameters	Hours/Year or Demands/Year
Selected Component Failure Recovery Duration Parameters	Hours/Event
Selected Component Failure Event Generation Losses	MWH/Event
Reactor Fuel Failure Rate	Events/Operating Hour/Unit

In addition to these input parameters, the fundamental station cost element parameters must be entered into the base case model. At STPNOC, there are approximately 10,000 of these cost element parameters identified by cross-referencing “cost center,” “program element,” and "element-of-expense" identification codes within the STPNOC accounting system. Then, in addition to the cost element parameters, there are PRA, BOP, and heat rate model input parameters that must be entered into their respective models. The data analysis work required for the development of these input parameters is an important part of the work scope discussed in Section 3 of this report.

2.2 Three-Tiered Evaluation Approach

For most practical applications of RIAM decision support for proposed station investments, a three-tiered or three-phase case study approach is recommended. Plant investment recommendations can be originated by plant organizations or outside organizations. These "investment package" recommendations can involve hardware design modifications, operations or maintenance procedure changes, management policy changes, or combinations of these investment sources. The first two phases of RIAM analysis are screening analyses of potential results of investment implementation on predicted plant long-term profitability. The third phase is a more detailed "best estimate" analysis of the predicted impact of the investment on corporate long-term profitability, including a presentation of uncertainty.

Level 1 Screening Analysis

In the first level of analysis for proposed investments, the RIAM team will, with assistance from other plant staff, identify the elements of the RIAM Reliability Model that could be affected by the proposed investment, and make rough optimistic bounding estimates of the implementation costs associated with the investment. Then the RIAM team will determine how to modify the reliability model data and/or model logic to estimate the maximum potential positive impact of the investment on predicted plant reliability. The RIAM team will then execute a reliability model case study incorporating these data and/or model changes. It may also be necessary to execute a limiting case study of the expected investment on the PRA results, but most frequently an estimate of the limiting positive effect on (i.e., maximum reduction in) predicted core/fuel damage frequency (CDF) performance indicators is sufficient. Similarly, the RIAM team will consult plant staff members to obtain a rough bounding estimate of the potential limiting positive impact on other plant cost impacts, such as reduction in operations and/or corrective or preventive maintenance costs. The results of the reliability model case study and estimates for change in CDF and/or other cost-benefit factors can then be incorporated into an optimistic "delta" profitability calculation. This can be accomplished using standard Microsoft Excel spreadsheets and may employ uncertainty analysis via supplementary software such as Crystal Ball or @Risk, but generally will be a point estimate calculation only. The result of this screening analysis is an "upper bound" estimate on the potential net benefit of the investment on plant long-term profitability. The key resultant performance indicators provided by the RIAM team in this bounding analysis will include predicted net benefit over the remainder of expected plant life, benefit-to-cost ratio, payback period, estimated gross investment implementation and maintenance cost, estimated change in long-term plant profitability, and return-on-asset annual percentage rate. The RIAM team can provide plant management with projections of these "optimistic" level 1 screening decision support performance indicators to help determine if the recommended investment package should be discontinued or developed further and analyzed in greater detail.

Level 2 Screening Analysis

The Level 2 screening analysis is very similar to the Level 1 analysis. The difference is that, in Level 2, the RIAM team, with additional support from other plant staff members as necessary, will expend additional effort in the development of initial "best estimate" parameters for reliability model failure rate and/or model changes, and for implementation and other cost impact factors expected to be associated with the proposed plant investment package. The RIAM team will then execute a reliability model case study incorporating these data and/or model changes. It may also be necessary for the RIAM team to execute a refined case study of the expected investment on the PRA results, but most frequently the team can just estimate the "best estimate" effect on predicted core/fuel damage frequency (CDF) performance indicators. Similarly, the RIAM team will consult plant staff members to obtain a rough best estimate of the potential impact on other plant cost impacts, such as change in operations and/or corrective or preventive maintenance costs. The results of the reliability model case study and estimates for change in CDF and/or other cost-benefit factors will then be incorporated into a rough best estimate "delta" profitability calculation that will normally be accomplished using standard Microsoft Excel spreadsheets and will generally employ uncertainty analysis via supplementary software such as Crystal Ball or @Risk. The result of this screening analysis is a rough best estimate on the potential net benefit of the investment on plant long-term profitability. The key resultant performance indicators provided by the RIAM team in this analysis will, as in Level 1, include predicted net benefit over the remainder of expected plant life, benefit-to-cost ratio, payback period, estimated gross investment implementation and maintenance cost, estimated change in long-term plant profitability, and return-on-asset annual percentage rate. The RIAM team can provide projections of these "more realistic" level 2 screening decision support performance indicators to help determine if the recommended investment package should be discontinued or developed further and analyzed in greater detail.

Level 3 Detailed Analysis

The Level 3 detailed analysis is a full scope profitability model analysis. In Level 3, the RIAM team, with additional support from other plant staff members as necessary, will expend additional effort in the development of final "best estimate" parameters for reliability model failure rate and/or model changes, and for implementation and other cost impact factors expected to be associated with the proposed plant investment package. The RIAM team will then execute a refined reliability model case study incorporating these data and/or model changes. The RIAM team will also execute a refined case study of the expected investment on the PRA results to develop a refined "best estimate" effect on (i.e., change in) predicted core/fuel damage frequency (CDF) performance indicators. Similarly, the RIAM team will consult plant staff members to obtain a refined best estimate of the potential impact on other plant cost impacts, such as reduction in operations and/or corrective or preventive maintenance costs. The results of the reliability model case study and estimates for change in CDF and/or other plant cost factors will then be incorporated into a refined best estimate profitability calculation. The result of this detailed analysis is a refined best estimate on the potential net benefit of the proposed investment package on plant long-term profitability. The key resultant performance indicators provided by the RIAM team in this bounding analysis will, as in Levels 1 and 2, include predicted net benefit over the remainder of expected plant life, benefit-to-cost ratio, payback period, estimated gross investment implementation and maintenance cost, estimated change in long-term plant profitability (i.e., earnings), and return-on-investment annual percentage rate. The RIAM team can provide plant management with projections of these "realistic" level 3 decision support performance indicators to help determine if the recommended investment package should be discontinued or implemented at the plant.

2.3 Analysis of Alternative Investment Packages

As outlined in this section, quantitative decision support performance indicators and associated decision criteria can provide valuable information to decision-makers in evaluating individual recommended investments in plant equipment, operation, and/or maintenance practices. These quantitative performance indicators and decision criteria can, when applied correctly, provide even greater support in prioritizing two or more "competing" recommended investment packages. The RIAM team can provide ranked lists of the competing investment packages based on each of the performance indicators used in the decision-making process (i.e., predicted NPV over the remainder of expected plant life, benefit-to-cost ratio, payback period, estimated gross investment implementation and maintenance cost, and investment option ROI). The RIAM team can also provide safety and reliability performance indicators associated with the investments, such as predicted core damage frequency, large early release frequency, plant reactor trip frequency, and, in most cases, projected generation losses (in MWH). Plant management may, at its discretion, develop a methodology for consistently prioritizing investment recommendations based, at least in part, on the ranked lists of investment packages by selected projected quantitative performance indicators. For example, plant management may choose to use ROI as its primary figure-of-merit for ranking, with total implementation/maintenance cost as a secondary performance indicator. Simultaneously, in the recommended RIAM approach, plant management will use core damage frequency (CDF) as its key "constraint" performance indicator. In this type of decision support scheme, only investment packages that meet the safety limitation requirements would be considered for implementation. Then, implementation would be prioritized based on descending values of projected ROI by investment package. Only those investment packages with total implementation/maintenance cost estimates within the bounds of the site predetermined budget for such investments would be recommended for implementation, unless and until special consideration was given to solicit and obtain additional funds for highly desirable (i.e., cost-beneficial) investment packages.

Decision-makers can very effectively apply confidence levels for performance indicators in their decision-making process. For example, for a given set of investment options that have been evaluated using RIAM, plant decision-makers may choose the following implementation decision criteria: 90% confidence that resulting plant CDF (following investment implementation) remains less than a specified limit (i.e., 5.00E-05 events per year), 90% confidence that investment option ROI is greater than the current prime interest rate, and 90% confidence that projected investment option implementation and maintenance costs are within the planned investment budget limit. Then the RIAM team would rank order each investment option that meets these criteria by descending mean values of projected ROI. The team would recommend successive implementation of these investment options until the next option on the list would exceed the planned budget limit. Other more complex combinations of performance indicators and confidence level parameters could be proposed by the RIAM team and implemented by decision-makers at a specific power station or within a specific company, as desired by management.

2.4 Applications of the Method

While RIAM is designed to be capable of providing the full spectrum of asset management decision support performance indicators, such as those previously applied in EPRI LCM and NAM methods, the RIAM methodology prescribed herein focuses primarily on internal station management issues and applications, summarized as follows:

- Refueling outage schedule and duration optimization
- Unit power upgrade or uprate case studies
- Specific equipment design modification case studies
- Capital spares procurement analysis and prioritization
- Major equipment refurbishment/replacement case studies
- Unit efficiency (i.e., heat rate) improvement case studies
- Station major maintenance activity prioritization
- Plant life extension and license renewal case studies
- Component aging case studies
- Component obsolescence case studies
- Operating procedure training prioritization
- Maintenance procedure training prioritization
- On-line versus off-line maintenance trade-off studies
- Procurement quality assurance (QA) audit/spot check prioritization
- . . . And many others

The focus of these RIAM applications is to continuously support development and implementation of effective and efficient station improvement investment options (i.e., those asset management decisions that support improved long-term profitability and/or safety) in a prudent, cost-effective manner. To date, RIAM has been applied using projected long-term average annual earnings (sometimes called profitability) as the key overriding or guiding performance indicator, with nuclear safety (and other performance indicators) used as decision "constraint" performance indicators.

STPNOC Plant-Specific RIAM Applications Examples

Valve Control Circuitry Modification

Several pilot applications of the phased analysis method described herein have been performed at STPNOC. First, the Level 1 and 2 screening processes were applied to a proposed design modification for three sets of key valves at STPNOC. The proposed modification involves changing the control circuitry for the main feedwater system regulating valves (FWRVs), the main feedwater system isolation valves (FWIVs), and the main steam system isolation valves (MSIVs) from a "de-energize-to-actuate" control scheme to an "energize-to-actuate" control scheme. The investment screening evaluation was applied to each target valve set investment individually, and to all three target valve sets grouped. The analysis showed that the grouping of all three sets was the most attractive from a cost-benefit standpoint. This evaluation also showed that there was an effective “win-win” or double benefit in the implementation of these design modifications, because they not only were shown to improve the profitability of the station, but also to improve reactor safety (i.e., decreased predicted reactor trip frequency and resultant core damage frequency). An example of the summary-level results of the phased level analysis is presented in Tables 2-3 and 2-4. These example results have been “sanitized” so as not to reveal any STPNOC proprietary or business-sensitive information.

Table 2-3
Example Return-on-Asset Analysis Results

Investment Case No.	Investment Case Description	Total Cost ($)	Projected Net Benefit Over Plant Life ($)	Projected Change in Profit ($/yr)	Projected Benefit-to-Cost Ratio Over Plant Life	Projected Payback Period (yrs)	Projected Equivalent Return on Equity APR (%/yr)	Remarks
0	Base Case (No Changes)	$0	$0	$0	0.00	0.00	0.00	Base Case
1	Reduced FWRV Spurious Closure	$180,300	$5,800,500	$241,600	33.17	0.72	15.56	Pass
2	Reduced FWIV Spurious Closure	$380,900	$4,850,000	$202,100	13.80	1.74	11.21	Pass
3	Reduced MSIV Spurious Closure	$375,000	$8,392,700	$349,700	23.38	1.03	13.83	Pass
4	Reduced FWRV Spurious Closure, Reduced FWIV Spurious Closure, and Reduced MSIV Spurious Closure	$934,200	$19,100,300	$795,000	21.42	1.12	13.39	Pass

Table 2-4
Example Nuclear Safety Impact Results

Investment Case No.	Investment Case Description	Uncontrolled Shutdown Frequency (Events/Yr/Unit)	Projected CDF (Events/Yr/Unit)	Change in CDF (Events /Yr/Unit)	Relative Change in CDF (%)
0	Base Case (No Changes)	1.72	1.64E-05	0.00E+00	0.00%
1	Reduced FWRV Spurious Closure	1.67	1.62E-05	-1.70E-07	-1.04%
2	Reduced FWIV Spurious Closure	1.68	1.63E-05	-1.36E-07	-0.83%
3	Reduced MSIV Spurious Closure	1.65	1.62E-05	-2.38E-07	-1.45%
4	Reduced FWRV Spurious Closure, Reduced FWIV Spurious Closure, and Reduced MSIV Spurious Closure	1.58	1.59E-05	-4.76E-07	-2.90%

Capital Spares Procurement Evaluation

A second application of the method involved the evaluation of a set of major equipment capital spares that were proposed to be procured for the station. The list of proposed capital spares included the following 12 items: turbine 1R blade, condensate pump motors, circulating water 96-inch valve, moisture separator drip tank pump, circulating water pump motor, open loop auxiliary cooling water pump, essential chiller 300-ton compressor, circulating water pump internals, condensate pump internals, feedwater regulating valve, feedwater regulating valve actuator, and an auxiliary feedwater pump motor. Again, using levels 1 and 2 screening analysis methods, the RIAM team showed that, based on available failure prediction and economic data, only five of these twelve items were recommended for procurement. The five recommended items were the moisture separator drip tank pump, essential chiller 300-ton compressor, feedwater regulating valve, feedwater regulating valve actuator, and the auxiliary feedwater pump motor. This analysis provided prudent decision support resulting in a station procurement cost savings of well over one million dollars.

