IAEA-TECDOC-1209

Risk management: A tool for improving nuclear power plant performance

INTERNATIONAL ATOMIC ENERGY AGENCY IAEA

April 2001

The originating Section of this publication in the IAEA was:

Nuclear Power Engineering Section
International Atomic Energy Agency
Wagramer Strasse 5
P.O. Box 100
A-1400 Vienna, Austria

RISK MANAGEMENT: A TOOL FOR IMPROVING NUCLEAR POWER PLANT PERFORMANCE
IAEA, VIENNA, 2001
IAEA-TECDOC-1209
ISSN 1011–4289

Printed by the IAEA in Austria
April 2001

FOREWORD

This technical document on risk management as a tool for improving nuclear power plant (NPP) operations is part of an ongoing project on management of NPP operations in a competitive environment. The overall objective of this project is to assist the management of operating organizations and NPPs in identifying and implementing appropriate measures to remain competitive in a rapidly changing business environment. Other reports developed through this project have identified overall strategies and techniques that NPP operating organization managers can use to succeed in more competitive energy markets. For example, in IAEA-TECDOC-1123, *Strategies for Competitive Nuclear Power Plants*, one of the most important strategies identified was integrated risk management. This publication provides a recommended structure for risk management along with examples of how NPP operating organizations are using this tool to help them integrate safety, operational and economic-related risks in a changing business environment.

The IAEA wishes to thank all participants and their Member States for their valuable contributions. The IAEA officer responsible for this publication is T. Mazour of the Division of Nuclear Power.

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

In today's global energy environment, nuclear power plant (NPP) managers need to consider many dimensions of risk in addition to nuclear safety-related risk. In order to stay competitive in modern energy markets, NPP managers must integrate management of production, safety-related, and economic risks in an effective way. This integrated risk management (RM) approach generates benefits that include the following:

- **Clearer criteria** for decision making.
- **Making effective use of investments** already made in probabilistic safety analysis (PSA) programs by applying these analyses to other areas and contexts.
- **Cost consciousness and innovation** in achieving nuclear safety and production goals.
- **Communication improvement** — more effective internal communication among all levels of the NPP operating organization, and clearer communication between the organization and its stakeholders.
- **Focus on safety —** ensuring an integrated focus on safety, production, and economics during times of change in the energy environment.

Over the last decade, in a number of Member States there has been a move from nationalized ownership of electric utilities within economies geared towards full and stable employment, to privatized, competitive markets with pressure to reduce costs, staff numbers, and the engineering workload. The focus now is on meeting the targets set by shareholders rather than governments. Some Member States have not seen such marked changes, however, these changes are indicative of the direction of the world's energy markets.

To survive in this new de-regulated and competitive environment, NPPs need to preserve and maintain safety and concentrate on market prices, supply and demand, and performance. Clearly, deregulation increases risks, but also generates opportunities for greater profits. It is in this context that NPP operators need to consider all aspects of risk, and come up with an optimum solution that does not compromise safety and performance.

One of the major benefits of an integrated risk management approach is that safety, operational, and financial performance (and risks) are often correlated. NPPs with good safety records tend to show strong economic performance, and vice versa. Evidence of this is provided in Figure 1, which shows date compiled by the Institute of Nuclear Power (INPO) for all NPPs operating in the USA in 1999. This figure compares economic performance (operating and maintenance (O&M) costs per kilowatt-hour) and INPO plant evaluation ratings (which are primarily related to nuclear safety). Figure 1 shows that as a group, those plants with the best safety ratings ("1") also had the lowest O&M costs.

The goal of an integrated risk management approach is to incorporate into the organization's management system a framework for systematic analysis, that views identification and management of risk in a portfolio context. This integrated (or portfolio) approach to risk analysis can help the organization determine the proper mix of preventive measures, transfer of risk to other parties, and retention of risk by the organization. The benefits will accrue to the stakeholders, including commercial or government owners and society.

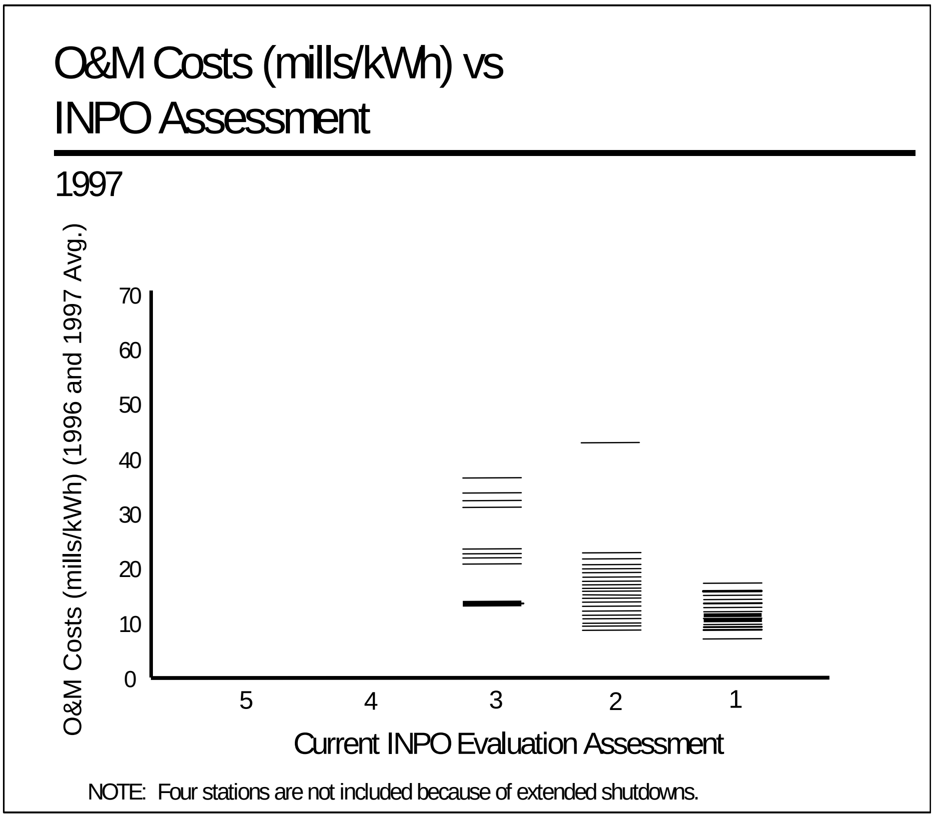

FIG. 1. Economic and safety performance correlation.

1.1. PURPOSE

The purpose of this report is to provide an integrated framework for risk management as a tool to enhance the performance of NPPs. It aims to explore a broad context of risk (safety, operations, financial/commercial, strategic), with a goal of providing a source document for use by managers of NPP operating organizations. This report describes the steps of the risk management process and provides examples of implementation. This framework can be used for large-scale proposals as well as smaller ventures. Applying a structured approach to address the elements of risk and use of integrated risk management techniques are key to improving performance and enhancing commercial success.

1.2. AUDIENCE

The intended audience for this document encompasses all levels of NPP operating organization management including managers responsible for setting policy on safety, operational, and commercial/financial aspects of NPP operation, and the hands-on managers directly implementing the organization’s policies.

1.3. DEFINITION AND TYPES OF RISK

In general, risk encompasses two aspects: the potential for things to change, and the magnitude of the consequences if they do change. The notion of risk includes both opportunities and threats. Different disciplines — economics, engineering, safety analysis — will have their own more specific definitions of risk, each reflecting a different disciplinary focus on parameters and consequences, but all will in some way encompass the frequency and consequences elements of risk. These different perceptions and definitions of risk are somewhat akin to the views of the proverbial blind men exploring an elephant. None is wrong; each represents a different point of view. Consider the following case.

A plant manager is considering replacement of the plant's instrumentation and control system as a prelude to plant life extension. The replacement has not (yet) been required by the nuclear safety regulatory body. The manager must weigh the risk of making this investment. Management's advisors may have the following views:

For the nuclear safety analyst, the relevant risk is the potential for ending up with a system that can demonstrate a frequency of radioactive release that satisfies established institutional and regulatory goals *(a focus on nuclear safety related risk*).

For the financial analyst, the relevant risk is the potential that the cost of the investment will not be recovered over the life of the investment (*a focus on financial risk).*

For plant operation, the relevant risk is that the installation and operation of the new system may introduce operational difficulties (or operational benefits) *(a focus on operational risk*).

For the project manager, the relevant risk is the probability that the project will be completed on schedule and within budget along with the associated cost impacts (a *focus on budget and schedule risks*).

All of these views encompass aspects of risk that are important to the organization. All must be considered to get a whole picture of 'the elephant' known as risk. All need to be considered in an integrated risk management framework.

Organizations are exposed to many sources of risk, which might be characterized into four broad categories:

1. safety related,
2. production/operations,
3. commercial/financial, and
4. strategic.

1.3.1. Safety related risks

Integrated risk management can improve the analysis and management of safety-related risks, including nuclear, radiological, industrial, and environmental areas. Nuclear safety issues are widely understood by IAEA Member States. The NPP industry's use of PSA for analysis of nuclear safety is arguably the most sophisticated risk analysis methodology in the world. For details regarding managing nuclear safety related risk, the reader is referred to the catalogue of IAEA publications (available on the IAEA website (www.iaea.org)), and in particular, to several recent IAEA technical documents related to the use of PSA that are listed at the end of this report, under "Related IAEA publications on risk management".

Other safety issues, such as industrial and environmental safety, have received less attention in most NPPs and are likely to benefit from closer study. An integrated risk management program will encompass this.

1.3.2. Production/operations risks

Operation and production risks are those relating to the resource and product markets in which a firm operates. They include plant and product design, production and marketing processes, labor force (human resources and training) management and organization, technological innovations, outage and inventory management, document handling, and configuration management. Limited aspects of these risks will have been picked up by nuclear safety risk assessment, particularly PSA. Revisiting this existing data from an operational point of view can yield significant benefits in understanding operational risk.

1.3.3. Commercial/financial risks

Movements in financial variables (such as prices of resources and finished product for sale, currency exchange rates, and interest rates) create risks for organizations. As the nuclear power industry moves from a regulated, rate-controlled environment to one of competitive selling of electricity, these financial variables can be expected to gain importance. For example:

- NPP operators are competing to provide electricity to commercial entities at prices agreed upon by contract.
- Just as local and long distance phone service can be provided over existing installed wire by competing providers, so can electricity customers gain options to buy electricity from multiple providers.
- Recent examples of extreme volatility in wholesale electricity prices illustrate both the upside and the downside of this market.
- Cross-border selling of nuclear power plant design, engineering, and construction services subjects the commercial entity to currency risk, as well as some of the strategic risks discussed in the next section.

1.3.4. Strategic risks

Strategic risks result from fundamental changes in the economic, commercial, or political environments. Examples include: shifts in governmental types; changes in governmental spending trends; expropriation, nationalization, and privatization challenges; changes in the nature of marketplace competition; and changes in public sentiment toward particular lines of business; ownership patterns; and regulatory and legal changes in both markets and safety arenas.

1.4. STRUCTURE OF THE REPORT

Section 2 presents a suggested framework for risk management. The four generic steps of the risk management framework are described in detail in Sections 3, 4, 5, and 6, in which are found presentation of the concepts as well as numerous short examples[1]. Discussion encompassing the whole of the framework is found in Section 7, followed by conclusions in Section 8. Extensive references found at the end of the report are from the public domain as well as the IAEA. Annexes provide more detailed examples of implementing this framework.

[1]In this discussion, most examples will be those NOT related to nuclear safety risk, because identification of this source of risk, its measurement, and management by PSA methodologies are widely understood and well documented in the industry. A list of IAEA documents relating to the use of PSA is located at the end of this report.

1.5. CAVEATS

1. There is no intention to denigrate nuclear safety as a primary objective in operating a NPP. Nuclear safety-related risk management is the minimum condition that NPPs need to achieve.
2. This report does not describe a detailed risk management model with step-by-step instructions. Instead, it presents a generic approach to help NPP operators (at all levels of the company) to 'tease out' the multiple dimensions of risk that are not always considered.
3. The framework presented may need to be modified in order for it to be integrated with an organization's and management system and associated procedures.
4. This report does not provide a definitive or exhaustive listing of risks. All examples are presented in order to illustrate particular points.
5. Many of the identification processes, measurements, and management tools are strictly qualitative in nature and dependent on the judgment of the managers involved. The industry does not have, for many areas, numerical tools for analysis and control as sophisticated as those in the nuclear safety risk arena.

2. FRAMEWORK FOR RISK MANAGEMENT IN AN NPP ENVIRONMENT

2.1. FRAMEWORK

The NPP operating organization is viewed in this report as comprising three major sectors (safety, production/operations, and financial/commercial) embedded within the strategic environment (see Figure 2). These sectors intersect one another, so that decisions in one arena have impact and are impacted by decisions in a different sector. In addition, there are stakeholders outside of the NPP who have impact on these three sectors as well as on the strategic environment.

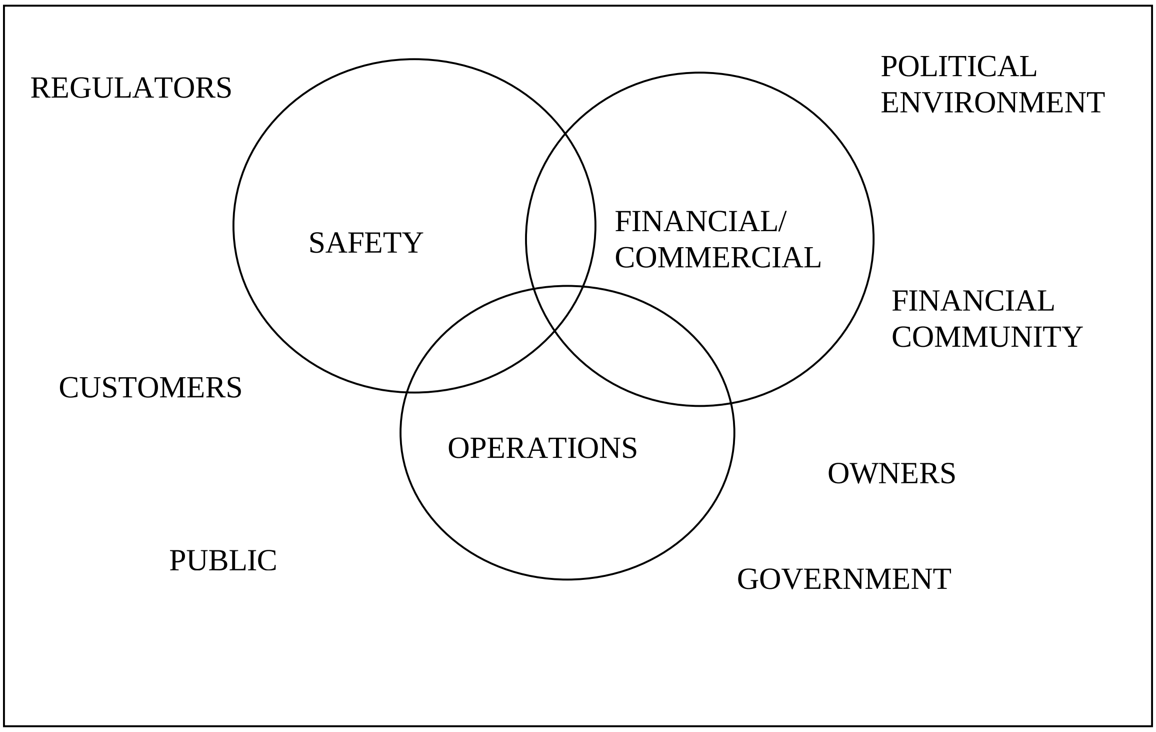

FIG 2. Risk management environment model for a nuclear power plant operator.

In the safety sector lie the much analyzed nuclear and radiological safety issues, as well as industrial safety and environmental protection. In Operations, are sources of risk related to factors such as training, configuration, human resources, inventory, security, and outage management. In the financial/commercial realm are issues of foreign exchange or currency risk, pricing of products and resources, escalation clauses, competitive pressures, insurance and derivatives pricing, interest rates on debt, and capital market performance. In the strategic environment are such issues as merger and acquisition, privatization responses, and diversification of products and markets.

For each issue or event requiring a decision, managers can benefit from adopting a systematic approach to identifying the potential risks, looking specifically at the sector in which the proposal falls, but also looking at the intersection with the other sectors. The idea is to try to identify all of the consequences of a particular issue or event, in order to find an optimal decision set to minimize adverse effects and maximize social and business objectives in a cost efficient manner. A risk management framework providing this systematic approach is shown graphically in Figure 3.

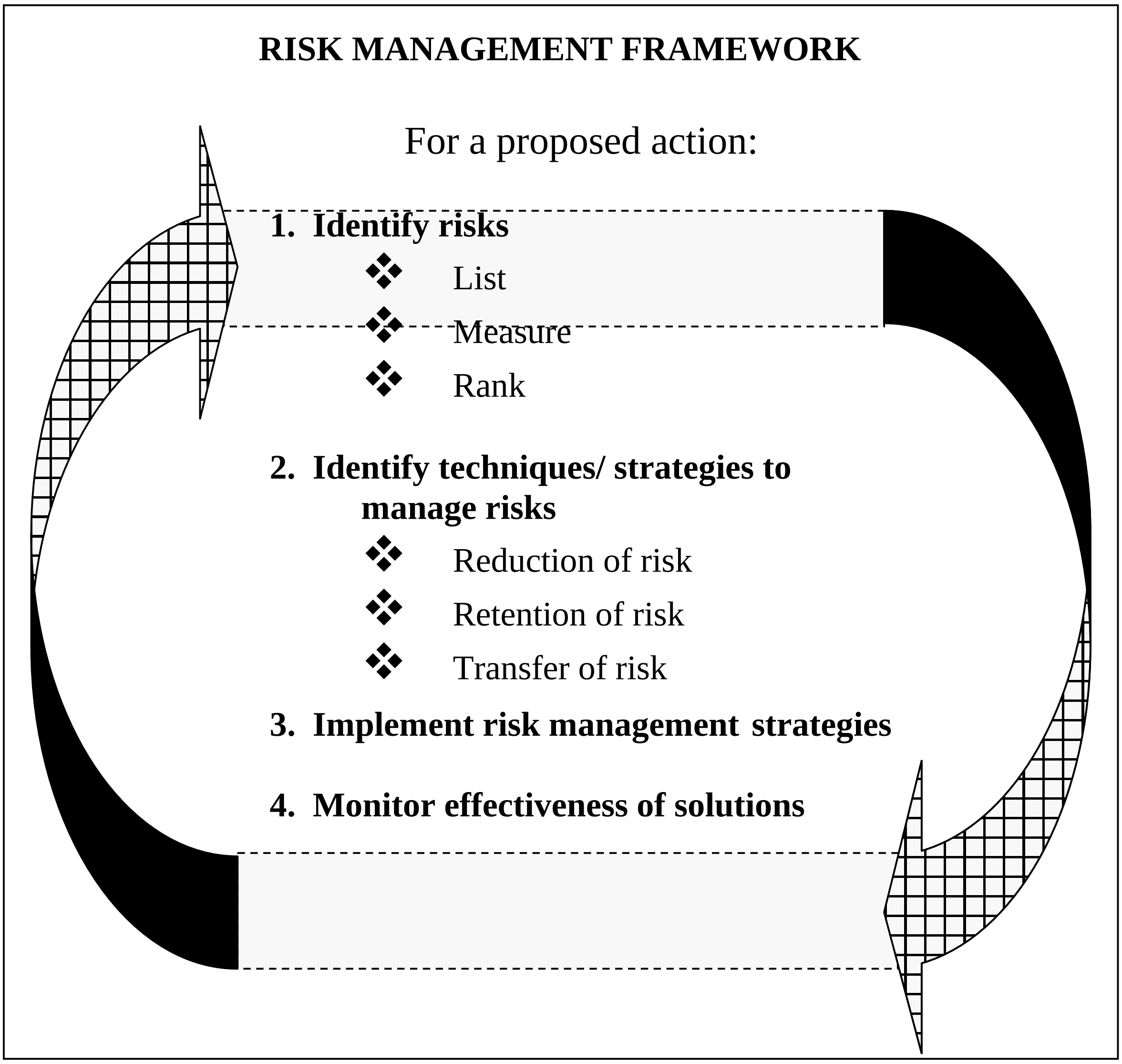

FIG. 3. Risk management framework.

Step 1, identify possible risks, includes:

- Determining what the potential consequences are associated with this issue or event (paying particular attention to interactions among the three sectors) For each of the consequences identified, assessing the likelihood that the consequence would occur.
- Estimating the impact and relative importance of each consequence, in terms of magnitude and timing of the impact.
- For each consequence, asking the question, “Is there any action we can take that will affect the probability, the magnitude, or the timing of the consequence?”

The risk identification step is discussed in more detail in Section 3, along with numerous examples.

Step 2 is to identify techniques or strategies to manage the risk. Three categories of risk management tools are; 1) risk reduction, 2) risk retention, and 3) risk transfer. In many cases, a combination of tools, techniques, and strategies will be used, rather than a single approach. Discussion and examples of the techniques to manage risk are found in Section 4.

Step 3 is to implement the chosen techniques or strategies, while Step 4 is to monitor the effectiveness of solutions, providing feedback so that risk analysis is always updated as the operating environment changes. As Figure 3 illustrates, this is an iterative process, in which the sources of risk change over time as consequences are controlled or developed and as the influences on the three sectors of the risk management environment change.

2.2. CHECKLIST FOR APPLICATION OF THE RISK MANAGEMENT FRAMEWORK

To use the framework presented in Figures 2 and 3, it is useful to have a “checklist” in order to prompt managers to think through the risks associated with management decisions regarding various issues/events. Figure 4 presents such a checklist, which is intended to initiate the thinking process, but it is NOT intended to be an exhaustive list. The idea is to take an issue for which there is a need to manage risk and work through the checklist to help identify the consequences, rank them for their importance, identify possible risk management techniques, highlight implementation issues, and identify monitoring and feedback needs. An issue is worked through the checklist; then, based on new understandings gained by this process, the parameters are iteratively refined until the relevant decision makers agree on a course of action, having objectively considered the associated risks.

Figure 4 illustrates the risk management process — identification, ranking, impact on other areas, proposed action or disposition, through to implementation. For Step 1 of the process, Figure 4 contains the following fields:

- *Category/Description* defines the four categories of risk, plus additional sub-level description. This next level description is not exhaustive (which is the case for all categories and tables in the checklist), but is meant to generate the appropriate starting points and examples.
- *Definition* further describes the sub-level components and highlights the application of risk
- *Opportunity/Threat*: as previously identified, the risk element can be viewed as an opportunity, or threat, the specific aspects of which are identified in this field.

- *Unit of Measure:* Defines the units by which the risk application can be measured, or expressed.
- *Ranking:* This three column field defines the risk element's ranking by (for example) the originator (preparer), followed by a peer-review ranking and validated at the decision-making (approval) level in the last column. The number of iterations depends on the user and circumstances.

ISSUE/EVENT ____

STEP 1. Identify Related Risks (search for consequences)

Category/Description	Definition	Opportunity/ Threat (+/-)	Unit of Measure	Ranking		
				by preparer	by reviewer	by approver
SAFETY RELATED						
Nuclear						
Radiological						
Industrial						
Environmental						
(Others…..)						
OPERATIONS						
Personnel Qualification						
Personnel Training						
Outage Management						
Inventory Management						
Documentation and Procedures						
Organizational Structure						
Physical Security						
Human Factors						
equency						
Spare Parts Inventory						
Obsolescence						
Ageing Effects						
(*Others…..)*						
FINANCIAL/COMMERCIAL						
Interest Rates						
Exchange Rates						
Supply/Demand Conditions						
Supplier Base						
Cash Flows						
Return on Investment						
(*Others…..)*						
STRATEGIC						
Political Environment						
Ownership Patterns						
Level of Competition						
Public Sentiment						
Market Regulatory and Legal Environment						
Safety Regulatory and Legal Environment						
(*Others…..)*						

FIG. 4. Risk management checklist.

ISSUE/EVENT ____

STEP 2. Identify Techniques and Strategies to Manage Risk

Reduce Risk	**Identification**
Engineering Changes	
Management or Organizational Changes	
Enforcement of Existing Standards	
Personnel Changes (Staffing, Training)	
Cost Changes (Increase efficiency, change spending patterns)	
(*Others…..)*	
Transfer Risk	
Contracts with Suppliers, Market	
Insurance	
Pooling	
Regulation/Legislation	
(*Others…..)*	
Retain Risk	
By Choice	
By Default	
Not Recognized	
Techniques to consider interactions with other risks	
Sensitivity Analysis	
Reduce to Monetary Terms to Compare	
Qualitative Comparison	
Multi-criteria Analysis	
Consistency with Company Culture and Policy	
Define Exit Strategy	
(*Others…..)*	

ISSUE/EVENT ____

STEP 3. Implement Integrated Solutions

Assign Responsibilities and Accountabilities	
Sanity Check — does the solution resolve the issue?	
Is the solution consistent with solutions to other issues?	
Are key risks being addressed?	
Can you exercise the exit strategy?	
Is flexibility maintained?	
(*Others…..)*	
DO IT!	

ISSUE/EVENT ____

STEP 4. Monitor Effectiveness of Solutions

Establish Measures of Success	
Establish Milestones and Check Points	
Look for Unintended Consequences	
Monitor Accountability	
Monitor for Emerging Risks	
Feed back results to appropriate step/point to adjust strategy or exit	

FIG. 4. (cont.)

The following two examples illustrate the intended use of the checklist. The completed checklists for these two examples are included in the Appendix (due to their length).

2.2.1. Example of use of checklist: provide additional interim spent fuel storage at an existing NPP site

Most older NPPs today are in need of additional interim spent fuel storage space capacity, to retain the “cooled” spent fuel in a secured, safe environment, prior to final disposition in long term storage. It is therefore extremely important that this additional capacity is provided in a safe and environmentally suitable manner in order to ensure continued plant operation. In today’s increasingly de-regulated power production environment, it is vitally important to recognize this need, which in effect protects the utility’s long term investment. It is also in this context that the value of additional investment needs to be weighed against all aspects of real, or perceived risk, in order to determine the appropriateness of this investment. The Appendix provides an example risk management checklist associated with a hypothetical management decision regarding a project for interim fuel storage.

2.2.2. Example of use of checklist: retirement of operational staff

Many of the NPPs operating today have been in operation for twenty years or more. They are now facing near term retirement of the personnel who initially commissioned the plant. At the same time the nuclear industry education infrastructure in a number of Member States is being reduced, and the competition for replacement personnel is quite strong. These phenomena have a major impact on availability of qualified personnel to replace these retirees, directly affecting the station’s performance, generating capacity, and availability. It is imperative that the potential risks associated with this situation and alternative solutions are identified as early as feasible, so that a preventive action can be taken to minimize negative impact on performance, i.e. address the issues of availability of properly trained staff, before the impact is imminent. The Appendix provides a completed risk management checklist associated with a hypothetical management decision regarding alternative solutions to replace retiring plant personnel.

2.3. APPLICABILITY TO A BROAD RANGE OF PROJECTS

Using the proposed risk management framework (Figures 3 and 4) will enable NPP operating organizations to more cost-effectively meet performance goals, for a broad range of projects. Following are three examples to illustrate this point.

- Fires that do not affect nuclear safety related equipment. A fire in a cooling tower, for example would likely have no effect on core melt frequency, but may cause the plant to be out of service for a substantial length of time, with associated financial and strategic risks.
- Risks associated with business processes and external sources will affect the performance of nuclear operating organizations. Examples include labor stoppages, raw material and spare part price fluctuations, currency changes, mergers and acquisitions amongst suppliers of essential equipment and materials, changes in regulatory and political environments, distribution failures due to natural disasters, and price fluctuations in the market.

- In the case of multi-plant operating companies, there are additional considerations, including sources of risk from multiple simultaneous outages, to additional possibilities for risk management in being able to operate the units as a portfolio of assets, rather than as isolated entities. See Annex 2 for a discussion of these issues for the Nuclear Power Corporation, of India, which operates twelve units of varying designs and ages.

3. RISK MANAGEMENT PROCESS, STEP 1. IDENTIFICATION, MEASUREMENT AND ASSESSMENT OF RISK

In the management of a nuclear power plant, risk can come from many sources — production processes, training processes, social responsibility (including communication with the public), outside influences (natural disasters and economic factors), and financial processes, to name a few. Many different sources of information can be used to identify sources of risk, such as industry (or company[2]) specific or generic risk exposure checklists, flowcharts of critical processes, examination of contracts, physical inspection, analysis of financial statements, and employee, contractor, or regulator interviews. A wide-reaching integrated information system needs to be used to provide continual updates about operations, acquisition of assets, and changing relationships with outside entities and stakeholders[3].

A major objective of risk identification is to avoid the unintentional or unconscious retention of risk that occurs when a source of performance variability remains undiscovered, and therefore, not part of the risk assessment/management system. Retention of risk is discussed in more detail in Section 5.4.

After identifying sources of risk, one needs to characterize the risk. Deterministic and probabilistic safety analyses have been used extensively in nuclear power plants around the world for assessment of nuclear safety risk. These techniques can be expanded, however, to measure and assess the risk of non-nuclear events, such as protecting plant investment, maintaining plant availability, and analysis of re-licensing issues.

Some qualitative questions can help the NPP manager examine the essential characteristics of the risk from a conceptual point of view:

- Does the risk produce opportunities and threats, or only one? If both, do we need to measure both?
- Is the cause of risk likely to be a continuously occurring or is it episodic or rare in time and space?
- Is the risk such that a risk management decision/action will be reversible in the future or is it likely that for this source of risk, the choices are basically irreversible?
- What are the potential effects of the risk on the performance of the NPP owner or operator?
- Is the source of risk such that it is mission critical, 'make-or-break', or is it a source of risk that will modify results in less severe ways?

---

[2]See Annex 3 for an example from British Energy, UK.

[3]It is very possible that these sources may also provide ideas for the entity that would increase variability of performance in positive directions. i.e., not all sources or consequences of risk are negative. A major principle in the discipline of finance relates to the risk/return relationship: to increase returns, it is often necessary to take on higher risk, or subject the stakeholders to higher variability of performance.

- Does the risk affect the actual ability to produce and sell or does it just affect the way that production and sales occur?
- What are the financial effects of the risk?

Section 3 examines the identification of risk with a series of examples, each focusing on a specific sector of the risk management environment (see Figure 2). The last part of Section 3 gives several integrated risk management examples in which the risks clearly cross sectors and require the manager to identify complex interactions.

3.1. SAFETY RELATED

Included in the safety-related sector of the model are the categories of nuclear, radiological, industrial, and environmental safety. In identifying and characterizing these risks, the operator needs to consider not only the type of risks involved, but also both internal and external consequences.

Tools for assessment of nuclear safety-related risks are, arguably, the best-developed risk assessment tools in any industry. Those for radiological, industrial, and environmental safety are also well researched and are already part of the standard safety assessments and management of the nuclear industry. Industry-wide standards and tools for nuclear and radiological safety assessment and management are supplemented by various national and international guidelines for industrial and environmental safety.

3.1.1. Example of identification of environmental hazard: British Energy, UK

Many companies have developed internal frameworks for identification and management of environmental hazards. For example, British Energy, UK, has such a framework that requires each NPP to provide an inventory of the potential environmental hazards and their magnitudes. This decision framework establishes the number and integrity of barriers required to avoid the hazard. This risk-informed approach ensures that resources are focused in a consistent fashion where they can provide the most benefit. Annex 3 shows the key stages of the process and an example assessment for a plant system.

3.1.2. Example of identification of safety related risk: Revised reactor oversight process: risk informed, performance based assessment, inspection and enforcement

In 1998, a sweeping change in the USNRC regulatory process began [10]. The USNRC began to move from the subjective, arbitrary, and resource intensive process of regulation based on detection and analysis of compliance errors in processes and procedures, toward a new regulatory oversight process based on objective, measurable, safety-significant performance indicators. USNRC focus, then, shifted to assessment, inspection, and enforcement activities ranging from minimal oversight to required agency action based on these indicators. The revised reactor oversight process includes seven cornerstones of safety, nineteen performance indicators, a baseline inspection program, a significance determination process, enforcement program, and an action matrix. A pilot program began in June 1999, with nine plants of varying design, level of performance, and geographic location. Full implementation was achieved in 2000.

3.1.3. Example of identification of safety related risk: Technical specifications

Use of PSA methodologies can be extended to analysis of the nature and impact of changes in technical specifications (TS). The USNRC has defined an acceptable approach to TS changes that bases decisions on the results of traditional engineering evaluations, supported by insights derived from the use of PSA methods to evaluate the risk significance of proposed changes [11].

3.2. OPERATIONS

Well run nuclear plants have made impressive improvements in production processes that have resulted in reduced outage lengths, decreased number of plant trips, reduced levels of staffing, and better-managed discretionary projects. For example, a recent EPRI document describes a step-by-step approach for evaluating typical plant maintenance processes and determining how to create a more effective living maintenance process (LMP) [2][4]. One of the focuses of that document is to identify tools for effectively balancing the competing objectives of maximizing safety and reliability while minimizing costs. Included in the following discussion are examples of identification of sources of operating performance variability.

3.2.1. Example of identification of operating risk: In-service inspection of piping

Use of PSA methodologies can help allocate in-service inspection (ISI) resources in a cost-effective manner and focus the inspections where they are most needed. Results [7] indicate that the application of PSA techniques will allow operating nuclear plants to reduce the examination scope of current ISI programs by as much as 60 to 80 percent, significantly reduce costs, and continue to maintain high nuclear plant safety standards. Costs savings are estimated to be $200 000 to $300 000 per outage. To recover the costs of implementing a PSA methodology, the plant would therefore need one or two operating cycles. EPRI, the USNRC, and the American Society of Mechanical Engineers have worked on delineating the conditions, processes, measurement criteria, etc. for risk-informed ISI.

3.2.2. Example of identification of operating risk: Critical rotating machinery failure diagnosis

Westinghouse’s Science and Technology Center is developing a chaos-theory methodology for early diagnosis of off-normal conditions in critical rotating machinery [8]. This innovative methodology uses a model-based approach that combines special adaptive filtering with chaos analysis tools to discriminate between different and progressively dangerous fault modes. While it is too early to know for certain how this new technique will work out, the goal is to make sure major maintenance tasks, such as changing a bearing or balancing a turbine, will be performed only when needed.

3.2.3. Example of identification of operating risk: Acts of god, property damage, seismic analysis using computer models

NPP operators must design systems, structures and components (SSC) to withstand natural disasters such as earthquakes and floods. In the past, the testing required expensive

[4]All references cited in this report are from publicly available sources, including government agencies, libraries, and internet sites, with the exception of [14] which was a personal interview. Nothing used in the research or writing was proprietary information.

specialized services and laboratory facilities. Significant cost savings can be garnered by development of computer models to test SSC integrity, rather than doing physical tests. Entergy Operations, Inc. operates four NPPs, one of which is at Russellville, Arkansas in the middle of a tornado prone area. The plant uses a large external emergency condensate storage tank that is the primary source for the emergency feedwater system if the main feedwater system fails.

When modifications to tank design and protection became necessary, the engineers used Algor's Accupak/VE Mechanical Event Simulation software to recreate tornadic events involving motion and its consequences, including inertial effects, impact, permanent deformation, and residual stresses. Use of the simulation software was shown to effectively duplicate the results of earlier physical tests at a substantially reduced cost. For a more complete description of the application of the software to this water tank test, see "Adjusting to Mother Nature" [12].

3.2.4. Example of identification of operating risk: Management by operators with multiple units

In Annex 2 is a discussion of the considerable challenges facing operators of multiple NPPs, including the particular staffing issues that develop when the international labor market for skilled nuclear engineers is very tight, requiring the development of an indigenous skill base, which can then be leveraged into improved performance in more than one plant of a multi-plant system.

3.2.5. Example of identification of operating risk: Safety upgrades on older NPPs — What are the real risks?

Periodic safety reviews often propose a significant upgrade to safety systems on NPPS. From a strict nuclear safety viewpoint the proposed upgrade should result in a clear reduction of risk. However, when other aspects of risk are accounted for, the overall benefit of the upgrades may be less obvious.

Two further aspects of risk are considered here. The industrial safety-related risk associated with performing the safety upgrade, and the operational risk associated with running the plant during installation and commissioning of the new safety systems.

Installing safety systems can be a major construction task. Attempting to fit new diverse systems onto a plant designed some decades ago with no provision of space or services to accommodate new systems is a major engineering challenge. It may well carry with it risk of severe injury or fatality greater than the nuclear safety risk that the new system is designed to reduce.

The plant operator will need to learn how to run the upgraded plant. There is therefore, some operational risk associated with the introduction of the upgraded safety system. This can be particularly acute when multiple reactor units are operated from the same control room. Installation of a new safety system is liable to be phased, perhaps by several years, across the reactor units. Through this transition period, operators will move from day to day, or even during shift between units with upgraded safety systems and units without, leading to a risk of confusion.

The true benefit of the safety upgrades therefore needs to take into account the full implementation risks of adopting the new system. Techniques such as ALARP can be applied to take account of the full balance of risks as well as the financial costs of the proposed upgrade.

3.3. COMMERCIAL/FINANCIAL SECTOR

Commercial/financial variables that need to be analyzed for volatility include prices of resources, prices of electricity produced and sold, credit risk of major customers, counter party risk in legal contracts, costs of financing of new ventures, probability of losses due to more than one unit being down at one time in a multi-unit operating organization, potential losses due to contractual agreements, and currency fluctuations when multi-national transactions are present in the company.

Financial market risks arise from changes in the prices of assets and liabilities and can include absolute risk (measured by potential loss in dollar or currency based value and related to volatility of total returns), relative risk (relative to benchmark indices), and basis risk (this occurs when the relationships between products used to hedge each other break down or are nonlinear, called *gamma* risk in finance).

Credit risk can lead to losses when a borrower's credit rating is downgraded, leading to decline in market values. Credit risk also arises when counter parties are unwilling or unable to fulfill their contractual obligations. The level of credit risk here is estimated by determining the cost of replacing cash flows if the other party defaults. Credit risk also includes the risk that a country may impose foreign-exchange controls that make it difficult for a counter party to meet obligations.

Liquidity risk arises when a transaction cannot be conducted at the prevailing market price due to insufficient market activity or when the inability to meet cash flow obligations forces an early liquidation of an asset position, thus transforming "paper" losses into actual losses.

Financial operations risk relates to potential losses resulting from model misspecification, inadequate systems, management failure, faulty controls, fraud, or human error in the management of financial resources.