Main Generator Rotor Replacement/Refurbishment Evaluation

A third application of the method involved the analysis of proposed main generator rotor replacement strategies and five associated implementation options. These options included consideration of both new rotor procurement and rotor refurbishment, and also considered the timing and sequencing of the rotor replacement/refurbishment activities and associated impacts on outage scheduling. The most cost-beneficial option, based on the analysis methods described herein and predicted return-on-asset results, was chosen for implementation. This application is an important one, not only because it involved high-cost activities, but also because it supported key decision analysis presentations made to both senior STPNOC management and to the station owners.

Feedwater Heater Improvement Evaluation

A fourth application involved the analysis of investments to improve station feedwater heaters. This application is important because it exercised the plant efficiency (or heat rate) investment analysis portion of the method. A level 1 analysis showed that the proposed investments were not predicted to be cost-beneficial, and were not recommended for further development or implementation, as proposed.

Other Proposed Evaluations

In addition to these pilot applications of the method, others have been proposed including analysis of proposed major maintenance activities at the station and prioritization of procurement quality assurance auditing and checking activities. These applications are currently under development at STPNOC.

Application of the RIAM method described herein provides rigorous, systematic, prudent decision-making support for proposed investments in equipment and associated operation and maintenance practices and policies at STPNOC. The phased approach helps keep the scope of the supporting analyses at a level that supports and promotes reasonable investment development efforts and costs. Consistent, continuous application and improvement of the methods described herein will significantly aid plant decision-makers in optimizing resources to maximize return-on-asset for the generating station.

Table 2-5 summarizes estimates of dollar value impacts to STPNOC associated with investment option decisions supported to date by the RIAM Methodology. It is important to note that the few examples listed in Table 2-5 represent only the "tip of the iceberg" of potential types of cost-beneficial RIAM applications that could be realized at a power station over its lifetime.

Table 2-5
Estimated Dollar Value Impacts of Examples of RIAM Application to STPNOC Decisions

Investment Decision No.	Investment Decision Description	Investment Analysis Cost ($)	Investment Implementation/ Maintenance Cost ($)	Total Cost ($)	Increase in Plant NPV ($)	Remarks
1	Refueling Outage Schedule Options Comparison	$180,000	$0	$180,000	$219,000,000	Benefit primarily from differential revenue impact of 21-day outages versus 30-day outages.
2	FWRV/FWIV/MSIV Design Modification	$8,000	$934,000	$942,000	$19,100,000	Benefits from both safety improvement and generation reliability improvement.
3	Capital Spares Procurement Prioritization	$16,000	$0	$16,000	$3,650,700	Benefit from reduction in previously planned procurement costs.
4	Main Generator Rotor Refurbishment / Replacement Options Comparison	$8,000	$6,032,000	$6,040,000	$33,000,000	Benefit primarily from avoided forced and planned outage time.
5	Main Feedwater Heater Performance Improvement Modification	$8,000	$0	$8,000	$3,524,900	Benefit primarily from reduction in previously planned modification costs.
6	Instrument Air System Design Modification	$8,000	$0	$8,000	$3,700,000	Benefit from reduction in previously planned procurement costs.

One of the key products of the proposed Phase 2 RIAM development, is an additional set of RIAM applications examples that will demonstrate the value of RIAM implementation to a broad, diverse group of electric utility companies and power generating stations.

3 RIAM SOFTWARE DEVELOPMENT PLAN

This section describes a preliminary plan to further develop RIAM to provide EPRI member utilities with production-grade RIAM software by 2003. The software should be generic and as comprehensive as practicable, while being customizable to allow automated input of data from any plant's existing databases.

Most aspects of the RIAM process described in Section 2 have been pioneered by the method, databases, and spreadsheets produced by STPNOC from 1997 through 2001. Rather than starting from scratch, the project will take advantage of the substantial progress already made by STPNOC. Appendix C summarizes the STPNOC work.

3.1 RIAM Software Development Steps

An overview of the proposed steps is presented in Figure 3-1. Development begins with the definition of the performance indicators desired by decision-makers to be monitored and predicted. The next five steps involve the development and adaptation of plant models and databases associated with the important cost and/or revenue impacting processes at a plant. See Section 2 for explanations of these models and processes. Most plants already have substantial portions of this modeling and data development completed as part of existing station programs and processes. Therefore, these project activities generally involve adaptation of existing models and databases for application in RIAM, and not fundamental development work.

The next step is the development of the RIAM NPV (or cash flow) model. This step is the heart of RIAM development. The NPV model calculates financial (profitability) performance indicators and associated decision criteria. This model integrates, accepts input data from, and compiles results from the plant cost, safety, availability, efficiency, and market price models. It statistically combines probabilistic data from the five submodels in accordance with the value map in Figure.2-1. This step of the development process also includes basic testing and demonstration of the RIAM NPV model via selected case studies (real or hypothetical examples).

Once the RIAM NPV model is developed and satisfactorily tested, plant staffs must be trained in RIAM concepts and software application. This training is frequently performed in a phased manner, first providing RIAM concept overview training to a large cross-section of plant or corporate personnel, then subsequently providing detailed RIAM applications training to targeted groups at the plant. Feedback from this training can be used in simplifying and streamlining RIAM applications processes, and tailoring RIAM software improvements to specific user needs and desires.

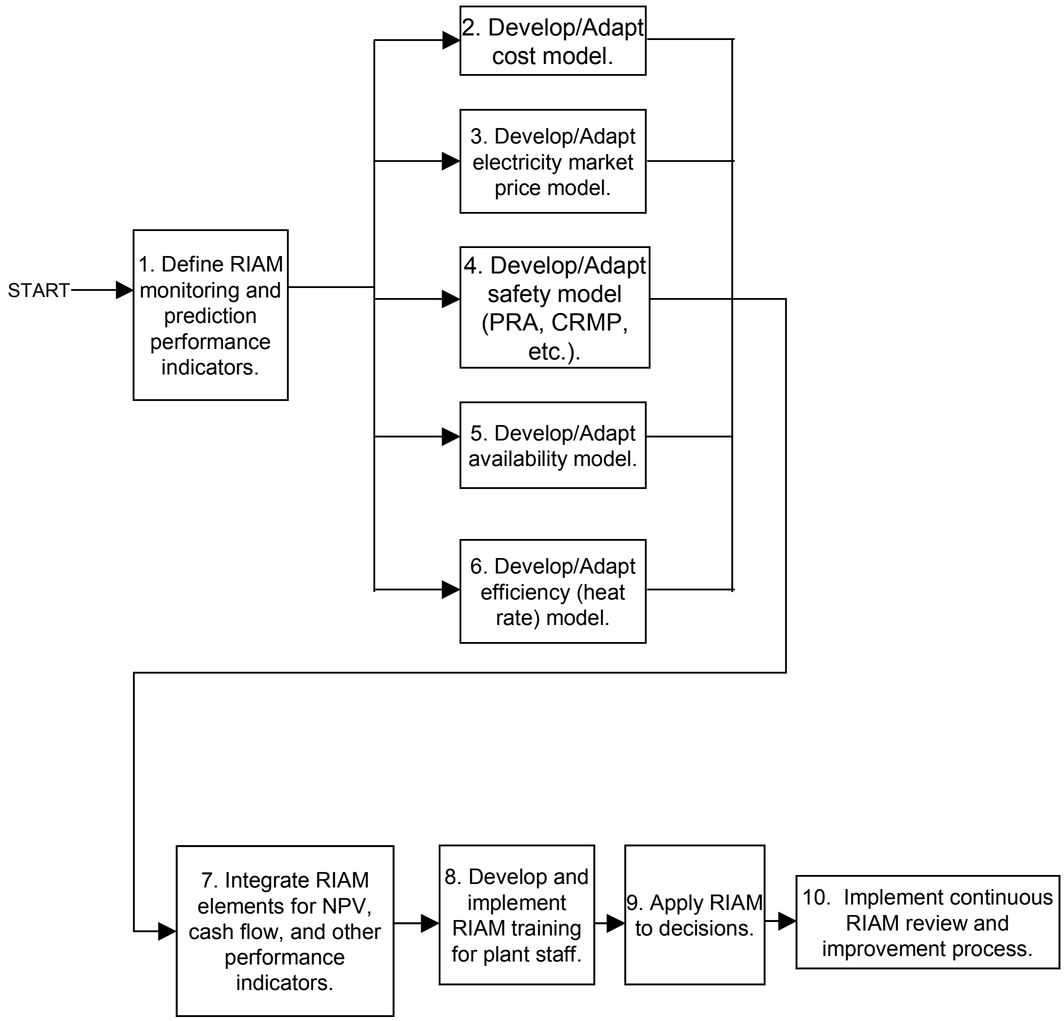

Figure 3-1
RIAM Development Steps

The next step of the process is to apply RIAM in the normal corporate and station decision-making processes. This step is ultimately most effective when the RIAM applications are designed to encompass the full spectrum of decisions involving revenue and/or cost impacting events and activities at the station. This project will give priority to non-fuel O&M costs associated with generation and revenues (see Figure. 2-1 and Table 2-1). Other cost categories such as for staffing, fuel, other operating costs, and decommissioning can be included as time and resources allow.

Finally, a full-scope RIAM development process is not complete until an effective, continuous review and improvement process has been established to support efficient RIAM application throughout the station life cycle. This step helps to ensure that on-going plant performance trends and new and emerging issues associated with station profitability will be properly incorporated into the RIAM process, as it is applied over the plant's remaining operating term.

3.2 RIAM Project Phases

The work activities associated with industry development of a generic RIAM software package are proposed to be carried out in four phases. The initial "Phase 1" effort, performed in 2001 and documented in this report communicates the proposed risk-informed asset management methods and processes to the nuclear power industry, and unveils this plan. Phases 2 and 3 include activities associated with both methodology improvement and production grade software development.

In Phase 2, the method described in Phase 1 would be applied and refined at STPEGS and the resulting processes would be automated in a developmental (alpha) version of the RIAM computer code. In this alpha version, all or most of the software would be comprised of commercially available "off-the-shelf" software such as Microsoft Access, Microsoft Excel, and Crystal Ball, integrated within an application program using Visual Basic or a similar computer language to facilitate the user interface for a selected set of typical value-added applications analyses. These initial applications would include two or more evaluations such as optimized resource allocation for plant modification case studies, refueling outage schedule duration optimization, capital spares procurement analysis, major planned maintenance item (i.e., equipment overhaul) prioritization, and/or others selected by a utility RIAM Technical Advisory Group (TAG). The resultant spreadsheet and database structures developed during Phase 2 could be made available to EPRI member staffs for review and internal development and application trials. The feedback from these trials could be applied in Phase 3 of the project.

In Phase 3, the project team would apply lessons learned from Phase 2 to develop a beta quality and production version of RIAM. This software package, to be developed in a language such as C++, C#, etc., would expand the detail of the Phase 2 alpha software. Advanced features to be included are:

- more seamless interface with existing plant database software (e.g., Oracle, Sybase, etc.) and associated operating company financial management data (such as direct operations and maintenance cost elements) and accounting processes.
- more refined options for evaluating the time-dependent market value of projected risk-informed electricity, using multiple bases for electricity pricing (i.e., daily spot pricing, projected owner-to-operator contracting/sales scenarios, long-term fixed pricing contracts, etc.).
- expanded and refined applications analysis to prioritize preventive maintenance activities, LCM alternative plans, test and inspections, quality assurance activities, operator and maintenance training activities, etc.
- comprehensive "living" plant value and earnings performance monitoring information output and
- improved investment case study and asset management decision support features.