3.3.1. Example of identification of commercial/financial risk: Use of value at risk methodology by energy companies

Current state of the art in measuring financial risk is the use of Value at Risk methodology [13], which summarizes the expected maximum loss, or worst loss, over a target horizon, within a given confidence interval. The organization specifies the confidence level needed. The calculation of Value at Risk uses standard statistical techniques (see Annex 4) to provide a summary measure of financial risk that can be used:

- To apprise senior management of the risk run by the trading and investment operations;
- To communicate financial risks to shareholders and the financial markets, leading to better pricing of debt in the market;
- To compare risky activities in diverse markets;

- To adjust performance measures for risk;
- To manage cash inflows and outflows denominated in multiple currencies or originating in diverse markets, such as commodity, debt, and currency markets.

One of the quantitative methods for Value at Risk calculation uses simulation based on historical data. Several major USA utility companies have used this technique for as long as a decade, with their securities markets portfolios. In one case, the utility calculated a Value at Risk of $8.14 million, with a 95% confidence level [14]. The question for the risk managers of the company, then, is whether this level of possible loss is tolerable.

Application of this technique in nuclear power production is not well developed, but as the industry moves towards a more comprehensive and integrative risk management regime, the Value at Risk (or similar) measures will enter the picture because of increased use of derivative instruments. As firms develop hedging, pricing, and marketing strategies for electricity, and increase the use of electricity, weather, and currency futures contracts and swap agreements, it will be necessary for these NPP operating companies to learn the Value at Risk approach to identifying and measuring volatility.

3.3.2. Example of identification of commercial/financial risk: portfolio diversification in response to market pressures

Strong competition and market regulated pressure in the UK is threatening electricity generators who cannot offer a flexible load following supply. British Energy, all of whose power stations were nuclear with very limited flexibility, needed to address this threat to their market. Their response has been to acquire a large fossil fuel plant with a high capacity for flexible response. British Energy considered and assessed key commercial and operational risks associated with such a purchase. These included

- The commercial benefit of including flexible plant in British Energy's portfolio;
- The condition, operability and longevity of targeted flexible plant;
- The potential that the market regulator might still want to see flexibility from the nuclear stations;
- Practicalities of running a single fossil fuel plant among an otherwise nuclear portfolio;
- The public and regulator perceptions of diversifying from environmentally benign nuclear energy to fossil fuel generation;
- The cost of acquisition and the running costs of flexible plant.

The risk assessment was influential in proceeding with the purchase of a fossil fuel plant and has also helped manage integration of the plant into British Energy's portfolio.

3.3.3. Example of identification of commercial/financial risk: environmental, safety, and health impacts

Fortum is a Nordic energy company, including operation of a nuclear power plant (a relatively small part of its portfolio. Fortum has a stated aim to take environmental, social and economic impacts into account in all of its operations. Fortum publishes an annual report entitled “A Report on Fortum as a Corporate Citizen”. In the 1999 Report, Fortum outlined three aims that it needs in order to have the trust of customers, employees and society. They are:

- be a forerunner in safety and environmental competitiveness in our different markets,
- offer superior products and services which are safe and environmentally preferred over their life cycle,
- act responsibly in society and in use of natural resources.

Among the mechanisms identified to achieve these aims are the use of risk management tools to assess the environmental, health and safety aspects of all projects. Fortum has integrating environmental, health and safety issues in its business strategy to the extent that its views this as a competitive advantage through reducing the commercial and financial risks related to environmental, safety and health impacts. See Annex 10 for a more complete discussion.

3.4. INTEGRATED RISK ANALYSIS EXAMPLES

Identification of risks in some or all sectors is the role of an integrated risk assessment. Frequently issues or events will have risks in the safety, commercial, operational and strategic sectors. In the new de-regulated environment, NPP operators must not only preserve safety, maintain reliability and comply with regulations, they must also concentrate on market prices driven by supply and demand. The de-regulated energy market environment poses new challenges and opportunities. It is in this environment particularly that the NPP operating organizations must consider all aspects of risk in making decisions.

3.4.1. Integrated example: license renewal strategic issues assessment

As NPPs approach the end of their licensed operating lives, many operators have begun the process of analyzing license renewal risks and rewards. These analyses encompass all of the sectors of the framework (safety, operations, commercial and strategic), with particular emphasis on addressing the concerns of stakeholders (for example, those entities outside the three sectors illustrated in Figure 1). One such analysis is the Strategic Issues Assessment developed by Fort Calhoun Station, USA. This Strategic Issues Assessment task was designed and undertaken to explore potential vulnerabilities and risks associated with the license renewal project for the NPP.

The systematic process employed in this assessment identified as priority issues three favorable and eight unfavorable issues. The unfavorable issues are considered to present a high risk to the success of the NPP’s continued operation through license renewal. The favorable issues represent some of the strengths supporting the continued operation of the NPP. Description and discussion of the process and the resulting action plan of the utility are found in Annex 5.

3.4.2. Integrated example: planning, design, and construction of new NPP

Another aspect of focus on the future relates to planning, design, and construction of new nuclear facilities. Although in some countries, there are no plans for new nuclear production facilities, that is not true everywhere in the world. In the new competitive environment, nuclear energy is seen as a clean, cost efficient source of energy to fuel growth of newly industrialized nations. Design alternatives must, of necessity, take account of not only the safety environment, but also the operating and commercial environments. Annex 7 is a detailed discussion of these issues considered by KEPCO, Korea Electric Power Corporation, in designing the Korean Next Generation Reactor (KNGR).

3.4.3. Integrated example: configuration management

Berg [3] discusses the risks associated with various approaches to configuration management. There are several mechanisms that can cause plant risks to change over time. The performance of individual components and whole systems may degrade due to aging or improve due to design modification or enhanced maintenance. Plant configurations also change from time to time as certain components are removed from or restored to service, while others may be removed through failure. Configurations also change when going from one operating mode to another, such as going from power operation to shutdown. Since the risk significance of a component or system is also a function of the plant's configuration, changing configurations yield different risk levels. Changes in configuration can impact safety and operation as components are removed and returned to service. These changes can also impact economic risk and regulatory aspects of strategic risk.

A joint project of Electricité de France and EPRI was conducted to analyze the use of configuration management and risk management tools at nuclear power plants [4]. A survey of EPRI member utilities and international partners was performed to gather data on various approaches, techniques, and software used to evaluate nuclear safety aspects of plant configuration changes during outages and power operation. The most important uses for outage configuration management and risk management programs cited in this survey include outage scheduling, evaluation of emergent work during outages, and reduction in risks of an accident during configuration changes. An underlying motivation for these programs is maintaining and reducing nuclear safety risk levels while efforts are focused on reducing outage duration.

Three examples of configuration management and risk management tools are detailed in [3] and outlined below:

- RELADS (Reliability Adviser System) is a risk management tool being developed to provide the user with the following online information, derived from an already existing PSA:
  - changes in risk level when certain system and reliability parameters are changed (for example, status of components, failure rates, test intervals),
  - changes in relative importance of the different event sequences and the various system functions within one event tree and the components within one system function.
- SAIS (Safety Analysis and Information System), Federal Republic of Germany, is being developed to include the level 1 PSA, data and computer tools for the modification and reevaluation of the event and fault trees. System and component data and graphics are part of SAIS to provide supporting information for plant engineers.
- The third example is the Essential System Status Monitor (ESSM), developed in the United Kingdom and implemented by British Energy at Heysham 2 to provide power station operators with an on-line aid for planning plant unavailability for maintenance.

The first application of a risk based configuration management tool was the ESSM at Heysham 2 in the late 1980s. This was followed by the Safety Monitor and the EOOS (Equipment Out of Service) risk monitor, both used by utilities in the USA and Europe.

Information about these tools is provided in IAEA-TECDOC-873, *Application and Development of Probabilistic Safety Assessment for Nuclear Power Plant Operations,* and IAEA-TECDOC-1138, *Advances in Safety Related Maintenance*. Descriptions of use of EOOS by Entergy Operation's River Bend plant and by Northeast Utilities can be found in Reference [6].

The South Texas Project Electric Generating Station, USA, uses PSA as a tool to proactively improve their work management processes [25]. The PSA program developed from a management need for a tool to better meet the maintenance needs at the site. Resources were invested to develop a good risk management tool, and there is a continuing effort to ensure the initial 'risk model' is maintained to be accurate and up to date.

South Texas uses a rolling 12-week maintenance cycle planning horizon. A risk assessment software tool, RASCAL, was initially used to review this 12-week cycle schedule based on the possible equipment combinations. This resulted in approximately 200 additional equipment configurations being added to the database. Subsequent efforts have increased this to over 12 000 combinations. These equipment combinations, fully backed by PSA qualification, enable South Texas to better justify the scheduling of maintenance activities.

The program provides a comprehensive risk management tool. Compensatory actions are proceduralized and include applying controls and compensatory actions such as excluding work activities on related equipment, protecting redundant equipment, posting notification signs, and requiring upper management approvals. The controls are assigned based on the level of assumed risk involved. The comprehensive risk management program has served as a basis for changes to allowed outage times and has improved the site's technical specifications. For example, extending the emergency diesel generator allowed outage times to 14 days has allowed work online that was previously completed during refueling outages.

A different approach to reducing plant unavailability is the use of a trip avoidance monitoring system. This analysis uses the PSA fault tree data, but the emphasis is on plant trips rather than on core damage. Configurations that could lead to plant trips are identified, leading to improved maintenance practices. In many cases, the NPP operator will be able to collect data and monitor systems that have not been modeled before [24].

3.4.4. Integrated example: outage and on-line maintenance scheduling

In a manner analogous to maintaining the configuration of a single plant the configuration of a group pf plants can impact all sectors of risk. Recognizing that scheduling of outages will be different for multiple-plant operators than for single-plant operators, Fourcade et al. [5], developed a mixed-integer programming model for scheduling of outages, to reduce variability of corporate entity performance due to plants being unavailable simultaneously. The authors develop the model for multiple-plant operators (up to 4 reactors with an average of 5 shutdowns each over a 5 year time frame); the model shows good results using a mixed-integer optimizer taking advantage of a strong linear programming formulation.

At least three effects occur when a plant shuts down: lost revenues, costs of purchasing replacement power, and outage costs. Global competitive pressures on power production have forced NPP operators to take measures to reduce downtime. Reduction in duration of planned outages means that more inspection, testing, and maintenance needs to be done while the plant is online, as well as more efficient and effective conduct of maintenance that needs to be performed during outages. There are several advantages to online maintenance, including:

- performance of the work in less time than during a refueling outage, assuming the task is adequately planned and prepared;
- scheduling of the maintenance at the most favorable time based on the status of the plant or the status of other operating units of the NPP operator;
- full attention of the personnel, undivided by other tasks typically needed in a refueling scenario, as well as assignment of the most suitable personnel to the task; and
- improved application of ALARA criteria by better scheduling of tasks and reduction of industrial accident risk by better preparation of the tasks.

Counterbalancing these advantages, however, are the following:

- Online maintenance can render equipment unavailable if needed. This means that safety analysis of the implications of planned online maintenance will need to be done. A dynamic tool for plant personnel to perform real time calculations of plant risk is needed. Software tools such as EOOS and the Safety Monitor have been developed to provide such information.
- Recoverability of functionality. Many activities of online maintenance do not render the affected equipment non-functional. Even though the equipment may be out of normal alignment, in the event of a need, it can be quickly restored to proper alignment. There is a need for risk modeling that takes this recoverability dimension into account.
- Some online maintenance activities can be overlapped, while others should not be. Risk modeling can delineate those combinations that are acceptable.

3.4.5. Integrated example: inventory management

Inventory management impacts the four sectors of risk identified in Figure 2. Spare part availability impacts the operation and safety sectors because a lack of the necessary parts can result in unplanned plant transients. Similarly spare parts inventory impacts the commercial sector as both a threat (excessive spare parts inventory) and an opportunity (minimizing down time). Because of past spare part procurement and level setting practices, excess inventories have accumulated at many plants. In addition, less than optimal coordination between maintenance work planning and scheduling often leads to inefficiencies in the material supply process, both in labor utilization and increased cost of procured materials. A typical nuclear power plant warehouse has 30 000 to 40 000 stocked items, many of which look very similar, but have very different technical specifications. Reducing inventories and procured material costs, and improving procurement and material management process efficiency while maintaining adequate availability of needed materials can significantly contribute to a reduction in operation and maintenance costs. An EPRI report [9] provides guidance for NPPs on how to install competitive inventory optimization processes and integrate them with work control scheduling.

However, a successful inventory management process, while decreasing total cost, may actually increase the volatility of those costs. Rather than maintaining a higher, more constant level of investment in parts, the NPP allows inventory investment to fluctuate. In the standard inventory management models of finance, there are two competing equations. The costs of holding inventory go down if less inventory is stored, while the ordering or procurement costs go up if less inventory is stored. The optimization problem balances these two equations to define the optimal level of inventory that minimizes cost, while providing a certain confidence level that needed spares will be there when needed.

Spare parts inventory planning based on component failure rates is a natural extension of current risk analysis techniques. EPRI has begun studies of spare parts inventory planning related to life cycle management, based on evaluating the consequences of failure, but not probability of failure. To really reduce volatility of performance due to inventory management, both the frequency and severity dimensions need to be addressed.

3.4.6. Integrated example: labor force and organization dynamics

Maidment and Rothwell [43] studied the variations in economic performance of US NPPs and found that the primary focus of attempts to improve economic performance should be in the area of operation and maintenance costs, of which 80 percent are labor-related. The primary way to reduce this category of costs is through reduced staffing levels. Staffing reductions have already begun, with plant labor down 10 percent in the last five years. However, the number of utility employees rose 20 percent over the same time period, suggesting that utilities are replacing private contractors with payroll employees. This trend cannot continue indefinitely.

> "For 20 years, contractors represented nearly 50 percent of the nuclear labor force. In the last five years, however, this ratio has dropped to 25 percent. Further reductions are possible but will be limited because some cyclical jobs, such as major maintenance and refueling outages, do not justify hiring permanent staff." [43]

The question utilities must answer is, "What specific categories can be reduced without jeopardizing safety and efficiency?" The most important finding by Maidment and Rothwell is that the optimal number of employees is related to a plant's size, age, and vintage, and to the NPP operator's number and type of reactors. They posit that these relationships can be predicted to within plus or minus 5 percent and vary significantly among labor categories.

> "Unlike in France, no two US plants are of identical size and vintage and have the same number and type of reactors. However, the wide variation in physical characteristics of US plants makes it easier to conduct economic analysis. With the right mathematical techniques, one can isolate precisely the individual economic effects of plant size, vintage and geography. Once this breakdown is done, one may calculate the economic potential for a nuclear plant with any given set of characteristics. This approach is equally valid for costs, labor requirements, safety criteria, and plant performance." [43]

In addressing the issue of staffing reductions, Fox [44] advocates development of better analysis techniques of industry-wide databases. He hypothesizes that there are many similarities in staffing issues amongst plants around the world and that plants should learn from each other by examining differences among specific subcategories of staffing to determine the "best practices"[5]. An example given by Fox is analysis of the security subcategory. Two approaches to security include a "swat team" approach and a generalist

[5] A note on "Best Practices" (BP). It is probably inappropriate to use a "best practices" model in looking for management strategies when we are dealing with low probability events because, typically, there have not been enough instances of the event occurring to develop statistically reliable best practice data. For low probability events, one is better off with descriptive models of what other industries have done rather than normative models like BP. For example, with sick building syndrome, BP says tear it down and start over rather than fighting it. But you can't tear down a "sick" NPP, so the BP doesn't give any guidance on this kind of problem. Staffing is a different issue. With over 2500 operating years in US plants alone, staffing analysis should be able to derive some BP guidance for labor force management.

security officer approach. The industry needs to examine the experience and cost structures of companies worldwide that use these two approaches.

Management of the labor force of organizations requiring high-reliability is the subject of study by the “high-reliability organization project” at the University of California Berkeley. In “When Failure is Not an Option”, Pool [45] reports on the project’s attempt to identify such organizations that manage risk successfully and to analyze the labor force management characteristics of these entities.

A layered organization structure seems to be basic to the effectiveness of these institutions. Depending on the demands of the situation, people will organize themselves into different patterns. This is quite surprising to organizational theorists, who have generally believed that a given organization would assume one structure. Some groups are bureaucratic and hierarchical, other professional and collegial, still others are emergency-response, but management theory has no place for an organization that switches amongst these models according to the situation. With technologies such as nuclear power plants and chemical plants, because of the complexity, they are best decentralized; because of their tight coupling, they are best centralized. While some mix of these might be possible and is sometimes tried, a mix is probably close to impossible for those organizations that highly complex and tightly coupled.

The UC Berkeley project [45] has identified two specific characteristics of such organizations that are known to manage risk successfully. One common characteristic is an emphasis on constant communication far in excess of what would be thought useful in normal organizations. The second common characteristic is emphasis on active learning.

> “Employees not only know why the procedures are written as they are but can challenge them and look for ways to make them better. The purpose behind this learning is not so much to improve safety although this often happens - but to keep the organization from regressing.”

> Pool concludes by saying

> “Organizational reliability is just as crucial to the safety of a technology as is the reliability of the equipment. If we are to keep our technological progress from backfiring we must be as clever with our organizations as we are with our machines.” [45]

Supportive of the conclusions from the UC Berkeley project are those of the Nuclear Energy Institute in its “Work Management Process Benchmarking Report” [25]. Benchmarking was done at Callaway, Peach Bottom, South Texas Project, and Surrey. These four United States plants were selected based on high performance at low cost. The Executive Summary of this report states:

> “Culture was found to be a key driver at all four sites, making the rest of the process work smoothly. Clear management expectations were understood at all levels of the organization. Effective use of performance indicators and meaningful self-critique gave a true evaluation against the expectations. Each site continued to make improvements to their process, resulting in redefined and raised expectations. Underlying this culture was a strong sense of ownership by those involved in the work management process.” [25]

3.4.7. Integrated example: BNFL's holistic approach to risk management

BNFL takes a holistic approach to management of risks, with safety as the first priority. Within the business there is a well defined set of procedures adhered to. The company also has a well established integrated process called the Corporate Risk Review (CRR), for dealing with the financial impact of all its risks, including safety and non-safety related risks. With the CRR, each department has developed a register of risks, with probabilities and financial impacts assigned. Spreadsheet models of the risks are used to derive probability distributions for the overall cost of risks in different areas and for BNFL as a whole. These are used to quantify risk in the company accounts, and also to rank risks in order of importance. Each department reports on actions it takes to manage its risks, with senior staff acting as "risk champions" to review the actions. The process is actively updated on an annual basis, and has the commitment of the BNFL Board of Directors. Lately the England and Wales Institute of Chartered Accountants produced guidance on how companies should manage their risk (the Turnbull report). BNFL's CRR process is compliant with and follows the recommendations of the guidance, resulting in good corporate governance.

4. RISK MANAGEMENT PROCESS, STEP 2. DETERMINATION OF APPROPRIATE RISK MANAGEMENT TECHNIQUES

Risks identified and characterized are next evaluated with respect to the best combination of techniques for management. Three generic categories of risk management techniques include reduction of risk, retention of risk, and transfer of risk. In practice one or more of these techniques is likely to be used in managing risks associated with a particular issue. It is also important to examine whether the use of a particular solution takes account of interaction amongst different areas of risk. For example, in the implementation of a design change to improve nuclear safety the manager needs to examine if the change would have unacceptable industrial safety consequences. Section 4 includes discussion and examples of the three generic risk management techniques. Many of these examples gain benefit from looking at interaction effects across the range of safety, production/operations, commercial/financial and strategic sectors associated with each particular risk.