Finally, in Phase 4, the project team would develop a detailed RIAM process application guideline for the industry and provide initial orientation and on-going "generic" RIAM training and support seminars as desired by EPRI and other industry organizations. Phase 4 could also include a vehicle for plant-specific initial installation and implementation training on RIAM software.

3.3 Proposed Phase 2 Tasks

- **Task 2.1 — Identify Key Performance Indicators**. The project team will meet with STPNOC to describe in detail the proposed approach for developing a pilot plant process for effective and efficient risk-informed asset management. In this task, an extended project team will define and describe key performance indicators to be developed and applied in RIAM. This extended project team will include key pilot plant staff involved in the project and members of an EPRI/utility Technical Advisory Group. In this task, the project team will also define a preliminary list of key investment implementation decision criteria, consistent with the key performance indicators identified in this task. The key product of this task is a well-defined set of RIAM performance indicators and associated decision criteria to be predicted and applied in this phase of RIAM work
- **Task 2.2 — Prepare a Requirements Document for RIAM.** In this task, the project team will develop a demonstration software requirements document for a "breadboard" alpha version of EPRI RIAM software. This document will be the key product of this task.
- **Task 2.3 — Develop and Demonstrate a Projected Power Price Model.** The project team will use historical information from standard industry electricity pricing data (such as Platts *Megawatt Daily*) and actual electricity sales price data for STP* to predict long-term electricity sales prices. The project team will work with an EPRI electricity market price forecasting expert to construct an easy-to-use price model for incorporation in RIAM. The key product of this task will be an electricity market price model suitable for the pilot plant. Also included will be software "hooks" for transferring price model output into the RIAM profitability model.
- **Task 2.4 —Adapt and Demonstrate an Availability Model.** The project team will use historical information from STPNOC historical power generation data to update STPNOC's current balance-of-plant (BOP) availability model to support *long-term* predictions for the potential cost or "asset loss" associated with lost generation (in MWH lost per year). STPNOC data may be supplemented by industry generic data, such as North American Electric Reliability Council Generation Availability Data System (NERC-GADS) data, in this task, thus forming a consolidated plant reliability database. The project team will, using the existing STPNOC BOP availability model, develop the software hooks designed to provide input from the BOP model to the generation risk assessment model (see Task 2.6). These hooks will be designed to provide the generation risk assessment model with long-term predictions of plant availability. Also, in this task, the project team will develop an alternative availability prediction example database structure using generic NERC-GADS data four-digit cause codes for nuclear power plants. This alternative database structure will be applied in Tasks 2.9 and 2.10 to illustrate its use in RIAM for those plants that do not currently have detailed availability logic models.
- **Task 2.5 —Adapt a Potential Efficiency Loss Model.** Virtually all plants employ some type of efficiency model to track and predict heat rate performance. The product of this task will be software hooks providing an interface between the STPNOC heat rate/plant efficiency model and the generation risk assessment model, which in turn feeds potential generation efficiency loss data into the RIAM profitability model.

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* EPRI will not release any STP-confidential information to other companies.

- **Task 2.6 – Develop/Adapt a Generation Risk Assessment Model.** In this task, the project team will, using the products of Tasks 2.4 and 2.5, develop software for a generation risk assessment model for incorporating gross and net power generation impacts into the RIAM profitability model. This model will incorporate uncertainty analysis and will yield a probability distribution for potential generation loss per year. This model will also produce a "critical items list" (CIL) of potential generation loss components ranked in decreasing order of importance to projected total potential generation loss per year due to vulnerabilities. The products of this task will be (1) the STPNOC generation loss CIL and (2) interface software hooks between the generation risk assessment model and the RIAM profitability model.
- **Task 2.7 – Develop/Adapt a Cost Element Model.** In this task, the project team will, using the existing STPNOC plant accounting database framework and historical data, develop a station cost element prediction model. These cost elements comprise all the key conventional direct costs associated with the plant, including operations and maintenance (O&M) costs, administrative and general (A&G) costs, capital costs, decommissioning costs, radioactive waste costs, etc. (see value map in Figure 3-2).*]. [make the previous sentence a footnote] The product of this task will be an interface (i.e., the software hooks) joining the cost/revenue impacting element analyses (or prediction model) to the RIAM profitability model.
- **Task 2.8 — Develop/Adapt a Safety Model (PRA).** In this task, the project team will, using information from the STPNOC probabilistic risk assessment (PRA) and/or individual plant examination (IPE), update the existing STPNOC simplified limited-scope Level 3 PRA for the station, based on conversions of similar previously-performed analyses, such as PLG's limited scope Level 3 PRA for the South Texas Project Electric Generating Station or those similar analyses documented in [96], [97], and [98]. Hard to grasp. Conversion of nuclear safety risk to projected cost-risk will be performed using techniques outlined in [29]. This analysis will be used to estimate the safety-related cost-risk impact of predicted core damage events at the pilot plant on long-term average station asset generation potential. The product of this task will be an interface (i.e., the software hooks) joining the plant Level 3 PRA and the RIAM profitability model.
- **Task 2.9 — Integrate Models into a RIAM Profitability Model.** In this task the project team will use the products of Tasks 2.2 through 2.8 to develop a comprehensive integrated information management support tool/model to aid in predicting and tracking station profitability (i.e., cash flow), net present value (NPV), and other selected performance indicators defined in Task 2.1 over the long term. The form of this model will be a probabilistic spreadsheet supported by relational database information from the other RIAM models. An integrated Visual Basic software tool will be developed to provide a user-friendly interface for this phase of RIAM profitability model development and application. Also, in this task the project team will identify and define potential additional RIAM-NAPE interfaces (see Task 2.3), and potential interfaces between RIAM and EPRI LCM processes and software (see [2], [63], [64], and [65]). These interface definitions will serve as a basis for more detailed modular RIAM software development in Phase 3 of this proposed project. The product of this task will be a "breadboard" RIAM alpha software package designed to

* In Phase 3, it is anticipated that this cost element prediction model will be developed to be consistent with existing standard industry activity based cost models such as the NEI Standard Nuclear Performance Model (SNPM) [91].

support meaningful illustrative case study examples (performed in Task 2.10). The case study output of this version of RIAM will include presentation of projected changes (or "deltas") from baseline performance indicators, as well as the application of user-supplied decision criteria. A brief, but fully functional, User Manual will also be prepared. This alpha version of RIAM software will serve as developmental software to support more full-featured production-grade RIAM software development in Phase 3.

- **Task 2.10 — Perform STP-Selected Case Studies to Demonstrate RIAM Profitability Model.** The project team will use the RIAM alpha software to perform up to five case studies selected by STP and EPRI to demonstrate and benchmark the tool. Both "Level 1" and "Level 2" analyses will be demonstrated. Typical application cases include: design modification benefit-risk, capital spares procurement prioritization, major maintenance item/action prioritization and scheduling, refueling outage schedule and duration optimization, major equipment replacement/refurbishment cost-benefit-risk, efficiency improvement options, and "graded" quality assurance audit/spot check prioritization. The product of this task will be a Microsoft Word report file, the Visual Basic (or similar software-based) applications interface program, one or more Microsoft Excel/Crystal Ball Investment Decision Support files, and any associated supporting Microsoft Access relational database files.
- **Task 2.11 – Prepare Final Report.** The final report will include at a minimum, the following sections: Executive Summary, Introduction, Project Approach and Methodology, Project Products Description, Example Case Study Approach and Results, Conclusions and Recommendations, References, and Appendices. One appendix will contain a requirements document for the production-grade RIAM software to be produced in Phase 3.

Phase 2 tasks can be related to the station value map presented in Figure 2-1 as shown in Table 3-1:

Table 3-1
Phase 2 Task Relationship to Value Map in Figure 2-1

PHASE 2 TASK	RELATED VALUE MAP ELEMENT IN FIGURE 2-1
2.3 — Develop and Demonstrate a Projected Power Price Model	5
2.4 — Adopt and Demonstrate an Availability Model	6, 11, 18, 19
2.5 — Adapt a Potential Efficiency Loss Model	6, 12
2.6 — Develop/Adapt a Generation Risk Assessment Model	6, 11, 12, 18, 19
2.7 — Develop/Adapt a Cost Element Model	7, 8, 9, 14, 15, 16, 17, 20
2.8 — Develop/Adapt a Safety Model (PRA)	1
2.9 — Integrate Models into a RIAM Profitability Model	1 through 20

(Element 21 of Figure 2-1, Power Uprate, is more a case issue than an element of a cost rollup.)

3.4 Proposed Phase 3 Tasks

- **Task 3.1 — Develop Specification for RIAM Production Grade Software.** In this task, the project team will develop a software specification for beta and production grade versions of RIAM, which will seamlessly integrate the data gathering and management processes, calculations, and results display functions identified in Phase 2. The software will automate many of the manual data handling steps identified in Phase 2 and will be implemented and demonstrated at STPNOC. This specification will also identify interfaces and modular applications of EPRI NAPE and LCM processes and software (see [1], [2], [4], [7], [63], [64], and [65]) with RIAM software.
- **Task 3.2 — Produce Beta and Production Grade Versions of RIAM. Upgraded Software Language.** In this task, the project team will follow the specification developed in Task 3.1 to develop beta and production grade versions of RIAM. The software will include an improved feature that carries out risk-based optimization of LCM planning at the integrated plant level. This task also includes development of a RIAM user manual, pre-beta testing by EPRI, beta testing by several potential users, post-beta improvements, and delivery of the production grade code and user manual to EPRI. This will all be accomplished under the software quality requirements of EPRI.
- **Task 3.3 — Implement RIAM Software Improvements at STPEGS.** In this task, the project team will install the software package developed in Task 3.2 at STPEGS and verify this software package on the plant's LAN computer system. Selected software applications examples will be run in place at the pilot plant as part of this on-site verification process. This task also includes a RIAM training seminar at STPNOC facilities and a presentation of RIAM at an industry conference.

3.5 Proposed Phase 4 Tasks

- **Task 4.1 — Develop a Draft Industry Guide for Top-Down Implementation and Integration of RIAM at Nuclear Power Stations Throughout the Nuclear Power Industry.** In this task, the project team will develop a draft industry guide for implementation of the RIAM processes and software. This draft guide will describe procedural steps for developing and implementing a station RIAM process.
- **Task 4.2 — Implement Industry Review Comments on the RIAM Guide.** In this task, the project team will solicit and collect review comments on the draft RIAM Guide developed in Task 4.1. One thorough round of review comments will be solicited and implemented.
- **Task 4.3 — Develop a Nuclear Power Industry Workshop Presentation for RIAM Development and Implementation.** In this task, the project team will develop a three-day workshop presentation for RIAM development and implementation at nuclear power stations. The training materials will consist of the guide developed in Task 4.2 and workshop presentation slides.
- **Task 4.4 — Provide Direct On-Going Continuous Support for RIAM Implementation and Training.** In this task, the project team will provide support as desired by EPRI to implement RIAM, including software installation and training at EPRI-member plants, and to perform industry workshops on RIAM development and implementation at intervals specified by EPRI. In association with this task and with Phase 3 activities, EPRI may wish to form a RIAM User Group to participate in software testing and organization-specific software trials.

4
POTENTIAL COST-BENEFIT OF RIAM IMPLEMENTATION

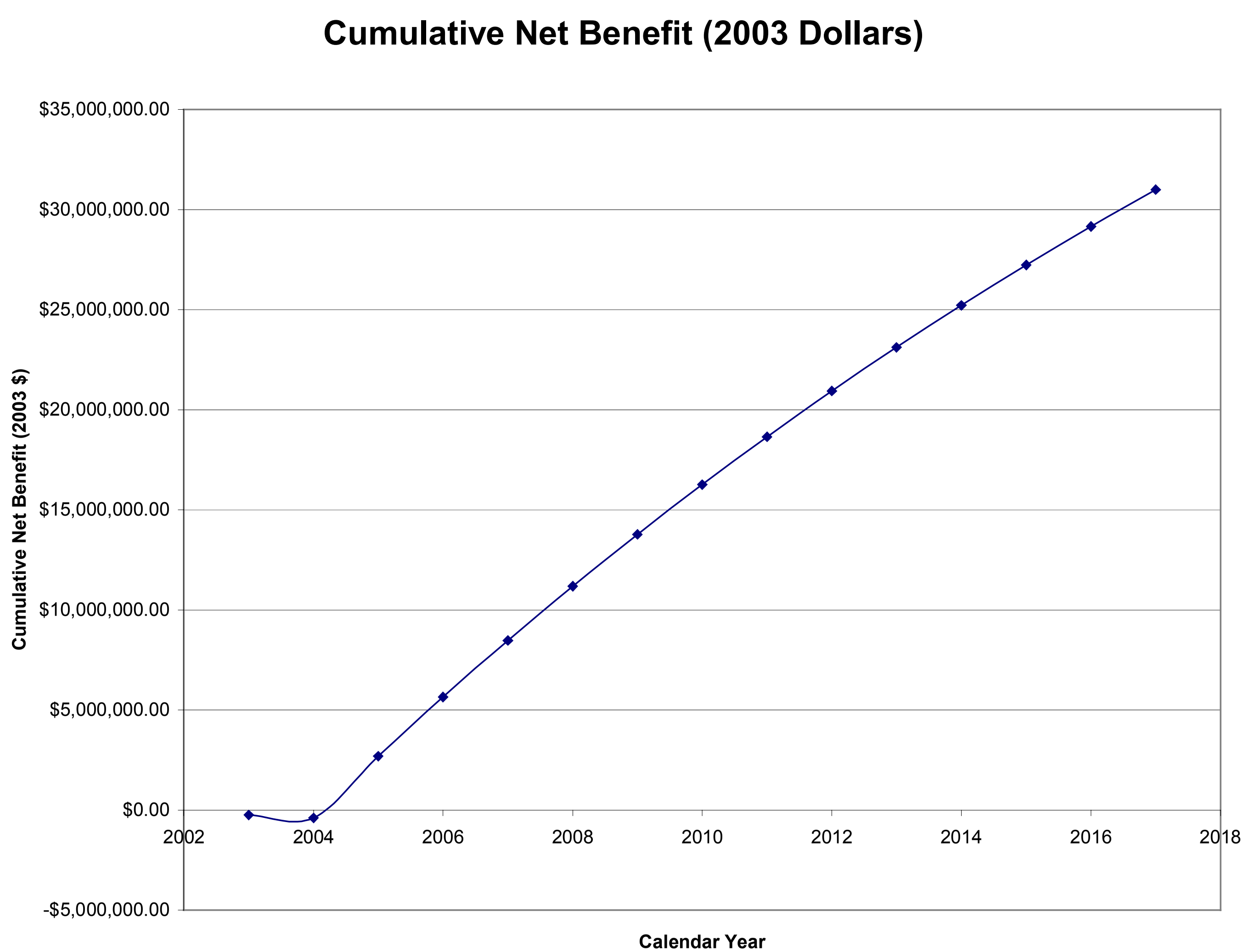
Clearly, one of the strongest motivations for nuclear utility companies to implement RIAM at their nuclear power plants is to optimize operations and maintenance costs and increase power sales revenues, which drive corporate profitability or “return-on-asset.” As of the writing of this report, there has been no formal detailed cost-benefit-risk analysis explicitly performed for RIAM implementation at a nuclear power station. However, STPNOC has applied RIAM tools and techniques at its plant (STPEGS) for the past four years. Using this experience and experience obtained via development of availability models for other power plants, we can estimate the value of RIAM implementation for a generic power plant. The following is an estimate of the level of return on asset that a plant could garner from application of the RIAM approach.

Experience has shown that, for nuclear power plants with historical equivalent availability performance at or below about 95% (which represents most plants), realistically achievable benefits of RIAM may be approximated by about half the total net present value of the equivalent unavailability of a station. We will assume conservatively that risk-informed management of investments and equipment reliability actions can increase the capacity factor by 1%.

Consider a hypothetical two-unit generating station where both units have a net dependable capacity rating of 1000 MW each, both units have an expected remaining life of, say, 15 years, and the projected average sales price of electricity is, say, $25.00 per MWH. In this example, we will assume that the cost of RIAM implementation, including all required data analyses, software development/procurement/installation activities, and associated staff training, is approximately $100,000 per implementing organization; that RIAM implementation will start in 2003 and take up to approximately 2 years before benefits start accruing; that the nuclear fuel cost for power production averages $5.00/MWH; that the average consolidated discount rate for “time-value-of-money” calculations is 7.5%, and that the average combined escalation-and-inflation rate is 3%. Also, let us assume that continuing maintenance and updating of the RIAM process over the entire 15-year life of this investment requires an additional staff analyst person-year per year (or about $150,000 per year of fully burdened cost). Given these additional assumptions, the net present value (i.e., the net benefit) of RIAM implementation at our example nuclear power station for a capacity factor improvement of 1% sustained over plant life was calculated. The results are shown in Table 4-1 and Figure 4-1.

Table 4-1
Example Cost-Benefit Versus Time Table

Calendar Year	Implementation Cost (Constant Dollars)	Change Maintenance Cost (Constant Dollars)	Total Cost (Constant Dollars)	Gross Benefit (Constant Dollars)	Net Benefit (Constant Dollars)	Total Cost (2003 Dollars)	Gross Benefit (2003 Dollars)	Net Benefit (2003 Dollars)	Cumulative Net Benefit (2003 Dollars)
2003	$100,000.00	$150,000.00	$250,000.00	$0.00	-$250,000.00	$250,000.00	$0.00	-$250,000.00	-$250,000.00
2004	$0.00	$150,000.00	$150,000.00	$0.00	-$150,000.00	$143,720.93	$0.00	-$143,720.93	-$393,720.93
2005	$0.00	$150,000.00	$150,000.00	$3,506,400.00	$3,356,400.00	$137,704.71	$3,218,985.19	$3,081,280.48	$2,687,559.55
2006	$0.00	$150,000.00	$150,000.00	$3,506,400.00	$3,356,400.00	$131,940.32	$3,084,236.97	$2,952,296.65	$5,639,856.20
2007	$0.00	$150,000.00	$150,000.00	$3,506,400.00	$3,356,400.00	$126,417.24	$2,955,129.38	$2,828,712.14	$8,468,568.34
2008	$0.00	$150,000.00	$150,000.00	$3,506,400.00	$3,356,400.00	$121,125.35	$2,831,426.29	$2,710,300.93	$11,178,869.28
2009	$0.00	$150,000.00	$150,000.00	$3,506,400.00	$3,356,400.00	$116,054.99	$2,712,901.47	$2,596,846.48	$13,775,715.75
2010	$0.00	$150,000.00	$150,000.00	$3,506,400.00	$3,356,400.00	$111,196.87	$2,599,338.15	$2,488,141.27	$16,263,857.03
2011	$0.00	$150,000.00	$150,000.00	$3,506,400.00	$3,356,400.00	$106,542.12	$2,490,528.65	$2,383,986.52	$18,647,843.55
2012	$0.00	$150,000.00	$150,000.00	$3,506,400.00	$3,356,400.00	$102,082.22	$2,386,273.96	$2,284,191.74	$20,932,035.29
2013	$0.00	$150,000.00	$150,000.00	$3,506,400.00	$3,356,400.00	$97,809.01	$2,286,383.42	$2,188,574.41	$23,120,609.70
2014	$0.00	$150,000.00	$150,000.00	$3,506,400.00	$3,356,400.00	$93,714.68	$2,190,674.35	$2,096,959.67	$25,217,569.37
2015	$0.00	$150,000.00	$150,000.00	$3,506,400.00	$3,356,400.00	$89,791.74	$2,098,971.70	$2,009,179.96	$27,226,749.33
2016	$0.00	$150,000.00	$150,000.00	$3,506,400.00	$3,356,400.00	$86,033.02	$2,011,107.77	$1,925,074.75	$29,151,824.08
2017	$0.00	$150,000.00	$150,000.00	$3,506,400.00	$3,356,400.00	$82,431.63	$1,926,921.86	$1,844,490.23	$30,996,314.31
Total:	$100,000.00	$2,250,000.00	$2,350,000.00	$45,583,200.00	$43,233,200.00	$1,796,564.84	$32,792,879.15	$30,996,314.31	
							Gross Benefit to Cost Ratio	Net Benefit to Cost Ratio	Equivalent ROI (APR)
							18.25	17.25	20.91%


Cumulative Net Benefit (2003 Dollars)
Cumulative Net Benefit (2003 $)
$35,000,000.00
$30,000,000.00
$25,000,000.00
$20,000,000.00
$15,000,000.00
$10,000,000.00
$5,000,000.00
$0.00
-$5,000,000.00
2002
2004
2006
2008
2010
2012
2014
2016
2018
Calendar Year

This calculation applies the simple “time-value-of-money” factor,

$$((1+IR)/(1+DR))^{(\text{Effective year} - \text{NPV year})}$$

where

IR = combined inflation and escalation rate = 3% (in this example),

DR = discount rate = 7.5% (in this example),

Effective year = year of incurred cost and/or benefit (calendar years 2003-2017 in this example), and

NPV year = net present value year = 2003 (in this example).

With the total equivalent 2003 dollar investment of about $1,500,000 over the life of the investment (including both RIAM implementation and maintenance costs), the investment net benefit (or NPV) is approximately $31,000,000, the gross benefit-to-cost ratio is about 18 and the equivalent annual percentage rate of return-on-investment (ROI) over the entire 15-year period is over 20%.

It is important to note that this is only the return on a conservatively low resultant 1% improvement in average capacity factor. Of course, specific nuclear plant staffs must apply their own station-specific parameters within these calculations to develop better estimates of potential RIAM benefits. This is simply an example estimation technique for “expected equivalent benefit” from the combination of reliability, safety, and efficiency improvements (i.e., potential revenue loss reductions), and prudent direct O&M and capital cost reductions that can be realized via implementation of an effective RIAM process. This estimated monetary net benefit is supplemented, by other important, but less tangible benefits, such as improved company reputation and credibility with investors, regulators (i.e., the NRC, FERC, state PUCs, etc.), and other stakeholders that result as a valuable by-product of the consistent, prudent approach to asset management applied within a rigorous, systematic RIAM process.

It is also important to note that RIAM “benefits” are not only derived from projected generation loss recovery (i.e., like the 1% capacity factor improvement example shown herein), but can be generated entirely through station cost savings associated with cost factors and associated improvement options identified and implemented via the RIAM process. This is particularly important for RIAM application at plants where capacity factor performance has been good (i.e., well over 90%) in recent years. Also, in plants where recent capacity factor performance has been good, RIAM does not only help staffs to prudently reduce overall generation costs, but also help ensure that continuous investment in plant O&M practices are focused on activities designed to ensure that the plant will maintain high levels of performance over the long term.

It is anticipated that, following initial implementation and verification, ongoing maintenance and application of the RIAM models, processes and databases would be performed by one trained engineer or analyst (the “RIAM owner”) at the implementing organization. We anticipate that this analyst would likely be either (1) a member of the plant’s PRA group who has been previously trained and qualified in risk analysis, reliability (i.e., Boolean logic) modeling, reliability data analysis, and uncertainty analysis methods; or (2) a member of an organization’s strategic planning group, business planning group, or program economic evaluation group with a familiarity of PRA methods. While the RIAM owner would, as applications require, be supported by other plant staff members, it is anticipated that there would be no change in underlying infrastructure or staffing required at the implementing organization. That is, RIAM application over plant life can be expected to be performed by the existing plant organization. This is because the RIAM applications support is expected to be subsumed within (or eventually replace) similar existing program/project economic evaluation and cost-benefit analysis practices at the implementing organization. In fact, it is likely that, for many generating stations, consistent RIAM application over plant life, through its continuous focus on station profitability, would identify and support prudent staff *reductions* in selected areas of current manning that would more than offset any single staff-person augmentation required for RIAM application.

Implementation of RIAM at a plant, assuming the availability of EPRI RIAM software and associated guidelines, is anticipated to require an “up-front” investment of roughly $100,000 for plants with existing models, analyses, and databases that can be applied to support the RIAM process. These include a safety model, availability model, efficiency model, cost model, electricity price model, detailed accounting system, and associated databases and supporting analyses. The $100,000 implementation cost estimate includes plant-specific implementation of the EPRI RIAM software, formulation of existing RIAM-supporting data into the proper format for application in the RIAM software, technical training of the plant staff assigned to perform RIAM applications and updates, and the performance of one (or a small set of) verification case study(ies) at the implementing station.