4.1. REDUCTION OF RISK

Reduction of risk involves at least two dimensions. First, to reduce the likelihood (or frequency) that an event occurs and second to reduce the consequences of an event, if it does occur. Techniques to reduce frequency of occurrence include, for example, engineering measures, education of employees, and enforcement of standards. Reduction of severity can include measures to keep events from progressing into more severe episodes, as well as measures to reduce the economic impact of severe disruptions. These risk reduction measures may be pre-event, simultaneous-with-event, and/or post-event actions. Another dimension of understanding reduction/control tools is to characterize them according to whether they focus attention on the behavior of the individuals involved, on the functioning of the physical assets (machinery, control systems, etc.), or the environment within which the event would occur.

Generic risk reduction techniques include duplication and separation of assets[6], salvage techniques, rehabilitation and repair or recovery, redundancy of systems, leasing, subcontracting, hold harmless agreements[7], and indemnity agreements. Actions or behaviors to change the nature of a risky situation include:

- Aim to reduce uncertainty and/or increase certainty
- Attempt to change high probability events to medium or low probabilities
- Increase the quality of a system or component to reduce likelihood of failure
- Improve training of personnel responsible for systems
- Reduce the time a system, component, or person is exposed to the risky environment
- Use well-defined and documented procedures
- Encourage peer review of processes and procedures.

4.1.1. Example of reduction of risk: remote diagnostics, smart instruments

Smart instruments facilitate remote diagnostic capabilities that allow operators, plant management, or outside experts to monitor the condition of key equipment, for example, identifying possible valve failures, pinpointing faulty meter readings, checking valve seat pressures, reporting process abnormalities, etc. Not only will the remote diagnostics be able to identify which valves need overhauling, for example, but that information can then be integrated with the plant preventive maintenance program to optimize the use of personnel and resources. Schimmoller [16] gives examples of companies using remote diagnostics, different applications for such systems, and cost/benefit analysis data.

4.1.2. Example of reduction of risk: component inspection and repair database

Another aspect of inventory management relates to reduction of downtime due to failures in installed components. Database software that organizes inspection and repair data can provide technical and budgetary information needed for effective outage planning and component management. This is a particularly powerful tool for entities with multiple power stations, providing a mechanism for reduction of the number of times that more than one power station is off-line due to component failures. CAMS, Component Assessment Management System, is an example of PC-based database software that does these things [17].

4.1.3. Example of reduction of risk: configuration management software

The risk based configuration management tools introduced as examples in Section 3.4.3 are used to reduce risks as well as to identify them.

---

[6]In a multi-plant operating company, duplication and separation of assets occurs almost naturally. There is, therefore, a natural set of risk reduction tools available in the judicious management of planned outages and the spare parts inventory management areas. Many multi-plant operators, however, have not taken full advantage of managing this 'portfolio' effect by systematically building in these considerations to the aggregate loss distribution models of the financial performance of the company.

[7]A contract entered into prior to a loss, in which one party agrees to assume a second party's responsibility should a loss occur. An example would be the case of a contractor who requires that a subcontractor provide the contractor with liability protection, should they be sued because of the subcontractor's activities.

4.1.4. Example of reduction of risk: monitoring and diagnostic software

These software tools, combined with workstations that convert data into intelligence, can help reduce both magnitude and volatility of maintenance costs by making available information as to the most efficient timing for maintenance tasks. A shift is going on from fixed interval preventive maintenance to risk-based reliability-centered maintenance (RCM) and predictive maintenance (PDM). The ideal PDM gives workers the information they need to maintain plant equipment at the most economical time, but before it fails or suffers significantly degraded performance. Examples of current uses include electric motor PDM and switchyard PDM. EPRI has developed vibration analysis, sound signature analysis, lubricant condition monitoring and infrared thermography techniques [21].

4.1.5. Example of reduction of risk: document management systems

Most NPPs still rely on paper as the medium for recording plant configuration and the processes and procedures for operations. Locating, copying, and distributing paper documents is an expensive overhead cost. It also takes time, and could mean delay in carrying out the work of a plant. This introduces consequent risk of delayed or lost production. Change of records or operating procedures is cumbersome and time consuming [22]. Consequences of lost or missing documents include:

- Delayed procedures while waiting for documentation or documentation update processes to be completed
- Loss of production because of unnecessary delays
- Use of previous revisions rather than the most recent one
- Confusion about which really IS the most recent revision.

A document management system can reduce all these sources of loss. British Energy, UK, has chosen the CIMAGE Document Management System for licensing, training, safety, and maintenance document storage and retrieval. The software stores, indexes, and enables retrieval of documents, as well as presenting customized interfaces to users. Some design features include:

- Integration with work management system
- Batch printing for outages
- Management of creation, capture, storage, and distribution of documents
- Access controls, revision controls.

Although conversion to a document management software system is probably out of the question for many existing NPPs, document management remains a monumental issue and is almost certainly a source of variability of performance that deserves attention of those developing a systematic approach to risk management.

4.1.6. Example of reduction of risk: staging and laydown logistics planning for outages

Plant owners are facing greater competitive pressures to minimize outages and keep their plants on line. Cutting down the number of days in an outage means less variability of financial performance. One way to attack this is to carefully plan the logistics for staging and laydown of the typical 150 tons of parts and equipment on a space limited turbine deck.

Positioning parts and equipment into modules and arranging them so that the right parts are available when needed, from one shift to the next, requires careful planning and coordination, but can result in as much as a 15 day reduction in the typical generator rewind cycle, according to Garwatoski [18].

4.1.7. Example of reduction of risk: enterprise management systems

Terry Bogard of Westinghouse Electric [23] defines an enterprise management system as a plant infrastructure merging information technology (IT) and instrumentation and controls systems (I&CS) into a common shared information repository. 'Enterprise management', then, includes not only operating the plant and tracking component status, but also using financial models that allow testing of various 'what-if' scenarios for the impact of control and maintenance actions on the plant's financial bottom line. Some benefits of enterprise management systems include:

- Traditional boundaries between instrumentation systems and information systems are gone.
- I&C systems can be built on non-proprietary networks.
- Controllers are commercially available PC platforms.
- User interfaces are familiar.

Of course some problems will also show up with the use of enterprise management systems. Data overload is an issue. It is imperative that the power plant has software to create useful operator information from voluminous plant data[8]. Plant wide implementation of an enterprise management system provides opportunity for significant operational improvements. For example, advance calibration monitoring software can replace the typical one to two technicians devoted to instrument calibration[9].

A big step in capturing the benefits of an enterprise management system comes when the system is integrated into financial models of the NPP. This will enable plant management to perform sensitivity, scenario, and simulation analyses of the effects of various decisions on the financial results, taking into account the multiple sources of risk delineated in this report.

4.2. USE OF PSA RESULTS AND TECHNIQUES TO CONTROL NUCLEAR SAFETY RISKS WHILE IMPROVING OPERATIONAL AND FINANCIAL PERFORMANCE

The substantial investment in research, software and hardware technology development, human resource knowledge and training, and regulatory "buy-in" that the NPP industry has made in probabilistic safety analysis has been principally focused on assessing and managing nuclear safety risks. While this is appropriate, there is also increasing attention being given to using PSA results and techniques to improve NPP operational and financial performance,

[8]One good example is in valve diagnostics. Control valves make myriad small movements to control plant parameters such as temperature, pressure, or flow rate. Diagnostic tools determine whether these valves are operating properly. With hundreds of valves and thousands of data points, the necessary manpower to interrogate each valve and perform the analysis is overwhelming. The standard communication protocol is a two-way protocol, enabling a "smart" valve to send back responses to multiple queries. When final position, air pressure on each side of the cylinder, stroke time, etc. data are combined with appropriate analysis software, the operator can identify many specific valve problems, such as stiction and hysteresis.

while also controlling, or even reducing nuclear safety risks. The following are examples of this process.

4.2.1. Example of reduction of risk: extension of PSA to trip avoidance monitor

A different approach to reducing plant unavailability is the use of a trip avoidance monitoring system. This analysis uses fault tree data, but the emphasis is on plant trips rather than on core damage. Configurations that could lead to plant trips are identified, leading to improved maintenance practices. In many cases, the NPP operator will be able to collect data and monitor systems that haven't been modeled before. An example of this software is PLANTFORMA, available from ERIN® Engineering and Research, Inc. [24].

4.2.2. Example of reduction of risk: extension of PSA to work management processes

The risk based configuration management tools introduced as examples in Section 3.4.3 are used to reduce risks as well as to identify them.

4.2.3. Example of reduction of risk: extension of PSA to training processes

PSA methodologies can be used by plant management to prioritize training on plant systems and to develop simulator-based training scenarios. In addition, operators undergoing training can benefit from PSA information that helps identify risk-significant systems, understand the event sequences that can lead to core damage, and be evaluated with PSA-modeled human errors analysis. Use of PSA information can substantially improve the training programs at an operating nuclear plant and thereby improve performance of the operators. Also participants in training can identify improvements that can be made in the PSA model.

At Monticello Nuclear Generating Plant, USA, operators are trained in the use of PSA in both initial and continuing training programs [26]. Operators understand PSA development, core damage sequences, and how to apply insights from the PSA to the plant's operations. System-specific lesson plans include information on important system components and operator actions as assessed and modeled in the Monticello PSA. Operators gain insight on the risk importance of successfully completing applicable tasks, such as controlling water level during an anticipated transient without scram. PSA system importance rankings — that is, the relative worth of a system from a risk perspective — are used to prioritize systems selected for continuing training. More frequent training is provided for systems with high PSA importance.

Simulator lesson plans and exam materials are developed using PSA information. Core damage sequences and risk-significant operator actions are used to create and enhance scenarios. An operations training PSA contact maintains the pertinent plant PSA information for simulator instructors to use in both training and evaluation scenario development. Operators are trained and evaluated on the most likely events and sequences that can lead to core damage. An operations training PSA contact works closely with the plant PSA group for information and guidance. Changes to the plant PSA are communicated to the operations training PSA contact.

PSA is also used in job performance measures at Monticello. Important operator actions modeled in the Monticello PSA are used to write job performance measures. For example, one job performance measure addresses cross-tying residual heat removal service water for injection to the reactor pressure vessel. The use of these tools increases the potential for the action to be done correctly, and plant safety is improved.

4.2.4. Example of reduction of Risk: use of PSA to reduce risks from fire

Since 1993, the USNRC has recognized the need for revisions to the fire protection regulations governing US nuclear power plants. EPRI (and others) have contributed to significant improvements in the fire modeling and risk analysis methods, of PSAs. These improvements form the base of a plan to apply these methods to fire protection programs in plant areas. It is recognized today that a PSA that does not include fire risk assessment is of limited value for decision making. A detailed description of the status of these studies can be found in [27]. While nuclear safety regulators are clearly interested in fire-related risks associated with nuclear safety, operating organizations can also use these analyses to assess operational and financial risks.

4.2.5. Example of reduction of risk: Extension of PSA to physical security management

Physical security at a NPP must address a broad spectrum of potential incidents, ranging from minor intrusions to radiological sabotage. An EPRI report [28] details the efforts by Northern States Power, at its Monticello plant, to develop a process that uses risk information contained in its PSA to modify the physical security plan. The risk information is used to focus the contingency plan and thereby support an efficient use of security resources. Every US nuclear power plant is required to have a Safeguards Contingency Plan in order to satisfy the NRC's requirements. This Safeguards Contingency Plan contains a predetermined set of decisions and actions to thwart a potential saboteur and assigns these decisions and actions to specified security personnel. Fulfillment of this plan determines the number of security personnel required to protect the plant.

Originally, most utility Safeguards Contingency Plans were predicated upon a perimeter defense or allocation of guards to most safety equipment by using 'common sense'. More recently, utilities have recognized the need to develop more comprehensive defensive strategies. Northern States Power revised its Safeguards Contingency Plan for the Monticello plant by using the risk information developed for its PSA to generate a list of sets of critical equipment, whose successful defense would prevent core damage and hence radiological sabotage. This list was used to prioritize the allocation of guards to critical locations within the plant. The risk information was also used to list sets of equipment whose concurrent destruction would cause core damage. These sets were used to develop scenarios for training the security force. The modified Safeguards Contingency Plan has been implemented at the Monticello plant. A recent NRC inspection of the plant tested the revised physical security plans and found them to be acceptable. By prioritizing the allocation of its security force, Northern States Power was able to avoid additional security costs of $400 000 per year.

4.3. TRANSFER OF RISK

Risk transfer means that the original party exposed to a loss is able to obtain a substitute party to bear the risk. These transfers occur by contract, through use of financial market instruments, or by terms and conditions of sale and delivery of products and services. In some cases, the degree of risk is reduced through a transfer if the risk-accepting party has portfolio effects (such as for insurance contracts where a pooling of risk takes place); in other cases, degree of risk stays the same but is transferred to another party willing to accept the variability of performance, for a given price.

Most risk transfer mechanisms are some form of contractual agreement with a counter party. In contracting, the idea is to put the risk to the party who can control the results, or prevent the problem, or manage the risk if it happens, or can best absorb the impact. The counter party then pays a 'premium' for being able to transfer the risk away. Examples of risk transfer mechanisms include hold-harmless agreements, incorporation[10], hedging in financial and commodity markets, operating lease agreements[11], penalties for late delivery of goods and services and missing of contract deadlines, warranties of quality or performance, and insurance contracts.

4.3.1. Example of transfer of risk: insurance contracts

By taking out an insurance contract, a NPP operator transfers a certain amount of risk to the insurer in that the NPP operator will be compensated for losses occurring within the definitions of the insurance contract. Policies can cover

- Public liability
- Employee liability
- Material damage or breakdown (compensation for a failed plant)
- Business interruption (compensation for lost output and sales).

The amount of coverage, and the deductible level, will vary with the size and financial robustness of the NPP operator and owner. A small, privately owned operator is likely to cover risk more extensively through insurance than a large and/or nationalized NPP operator who will be more able to bear losses internally.

Insurance contracts are only a partial transfer of risk. Typical deductibles would be at least $1 million, and these would be borne by the operator in the event of a risk occurring. Only direct losses are insurable; indirect losses (for example due to shutdown/refurbishment of sister units following breakdown of one unit) are not covered. For these reasons, it is prudent for insurance contracts to be considered hand-in-hand with other risk management measures, such as operational and safety reviews, loss control surveys, and consequent repairs/refurbishments of the vulnerable plant.

4.3.2. Example of transfer of risk: financial derivatives: call option

Another mechanism for hedging risk is use of a call option. A call option gives the buyer the right to buy the commodity at a specified price. If market prices are higher than the call's strike price when the need to purchase electricity arises, then the call would be

[10] Under the laws of most Member States, an incorporated business is a legal entity in, and of, itself. This means that the owners are protected from losses beyond the amount of their investment in the firm; i.e. their personal assets are not at risk, but only those encumbered in the business.

[11] An operating lease has the characteristic of being shorter term (not a 20 or 30 year period, for example) and being cancelable at the option of the lessee (user of the equipment) so that the risk of obsolescence is transferred to the lessor (owner) of the equipment from the user. This is in contrast to a capital lease, which is, in essence, a financing mechanism for use of an asset while it is being paid for, using the credit rating of the lessor to substitute for the lower credit rating of the lessee.

exercised, allowing the buyer to get the needed commodity at a lower-than-market price. See [30] for a discussion of call options.

4.3.3. Example of transfer of risk: multiple trigger insurance coverages

A new risk transfer mechanism, the multiple trigger insurance policy, has been developed by the insurance industry in its attempt to compete in the capital markets [31]. Fortunately for the nuclear power industry, this new mechanism also provides a competitive advantage to operators who use it to hedge risk in world electricity production markets. In a double trigger policy, for example, two uncorrelated events are specified that, if occurring simultaneously, would trigger a payment under the policy. Usually one event is a typical insurance exposure (example: steam line explosion, storm damage, or workers compensation risks) and the other is an event tied to a financial index or recognized source of quantifiable data (example: equity portfolio value, meteorological data, NRC nuclear plant shutdown data).

Although a number of companies have bought such policies, few are publicizing the purchase or the trigger events, citing competitive pressures. One company that has released such information is Great Bay Power of Portsmouth, New Hampshire. Great Bay's double triggers are a plant shutdown (their generation comes from the Seabrook NPP) and a specified strike price for replacement generation. The insurance carrier, Cigna, will pay the difference between the insured (strike) price and the actual market price for replacement power if the price of electricity at the time of an unplanned shutdown is higher than the pre-negotiated strike point. Marsh Inc. and AIG Risk Finance have also helped devise multiple trigger policies. Examples of policies developed are shown in Table 1.

Table 1. Examples of multiple trigger insurance policies [36, 37]

TYPE OF COMPANY	➢ TRIGGERS	PURPOSE
Electric utility	➢ Inches of rainfall over a period of time ➢ Greater than $X maintenance expenses from a particular storm	To pay for much-higher-than-normal maintenance expenses.
Railroad	➢ Inches of snowfall during a period of time ➢ Extra expenses due to rerouting trains during a particular snow episode	To pay for higher-than-normal operating costs
Columbia Energy (a Dulles, Virginia natural gas utility)	➢ Triggers unknown	To transfer to the insurance company customer price volatility in the event fuel adjustment costs caused retail prices to go up.
Hospital	➢ Medical malpractice costs ➢ Value of equity portfolio	To provide additional medical malpractice insurance and equity portfolio insurance
Copper mining company	➢ Price of copper vs. company profits	To expand or contract the workers' compensation insurance protection and its associated costs
Energy trading company in New Zealand	➢ Spot price of electricity vs. water current of specific streams in New Zealand	To pay for higher than normal prices for purchase of electricity
Electric utility	➢ Example of a three trigger policy: boiler breakdown vs. number of days in which temperature exceeds a certain threshold vs. price of electricity above a specific strike price	To pay for higher than normal prices for purchase of replacement electricity
Toy company providing promotional items to the film industry	➢ Low associated movie revenues vs. excess workers' compensation losses	To avoid dual sources of loss (decreased revenue and increased costs) occurring simultaneously

Costs associated with multiple trigger policies are lower than either traditional insurance or derivative instruments. FirstEnergy Corp.'s Director of Risk Management, Joseph Spencer, evaluated the cost of a derivative as four to five times more than the cost of the dual-trigger policy.[12] The lower the correlation of the triggers, the lower the costs. Like traditional insurance products, multiple trigger policies are priced according to probability of occurrence. Accordingly, the lower the correlation of the two series, the lower the probability of a trigger of the policy. As an added benefit, the cost of the policy to the utility is predictable because it is agreed upon in advance.

4.3.4. Example of transfer of risk: financial derivative: swap contract

A swap is a derivative contract with a counter party that has an opposite type of problem to solve. In the case of weather derivatives, a swap might be arranged with a counter party to protect against revenue loss generated by a warmer than expected winter. Valley Resources, Inc., Cumberland, Rhode Island, USA, recently negotiated such a swap [32]. The 'strike' point was a plus or minus 2.5 percent difference from a specified temperature. Valley pays an energy company on the West Coast a fixed dollar amount if it gets colder than the minus strike point. The cash flow goes the other direction if the temperature gets warmer than the plus strike point. In the winter of 1998, Valley received $250 000, almost 10 percent of their annual earnings, because the expected 'La Niña' colder-than-normal winter turned out to be 6 percent warmer than usual.