Most plants have models, analyses, and databases in place that can adequately support the initial implementation of RIAM. For example,

- All stations have some type of safety model (or probabilistic risk assessment) that was developed to satisfy NRC Generic Letter 88-20 requirements, and that is currently applied to address implementation of industry-wide programs and requirements such as Maintenance Rule requirement 10 CFR 50.65(a)(4).
- Virtually all stations have some type of model or analysis relating to the evaluation and/or prediction of plant heat rate performance.
- All stations have some type of database that captures historical O&M, capital, and other costs by category (at least by FERC category, as this is a formal regulatory requirement).
- Most stations have some type of availability (or BOP) model designed to support maintenance planning, equipment outage management, and implementation of INPO AP-913 requirements. But even those that don’t have formal availability logic models have historical generation-impacting event data reported to NERC-GADS (www.nerc.com) by GADS four-digit cause code or similar data routinely reported to the INPO EPIX data management system. The NERC-GADS four-digit cause code framework for nuclear power plants can serve as a surrogate to a plant-specific availability logic model for purposes of initial RIAM implementation. The information needed by RIAM is the quantified level of contribution of components to lost generation. An availability model calculates this level based on reliability data and reliability logic model (event tree/fault tree) analysis; the NERC-GADS approach estimates it on the basis of historical failures.
- For stations that do not currently have a formal power price projection model, simple predictions of future electricity sales prices can be easily developed via review of readily-available commodity pricing data, such as Platts *Megawatt Daily* (www.platts.com)

for the specified plant's sales region. Also, the RIAM development work will include provision of a simple price model based on EPRI technology in this area.

Of course, the cost of implementing RIAM would increase if work were needed to put some of these supporting models in place. However, the costs of these plant technology improvements would be paid back with their benefits to both RIAM applications and other plant programs.

Regarding the on-going costs to employ RIAM for project prioritization on an on-going basis, as indicated above, we believe that this effort could be subsumed within existing level-of-effort O&M costs. Nevertheless, we can conservatively estimate that the scope of work required for RIAM applications will require, on average, approximately one full-time equivalent employee over the remaining plant operating term. This translates to a fully burdened additional cost impact of approximately $150,000 per year per station, on average. As this is only a fraction of one unit-day's worth of power generation value at most power plants ($480,000 for our example unit), the added cost is expected to result in a strong positive net benefit for RIAM-supported decision-making, as outlined in the example presented above and as illustrated in the STPNOC examples summarized in Table 2-5.

5
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A
GLOSSARY OF KEY TERMS

This appendix provides a glossary of key terms used in this report and within the context of RIAM development and implementation, in general. At the end of each definition an abbreviation is listed (in parentheses) identifying a source reference for the associated term. These glossary source references are listed as follows:

(CAT) – Common Aging Terminology, EPRI TR-100844.

(CEG) – Cost Estimating Groundrules, Chapter 1, Appendix C of the EPRI Advanced Light Water Reactor Requirements Document, EPRI NP-6780-L.

(NOM) – Valuation and Management of Nuclear Assets, EPRI TR-107541.

(RIISMS 1) – Risk-Informed Integrated Safety Management Specification (RIISMS) Implementation Programs, EPRI 1000893.

(RIAM 1) – this EPRI report.

(TAG) – Technical Assessment Guide, Vol. 3, Rev. 7, EPRI TR-100281.

Key Terms

- *Accelerated Aging*: Artificial aging in which the simulation of natural aging approximates, in a short time, the aging effects of longer-term service conditions (CAT).
- *Acceptance Criterion*: Specified limit of a functional or condition indicator used to assess the ability of an SSC[1] to perform its design function (CAT).
- *Age*: (noun) Time from fabrication of an SSC to a stated time (CAT).
- *Age Conditioning*: Simulation of natural aging effects in an SSC by the application of any combination of artificial and natural aging (CAT).
- *Age-Related Degradation:* Synonym for "aging degradation" (CAT).
- *Aging (Noun):* General process in which characteristics of an SSC gradually change with time or use (CAT).

[1] SSC = system, structure, or component

- *Aging Assessment:* Evaluation of appropriate information for determining the effects of aging on the current and future ability of SSCs to function within acceptance criteria (CAT).
- *Aging Degradation*: Aging effects that could impair the ability of an SSC to function within acceptable criteria (CAT).
  Examples: Reduction in diameter of wear of a rotating shaft, loss in material strength from fatigue or thermal aging, swell of potting compounds, and loss of dielectric strength or cracking of insulation.
- *Aging Effects*: Net changes in characteristics of an SSC that occur with time or use and are due to aging mechanisms (CAT).
  Examples: Negative Effects – see Aging Degradation; positive effects – increase in concrete strength from curing; reduced vibration from wear-in of rotating machinery.
- *Aging Management*: Engineering, operations, and maintenance actions to control within acceptance limits aging degradation and wearout of SSCs (CAT).
  Examples of Engineering Actions: Design, qualification, and failure analysis.
  Examples of operations actions: surveillance, carrying out operational procedures within specified limits, and performing environmental measurements.
- *Aging Mechanism*: Specific process that gradually changes characteristics of an SSC with time or use (CAT).
  Examples: Curing, wear, fatigue, creep, erosion, microbiological fouling, corrosion, embrittlement, and chemical or biological reactions.
- *Allowable Incremental Risk Limit*: A plant-specific risk limit, which, if equaled or exceeded, requires entry into a specific action level specified in the plant RIISMS program or technical specifications (RIISMS 1).
- *Apparent Escalation Rate*: Inflation rate plus real escalation rate (LCM).
- *Artificial Aging*: Simulation of natural aging effects on SSCs by application of stressors representing plant pre-service and service conditions, but perhaps different in intensity, duration, and manner of application (CAT).
- *Asset Management*: Process for making resource allocation and risk management decisions at all levels of a nuclear generation business to maximize value/profitability for all stakeholders while maintaining plant safety (LCM).
- *Balance of Plant (BOP)*: All system, structures, components, and facilities of the plant not a part of or included in the nuclear island (CEG).
- *Breakdown:* Synonym for complete failure (CAT).
- *Bulk Commodity*: Item having a generic application throughout a plant, which lends itself to bulk procurement (e.g., concrete, small-bore piping, lubricants, nuts, bolts, gaskets, fuses, relays, resistors) (CEG).
- *Burden:* General and administrative costs added to hourly labor rates,

  or

  expenses for performing a plant activity that are over and above the hourly costs for direct performance of the activity; burden costs include decontamination of materials, scaffolding, removal of insulation, engineering analyses, laboratory testing, offsite services, and NSSS services (LCM).

- *Capacity Factor:* Ratio of the total net energy generated during a period to the total energy that could be generated at rated power during the same period (LCM).
- *Characteristic*: Property or attribute of an SSC (such as shape; dimension; weight; condition indicator; functional indicator; performance; or mechanical, chemical, or electrical property) (CAT).
- *Combined Effects*: Net changes in characteristics of an SSC produced by two or more stressors (CAT).
- *Commodity:* Same as "bulk commodity" (CEG); also, any component common across several systems, such as a pump, valve, or relay.
- *Common Cause Failure*: Two or more failures due to a single cause (CAT).
- *Common Mode Failure*: Two or more failures in the same manner or mode due to a single cause (CAT).
- *Complete Failure*: Failure in which there is a complete loss of function (CAT).
- *Component:* An identifiable element within a system or structure such as a reactor vessel, core support structure, pump, valve, fan, motor, relay, or I-beam; an assembly of parts viewed as an entity for purposes of design, operation, and reporting (each component has a unique identification number within the plant) (CAT).
- *Condition*: Surrounding physical state or influence that can affect an SSC; also, the state or level of characteristics of an SSC that can affect its ability to perform a design function (CAT).
- *Condition Indicator*: Characteristic that can be observed, measured, or trended to infer or directly indicate the current and future ability of an SSC to function within acceptance criteria (CAT).
- *Condition Monitoring:* Observation, measurement, or trending of condition or functional indicators with respect to some independent parameter (usually time or cycles) to indicate the current and future ability of an SSC to function within acceptance criteria (CAT).
- *Condition Trending*: Synonym for condition monitoring (CAT).
- *Configuration Risk Management Program (CRMP)*: The mechanism for assessing plant configurations and maintaining station risk at desired levels (RIISMS 1).
- *Consequential Cost:* Cost resulting from failure over and above the costs to perform corrective maintenance and the cost of lost production.
  Examples: costs of confrontational regulatory climate, regulatory sanctions, liability, poor public relations, and poor reputation (LCM).
- *Core Damage Frequency (CDF)*: The frequency (generally expressed in terms of events per calendar year) that one can expect a reactor fuel core damaging event to occur for a nuclear power plant of interest. In the context of this report, CDF encompasses both (i.e., represents the sum of) operating plant core damage frequency and shutdown plant fuel damage frequency (RIISMS 1).
- *Core Damage Probability (CDP)*: The integral of CDF over time; the classical cumulative probability of core damage (i.e., instantaneous core or fuel damage frequency integrated over

a specified duration), over a given period of time. CDP is unit-less.
Weekly risk is calculated for the 168-hour time period over each calendar week.
Annual risk is a 52-week rolling average, calculated week by week (RIISMS 1).

- *Corrective Maintenance*: Actions that restore, by repair, overhaul, or replacement, the capability of a failed SSC to function within acceptable criteria (CAT).
- *Critical SSC*: Level A SSC (LCM).
- *Current Licensing Basis*: Set of NRC requirements applicable to a specific plant and a licensee's written commitments for ensuring compliance with and operation within applicable NRC requirements and the plant-specific design basis (including all modifications and additions to such commitments over the life of the license) that are docketed and in effect (LCM).
- *Degradation*: Immediate or gradual deterioration of characteristics of an SSC that could impair its ability to function within acceptance criteria (CAT).
- *Degraded Condition*: Marginally acceptable condition of an unfailed SSC that could lead to a decision to perform planned maintenance (CAT).
- *Degraded Failure*: Failure in which a functional indicator does not meet an acceptance criterion, but design function is not completely lost (CAT).
- *Design Basis Conditions*: Synonym for design conditions (CAT).
- *Design Basis Event*: Any of the events specified in the station's safety analysis that are used to establish acceptable performance for safety-related functions of SSCs; events include anticipated transients, design basis accidents, external events, and natural phenomena (CAT).
- *Design Basis Event Conditions*: service conditions produced by design basis events (CAT).
- *Design Basis Event Stressor*: Stressor that stems from design basis events and can produce immediate or aging degradation beyond that produced by normal stressors (CAT).
- *Design Conditions*: Specified service conditions used to establish the specifications of an SSC (generally includes margin of conservatism beyond expected service conditions) (CAT).
- *Design Life*: Period during which an SSC is expected to function within acceptance criteria (CAT).
- *Design Service Conditions*: Synonym for design conditions (CAT).
- *Deterioration*: Synonym for degradation (CAT).
- *Diagnosis*: Examination and evaluation of data to determine either the condition of an SSC or the causes of the condition (CAT).
- *Diagnostic Evaluation*: Synonym for diagnosis (CAT).
- *Discount Rate*: Weighted average cost of capital; percentage rate used to calculate the net present value of a future year's cost (LCM).
- *Discounted Cash Flow Analysis*: Method for calculating net present value based on the future stream of after tax cash flows (revenues minus expenses) discounted back to the present using the cost of capital as the discount rate (LCM).

- *Economically Critical SSCs*: SSCs whose performance or maintenance/replacement costs can have a significant effect on a decision to operate a nuclear plant to a target operating term (LCM).
- *Environmental Conditions*: Ambient physical states surrounding an SSC (CAT). *Examples: temperature, radiation, and humidity in containment during normal operation or accidents.*
- *Equipment:* Manufactured item ordered for installation in the plant (custom-fabricated pipe is an equipment item; non-custom piping is a bulk commodity; bulk commodities are not equipment; systems and structures are not equipment – they are assemblies of equipment, components, and commodities) (CAT).
- *Error-Induced Aging Degradation*: Aging degradation produced by error-induced conditions (CAT).
- *Error-Induced Conditions*: Adverse pre-service or service conditions produced by design, fabrication, installation, operation, or maintenance errors (CAT).
- *Error-Induced Stressor*: Stressor that stems from error-induced conditions and can produce immediate or aging degradation beyond that produced by normal stressors (CAT).
- *Failure*: Inability or interruption of ability of an SSC to function within acceptance criteria (CAT).
- *Failure Analysis*: Systematic process of determining and documenting the mode, mechanism, causes, and root cause of failure of an SSC (CAT).
- *Failure Cause*: Circumstances during design, manufacture, test, or use that have led to failure (CAT).
- *Failure Evaluation*: Synonym for failure analysis (CAT).
- *Failure Mechanism*: Physical process that results in failure (CAT). *Examples: cracking of an embrittled cable insulation (aging-related); an object obstructing flow (non-aging-related).*
- *Failure Mode*: The manner or state in which an SSC fails (CAT). *Examples: stuck open (valve), short to ground (cable), bearing seizure (motor), leakage (valve, vessel, or containment), flow stoppage (pipe or valve), failure to produce a signal that drops control rods (reactor protection system), and crack or break (structure).*
- *Failure Modes And Effects Analysis*: Systematic process for determining and documenting potential failure modes and their effects on SSCs (CAT).
- *Failure Rate*: Average number of failures per unit time for an SSC or part (RIAM 1).
- *Failure Trending*: Recording, analyzing, and extrapolating inservice failures of an SSC with respect to some independent parameter (usually time or cycles) (CAT).
- *Functional*: SSC is capable of performing its intended function for both normal and emergency operations as modeled in the plant-specific PRA (RIISMS 1).
- *Functional Conditions*: Influences on an SSC resulting from the performance of design functions (operation of a system or component and loading of a structure) (CAT). *Examples: for a check valve -- operational cycling and chatter; for a reactor vessel relief*

valve -- reactor coolant pressure, high flow velocities, and temperature increase from the reactor coolant.

- *Functional Indicator*: Condition indicator that is a direct indication of the current ability of an SSC to function within acceptance criteria (CAT).
- *Important SSC*: Level B SSC (LCM).
- *Inflation Rate*: Annual percentage increase in levels caused by an increase in available currency and credit without a proportionate increase in available goods and services of equal quality. Inflation does not include real escalation (TAG).
- *Inservice Inspection*: Methods and actions for assuring the structural and pressure-retaining integrity of safety-related nuclear power plant components in accordance with the rules of ASME Code, Section XI (CAT).
- *Inservice Life*: Synonym for service life (especially in discussions involving ASME Code, Section XI) (CAT).
- *Inservice Test*: A test to determine the operational readiness of a component or system [ASME Code, Section XI][2] (CAT).
- *Inspection*: Synonym for surveillance (CAT).
- *Installed Life*: Period from installation to retirement of an SSC (CAT).
- *Instantaneous Core Damage Frequency*: The instantaneous expected core damage frequency resulting from continued operation in a specific plant mode and a given plant configuration (generally presented with units of events/year). In the context of RIAM, this parameter would likely be calculated continuously and reported hourly or upon a change in value (RIISMS 1).
- *Instantaneous Large Early Release Frequency*: The instantaneous expected large early release frequency resulting from continued operation in a specific plant mode and a given plant configuration (generally presented with units of events/year). In the context of a RIAM, this parameter would likely be calculated continuously and reported hourly or upon a change in value (RIISMS 1).
- *Large Early Release Frequency (LERF)*: The frequency (generally expressed in terms of events per calendar year) that one can expect a large early release of radioactivity (as defined in [9]) from a reactor core damaging event to occur for a nuclear power plant of interest. In the context of this report, LERF encompasses both (i.e., represents the sum of) operating plant and shutdown plant large early release frequency (RIISMS 1).
- *Large Early Release Probability (LERP)*: The classical cumulative probability of large early release of radioactivity (i.e., instantaneous large early release frequency integrated over a specified duration), over a given period of time. LERP is unit-less. *Weekly risk* is calculated for the 168-hour time period over each calendar week. *Annual risk* is a 52-week rolling average, calculated week by week (RIISMS 1).
- *LCM Plan*: For systems, structures, and components – specifies the least-life-cycle-cost preventive maintenance, replacement, or design/operation modifications and schedules throughout the remaining operating term of the plant. For a plant – optimizes plant

[2] Brackets indicate adoption of a formal definition from codes, standards, or regulations.

performance and cost (and therefore plant value) including the optimum allocation of plant expenditures for O&M, capital improvements, fuel, and decommissioning (LCM).

- *LCM Plan Alternative:* One of a set of LCM plans considered for implementation (also "LCM alternative" or "alternative") (LCM).
- *License Renewal:* Regulatory process for extending the licensed term of operation of a nuclear plant (usually from 40 years to 60 years) (LCM).
- *Life*: Period from fabrication to retirement of an SSC (CAT).
- *Life Assessment*: synonym for aging assessment (CAT).
- *Life Cycle Management (LCM):* Process by which nuclear power plants integrate operations, maintenance, engineering, regulatory, environmental, and economic planning activities in a manner that (1) manages plant material condition (e.g., aging and obsolescence of systems, structures, and components – SSCs), (2) optimizes operating life (including the options of early retirement and license renewal), and (3) maximizes plant value while maintaining plant safety (LCM).
- *Life Management*: Integration of aging management and economic planning to: (1) optimize the operation, maintenance, and service life of SSCs; (2) maintain an acceptable level of performance and safety; and (3) maximize return on investment over the service life of the plant (CAT).
- *Lifetime*: Synonym for life (CAT).
- *Lost Production Cost:* Loss in revenues associated with energy not generated due to forced outages, outage extensions, or derates in power during operation (LCM).
- *Maintenance:* Aggregate of direct and supporting actions that detect, preclude, or mitigate degradation of a functioning SSC, or restore to an acceptable level the design functions of a failed SSC (CAT).
- *Malfunction*: Synonym for failure (CAT).
- *Mean Time Between Failures*: Arithmetic average of operating times between failures of an item [IEEE Std 100] (CAT).
- *Natural Aging*: Aging of an SSC that occurs under pre-service and service conditions, including error-induced conditions (CAT).
- *Normal Aging*: Natural aging from error-free pre-service or service conditions (CAT).
- *Normal Aging Degradation*: Aging degradation produced by normal conditions (CAT).
- *Normal Conditions*: Operating conditions of a properly designed, fabricated, installed, operated, and maintained SSC, excluding design basis event conditions (CAT).
- *Normal Operating Conditions*: Synonym for normal conditions (CAT).
- *Normal Stressor*: Stressor that stems from normal conditions and can produce aging mechanisms and effects in an SSC (CAT).
- *Nuclear Asset Management:* Process for calculating the market value of a nuclear power station taking into account the early retirement and license renewal options (NOM).

- *Nuclear Steam Supply System (NSSS):* Nuclear power plant SSCs that generate steam for the main turbine generators and were originally within the scope of supply of the reactor supplier (LCM).
- *Obsolescence:* State of an older system or component, for which spare parts are no longer readily available, original vendors have gone out of business, the technology is outdated, and replacement or repair is no longer an option (LCM).
- *Operating Conditions*: Service conditions, including normal and error-induced conditions, prior to the start of a design basis accident or earthquake (CAT).
- *Operating Service Conditions*: Synonym for operating conditions (CAT).
- *Operational Conditions*: Synonym for functional conditions (CAT).
- *Overhaul:* Extensive repair, refurbishment, or both (CAT).
- *Performance Indicator*: Synonym for functional indicator (CAT).
- *Periodic Maintenance:* Form of preventive maintenance consisting of servicing, parts replacement, surveillance, or testing at predetermined intervals of calendar time, operating time, or number of cycles (CAT).
- *Planned Maintenance:* Form of preventive maintenance consisting of refurbishment or replacement that is scheduled and performed prior to failure of an SSC (CAT).
- *Post-Maintenance Testing*: Testing after maintenance to verify that maintenance was performed correctly and that the SSC can function within acceptance criteria (CAT).
- *Preconditioning*: Synonym for age conditioning (CAT).
- *Predictive Maintenance:* Form of preventive maintenance performed continuously or at intervals governed by observed condition to monitor, diagnose, or trend an SSC's functional or condition indicators; results indicate current and future functional ability or the nature and schedule for planned maintenance (CAT).
- *Premature Aging*: Aging effects of an SSC that occur earlier than expected because of errors or pre-service and service conditions not considered explicitly in design (CAT).
- *Pre-Service Conditions*: Actual physical states or influences on an SSC prior to initial operation (e.g., fabrication, storage, transportation, installation, and pre-operational testing) (CAT).
- *Preventive Maintenance:* Actions that detect, preclude, or mitigate degradation of a functional SSC to sustain or extend its useful life by controlling degradation and failures to an acceptable level; there are three types of preventive maintenance: periodic, predictive, and planned (CAT).
- *Preventive Maintenance Basis (PM Basis):* Industry consensus on preventive maintenance task selection for nuclear power plant components; consists of a synopsis (template) of maintenance tasks, task interval recommendations, and the associated technical basis for the tasks and intervals (LCM).
- *Probabilistic Analysis:* Same as "uncertainty analysis" (CEG).

- *Probabilistic Risk Assessment (PRA)*: A plant-specific integrated analysis model that estimates the frequency of a core damage event or large early release occurring as a result of various initiating events (e.g., turbine trip, reactor trip, steam generator tube rupture, etc.) (RIISMS 1).
- *Qualified Life*: Period for which an SSC has been demonstrated, through testing, analysis, or experience, to be capable of functioning within acceptance criteria during specified operating conditions while retaining the ability to perform its safety functions in a design basis accident or earthquake (CAT).
- *Random Failure*: Any failure whose cause or mechanism, or both, make its time of occurrence unpredictable [IEEE Std 100] (CAT).
- *Real Escalation Rate*: Annual percentage increase of an expenditure that is due to factors such as resource depletion and increased demand. The real escalation rate does not include inflation (TAG).
- *Reconditioning*: Synonym for overhaul (CAT).
- *Refurbishment*: Planned actions to improve the condition of an unfailed SSC (CAT).
- *Remaining Design Life*: Period from a stated time to planned retirement of an SSC (CAT).
- *Remaining Life*: Actual period from a stated time to retirement of an SSC (CAT).
- *Remaining Service Life*: Synonym for remaining life (CAT).
- *Remaining Useful Life*: Synonym for remaining life (CAT).
- *Repair*: Actions to return a failed SSC to an acceptable condition (CAT).
- *Replacement*: Removal of an undegraded, degraded, or failed SSC or a part thereof and installation of another in its place that can function within the original acceptance criteria (CAT).
- *Residual Life*: Synonym for remaining life (CAT).
- *Retirement*: Final withdrawal from service of an SSC (CAT).
- *Rework*: Correction of inadequately performed fabrication, installation, or maintenance (CAT).
- *Risk-Informed Asset Management (RIAM)*: A probabilistic plant-specific process for assessing, analyzing, predicting, monitoring, and managing power plant physical and financial assets to optimize reliability, maximize plant value and long-term net cash flow, and maintain an acceptable level of safety (RIAM 1).
- *Risk-Informed Integrated Safety Management Specification (RISMS)*: A plant-specific safety management specification, based on a formally approved probabilistic risk assessment, designed to replace previous plant technical specifications (RIISMS 1).
- *Root Cause*: Fundamental reason(s) for an observed condition of an SSC that if corrected prevents recurrence of the condition (CAT).
- *Root Cause Analysis*: Synonym for failure analysis (CAT).

- *Run-to-Failure:* Maintenance or aging management approach that relies upon corrective maintenance to control degradation of an SSC (LCM).
- *Service Conditions*: Actual physical states or influences during the service life of an SSC, including operating conditions (normal and error-induced), design basis event conditions, and post design basis event conditions (CAT).
- *Service Life*: Actual period from initial operation to retirement of an SSC (CAT).
- *Servicing*: Routine actions (including cleaning, adjustment, calibration, and replacement of consumables) that sustain or extend the useful life of an SSC (CAT).
- *Simultaneous Effects*: Combined effects from stressors acting simultaneously (CAT).
- *Surveillance Requirements*: Test, calibration, or inspection to assure that the necessary quality of systems and components is maintained, that facility operation will be within the safety limits, and that the limiting conditions of operation will be met [10 CFR 50.36] (use only when specific regulatory and legal connotations are called for) (CAT).
- *Surveillance Testing*: Synonym for surveillance, surveillance requirements, and testing (use only when specific regulatory and legal connotations are called for) (CAT).
- *Stress*: Synonym for stressor (CAT).
- *Stressor*: Agent or stimulus that stems from pre-service and service conditions and can produce immediate or aging degradation of an SSC (CAT).
- *Structure:* Collection of components such as beams, rebars, walls, and floors that are joined together to form rooms and buildings and to support components and systems (CAT).
- *Surveillance:* Observation or measurement of condition or functional indicators to verify that an SSC currently can function within acceptance criteria (LCM).
- *Synergistic Effects*: Portion of changes in characteristics of an SSC produced solely by the interaction of stressors acting simultaneously, as distinguished from changes produced by superposition from each stressor acting independently (CAT).
- *System:* Group of components integrated to perform a specific identifiable function (CAT).
- *Testing*: Observation or measurement of condition indicators under controlled conditions to verify that an SSC currently conforms to acceptance criteria (CAT).
- *Time in Service*: Time from initial operation of an SSC to a stated time (CAT).
- *Tornado Diagram:* Bar chart displaying the upper and lower ranges of net present value for variables assigned upper and lower limits, where each upper and lower range represents the value calculated with that variable set to a limit while setting other variables to their central value (mean or median); because the bars are displayed in descending order of impact on the outcome, the chart resembles a tornado (LCM).
- *Unplanned Event*: Any condition, which is NOT in the planned work schedule, which renders station equipment non-functional or extends non-functional equipment scheduled outage time beyond its planned duration (RIISMS 1).
- *Useful Life*: Synonym for service life (CAT).
- *Wearout*: Failure produced by an aging mechanism (CAT).