Each of these four risk management tools examples for financial transfer of risk requires substantial use of production/operations, financial, and markets databases to analyze the risks and rewards. In a dynamic demand and pricing environment, there is increased volatility in corporate cash flow, creating incentive to invest resources in developing the databases needed to measure total corporate performance volatility, rather than the piecemeal approach of the past. Volatility can be hedged or negated through these financial contracts, but also through capital expenditures (the 'real options' analysis currently being used, for example, to evaluate operating lifetime extension expenditures [33]).

4.4. RETENTION OF RISK

The third risk management technique, retention of risk, is, perhaps, the most difficult concept to understand for managers in the NPP industry. Because of the almost one-minded concept of risk as meaning nuclear safety risk, and the perception that nuclear safety-related risk must be managed to negligible levels, it is harder for managers on the nuclear side of these organizations to consider the idea of deliberately accepting measurable levels of other types of risk, than perhaps in any other industry. Think of the situation of someone starting a business. All risk 'resides' in the owner's pockets. As the business evolves, the owner identifies sources of risk that can be reduced or transferred to others, but a degree of risk inevitably remains. Some factors that cause this risk may be understood by the owner and accepted as being reasonable tradeoffs for the possibilities of high returns. In fact, this

[12] FirstEnergy, in June 1998, suffered a triple whammy. A transformer failure in Cleveland, Ohio, knocked out 600 MW; the next day a tornado blew away transmission lines in Toledo, Ohio, knocking out another 600 MW; replacement power prices went to $7,000 per MW hour (compared to the $50 per MW hour they expected to have to pay under such conditions). As a result, the company's earnings dropped $104 million for the year. FirstEnergy subsequently purchased a dual-trigger to pay costs over its $25 million deductible. The two triggers are a 600 MW loss of production capacity and a spot market price for power greater than $74 per MW hour.

‘accepted’ or retained risk is the real reason that owners are involved in the business in the first place. The retained risk produces the possibility of high returns for the investment made. Only if financial risk is present, is there any possibility of high returns.

However, it is also likely that some of the factors causing variability are not understood, have not been identified, are not being ‘risk managed’, are being ineffectively ‘risk-managed’, or are not being consciously accepted as tradeoff for possible high returns. In addition, it should be recognized that risk could actually be increased in a particular process by the actions taken to reduce risk in some other project. This would also create unintentional retention of risk, if the corollary effects were not adequately identified. Reduction of unintentional retention of risk is one of the underlying goals of Step 1 of the risk management framework presented in Figure 3 (that of identifying and measuring sources of risk). The unintentional retention of risk basically bypasses the risk management process and rational decision-making.

With respect to conscious retention of risk, firms need to determine how much variability they are willing to retain. To reiterate the point, retention of risk does not mean that the power producer does nothing to manage these risks. In fact, retention of risk, for most firms, requires aggressive risk reduction and transfer techniques to complement the retention decision.

Some techniques used in retention decisions include reserving for losses (determination of reserve requirements and the source of the reserves), considering the whole portfolio of producing plants in a multi-plant firm, and considering the whole portfolio of products and services within a firm (for example, development of new or ancillary product lines such as sale of heat pumps, online services, exploitation of installed copper wire base, etc.).

Determination of loss reserves involves several considerations:

- The firm estimates the “normal loss”.
- The firm estimates its “loss bearing” capacity. Many firm characteristics will affect this, including the considerations in the previous paragraph, the financial strength of the organization, and potential effects on the earnings capacity of the firm.
- The firm devises strategies for investing, managing, and accounting for reserves set aside to cover losses, including the tax consequences.

4.4.1. Example of retention of risk: risk informed flaw tolerance determination

An example of retention of risk is the use of a risk informed flaw tolerance approach to define less restrictive pressure temperature limits. An EPRI study [34] found that the allowable pressure (of the current flaw tolerance specified in ASME Section XI, Annex G) could be increased by 50 psi without significant increased risk of vessel failure.

4.4.2. Example of retention of risk: Quality Assurance applications of PSA

Application of PSA methodology to the quality assurance program can impact the cost structure of a NPP and allow focus on components with highest safety significance, while retaining some level of risk in performance of components lower on the safety significance list [35]. Structures, systems, and components identified as safety related have, in the past, been required by the USNRC to be procured using elaborate and costly quality assurance procedures. With as many as 75 000 parts being connected to safety in some way, this was a large expenditure of resources. At Grand Gulf Nuclear Station, USA, PSA results were used to identify safety significant structures, systems, and components. Subsequently, many other structures, systems and components were removed from the ‘Q-list’ and treated with reduced quality assurance techniques [36] and [37].

4.4.3. Example of retention of risk: continued operation with known turbo generator flaw

Upon detecting a fault in part of the turbine-generator system an NPP operating organization has a number of options including:

- taking the unit off load and effecting immediate repair
- continuing to run until the next planned outage accepting an increased risk in the meanwhile.

The second option is an example of risk retention. It is likely that the operating organization managers would consider the following areas in reaching a decision:

- what is the financial penalty of fixing the fault now against waiting to the planned outage?
- How much more likely is the turbine-generator to fail given that it already has a fault?
- How likely is the fault to develop into a catastrophic breakdown (presenting a safety risk)?
- If the fault develops into a breakdown what is the impact in terms of cost of repair and length of outage (i.e. what is the financial risk)?
- Is failure of the turbo-generator covered by an insurance contract of any type? Will the insurance be invalidated by running with a known fault?
- What is the likely operational disruption of
  - repairing the turbine-generator now, or
  - repairing the turbine-generator at the next planned outage, or
  - dealing with the consequences if the fault develops into a breakdown prior to the outage.

So in reaching a decision as to whether to continue operating (and hence retain the risk), the operator would be prudent to consider the safety, operational and financial risks associated with this option and the alternatives.

5. RISK MANAGEMENT PROCESS, STEP 3. IMPLEMENTATION

Step 3 outlined in the framework (Figure 3) is to implement the chosen techniques or strategies. Step 4 is to monitor the results, providing feedback so that risk analysis is always updated as the operating environment changes. As Figure 3 illustrates, this is an iterative process, in which the sources of risk change over time, as negative consequences are controlled and as the external influences on the three sectors of the risk management environment change.

Before implementing the chosen strategies some final checks are suggested:

- Does the strategy or solution address the identified risks?
- Is the selected solution consistent with the solutions to other risks?
- Are the key risks addressed by the selected strategy
- Can the exit strategy be exercised?
- Is flexibility maintained?

The key aspects of implementation are to assign responsibilities and accountabilities. It is helpful to establish milestones and checkpoints to allow verification that responsibilities and accountabilities are being met. Measures or indicators of success should also be established to track the success of the strategies.

During implementation, measures of success, milestones and checkpoints should be monitored regularly. If the measures of success show the selected strategy is not being successful the risks should be re-assessed and careful consideration should be given to the exit strategy. One must also monitor for emerging risks and unintended consequences of the selected strategies. The results from the monitoring activities should be feedback in to the appropriate step in the framework to continually improve the risk management process.

5.1. CHANGE MANAGEMENT

Delineation of a change management process institutionalizes the actions of members of NPP professional staff in making organizational changes that impact the various sources of risk. A formal change management process will specify the types of activities for which the formal process should be used, the responsible parties, the step-wise progression of a decision, and the monitoring mechanisms, including the degree of external third party involvement. The goal of the Management of Change document for British Energy, UK (See Annex 8) was to ensure that all “changes were properly considered, justified, and auditable”. A key feature of the process was the identification of changes with respect to their potential impact on nuclear safety. Items were graded ‘A’ to ‘C’, based on the potential that, “if inadequately conceived or executed”, the change would seriously reduce the “capability of the organization to maintain safe operation and compliance with the Site License”.

A similar document from Atomic Energy of Canada, Ltd., their internal Decision Making Process, provides a systemic checklist of impact on design, material or equipment supply, and construction activity when a “change request” form details a specific change, modification, or requirement (see Annex 9). The document includes a “risk assessment” appendix that defines the risks or opportunities associated with each task. In this way, risk assessment has been built into the organization’s decisions making process.

5.2. INTEGRATIVE DECISION SUPPORT

Development of integrative analysis and decision support software should help NPP operators achieve optimal long term performance and maximum economic benefit from their nuclear utility assets in order to be more competitive in the marketplace. Two examples are described here.

5.2.1. Example of integrated decision support: nuclear asset decision analysis (NADA)

This application of asset management is utilized by Baltimore Gas and Electric and Omaha Public Power District (both utilities in the USA) to determine future operating plans for their NPPs [39]. Asset management's purpose is to maximize the value of the plant. The process uses a team of stakeholders (including shareholders, customers, plant neighbors, and employees from engineering, operations, financial planning, system planning, legal, environmental affairs, public affairs, and corporate planning areas of the organization) to analyze those factors influencing the economic, technical, environmental, and political viability of the company's nuclear assets and to select a strategy for the operation of their NPP in a competitive future. The information collected in the analysis process is organized in a manner that allows the NPP operating company to develop and compare scenarios and their resulting cost profiles.

5.2.2. Example of integrated decision support: life cycle management (LCM)

This decision-making model integrates aging management (maintaining the availability of costly-to-replace components and structures) with asset management (plant valuation and investment strategies that account for economic, performance, regulatory, and environmental uncertainties). The application to NPPs of this well-known process that optimizes the service life of an industrial facility is described in [40]. Existing plant activities already comprise a large majority of LCM programs, but what is needed further is a staff of professionals to integrate these activities and focus on long-term aging and economic issues. The EPRI project was begun 17 years ago, with the goal of determining a process for evaluation of license renewal. The first applications have been submitted to the NRC. Although there are a substantial number of theoretical analyses of LCM models and some demonstration projects funded, there is still fundamental disagreement among practitioners as to the role of financial variables in LCM models.

5.3. INTEGRATIVE DECISION SUPPORT INCLUDING FINANCIAL VARIABLES

Traditionally there has been such separation of the insurance, financial, and physical asset risk databases and managers that analysis including data relating to the financial portfolio of a utility would have been difficult to accomplish. With the use of integrated risk management packages, the analysis becomes do-able. Coming onto the market are integrated risk management packages that attempt to capture a large number of the variables discussed in this report.

5.3.1. Example of integrated decision support: POMAX analyzer

An example is the POMAX Analyzer, a product of OM Technology [41]. The product claims to be "the only risk management tool that integrates production scheduling, risk management and portfolio management". The software can be used by multiple unit power producers to use current market conditions to calculate the rate of return to producing and selling power for a given production risk structure, or to predict volatility of returns for future market conditions. With a three-year analysis horizon, the decision support provides alternative strategies to match the company's stated risk profile. Some of the variables listed in the OM Technology's description of the product include electricity forward prices, temperature and precipitation statistics, resource costs, fuel prices, heat-rate curves, ramptimes, reservoir levels, availability history. The product supports financial budgeting and deviation analysis.

5.3.2. Example of Integrated Decision Support: Optimizing Asset Value Toolkit

From TENERA Energy, this integrated software package integrates corporate finance and trading activities with physical asset risks to provide a decision tool that can be used to assess an organization’s overall portfolio risk [42]. The methodology is used to dynamically assess and manage the firm’s financial risks, taking into account the entire risk profile, and to identify actions that can be taken for both short term and long term risk reduction. The software can accommodate multiple-plant operators, treating the set of operating units as a portfolio, helping management make integrated decisions about outages and sales and distribution of output, as well as management of financial risks. Variables programmed into the analysis include equipment outages, capacity factors, interest rates, foreign exchange rates, fuel price fluctuations, construction and acquisition risks, credit risk, regulatory risk, liquidity risk, fuel supply and long-term contract risk, insurance risk, futures and options contracts, and trading activities.

6. RISK MANAGEMENT PROCESS, STEP 4. MONITORING AND FEEDBACK

Nearly all of the examples of tools for identification, measurement, and management of risk have built into them the monitoring and feedback mechanisms that constitute the third step in a comprehensive risk management program. The risk management process illustrated in Figure 2 is iterative. In many cases the feedback mechanisms are automatically built into the tool, while in other cases, a more formal feedback analysis, outside of the tool, is necessary. We would like to know what is the impact of use of the tool on the variable of interest, i.e., the particular cause of volatility of performance that the tool is designed to address, and any resulting impacts on other variables, for example, if a degradation or improvement of performance occurs.

One purpose of monitoring and feedback mechanisms is to help the utility recognize if (or when) an exit strategy needs to be invoked. Recalling the generic questions about the nature of risk (Introduction to Section 4, above), one of the issues for characterizing a source of risk is the extent to which a management tool can be backed out of; i.e., whether the risk management strategy can be reversed or if it is a permanent choice. When an exit strategy is possible, the monitoring and feedback loop will be continually reevaluating the data to determine if the risk management should continue or if the situation should be terminated.

Another aspect of the monitor and feedback process is explicit recognition of where the responsibility lies for overseeing the risk management program. Use of diagnostic information and reporting systems, coupled with regular in-house risk management meetings and periodic reviews by outside experts will help ensure that company risk management policies are followed in general, in addition to the more specific actions relating to particular plant systems. These should be in addition to the analysis and reporting requirements of regulatory authorities to which the management must answer.

In choosing tools for monitoring and feedback, management needs to look for risk management packages that are integrative; i.e., that can take information from many systems and, over time, build models that effectively predict the results of actions taken. Management needs to be able to update the external environment variables that feed into the package as well as being able to change the model to reflect new plant conditions.

6.1. EXAMPLE OF MONITORING AND FEEDBACK – ATOMIC ENERGY OF CANADA, LTD., (AECL) INTERNAL DECISION MAKING PROCESS

AECL has a standard decision making process, applied in phases of design, construction, configuration management, proposal preparation, or project implementation that illustrates each of the above points about the monitoring and feedback process. The process includes evaluation of impacts from the variable in question, as well as corollary impacts of other parts of the company. The process includes analysis of exit strategies, as well as continual monitoring of the environment to determine if exit or continuance is appropriate. The schedule for feedback is specified with particular responsibility assigned.

The intent is to provide management with an up-to-date snapshot of overall performance against the target, monitoring progress on a measurable level, with feedback flowing into the appropriate management level. The direct result of having this systematic process delineated is the ability of the company to react in time, when it is appropriate, for either maintaining the activities, altering the course, or exiting from the exposure. See Annex 6 for the complete description.

6.2. EXAMPLE OF MONITORING AND FEEDBACK – BRITISH ENERGY, UK, CHANGE OF FUEL VENDOR FOR SIZEWELL B PWR

In 1997, after carrying out a risk assessment, looking at safety, operational, and economic aspects, British Energy chose to change fuel vendors for its only PWR, Sizewell B. The first load of new fuel is due to be loaded in autumn, 2000. Throughout the project, BE has monitored the threats and opportunities initially associated with the fuel change and has surveyed for more. The result is that the fuel load is expected to be completed on time, with the project staying within budget and with safety and operation considerations addressed. Continuous monitoring of the risks associated with the project has helped with this high level of control and understanding. It has also led to reassessment of the benefits associated with the project. Initially, security of supply was considered to be the major driver for change. It has become clear through the ongoing monitoring of risk that the new fuel should also provide better operational and safety performance.

Establishment of an exit strategy (i.e., revert to original fuel supplier) formed part of the initial risk assessment. This exit strategy was revised and reviewed through the project duration.

6.3. EXAMPLE OF MONITORING AND FEEDBACK: FORTUM AS A CORPORATE CITIZEN

Fortum, is a major Nordic energy company, providing electricity, heat and fuels. It is the operator of the Loviisa Nuclear Power Plant, a relatively small part of its overall portfolio. It publishes an annual report entitled, Fortum in Society, A Report on Fortum as a Corporate Citizen. In this report, Fortum has committed to take environmental, social and economic impacts into account in all of its operations, and has outlined three aims that it needs in order to have the trust of customers, employees and society:

- to be a forerunner in safety and environmental competitiveness in our different markets
- to offer superior products and services which are safe and environmentally preferred over their life cycle
- to act responsibly in society and in use of natural resources.

Large scale investment projects are discussed by an Investment Committee of the Board of Directors which ensures that the projects meet economic, environmental and social requirements (e.g., that risks in all these areas are properly identified and managed). Integration of EHS issues into management also means that in order to monitor progress and carry out corrective measures, the various business units must have clear goals and indicators. A summary report on occupational injuries, accidental spills, fires and other accidents is drawn up quarterly and discussed in the meetings of the Corporate Executive Committee. Fortum also reports annually in the Fortum in Society report and on its website regarding progress made in implementing its EHS programme.

7. RISK MANAGEMENT, COMMUNICATION, AND ORGANIZATIONAL CULTURE

Organizational culture in many NPPs is now rapidly changing, providing organizations with an opportunity to integrate a 'risk management way of thinking' into the new business environment of the firm. It is very difficult, however, to measure the potential for reduction of risk from having an organizational culture that really embraces systematic analysis of risk. There is evidence that when the organizational culture is supportive, employees are more likely to be motivated and committed in the performance of risky activities and less likely to be distrustful of management; that stresses within the organization should be monitored; and that employee commitment relates to organizational culture.

7.1. ORGANIZATIONAL CULTURE AND SAFETY

In the insurance literature, an important type of hazard is discussed, in which likelihood of adverse events occurring is increased when workers have low morale. When workers have low morale they pay less attention to detail in behavior, have less preference for behaving in a prudent way, and generally exhibit lack of interest in being responsible. To the extent then, that the organizational culture is supportive, worker morale should be higher and fewer and less severe negative consequences are likely. Tuler, et.al. [46], found organizational culture to be an important mediating factor in determining both individual risk decisions of team members as well as the team's overall level of their performance. A bibliography of studies of this phenomenon is provided in Tuler, et.al. [46].

Another study of the interaction between organizational culture and employee perceptions [47] studied perceived nuclear risk among employees in an NPP. They were studied to see if perceived nuclear safety-related risk was associated with employee involvement in the organization, or commitment to the organization. Items in the survey dealt with, among other things, acceptance of the organization's goals and values, willingness to exert effort on behalf of the organization, and desire to stay with the organization. Perceived nuclear safety-related risk correlated with acceptance of the organization's goals and values in that employees who did not accept the goals and values of the organization estimated higher risks. Likewise, perceived nuclear risk increased as trust and satisfaction with top management decreased.

7.2. SAFETY CULTURE

The nuclear industry has developed the concept of a 'safety culture' to instill an organizational culture that encourages a systematic approach to safety. It behooves us to examine a statement of the concept of a safety culture, to see how the components apply in a broader risk management approach to safety. The concepts of safety culture are applicable to building a good safety environment. The safety culture principles are not only for nuclear safety but are equally applicable to radiological, industrial and environmental safety. Individuals at all levels of the organization must consider nuclear, radiological, industrial and environmental safety as a priority. Their decisions and actions need to based on this priority, and they then need to follow up to verify that safety concerns receive appropriate attention. The work environment, the attitudes and behaviors of individuals, and the policies and procedures foster such a safety culture.

An effective safety culture has the following characteristics:

First, individuals at all levels in the organization contribute to the safety culture of the work environment through the following behaviors:

- Demonstrate great respect for the reactor core — for reactor safety — in all decisions and actions.
- Demonstrate a questioning attitude by challenging existing conditions and actions to meet the high standards of nuclear safety and by considering the potential adverse consequences prior to taking actions.
- Use a rigorous and prudent approach in daily activities.
- Openly communicate and identify problems through rigorous self-evaluation.
- Share and use operating experience.
- Accept accountability for their shortfalls in performance and hold themselves and others accountable to high standards of performance.
- Make nuclear, radiological, industrial and environmental safety a priority.
- Demonstrate personal integrity.
- Demonstrate an understanding of reactor theory and other fundamental topics, equipment operation, and policies and procedures applicable to the position held, and apply this understanding in operational decision-making.
- Demonstrate a conservative approach toward plant operations when faced with unknown conditions or conditions that are outside procedures and policies.