B
LIST OF ACRONYMS

A

AAC	Alternate AC
ADVs	Atmospheric Dump Valves
AE	Auxiliary Feedwater
AOO	Anticipated Operational Occurrence
AOT	Allowed Outage Time
ASME	American Society of Mechanical Engineers
ASP	Alternate Shutdown Panel
ATWS	Anticipated Transient without Scram

B

BAMU	Boric Acid Makeup
BAT	Boric Acid Tank
BWRs	Boiling Water Reactors

C

CC	Containment Cooling
CCAS	Containment Cooling Actuation Signal
CCF	Common Cause Failure
CCW	Component Cooling Water
CD	Core Damage
CDF	Core Damage Frequency
CEA	Control Element Assembly
CEOG	Combustion Engineering Owners Group
CHARMs	Containment High Area Radiation Monitors
CIAS	Containment Isolation Actuation Signal
CIV	Containment Isolation Valve
CLB	Current Licensing Basis
CM	Corrective Maintenance
CPIS	Containment Purge Isolation Signal
CPS	Power Conversion System
CR	Control Room
CRC	Control Room Cooling
CREACUS	Control Room Emergency Air Cleanup System
CRMP	Configuration Risk Management Program

CRV	Control Room Ventilation
CS	Containment Spray
CST	Condensate Storage Tank
CT	Completion Time
CTMT	Containment
CVCS	Chemical and Volume Control System
CVCSIS	Chemical and Volume Control System Isolation Signal

D

DBA	Design Basis Accident
DBD	Design Basis Documents
DEI	Dominion Engineering, Inc.
DGs	Diesel Generators

E

EAB	Exclusion Area Boundary
ECCS	Emergency Core Cooling System
ECW	Emergency Chilled Water
EDGs	Emergency Diesel Generators
EHC	Electro Hydraulic Control
EOPs	Emergency Operating Procedures
EPGs	Emergency Procedure Guidelines
EPIX	Equipment Performance Information Exchange, a database maintained by INPO
EQ	Equipment Qualification or Environmental Qualification
ERM	Enterprise Risk Management
ESF	Engineered Safety Feature
ESFAS	Engineered Safety Feature Actuation System
ESP	Engineering Support Program (a Duke Power program to manage the condition of SSCs)

F

FCS	Ft. Calhoun Station
FSD	Functional System Description

G

GL	Generic Letter

H

HEP	Human Error Probabilities
HEPA	High Efficiency Particulate Air
HPSI	High Pressure Safety Injection

I

IASCC	Irradiation Assisted Stress Corrosion Cracking
I&C	Instrumentation & Control
ICCDP	Incremental Conditional Core Damage Probability
ICLERP	Incremental Conditional Large Early Release Probability
IEF	Initiating Event Frequency
INEL	Idaho Nuclear Engineering Laboratory
INPO	Institute of Nuclear Power Operations
Ins	Information Notices
IPE	Individual Plant Examination
IPEEE	Individual Plant Examination of External Events
IPP	Integrated Planning Process (at Prairie Island)
IRM	Intermediate Range Monitor (nuclear instrumentation)
ISI	In-service Inspection
ISLOCA	Intersystem LOCA
IST	In-service Testing
ISTS	Improved Standard Technical Specifications

L

LCM	Life Cycle Management
LCMT	LCM Technology, L.C.
LcmPLATO	*L*ife *C*ycle *M*anagement *Pla*nning *To*ol
LcmTEMPLATE	*L*ife *C*ycle *M*anagement *Template*
LcmVALUE	*L*ife *C*ycle *M*anagement *Value*
LCO	Limiting Conditions for Operation
LERF	Large Early Release Frequency
LERP	Large Early Release Probability
LLW	Low Level Waste
LOCA	Loss of Coolant Accidents
LOFW	Loss of Feedwater Events
LOI	Loss of Inventory
LOOP	Loss of Offsite Power
LOSDC	Loss of Shutdown Cooling
LOW	Low Population Zone
LP	Low Pressure
LPRM	Low Power Range Monitor (nuclear instrumentation)
LPSI	Low Pressure Safety Injection
LPZ	Low Population Zone
LR	License Renewal
LTOP	Low Temperature Overpressure Protection

M	
MCC	Motor Control Center
MDAFW	Motor Driven Auxiliary Feedwater
MFW	Main Feedwater
MHA	Maximum Hypothetical Accident
MPFF	Maintenance Preventable Functional Failure as defined by the MR
MR	Maintenance Rule
MSIV	Main Steam Isolation Valve
MSLB	Main Steam Line Break
MSSV	Main Steam Safety Valves
MWH or MWh	Megawatt Hour
N	
NAM	Nuclear Asset Management
NEI	Nuclear Energy Institute
NIS	Nuclear Instrumentation System
NOM	Nuclear Options Model
NPRDS	Nuclear Power Reliability Data System, a discontinued database formerly maintained by INPO
NPV	Net Present Value
NSSS	Nuclear Steam Supply System
NUREG	NRC Report Designator
O	
OEM	Original Equipment Manufacturer
O&M	Operations & Maintenance
OTCC	Once Through Core Cooling
P	
PCS	Power Conversion System
PIP	Problem Identification Process
PM	Preventive Maintenance
PdM	Predictive Maintenance
PORV	Power Operated Relief Valve
PRA	Probabilistic Risk Assessment
PSA	Probabilistic Safety Assessment
PWR	Pressurized Water Reactor
R	
RAS	Recirculation Actuation Signal
RCM	Reliability Centered Maintenance
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RGs	Regulatory Guides

RIAM	Risk-Informed Asset Management
RIISMS	Risk-Informed Integrated Safety Management Specification
RMPFF	Repetitive Maintenance Preventable Functional Failure
RPS	Reactor Protection System
RWST	Refueling Water Storage Tank
S	
SA	System Air (Prairie Island)
SAR	Safety Analysis Report
SB	Shield Building
SBEACS	Shield Building Exhaust Air Cleanup System
SBFAS	Shield Building Filtration Actuation Signal
SDC	Shutdown Cooling
SDCS	Shutdown Cooling System
SDM	Shutdown Margin
SER	Safety Evaluation Report
SG	Steam Generator
SGHR	Steam Generator Heat Removal
SGTR	Steam Generator Tube Rupture
SIAS	Safety Injection Actuation Signal
SIRWT	Safety Injection Refueling Water Tank
SIT	Safety Injection Tank
SLB	Steam Line Break
SRPs	Standard Review Plans
SS	System/Structure
SSC	Structures, Systems and Components
SWC	Salt Water Cooling
SYSMON	System Monitoring for System Engineers
T	
TDAFW	Turbine Driven Auxiliary Feedwater
TS	Technical Specification
U	
UHS	Ultimate Heat Sink
W	
WANO	World Association of Nuclear Operators
WOG	Westinghouse Owners Group

C PIONEERING RIAM DEVELOPMENT AT STPNOC

Overview

At STPNOC, the methodology for RIAM development incorporates the relationship of reliability, safety, efficiency, and other station cost element measures to a plant profitability measure. In this methodology, the plant reliability measure is based, in large part, on a station balance-of-plant availability model (BOP model) “Unplanned Production Loss” performance indicator. The BOP model ranks each basic event within its scope using well-known fractional importance measure techniques. The STPNOC BOP model encompasses all major production loss scenarios (plant trips, controlled shutdowns, reduced power operation, etc.) as contributors to production loss. The BOP model is based on a combination of generic and station-specific data that has an historical baseline. The BOP model will be periodically updated to reflect new historical performance data and generic data updates, but, it is important to note that, even without these updates, the relative performance indicators (i.e., percentage contributions) associated with specific components or operations issues are not expected to change dramatically from update to update, unless there are real changes implemented at the plant. BOP relative performance is probably more important than absolute performance parameters in the process of component prioritization and improvement option assessment. In the case of ranking, the model is normalized to actual performance at the component level. For prioritizing modifications, the differential Unplanned Production Loss (Base Case to Simulation Case) can be used as an initial indicator to identify potential areas for BOP improvement.

The plant profitability measure uses the STPNOC Operations and Maintenance Cost-Benefit-Risk Analysis (OMCBRA), which is a comprehensive profitability model benchmarked for STPNOC. The OMCBRA model includes unplanned production loss as well as plant modification, maintenance and engineering costs. It also includes a translation of changes in plant safety performance to cost. For any proposed change, the reliability performance indicators, safety performance indicators, and associated input cost impacts can be entered into the OMCBRA model to simulate the new profitability performance indicators for the station. The projected change in profitability is then applied in decision-making associated with BOP improvement option evaluations. The product of the fractional importance and unplanned production loss is the basis for the ranking measure. That is, the change in profitability due to the change in fractional importance of a specific component unreliability change associated with a BOP improvement option. Effects of equipment aging can be applied within the plant safety and reliability models by modifying component failure rate equations appropriately for age-related failure rate acceleration.

OMCBRA Project Tasks

Within the scope of the original OMCBRA project work at STPNOC, the Risk & Reliability Analysis Section (RRA) of the STPNOC Risk Management Department performed the following tasks:

- **TASK 1 – Key Cost Variable Determination And Familiarization:** RRA worked with STPNOC outage management and cost estimation experts to identify and define quantitatively the key variables impacting operating plant versus plant outage costs under the current outage schedule being implemented at STPNOC (i.e., the 21 day outage schedule profile performed at currently planned time intervals). This task required access to key STPNOC staff. The product of this task is a list of key cost and cost-determining variables for the project analysis. This list is contained in both key product files for this project (see tables and appendices presented in [72]).
- **TASK 2 – Cost Variable Comparison Database Development:**
  In this task, RRA developed a relational database defining and relating key cost variables in a format applicable to this baseline study and useful to STPNOC as a product which can be continuously updated to support their future analyses of improvement options. The product of this task is a relational database encoded in readily available software (i.e., Microsoft Access) defining, both qualitatively and quantitatively, the key cost and cost-determining variables in this analysis.
- **TASK 3 – Cost-Benefit-Risk Analysis Quantification:** In this task, RRA developed a cost-benefit-risk analysis spreadsheet workbook using commercially available software (i.e., Microsoft Excel) which is designed to perform the quantitative analysis of the baseline case and two alternative option or "delta" cases, one in which the outage schedule duration is increased to 30 days and another in which the outage schedule duration is decreased to 14 days. The primary performance indicator for this analysis is average expected total cost of power generation in dollars per megawatt-hour generated, where "total cost" includes all key operation and maintenance costs during both plant operation and refueling outages. Also, in this task, an uncertainty analysis of the results was constructed using a format consistent with commercially available software (i.e., Crystal Ball) compatible with the baseline point estimate spreadsheet. The methodology in this task followed, in general terms, but was not limited by, the processes outlined in NUREG/CR-6349, "Cost-Benefit Considerations in Regulatory Analysis," NUREG/BR-0058, "Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission," NUREG/CR-3568, "Handbook for Value-Impact Assessment," NUREG/BR-0184, "Regulatory Analysis Technical Evaluation Handbook – Draft Report," and other industry documents on cost-benefit analysis. The product of this task is an integrated Excel/Crystal Ball spreadsheet including tables of quantitative results and associated cost comparison charts and graphs.
- **TASK 4 – Omcbra Project Final Report And Presentation:** In this task, RRA developed a brief project final report (this report) presenting the results of all task work. The sections of the report are: Introduction, Technical Approach and Methodology, Results, Conclusions, and References. Also, appendices including key project databases, results tables, and graphics are included. Also in this task, RRA developed and presented a brief viewgraph presentation of the project results. This presentation is designed to be approximately one hour

in duration and is presented as an appendix to the final report [72]. The products of this task are one hard copy of the project final report, copies of computer files developed as product files in all tasks of this project including the final presentation, and one hard copy of the final project results presentation viewgraphs, presented as a final report appendix (see [72]).

The original OMCBRA model focused on the analysis of alternative refueling outage durations. Since the original development and application of OMCBRA, described in [72], the tool has been expanded to include all operations and maintenance (O&M) cost elements used at STPNOC, representing approximately 11,000 model variables.