Second, managers in the organization contribute to the safety culture of the work environment through the following behaviors:

- Establish expectations of performance that clearly recognize safety as the overriding priority.
- Solicit feedback from personnel to identify problems, impediments, and opportunities to improve. Reinforce individual behaviors that promptly and forthrightly identify problems.
- Emphasize the importance of understanding the scope of identified problems and finding the best solutions without being diverted by who identified or contributed to the problem; that is, reinforce the principle of "what's right," not "who's right".
- Proactively identify needed improvements and implement solutions, maintaining adequate operating and design plant margin of safety.

- Verify work is performed in accordance with established plans, schedules, and procedures to achieve clarity of direction, quality of performance, and credibility of management.
- Reinforce the use and sharing of operating experience to apply lessons learned to prevent recurrence of events.

Third, work practice norms in the organization promote the safety culture through the following behaviors:

- Defense-in-depth and risk management practices are employed throughout the organization to maintain plant safety and reliability and to reduce the consequences of events. Appropriate defenses are explicitly embedded in procedures, processes, and equipment configuration to mitigate the consequences of inappropriate actions. Safety analyses are used to complement defense-in-depth.
- Operational decisions are based on sound judgment and appropriate safety analyses, include the use of procedures, and involve appropriate line managers.
- Safety operational problems are promptly identified and resolved. Interim corrective actions are implemented, such as ensuring that the oncoming operations shift crew is thoroughly briefed. Long-term corrective actions are developed and effectively implemented.
- A direct and open means of raising safety concerns is established and is available to all personnel. Safety concerns are promptly addressed and resolved.
- An attitude of trust is demonstrated throughout the organization.
- Training reinforces expected behaviors.

These three sets of behaviors can be seen to be consistent with the risk management framework proposed in Figures 2 and 3. Identification and characterization of sources of risk in performance, identification and implementation of appropriate ameliorative measures, and continuous monitoring and feedback into the process are essential elements of a safety culture.

The International Nuclear Safety Advisory Group, formed by the IAEA, maintained in its report INSAG-4 (1991), *Safety Culture*, that the establishment of a safety culture within an organization is one of the fundamental management principles necessary for the safe operation of a nuclear power plants. INSAG-4 presents a complete description of the safety culture concept along with its definition, features and tangible manifestations. A more recent publication by INSAG, INSAG-13, *Management of Operational Safety in Nuclear Power Plants*, builds upon the ideas outlined in INSAG-4 and develops a set of universal features for an effective safety management system. IAEA publications in the are of safety culture are IAEA-TECDOC-821, *Experience with Strengthening Safety Culture in Nuclear Power Plants* (1995), IAEA-TECDOC-860, *ASCOT (Assessment of Safety Culture in Organizations Team) Guidelines* (1996), which is based on the Appendix of INSAG-4, and proposes key indicators for the different areas that need to be considered when assessing safety culture at NPPs, and IAEA Safety Reports Series No. 11, *Developing Safety Culture in Nuclear Activities* (1998) which offers practical advice to assist in the development, improvement or evaluation of a progressive safety culture.

7.3. CORPORATE SOCIAL RESPONSIBILITY

Corporate social responsibility is the notion that companies are responsible for their social impacts. Oil companies, which have been criticized for their environmental and human rights records, are using corporate social responsibility concepts to improve their damaged reputations. Using corporate social responsibility concepts, companies' risk assessments must include the risk posed to reputations and business goals by environmental mishaps and social blunders. Ignoring these areas can lead to difficulties in raising financing, attracting qualified staff, consumer boycotts and litigation. Using corporate social responsibility goals, companies measure their environmental and social performance to demonstrate that they have acted correctly. Corporate social responsibility has a potential benefit for the nuclear power industry as a means to highlight the relatively benign environmental impacts of nuclear power compared to alternate sources, and even to highlight the comparative impacts of waste from NPPs versus fossil plants, particularly coal plants.

Safety culture is a dimension of corporate social responsibility as it represents a corporate code of conduct with regard to environmental protection and human rights. Again this is potentially a way for NPPs to receive additional credit/visibility for actions that have been universally taken such as the Nuclear Safety Convention and assessment of safety culture, and encouragement of a safety conscious work environment and industrial safety record.

A dimension of corporate social responsibility has also been a corporate code of conduct with regard to environmental protection and human rights. Again this is potentially a way for NPPs to receive additional credit/visibility for actions that have been universally taken such as the Nuclear Safety Convention and assessment of safety culture, and encouragement of a safety conscious work environment and industrial safety record. See Annex 10 for an example of how one company communicates its policies and record on these issues to its stakeholders.

7.4. ORGANIZATION DYNAMICS

A recent study from the Harvard Business School [48] explores another aspect of corporate culture and risk management. It highlights the origins of stress in a workplace with the development of a 'risk exposure calculator'[13], in which three sets of keys 'add up' to higher levels of risk. The major components or pressure points are:

- Pressures from growth[14] (for example: increased performance expectations, intense pressure from bosses or outsiders to succeed, goal setting from the top, high rate of expansion in operations, high hiring rate, ambiguous company value statements)
- Pressure points due to culture (for example: excessive reward for entrepreneurial behavior, failure to appropriately reward entrepreneurial behavior, percentage of business based on new products or services or requiring new skill sets, bad news rejection by upper management, internal competition encouraged)
- Pressure points due to information management[15] (for example: inadequate management information systems, specialized information resides in well protected pockets, volume and velocity of information transactions that makes analysis more difficult, internal

[13] This particular study highlights the iterative and interactive nature of risk management. The risk exposure calculator and the subsequent 'Five important questions' address both Step 1 (identification of risk sources) and Step 2 (management of risk), as well as highlighting feedback mechanisms (Step 3, Monitoring and Feedback) by which upper management reinforces (or denigrates!) stated company policies and values.

[14] Few NPPs face substantial growth internal to the company. However, consolidation of the industry from merger and acquisition is occurring worldwide in the nuclear industry, creating growth and the resulting stresses for many operating companies.

[15] Nearly every item in this example list is true in NPP operating companies.

reporting systems that cannot keep up with internal needs, gaps in diagnostic performance measures, decreased frequency of standard performance reports, too — decentralized decision making).

The author, Robert Simons poses five questions that are critical for a complex organization such as a NPP to operate effectively and at an acceptable level of risk.

1. Have senior managers communicated the core values of the business in a way that people understand and embrace? A corollary to this is that senior management must reinforce stated beliefs through visible actions.

2. Have managers clearly identified the specific actions and behaviors that are off-limits?

3. Are diagnostic control systems adequate at monitoring critical performance variables? Managers need to determine which performance variables matter most and then design ways to ensure that key managers are regularly informed of those figures so they can take action when needed.

4. Are control systems interactive and designed to stimulate learning? Exception-based diagnostic reports are not sufficient if they are one-way only.

5. Is the organization paying enough for traditional internal controls?[16]

The UC Berkeley project [45] has identified two specific characteristics of complex organizations that are known to manage risk successfully. One common characteristic is an emphasis on constant communication far in excess of what would be thought useful in normal organizations. The second common characteristic is emphasis on active learning.

> "Employees not only know why the procedures are written as they are but can challenge them and look for ways to make them better. The purpose behind this learning is not so much to improve safety although this often happens — but to keep the organization from regressing."

Pool concludes by saying:

> "Organizational reliability is just as crucial to the safety of a technology as is the reliability of the equipment. If we are to keep our technological progress from backfiring we must be as clever with our organizations as we are with our machines." [45]

Supportive of the conclusions from the UC Berkeley project are those of the Nuclear Energy Institute in its "Work Management Process Benchmarking Report" [25]. Benchmarking was done at Callaway, Peach Bottom, South Texas Project, and Surrey. These four United States plants were selected based on high performance at low cost. The Executive Summary of this report states:

[16] Simons is referring here to time-tested practices such as segregating duties, limiting access to critical information, and adequate staffing of control and risk management positions; i.e., whether the checks and balances are effective.

> "Culture was found to be a key driver at all four sites, making the rest of the process work smoothly. Clear management expectations were understood at all levels of the organization. Effective use of performance indicators and meaningful self-critique gave a true evaluation against the expectations. Each site continued to make improvements to their process, resulting in redefined and raised expectations. Underlying this culture was a strong sense of ownership by those involved in the work management process." [25]

7.5. CHANGE MANAGEMENT PROCESSES

Delineation of a change management process institutionalizes the actions of members of NPP professional staff in making organizational changes that impact the various sources of risk. A formal change management process will specify the types of activities for which the formal process should be used, the responsible parties, the step-wise progression of a decision, and the monitoring mechanisms, including the degree of external third party involvement. The goal of the Management of Change document for British Energy, UK (see Annex 8) is to ensure that all "changes are properly considered, justified, and auditable". A key feature of the process is the identification of changes with respect to their potential impact on nuclear safety. Items are graded 'A' to 'C', based on the potential that, "if inadequately conceived or executed", the change would seriously reduce the "capability of the organization to maintain safe operation and compliance with the Site License".

A similar document from Atomic Energy of Canada, Ltd., their internal Decision Making Process, provides a systemic checklist of impact on design, material or equipment supply, and construction activity when a Change Request form details a specific change, modification, or requirement (see Annex 9). The document carries a Risk Assessment appendix that defines the risks or opportunities associated with the task. In this way, risk assessment has been built into the normal channels by which decisions are made.

8. CONCLUSIONS

As was indicated at the beginning of this report, in today's global energy environment, NPP managers need to consider many dimensions of risk in addition to nuclear safety-related risk. In this context, the following are considered to be the most important messages in this report:

- The benefits/value of integrated risk management have been demonstrated.
- It is necessary for NPP managers to main a broad perspective in integrated management of safety-related, operational, commercial/financial and strategic risks.
- Risk management should be integrated into an organization's management systems, not be a stand along process.
- A framework for conducting risk management has been provided along with examples illustrating use of the framework.
- A broad range of examples have been provided of an integrated application of risk management.
- Examples are provided where existing PSA tools/results related to nuclear safety-related risks have been used to help manage other risk areas.

APPENDIX

EXAMPLES OF COMPLETED RISK MANAGEMENT CHECKLISTS

Example 1: Completed Checklist to Manage Risks Associated with a Hypothetical Project to Provide Additional Interim Spent Fuel Storage at an Existing NPP Site

Most older NPPs today are in need of additional interim spent fuel storage space capacity, to retain the "cooled" spent fuel in a secured, safe environment, prior to the final disposition in long term storage. It is therefore extremely important that this additional capacity is provided in a safe and environmentally suitable manner in order to ensure continued plant operation. In today's increasingly de-regulated power production environment, it is vitally important to recognize this need, which in effect protects the utility's long term investment. It is also in this context that the value of additional investment needs to be weighed against all aspects of real, or perceived risk, in order to determine the appropriateness of this investment. Provided below is a completed risk management checklist associated with a hypothetical management decision regarding a project for interim fuel storage.

NOTE: In order to provide clarity, this example was constructed in such a way that the initially identified risks were assessed together through all four steps of the process. In actual application it is suggested that each individual risk component identified in Step 1 of the process be assessed in a single focus through the remaining steps 2 through 4. (i.e., if you identify 5 risk components, there would be five sets of the Steps 2 through 4 checks). This allows the process to concentrate on a single issue and associated risk impact, mitigating circumstances, individual disposition, and proposed solutions.

Example checklist for:

ISSUE/EVENT: Additional interim spent fuel storage at an existing NPP site

STEP 1. Identify and characterize risks related to this issue/event
(search for all potential consequences of the event)

Category/Description	**Definition**	**Opportunity/ Threat (+/-)**	**Unit of Measure**	**Ranking**		
				by preparer	by reviewer	by approver
SAFETY RELATED						
Nuclear						
Radiological	Limit future exposures	+	mRem	2		
Industrial						
Environmental	Better solution	+	mRem	2		
OPERATIONS						
Personnel Qualification	Additional	-	staff	3		
Personnel Training	Additional	-	mhrs	3		
Outage Management						
Inventory Management						

Documentation and Procedures	May need new ones	-	mhrs	3		
Organizational Structure	Expand	-	staff	4		
Physical Security						
FINANCIAL/ COMMERCIAL						
Interest Rates	Lending rates	-	$	4		
Exchange Rates						
Supply/Demand Conditions	Site pool capacity	-	fuel rods	4		
Supplier Base						
Cash Flows						
Return on Investment						
Plant Availability	Uninterrupted operation	+	$	1		
Life Expectancy	Affected	+/-	%	1		
STRATEGIC						
Political Environment						
Ownership Patterns						
Level of Competition						
Public Sentiment	Prevents perceived exposure problem	-	Qualitative	1		
Safety Regulatory and Legal Environment	Regulator could mandate a particular approach	-	$	3		

ISSUE/EVENT: Additional interim spent fuel storage at an existing NPP site

STEP 2. Identify techniques and strategies to manage the specific risk

Reduce Risk	
Engineering Changes	
Management or Organizational Changes	Need to identify early-on
Enforcement of Existing Standards	
Personnel Changes (Staffing, Training)	
Cost Changes (Increase efficiency, change spending patterns)	
Transfer Risk	
Contracts with Suppliers, Market	
Insurance	Apply for potential labour issues exposure, to prevent penalties of time delays
Pooling	
Regulation/Legislation	Work closely with the regulator to prevent legislative impact
Retain Risk	
By Choice	
By Default	
Not Recognized	
Techniques to consider interactions with other risks	
Sensitivity Analysis	Identify impact through station life vs. investment
Reduce to Monetary Terms to Compare	Convert to monetary value
Qualitative Comparison	
Multi-criteria Analysis	
Consistency with Company Culture and Policy	
Define Exit Strategy	Based on the above Sensitivity assessment — define strategy for ROI

ISSUE/EVENT: Additional interim spent fuel storage at an existing NPP site

STEP 3. Implement integrated solutions

Assign Responsibilities and Accountabilities	
Sanity Check—does the solution resolve the issue?	
Is the solution consistent with solutions to other issues?	
Are key risks being addressed?	Provide an independent panel review
Can you exercise the exit strategy?	Yes
Is flexibility maintained?	
DO IT!	✔

ISSUE/EVENT: Additional interim spent fuel storage at an existing NPP site

STEP 4. Monitor effectiveness of solutions

Establish Measures of Success	Investment / ROI
Establish Milestones and Check Points	Prepare detail schedule and milestone chart for implementation
Look for Unintended Consequences	Yes
Monitor Accountability	Assume quarterly project reviews
Monitor for Emerging Risks	
Feed back results to appropriate step/point to adjust strategy or exit	Yes

Example 2: Completed checklist to manage risks associated with the hypothetical retirement of experienced plant staff

Many of the NPPs operating today have been in operation for twenty years or more. They are now facing near term retirement of the personnel who initially commissioned the plant. At the same time the nuclear industry education infrastructure in a number of Member States is being reduced, and the competition for replacement personnel is quite strong. These phenomena have a major impact on availability of qualified personnel to replace these retirees, directly affecting the station's performance, generating capacity, and availability. It is imperative that the potential risks associated with this situation and alternative solutions are identified as early as feasible, so that a preventive action can be taken to minimize negative impact on performance, i.e. address the issues of availability of properly trained staff, before the impact is imminent. Provided below is a completed risk management checklist associated with a hypothetical management decision regarding alternative solutions to replace retiring plant personnel.

NOTE: In order to provide clarity, this example was constructed in such a way that the initially identified risks were assessed together through all four steps of the process. In actual application it is suggested that each individual risk component identified in Step 1 of the process be assessed in a single focus through the remaining steps 2 through 4. (i.e., if you identify 5 risk components, there would be five sets of the Steps 2 through 4 checks). This allows the process to concentrate on a single issue and associated risk impact, mitigating circumstances, individual disposition, and proposed solutions.

Completed example checklist for:

ISSUE/EVENT: Retirement of Operational Staff

STEP 1. Identify and characterize risks related to this issue/event
(search for all potential consequences of the event)

Category/Description	Definition	Opportunity/ Threat (+/-)	Unit of Measure	Ranking		
				by preparer	by reviewer	by approver
SAFETY-RELATED						
Nuclear	Higher safety risk	-	Qualitative	1		
Radiological	Potential accident exposure	-	mRem	2		
Industrial						
Environmental						
OPERATIONS						
Personnel Qualification	Additional	-	staff	3		
Personnel Training	Additional	-	mhrs	3		
Outage Management	Additional	-	mhrs	3		
Inventory Management	Additional	-	mhrs	3		
Documentation and Procedures						
Organizational Structure						
Physical Security						
Fresh view of operation processes		+/-	kwhrs			
FINANCIAL/COMMERCIAL						
Interest Rates						
Exchange Rates						
Supply/Demand Conditions	Limits supply	-	kwhrs	1		
Supplier Base						
Cash Flows						
Return on Investment	Negative impact	-	$	1		
Plant Availability	Down	-	%	1		
STRATEGIC						
Political Environment						
Ownership Patterns	Bad image	-	Qualitative	4		
Level of Competition						
Public Sentiment	Loss of expertise/ job opportunities	+/-	Qualitative	2		
Market Regulatory and Legal Environment		+/-	$	3		
Safety Regulatory and Legal Environment	Loss of expertise	-	Qualitative	3		

ISSUE/EVENT: Retirement of Operational Staff

STEP 2. Identify techniques and strategies to manage the specific risk

Reduce Risk	
Engineering Changes	
Management or Organizational Changes	Identify and address
Enforcement of Existing Standards	
Personnel Changes (Staffing, Training)	High impact
Cost Changes (Increase efficiency, change spending patterns)	Invest for future
Transfer Risk	
Contracts with Suppliers, Market	
Insurance	
Pooling	
Regulation/Legislation	
Retain Risk	
By Choice	
By Default	
Not Recognized	
Techniques to consider interactions with other risks	
Sensitivity Analysis	
Reduce to Monetary Terms to Compare	
Qualitative Comparison	
Multi-criteria Analysis	
Consistency with Company Culture and Policy	Preventive vs. reactive action
Define Exit Strategy	

ISSUE/EVENT: Retirement of Operational Staff

STEP 3. Implement integrated solutions

Assign Responsibilities and Accountabilities	
Sanity Check—does the solution resolve the issue?	
Is the solution consistent with solutions to other issues?	
Are key risks being addressed?	
Can you exercise the exit strategy?	
Is flexibility maintained?	
DO IT!	✔

ISSUE/EVENT: Retirement of Operational Staff

STEP 4. Monitor effectiveness of solutions

Establish Measures of Success	Uninterrupted performance
Establish Milestones and Check Points	Follow-up on implementation
Look for Unintended Consequences	Yes
Monitor Accountability	
Monitor for Emerging Risks	
Feed back results to appropriate step/point to adjust strategy or exit	Yes

ANNEXES 1–10

ANNEX 1

USE OF RISK ASSESSMENT PROCESS FOR SECONDARY QUICK CLOSURE VALVE REPLACEMENT DECISION, BRITISH ENERGY, UK, 1999

Summary:

British Energy initiated a project to carry out a safety back fit of a plant sub-system. After the design had been agreed, it became apparent that one of the components selected would not meet the design reliability requirements. A comparative risk assessment showed that retaining the planned component was the optimum course of action.