The OMCBRA 2000 spreadsheet was originally used to perform project point estimate calculations for cost-benefit-risk parameters. This spreadsheet contains several worksheets, including one for key data input, one for key parameter estimation/calculation, one for total O&M direct cost calculation, one for outage-related O&M cost calculation, and one results summary worksheet containing bottom-line generation cost results.

Direct cost fractional importance for each direct cost variable is calculated in the direct cost worksheets of the OMCBRA 2000 spreadsheet. This spreadsheet is linked with the project relational database file. In this way, the cost variable fractional importance can be used to automatically develop ranked lists of cost variables by importance to total cost of generation, even when input variables are changed in future case studies. “Fractional importance” is simply the contribution of one cost variable (or element) divided by the total absolute value of the variable category for the station (i.e., the sum of the individual element contributions here).

The following references and information sources were used in support of the original OMCBRA project:

1. 1999-2003 STPNOC Business Plan (20/20 Vision).
2. STPNOC Long-Range Strategic Outage Plan.
3. STPNOC Probabilistic Risk Assessment (PRA).
4. STP Business Planning Guideline (particularly the Economic Analysis Section)
5. NUREG/CR-6349, “Cost-Benefit Considerations in Regulatory Analysis,” October 1995.
6. Cost and Plant Performance Data from STPNOC Planning and Controls Group.
7. Net Power Generation Estimates from STPNOC Thermal Performance Group.
8. Electric Power Research Institute (EPRI), Outage Risk Assessment and Management (ORAM) Studies (Diablo Canyon Nuclear Power Plant and others).
9. NUREG/BR-0058, “Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission,” 1995.
10. NUREG/CR-3568, “Handbook for Value-Impact Assessment,” December 1983.

11. NUREG/BR-0184, "Regulatory Analysis Technical Evaluation Handbook – Draft Report," Unpublished draft circulated for review and comment.

12. "STPNOC 10 CFR 50 Appendix J Local Leakage Rate Test Improvement Analysis," January 1996.

13. TVA, "Watts Bar Severe Accident Mitigation Design Alternative (SAMDA) Potential Enhancement Value-Impact Case Study Analysis," May 1994.

14. Electric Reliability Council of Texas (ERCOT) Data from Financial Times Megawatt Daily, 1998.

As time progresses, the associated input data in the OMCBRA spreadsheet is periodically updated to ensure accurate profitability predictions.

STPNOC RIAM Technical Approach

Component ranking and prioritization of proposed investments in BOP design, operation, and/or maintenance activities can be determined by studying the effect on BOP component reliability and using the change as input to plant safety, reliability (or availability), and efficiency models, which, in turn, provide input to the OMCBRA model. The BOP model BOP model can be used to simulate the effect of planned investments on overall plant reliability by modifying component failure probability appropriately. Plant investments at the component level can be evaluated directly in BOP model. In general, significant plant investments may be made at the component level. The effect of investments at the component level needs to be accurately reflected in the performance indicator.

The effect of investments in BOP equipment at the component level can be estimated by developing a component fault tree that is normalized to the current component failure rate. There are several computer codes (e.g., SAPHIRE) that can be used for detailed fault tree development. For simple models (where the only important failures are single point failures for instance) a spreadsheet could be used. SAPHIRE would require as input the fault tree structure as well as component failure rate data. A change to the component design and/or maintenance program can then be simulated in the component fault tree, producing a new component failure rate. The new failure rate can then used at the component level in the BOP model to assess the new plant performance. The new plant performance is then entered into the OMCBRA model along with associated costs to evaluate profitability. This profitability measure then becomes the basis for prioritizing a investment.

The key information provided by the BOP model includes the following general unit-level performance indicators: availability (A), capacity factor (CF), forced outage rate (FOR), unplanned capability loss factor (UCLF), frequency of reduced production operations, frequency of elective controlled shutdowns, frequency of required controlled shutdowns, frequency of uncontrolled shutdowns, frequency of all production loss scenarios, unplanned down time, unplanned production loss, and the value of unplanned production loss. In addition to these unit-level performance indicators, BOP model can be used to produce several summary reports and importance measure reports that can aid in the development of economic data for use in the evaluation of plant performance and potential reliability improvement options.

For example, key importance reports can be generated at the system, component type, and basic event levels of indenture in BOP model. Among other parameters, these importance reports provide the following key parameters: expected frequency of events (F), expected down time (DT), expected production loss (EPL), and expected production loss cost (EPLC). In practice, the results of these reports are exported to MS Excel files, and the results are “post-processed” to be compatible with OMCBRA profitability measures. Three key parameters are calculated at all available levels of indenture in the BOP model importance reports. These three parameters are: expected production loss cost for the station (EPLCS) in dollars per calendar year, expected recoverable production loss cost “if perfect” for the station (ERPLCS) in dollars per calendar year, and profitability achievement worth (PAW). As previously stated, the values of F, DT, EPL, and EPLC are provided via the BOP model quantification. The values of the three post-processed parameters are calculated as follows:

EPLCS = (Number of Station Generating Units)*EPLC (Note: an adjustment for actual production loss value can also be made here if a difference between BOP model and OMCBRA exists.)

$$ERPLCS = EPLCS*UF*PF$$

$$PAW = (CP+ERPLCS)/CP$$

where

UF = Unshadowing Factor = CF+(EPL/8766 Hours per Calendar Year)

PF = Profitability Factor = (SP-FC)/SP

CP = Current Baseline Projected Profitability Value for the Station ($/Calendar Year)

SP = Average Projected Sales Price of Electricity for STPNOC ($/MWH)

and

FC = Average Projected Cost of Fuel ($/MWH).

The resultant ERPLCS and PAW performance indicators can be useful in decision-support to direct station resources for the effective and efficient development of proposed plant reliability improvements options.

The effect of investments on plant safety (measured primarily in terms of associated change in reactor core damage frequency (CDF), from both operating plant and shutdown plant models) are analyzed via the plant PRA and PSSA. The results are applied directly within the decision-making process to ensure that no safety limits are challenged. The results are also incorporated within the OMCBRA model to aid in calculating predicted long-term profitability impacts.

The effect of investments on plant efficiency (measured primarily in terms of associated change in heat rate) is analyzed via the plant efficiency model (e.g. PEPSE model). The results are then incorporated within the OMCBRA model to aid in calculating predicted long-term profitability impacts.

Data Requirements

Sufficient data are required to support all program requirements. These data include equipment unavailability due to preventive and corrective maintenance. Data are required in some cases at the component or component level of indenture. Cost data are required for the OMCBRA model. Much of this data is developed at the individual cost element level of indenture defined by a "triplet" of the associated STPNOC cost center (CC), program element (PE), and element of expense (EE) applied within the STPNOC accounting system. Reliability data need to be compatible with the current BOP model description of the BOP.

To apply the BOP asset management support, periodic (ideally continuous) data updating for BOP equipment is necessary. The scope of this data ideally includes BOP equipment failure, success, and maintenance data for all key BOP components modeled in the BOP model. This data should be developed and updated using Bayesian updating techniques outlined in [75]. The processes and work effort involved with this activity should be integrated with similar data collection and analysis activity associated with Maintenance Rule application at STPNOC.

Aging Considerations

Equipment aging can be accounted for in out years using appropriately modified basic event probabilities. The typical way that aging is accounted for in reliability calculations is to apply a failure rate "acceleration factor" which takes effect after the equipment of interest exceeds its normal design life (usually assumed to be 30 years for most equipment). If we assume that a certain component of interest has a baseline constant failure rate of F_0 that is effective during design life and an age-related failure rate acceleration of X% per year past design life, then we can calculate (and apply in risk calculations) an updated failure rate, F, as follows:

$$F = F_0 \, (1+(X/100))^{(n-d)}$$

where n represents the current total age of the component in years and d represents design life in years. Assumptions on age acceleration rates and design life values can, of course, be varied as desired for different components by applying appropriate corresponding variations of this equation. For example, if we are interested in a component with a baseline failure rate of 1.00E-04 failures per operating hour, a design age of 30 years, a current age of 37 years, and an age-related failure rate acceleration rate of 25% per year past design life, then the current failure rate of the component, using the above equation would be calculated as follows:

$$F = (1.00E\text{-}04)(1+(25/100))^{(37-30)}$$

yielding a current failure rate of 4.77E-04 failures per operating hour for the component of interest. As more sophisticated aging and/or obsolescence analyses are performed for specific equipment (see [2]), new component failure mode failure rates can be manually entered into the BOP model input database for incorporation into RIAM predictions.

Information Flow

The basic data flow for a single evaluation is shown schematically in Figure C-1. As shown, basic data at the component level are made available to the reliability model from the appropriate databases. In the case of ranking, data are required at the component level. These data are already in BOP model Where component data only are required (for ranking, for example) the SAPHIRE process is not required since the model has the necessary information already. Currently, the model input data are static (OMCBRA, BOP model, and SAPHIRE). BOP model data at the component level will be updated commensurate with implementation of the BOP on- line maintenance and Trip Avoidance project. A new process is required to update OMCBRA and component databases.

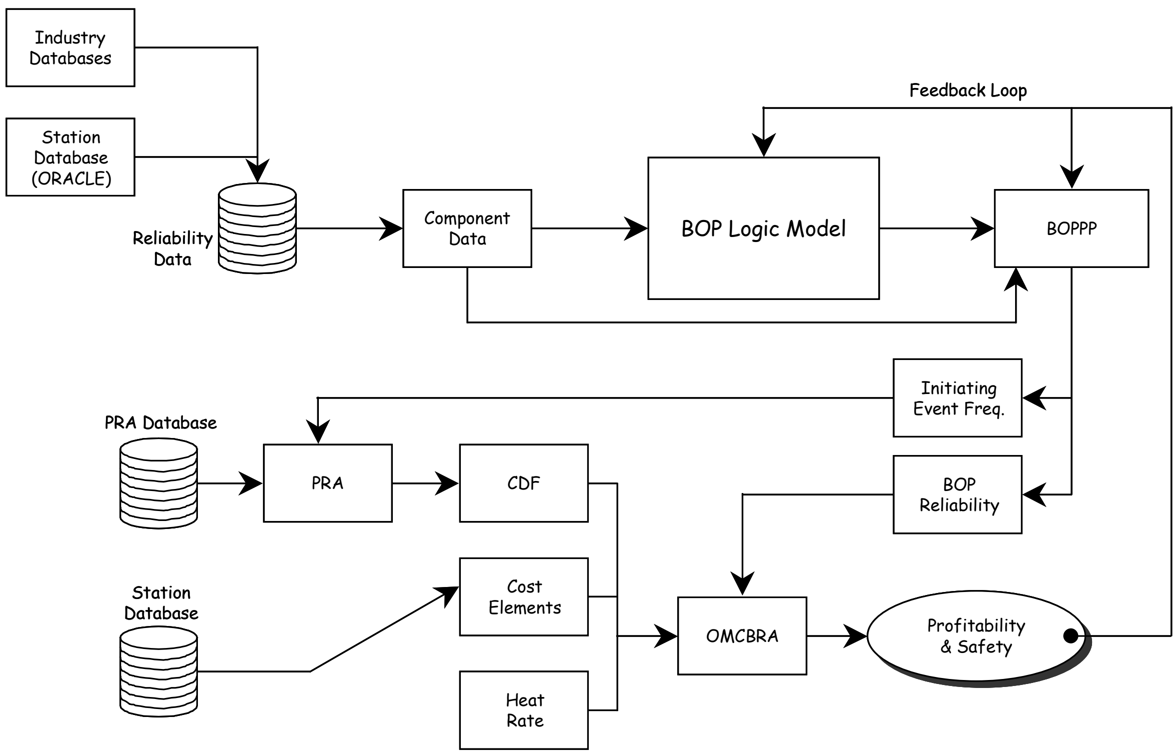

Figure C-1
Schematic Diagram of STPNOC RIAM Information Flow Example

The process needs to be duplicated for simulation of an investment or set of investments. The indices so produced are then tied to the associated plant investment, allowing prioritization of reliability improvements (based on maximizing profitability.) Proposed investments can be analyzed individually or in groups (i.e., investment “packages”). The process is combined with the STPNOC investment cost-benefit analysis spreadsheet, which predicts investment cost recovery times (or payback periods) and net benefit of investments.

One of the primary recommendations resulting from the work performed on this project and reported in this document is to develop a software package designed to streamline, consolidate, and integrate the key elements of the RIAM development process for nuclear power stations and operating companies.

Target:
Nuclear Power

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