Impacts:

1. This activity was primarily initiated because of safety.
2. The principal impacts of implementing this activity were in the safety, operational and commercial areas.

Lessons Learned with Respect to Risk Management:

That for specific plant issues like this, a systematic assessment could be carried out using only minimal resource and time, which would provide a robust and auditable defense of engineering decisions.

Detailed Description:

Modifications were in hand to provide secondary quick closing isolation valves for the primary coolant clean-up circuit pipe work on an Advanced Gas Cooled Reactor. This was required to provide redundancy for the existing valve in the event of a seismic event and consequential rupture of the clean up circuit pipe work. After the design had been agreed, it became apparent that the valve selected would not meet the design reliability requirements. An assessment was carried out in which it was shown that the disbenefits in terms of operations, safety and commercial consideration associated with changing to a higher integrity valve were disproportionately higher than the safety benefit that would be achieved. This assessment was carried out using the company's guidance on decision making to ensure risks are ALARP (as low as reasonably practicable).

The dominant factors in balancing the risks associated with either retaining the current intended valve or installing the more sophisticated valve was the delay that changing components would introduce, which was a net reduction in safety because the implementation of the safety enhancement would be delayed, although cost considerations and engineering risks associated with the higher integrity valve were also important. As a result of this assessment, this project was able to continue and reach an acceptable conclusion with no delay or increase in cost.

ANNEX 2

PORTFOLIO MANAGEMENT OF A MULTI-PLANT COMPANY, NUCLEAR POWER CORPORATION, INDIA

Summary:

A multi-plant company faces many challenges concurrently:

- Operation and relicensing of older plants, including life extension/management.
- Performance improvement of operating plants
- Speedy implementation of new plants towards early realization of the return on investment.

While addressing the above issues, technology upgrades/innovations to meet future challenges need to be kept in focus. With this in mind, even though the initial plan contemplated introduction of several 220 MWe PHWRs, it was recognized that larger size units, i.e. 500 MWe PHWRs, would be able to contribute significantly towards the power needs, without major additions to the existing resources (other than financial) in the company or to the infrastructure available in the country. Assuming that financial resources would not be a major constraint, in the same time frame, more than double the capacity addition was considered as a possibility. Portfolio management under the above situation has some attendant risks. Cost effective management of the company portfolio of multiple plants is a major challenge.

Lessons Learned:

A multi plant corporation should be alert in order to meet safety standards in design and safety in operations, while ensuring commercial viability of nuclear power and also being ready to face challenges from external factors. Having several plants in the portfolio makes meeting these goals more possible than if only a single plant were owned.

Detailed Description:

History

In India, nuclear power was introduced in the mid 1960s. Based on the provincial grid size, the size of the nuclear power plant was chosen to be around 220 MWe. While based on the available moderate uranium resources and large thorium reserves, it was decided to go in for a program based on natural uranium and heavy water reactors. In order to obtain operation of nuclear power plants in the weak grids, the first two units built were of BWR technology on a turnkey basis. Two units built with Canadian collaboration, based on PHWR technology, followed these. The choice of PHWR also was based on the easy indigenisation possibility as well as long-term self-reliance in the nuclear power program.

During late 1970s, with the formation of regional grids of larger size, it was considered feasible to implement 500 MWe PHWRs into the Indian grids. A start was made towards designing 500 MWe PHWRs. At the same time the Indian industry, particularly thermal power plants manufacturers, were already installing 500 MWe units. A final decision was made in 1984 to start designing 500 MWe PHWRs with a dedicated team, and the conceptual design for a 500 MWe PHWR was completed by 1987 while detailed engineering proceeded concurrently.

During this period two more 220 MWe PHWR units were made operational near Madras (MAPS) and two units were in advanced construction/commissioning stage at Narora (NAPS). Planning and construction commencement for KAPS and Kaiga also started in this period. In 1997 the Nuclear Power Board, a government department charged with looking after nuclear power implementation, was converted into the Nuclear Power Corporation (NPCIL).

Operational Issues of a Multi-Plant Company:

Subsequently one of the PHWR units, which had completed more than 8.5 effective full power years, was taken out of production for retubing of the reactor and also upgrade of safety systems. This lasted from 1994-98. The whole exercise was completed successfully with indigenous development. Concurrently, with indigenously developed techniques, another PHWR unit at the same site, that had a leak from the gasket of the over pressure relief device, was rectified and made operational. These two jobs were major technical challenges that gave life extension to two of the PHWRs. Presently both of these are operating at the authorized power.

In-service inspection (ISI) of the coolant channel in a PHWR is an important aspect of safety. In view of non-availability of necessary tooling from international sources, India had to develop these indigenously and perform the necessary inspections of the older PHWRs. This had some impact on the overall operations as well as capacity factors. The experience with the ISI equipment and garter spring relocation equipment during the recent campaign has been quite encouraging and NPCIL is confident that it will be able to meet the regulatory requirements in ISI of coolant channels in future. However, it must be recognized that this is still evolving and a better understanding and techniques are expected to improve the situation.

The partial delamination of the inner containment dome resulted in extensive investigations, redesign of the dome, development of high performance concrete, etc., which resulted in considerable delays in the construction of four units of PHWRs. After satisfactory resolution of all these problems, the inner containment work on the four domes has been completed and tested. Two of these units have been commissioned and are operational. The other two units are expected to become operational later this year. NPCIL is gearing up for re-tubing of two more PHWRs in the next 2 to 4 years while the construction of 2 × 500 MWe and 2 × 220 MWe will be ongoing.

From the above description it can be seen that a multi plant corporation should be constantly on the vigil in order to meet safety standards in design, safety in operations, while ensuring commercial viability of nuclear power and also being ready to face challenges from external factors (such as public perception, cheaper conventional sources of power etc.). These challenges can be met by a dynamic leadership/management which is ready to look at various options and priorities without compromising safety and ensuring commercial viability, at all times.

ANNEX 3

ENVIRONMENTAL RISK ASSESSMENT, BRITISH ENERGY, UK: ESSENTIAL DIESEL GENERATOR FUEL OIL SYSTEM, 1999–PRESENT

Summary:

A framework has been developed to enable risks from environmental hazards to be managed in a consistent fashion. It requires each NPP to provide an inventory of the potential environment hazards, and their magnitude in terms of source term and potential hazards. The framework establishes the number and integrity of the barriers required to avoid the hazard, and takes due account of legal and regulatory environmental requirements. This risk-informed approach ensures that resources are focussed in a consistent fashion where they can provide most benefit.

Impacts:

1. This activity was primarily initiated because of increased regulatory constraints particularly from the environmental regulators.
2. The principal impacts of implementing this activity were improving the environmental performance of the plant as well as in the safety, operational, commercial and external factors area.

Detailed Description of the Activity/Example:

The key stages in the process are shown in Figure 1. An example assessment for a particular system, the Essential Diesel Generator Fuel Oil System, is also shown in Figure 2.

Primary barrier – the main physical design of the equipment that prevents an environmental impact e.g. Tank, pipework.

Secondary barrier – a barrier (diverse/segregated from the primary barrier) that will prevent an environmental impact on its own (defence in depth) e.g. Bund or operational control.

Tertiary barrier – a third order barrier that will reduce and probably avoid an environmental impact e.g. oil separator, lagoon. Other examples would be CCR alarms, plant visual inspections to identify leak or stack black smoke.

Mitigation barrier – a barrier that will mitigate the damage to a receptor when the primary and secondary barriers have been breached e.g. responding to emergency plan procedures for oil spill.

Administrative controls – Plant operating instructions, permit for work isolations.

ASSESSMENT – Assess high score areas and barrier compliance.

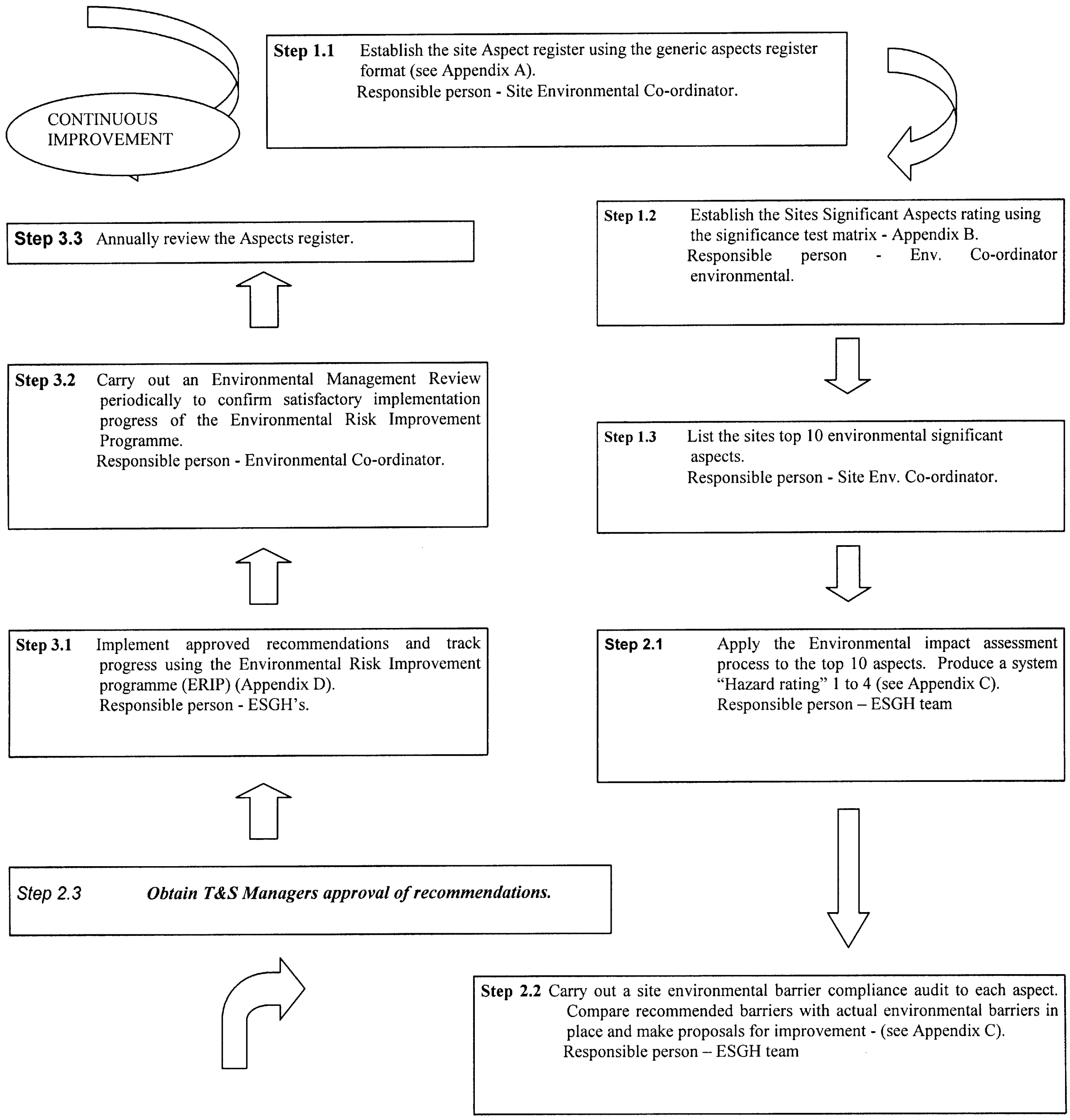

FIG. 1. Environmental risk assessment methodology.

The highest consequence score was the Quantity of the material on site which was rated as 4; the only possibility of reducing this impact is reducing the current stock levels which is not practical.

The primary barriers i.e. tanks and pipework are not maintained and although 2 secondary barriers exist this is not considered acceptable for a system risk rating of 3.

Two physical secondary barriers are required and are in existence below ground level which were the bunded room below ground level and a sump pump pumping to the blind sump. It is important to confirm regular inspection of the sump level (see recommendations).

ENVIRONMENTAL IMPACT ASSESSMENT REPORT
ESSENTIAL DIESEL GENERATORS (passport plant code 65 headers)

Fuel oil system
delete systems not applicable to this assessment

Plant scope - Lubricating oil system as per drawing HYB 52/2

IMPACT ASSESSMENT MATRIX

									Score	
NATURE OF MATERIAL (Source Hazard)	1	No environmental impact	2	Noxious Combustible Flammable e.g. sewage, smoke	3	Toxic Corrosive Volatile Reactive e.g. acids, oils	4	Eco toxic damaging Very toxic Explosive e.g. halons, nox, sox	3	
QUANTITY Solid/liquid or	1	<1 Tonne or 1m3	2	1 – 20 tonnes	3	20 – 200 tonnes	4	> 200 tonnes	4	
QUANTITY Gaseous	1	<0.1 tonne	2	0.1 – 1 tonne	3	1 – 10 tonnes	4	> 10 tonnes		
RECEPTOR SENSITIVITY	1	Emission within secondary boundary	2	Emission within site boundary	3	Emission within land and outside site boundary	4	Conservation interest (NNR, SAC, SSSI) Potable aquifer	3	
IMPACTS – Regulatory Public Financial	1	Undesirable, not reportable	2	Reportable, Regulator Action unlikely Remediation possible	3	Outside licence/ authorisation Regulator action likely Remediation probable	4	Public concern. Regulator action Remediation costs extensive	3	
Hazard rating (average score divide by 4) = 3								**Total**	13	

Rating	Risk Category	Barriers required	Details of barrier compliance
1	Low	Maintain Primary barrier - physical or administrative control	
2	Moderate	Maintain Primary barrier or 2 Secondary barriers; + 1 Secondary barrier required - physical or admin control or 2 Tertiary barrier + 1 Mitigation barrier	
3	High	Maintain primary barrier + 1 Secondary barrier required - physical + 1 Tertiary barrier + 1 Mitigation barrier	No Yes 1) Bunded room 2) Blind sump Yes 1) Tank HLA 2) Ops plant tour Yes 1) spill kits 2) Emplan procedures/trng
4	Very High	Maintain primary barrier + 2 Secondary barriers required - min of 1 physical 1admin barrier + 1 Tertiary barrier + 1 Mitigation barrier	

FIG. 2. Environmental impact assessment report for essential diesel generator fuel oil system.

However the Y system tanks bund drain to the interceptor and a large leak from the fuel tanks or the day tank drain on the roof would overflow the separator and provide a pathway to sea.

Past events at other sites suggests that automatic cut-in of sumps and day tank filling can cause overflows leading to oil loss to sea by overloading interceptors (see recommendations).

RECOMMENDATIONS FOR RISK REDUCTION — use BATNEEC — best available technique not entailing excessive cost.

1. Maintain the primary barrier of tanks and pipework by implementing a routine visual inspection programme and NDT where the probability of deep corrosion exists. This is particularly important on Y system which is outside and has evidence of external pipework corrosion.

2. Remove paint partially blocking the day tank bund drain to the main storage tank areas.
3. Check daily the blind sumps that are fed from these tank areas to ensure empty of water and no evidence of oil.
4. Consider switching automatic fuel oil transfer to manual avoiding auto cut in and feeding a leak on the day tank system which would overflow blind sumps or overflowing the oil separator on Y system.
5. Secondary barrier unacceptable on Y system since a leak will overflow the separator, recommend the Sizewell B design solution which is to fit plug valves to the outlet drains of the bund. Ops only drain the bund after assessment of liquid in bund e.g. oil or antifreeze.
6. Re-route DY roof drain to bund if plug valves are fitted (see water systems recommendations).
7. Blind sump requires a separate risk assessment on the inspection/emptying process.
8. Blind sump is not alarmed therefore needs inspection daily.
9. Action on receipt of alarm High level Day tank alarm PIOI requires immediate investigation.
10. Fuel oil tank delivery and fuel transfer PIOI’s need reviewing for environmental impact.

ANNEX 4

VALUE AT RISK (VaR) METHODOLOGY

Summary:

Value at Risk methodology is described as it might be applied to the portfolio of a NPP operator.

Impacts:

Use of the methodology allows a NPP operator to explicitly recognize and measure the portfolio effects of a complex commercial enterprise, by factoring in numerous sources of variability, to measure the maximum expected loss, given the probability distributions of diverse events.

Detailed Description of the Activity/Example:

Value at Risk summarizes, in a single number, the exposure of a firm to market financial risk. VaR is quickly becoming an essential tool for conveying risk exposure to top management. The procedure followed is to choose an appropriate time horizon, calculate the magnitude of the VaR, and then verify that the model used for the calculation is indeed predictive of maximum possible loss for the given confidence level.

Calculation of VaR requires choice of a holding horizon (time frame for analysis of potential loss) that reflects the time it takes the organization to adjust its portfolio of holdings[17]. According to one industry expert, a major utility will calculate its portfolio value on a daily basis and can substantially adjust its parameters in very short order, perhaps as little as two or three days [14]. In addition, the entity needs to choose how precise the estimate needs to be, in terms of standard confidence intervals (95% or 99% confidence, for example, that the losses will not exceed the VaR). Next the distribution of possible returns is estimated, to identify the dollar value of loss corresponding to the chosen confidence level.

Verification of the VaR requires estimation of the sampling or estimation error. Statistically this requires that a large number of sampling periods be measured, so shorter holding horizons facilitate verification. Model verification is based on the failure rate, or the proportion of times that the modeled VaR is exceeded by actual losses. This is compared to the confidence level assumed in the modeling to determine if the modeling equations are sufficiently predictive of maximum possible loss.

The VaR calculation, then, encompasses consideration of the standard deviation and liquidity of a portfolio. According to Jorion [13] the VaR calculation can be conducted in one of three ways: using delta-normal estimation, historical simulation, or Monte Carlo simulation. The delta-normal estimation method is especially for those portfolios that are merely delta-hedged; i.e., for portfolios where price risk is reduced using combinations of instruments that have inversely proportional prices. Most financial risk managers address more than price risk, so a simulation estimation technique is often adopted.

[17] Jorion's wording is that the holding period "should correspond to the longest period needed for an orderly portfolio liquidation", taking into account liquidity of assets, and normal transaction volumes in the markets for those assets (p. 86).

Historical simulation is a widely-used estimation technique, and has been used by several major United States utility companies for nearly a decade. It uses company experience as a basis for the estimation. The utility's financial security portfolio value is calculated on a daily basis; the observations are collected over time. The variability of the portfolio value is used in determining the standard deviation. The VaR is a function of that standard deviation.

Using historical simulation estimation, the VaR is the normal distribution's Z-factor multiplied by the historically observed standard deviation, multiplied by the square root of the liquidation period in days (i.e., at the 95% confidence level, 1.645 times standard deviation times square root of the number of days to liquidate) [54]. So if a utility has observed portfolio value over a number of days (say, 30) and has used those values to calculate a standard deviation of $3.5 million, then with a two-day 'adjustment' or liquidation period, and 95% confidence level, the VaR would be

$$\text{VaR} = 1.645 \times \$3.5 \text{ million} \times 1.414 = \$8.14 \text{ million}$$

The question, then, for utility management is whether $8.14 million maximum loss (at 95% confidence) is an acceptable tradeoff for the returns being garnered from the portfolio.

As stated in the main report, Section 4.3.1, application of this technique in nuclear power production is not well developed, but as the industry moves towards a more comprehensive and integrative risk management regime, the Value at Risk (or similar) measures will enter the picture because of increased use of derivative instruments. As firms develop hedging, pricing, and marketing strategies for electricity, and increase the use of electricity, weather, and currency futures contracts and swap agreements, it will be necessary for these NPP operating companies to learn the Value at Risk approach to identify and measure volatility.

ANNEX 5

STRATEGIC ISSUES ASSESSMENT, FORT CALHOUN STATION (FCS), USA

Summary:

A framework has been developed to enable a USA NPP to explore potential vulnerabilities, risks, and strengths in support of the decision to pursue license renewal of the plant.

Impacts:

All three sectors of the risk management model proposed in this report influence the results of, and are impacted by, this Strategic Issues Assessment.

Detailed Description of Activity:

The process employed in this assessment identified favorable and unfavorable issues. The systematic assessment of all potential issues resulted in a listing of 18 issues considered unfavorable and presenting a high risk to the success of the NPP's continued operation through license renewal. The unfavorable issues were narrowed through a process of combining similar issues and prioritizing the results. Eight priority issues were identified via this narrowing process. The assessment identified three issues that are favorable to the FCS license renewal option. The favorable issues represent some of the strengths supporting the continued operation of the NPP.

The assessment focused on potential barriers to the prospect of license renewal. The assessment identified and analyzed numerous technical, environmental, economic, social, political, and regulatory issues. Although no insurmountable barriers were identified, several issues were identified that may jeopardize the technical or economic basis for license renewal and several issues that could influence stakeholder confidence. Stakeholder confidence is vitally important to the success of license renewal and is important to utility reputation management. The outcome of this assessment identified very general risk mitigation plans to address those issues for which the NPP may be vulnerable, so that they can be managed separately in preparation for license renewal. Taking this approach will allow utility to manage the issues so that they do not become barriers to license renewal or to the continued operation of the NPP.

The utility established an issues management program to mitigate the risks identified through the assessment. Risk mitigation strategies were developed and implementation plans created to achieve and/or maintain the desired state of stakeholder confidence.

The strategic issues team worked with the appropriate utility organizations and key individuals to identify stakeholders and to establish a formalized 'relationship management' plan for every key stakeholder group that may exert influence on the license renewal process for the NPP. The strategic issues team developed the reference documents necessary to inform and prepare utility personnel to effect good relationship management. Briefing papers were developed for every identified issue as part of those reference materials. These issue briefs are used as part of a stakeholder education plan that will generate stakeholder confidence in the NPP and utility. The strategic issues team also identified the 'issue drivers' or events that can stimulate public discussion or examination of the issues, e.g. elections, public hearings, publications, and special interest group meetings.

The identified issues will manifest at different times. The timing of strategic decision-making and action plan implementation is critical to accomplishment of the ‘no surprise’ objective. A chart was prepared to illustrate how many of the issues will play out in the next decade and how they can cloud the license renewal decision and process. These peripheral issues can influence the process by creating significant distractions and possible obstacles to the successful attainment of license renewal. Action plan implementation could shift an issue status closer to the desired state, removing the ‘clouds’ and creating a positive influence.

ANNEX 6

MONITORING PROCESS, ATOMIC ENERGY OF CANADA, LTD (AECL)

Summary:

AECL, a nuclear vendor company, is an engineering-design-project management type organization, which markets and supplies pressurized heavy water reactors (PHWRs) on a worldwide scale. As such, it deals with complex engineering, commercial, safety, construction and project management related issues that need to be addressed and resolved in an efficient, responsible and timely manner. This example contains the description of AECL's internal Decision Making Process, applied in phases of design, construction, configuration management, proposal preparation, or project implementation.

Impact:

This activity normally covers issues impacting safety, operational nature, commercial or other external issues, or design aspects.

Lessons Learned with Respect to Risk Management:

Provides an insight into the implementation process of a project/activity, based on the previous risk/opportunity identification. Invaluable tool for follow-up through to completion, ensuring that progress according to projected schedule is maintained.

Detailed Description:

This example describes the existing monitoring and control process of the project/activity implementation. The period covers project lifecycle, from the design concept, detail engineering, to construction and business follow-up aspects. The purpose is to ensure that a full oversight control is in place and maintained at the appropriate levels. All previously identified risks/opportunities are monitored to the lowest level.

- **ATP** – At the onset of a project, the Authorization to Proceed (ATP) budget control system is established and project cost control model put in place. This document platform is aligned with the Division of Responsibility (DOR) and the Scope of Work, together with schedules for deliverables, payments and individual milestones.
- **Project Review** – A project specific milestone review process is established (over the normal project duration of six to seven years) and adhered to. The Project Review (internal) follows a monthly schedule, whereas the Client Review (external) maintains a quarterly schedule.
- **VP Level Review** – Project Director reports to Vice President of Commercial Operation, who in turn holds a monthly Operations Review (immediately subsequent to the Project Monthly Progress Review). This is a high-level review process, taking place in half a day, where each project highlights issues only.
- **Financial Review** – An input from the Finance department is provided prior to the Project and VP Level Review process, in order to establish correlation between overall project processes, tying the deliverables to the revenue in/cash out process.

- **Actions –** Potential for identification of preventive action exists early in the process, to prevent a future exposure to additional risks.
- **Process –** The overall process is streamlined, to allow immediate problem identification and responsive actions to be implemented on as-required basis. Mot reports and presentations are done in real-time, on a local area network, and without many paper reports.

The intent is to provide management with an up-to-date snapshot of overall performance against the set-out target (budget), monitoring progress on a measurable level, with feedback flowing into different management levels. The direct result is the ability to react in time, when it is appropriate, for either maintaining the activities, altering course (if deemed so), or exiting from the exposure.

ANNEX 7

INTEGRATION OF SAFETY, OPERATIONS, AND COMMERCIAL GOALS FOR A NEW NUCLEAR POWER PLANT, KOREA ELECTRIC POWER CORPORATION (KEPCO)

Summary:

To reinforce the economic competitiveness of KNGR (Korean Next Generation Reactor) while maintaining safety goals, the design alternatives are studied and the design requirements from the conceptual and basic design phase are being reviewed. This example summarizes the effort for design optimization focusing on the integration of safety, operations and cost goals for the development of KNGR.

Impacts:

This activity was primarily initiated because of economic factors. In basic design, the focus was more on safety than on economic factors, even though the economic factors were also embodied by power level increase and general configuration optimization. The principal impacts of implementing this activity were the gaining of cost goals without sacrificing the safety goals. Also, operational and maintenance improvements were considered.

Lessons Learned with Respect to Risk Management:

The KNGR design is expected to be optimized by this process,

- because it reflects the design, construction, and operating experience of Korean NPPs;
- enabling economic competitiveness even though the commercial energy environment is constantly changing; and
- due to consensus among experts inside and outside of the company about the stable detailed design of the prototype.

Because of implementing the design optimization process described here, the final output will be an economically sound and safety unimpaired plant for the early part of 21st century of Korean domestic energy industry, and perhaps represents the future standard model for NPPs worldwide. The methodology described here represents a useful tool for integrated risk management in the basic design of new NPPs.

Detailed description of the Activity/Example:

In a long-term advanced nuclear reactor development program, Korea Electric Power Corporation (KEPCO) has been developing an evolutionary PWR plant called KNGR, for the standard nuclear power plant with a 4000 MWt power output. The project has three development phases. The major goals in Phase I, finished in 1994, were to determine the type of reactor, to study feasibility on the selection of preliminary design concepts, and to develop the top-tier design requirement. Phase II was a four year program from 1995 to 1999 to develop the basic design for the licensing review, to assure safety and licensability. Basic design features include:

- Advanced Design Features (ADF)
  - Four-train safety injection system (SIS)
  - In-containment refueling water system (IRWST)
  - Pilot operated safety and relief valve (POSRV)
  - Auxiliary feedwater water system (AFWS)
  - Double containment with annulus ventilation system

- Passive Design Features (PDF)
  - Passive secondary condensing system (PSCS)
  - Passive auto-catalytic recombiner
  - Fusible plugs in cavity flooding system
  - Fluidic device in safety injection tank.

At the completion of basic design, KEPCO has been forced to design for cost optimization. All the safety systems in the basic design are believed to be superior to those of existing domestic plants and foreign ALWRs. But there was concern about the economic viability of the new design when compared to fossil plants and competing, already operating, NPPs.

Phase III is scheduled from 1999 to 2001, with a main objective being design optimization. Originally, the purpose was to develop the detailed design. The focus was changed to include additional consideration of the balance between safety and cost of the advanced design features in KNGR design. Therefore between Phases II and III, some technical issues were optimized through an integrated review of the adequacy and effectiveness of the basic design, taking into account safety, economy, operability and maintainability aspects.

KNGR Design Optimization Review Process

As depicted in Figure 1, the optimization comprised three steps:

- identification of issues (internal design team)
- technical feasibility analyses (internal design team)
- decision by the design review and evaluation committee (DERC) (high level managers and experts in and outside of KEPCO, in order to establish consensus among participants in the project).

In the identification stage, technical and/or economic issues that need detailed investigation are selected and categorized into several groups. Design feasibility analysis, licensing impact analysis, and cost/benefit analysis are then performed for these issues. The analysis results are reported to DREC for decision-making.

After a through review process, KEPCO has decided to remove some systems to improve the economic competitiveness. The changes do not increase safety losses; for example, while double containment and the Passive Secondary Condensing System (PSCS) have been removed from the design, other hardware has been added; namely, diesel driven pumps for backup of the auxiliary feedwater system and an in-vessel retention strategy (IVR) for severe accident mitigation.

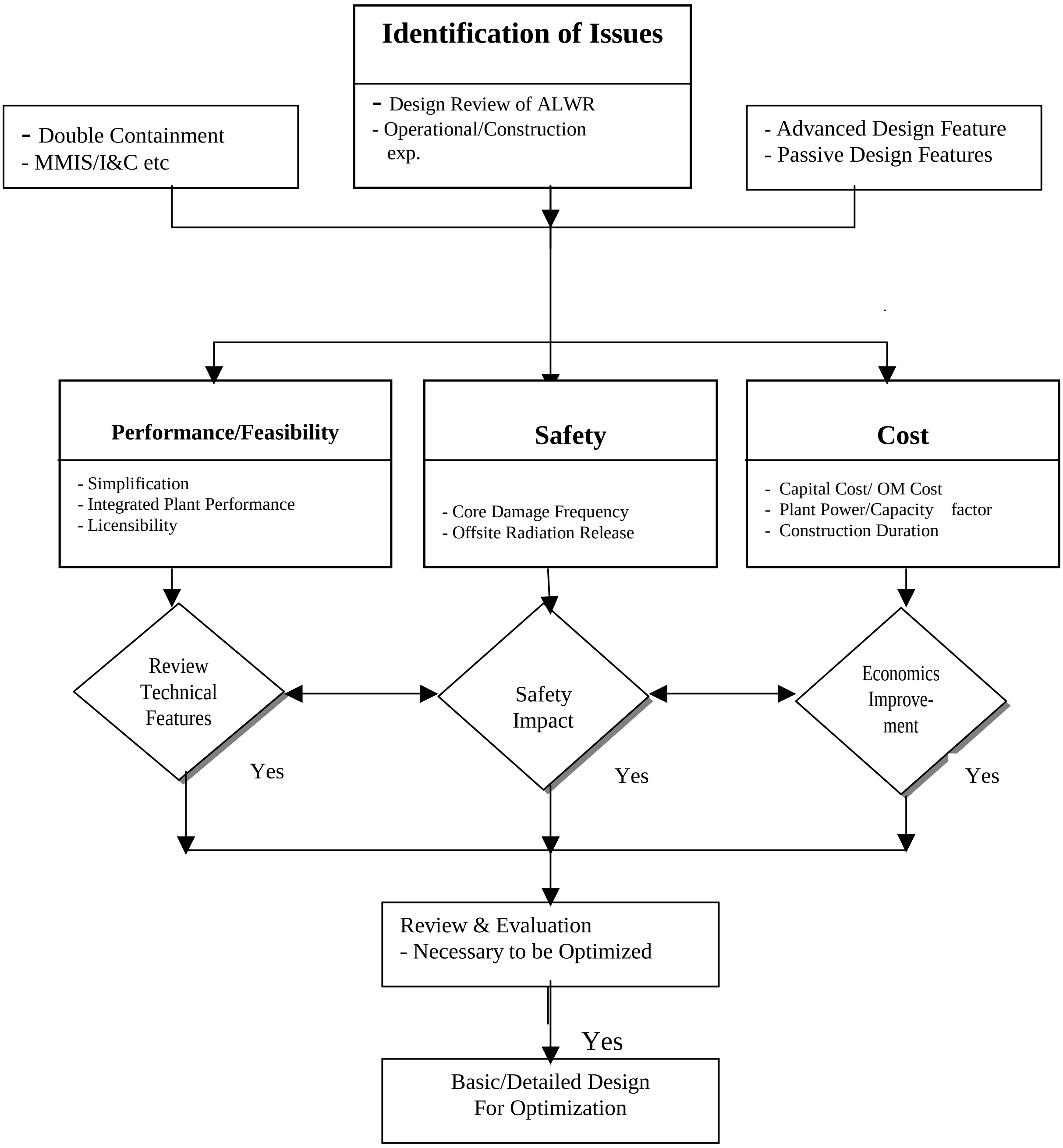

FIG. 1. Schematic of the KNGR design optimization process.

There was a long debate about the mitigation of the thirty minutes of steam generator dry-out time, which is one of KNGR top-tier requirements. The debate related to several factors, including safety, operational philosophy, manufacturing, and so on. In addition, KEPCO has reduced the length of steam generator tubes for the purpose of reducing the flow-induced vibration, while we increased steam generator radial size in order to achieve the increased 4000 MWth NSSS thermal power.

During this decision process, KEPCO did several sensitivity studies (including PSA and cost analyses) to evaluate the effects of these changes on safety, operations, and commercial factors (including public acceptance effects). With respect to the decision to use a single containment design, they performed the evaluation for containment failure frequency, offsite dose, and the impact of reinforcement on the severe accident mitigation facility. In evaluating removal of the passive condensation system, KEPCO was concerned with meeting their internal goal of core damage frequency, which is a tighter goal than the top-tier one. Other alternative cost-effective options were reviewed for coping with core damage frequency and station blackout. Based on these analyses, it was decided to add a diesel driven pump that backs up the auxiliary feedwater system.

Optimization Results of KNGR

There were more than twenty optimized items, including the following major items:

- Electric power up-rating by turbine system
- NSSS design optimization for performance enhancement
- NSSS and BOP safety system optimization
- Fuel and core design optimization for thermal margin and fuel performance
- Containment and severe accident mitigation system optimization
- General arrangement (GA) and building structure optimization for construction and maintenance convenience.

PSCS

In Phase 2, the basic design of the PSCS has been completed. As a part of the optimization study, we examined whether there are other alternatives. Because it was a safety significant system in previous safety evaluation, we were concerned about the safety loss due to its removal. So, we have reviewed the several related factors such as technical feasibility, offsite radiation goal, adverse effect by undesired operation and cost effectiveness in addition to core damage frequency for alternative design options. The alternative design options considered are upgrading of the system which is ultimately replacing the AFWS (Option 1), simply removing the system (Option 2), and addition of the alternate system (Option 3). At this time, one diesel driven pump of non-safety grade is considered as an alternative system to examine the safety impacts.

Table 1 shows that the cost-benefit is very competitive for Option 3 and the other two options are almost the same. However, the two options are very different if we considered licensing and performance issues because Option 1 is a very innovative concept not embodied in previous ALWR designs. It is clear that Option 3 has a cost advantage over the other two options. With this analysis and detailed consideration of other safety goals, KEPCO made the decision to add one diesel driven pump of non-safety grade, which is backup to the auxiliary feedwater system.

Table 1. The safety-cost impact of PSCS design alternatives

Contents	Basic Design	Option 1	Option 2	Option 3
CDF*	1.0	1.6	3.0	1.7
Cost	25 M$	22 M$(-3)	14.8 M$(-10.2)	16.6M$(-8.4)
Remarks	AFWS + Non Safety PSCS (50%)	Safety grade PSCS(100%)	AFWS + Removal of PSCS	AFWS + Removal of PSCS + DDP

*Relative CDF change of each design alternative based on basic design

Double containment

It was decided in phase 1 to have a double containment to enhance the safety and to increase the public confidence on KNGR. The double containment consists of pre-stressed inner containment with reinforced outer containment. During the phase 2 of KNGR development, we examined the possibility of removing containment liner. However, we concluded to keep the liner since its removal will increase the licensing risk. With the liner in place, the benefit on radiation release has been reduced. The operation and construction crews raised questions on the constructibility and maintainability of annulus region of in and outside of containment. So the expert consultation from existing plant construction members were elicited in the review process.

For the optimization of outer containment, we have to show the safety standard could be maintained by reviewing the containment integrity and the radiation release goals. The sensitivity analysis showed that the addition of severe accident mitigation features such as the external cooling of reactor pressure vessel (RPV) is more beneficial than the addition of the outer containment from the containment integrity perspective.

Table 2 shows the optimized design and its determining factors related to safety, operational and cost impacts. It indicates that the removal of PSCS and double containment is cost-effective. The monetary benefit for the removal of double containment is more than $10 million, considering only direct cost savings, without a large impact on safety.

Table 2. Optimization results for design alternatives

Group	Items	Results	Remarks
Plant Power Level	Electrical power Up-rating (3931→ 4000 MWth)	- 52” Last Stage Blade (LSB) adoption - Increase in Fuel Enrichment and new Fuel in refueling	Cost saving 23M$/ unit-year including 13M$ by 52” LSB
NSSS Safety System	-Safety Injection System with DVI -POSRV -Fluidic Device in Safety Injection Tank	- SIS with Direct Vessel Injection - POSRV design - Fluidic Device (FD) adoption	- No change from basic design
Fuel and Core Design	-24M Fuel Cycle -High Burn-up Fuel -MOX Core Design	- 18 Month fuel cycle - 30% MOX design cap.	Change to 24 Month Cycle if necessary - Long term R&D item
Containment and Severe Accident	-Double Containment -In-vessel Retention (IVR) -Cavity Flooding System(CFS) -Hydrogen Mitigation System	- Removal of Double Containment - Replacement of Fusible Plug with MOV(Motor Operated Valve) - Passive Auto-catalytic Recombiner + Igniter	Accident mitigation Measure such as IVR adopted
General Arrangement	-Structural Design Optimization	- Compound building - System, Building, Structure optimization	Reduction of 5~10% of volume & bulk material
PSCS	-PSCS Removal	- Removal of PSCS and addition of Diesel Driven Pump	Cost-benefit analysis
Performance Requirement	- Load Follow Capability - SG Dryout Time	- Daily load follow - Relaxation of dryout time to 20 minutes	-Excluding frequency control - Related to PSCS removal

The final cost comparison after design optimization shows that the cost is reduced by millions of dollars per unit. The reduction in the construction duration is not credited in this cost assessment. The construction schedule experts estimated that the construction duration could be reduced by 1~3 months by elimination of outer containment.

Implications of Use of the Design Optimization Review Process for Integration of Safety, Operations, and Cost Considerations

It is shown here that balancing safety, operations, and cost considerations can provide for efficient NPP design, as demonstrated for KEPCO's KNGR design. Although the presence of a passive system such as PSCS showed a significant safety enhancement to the design, it was shown to be less cost effective. At this time, alternative design options such as addition of diesel driven pump can cope with station blackout and transient accidents. Because of the design optimization, the final KNGR output will be economically sounded and safety unimpaired. It is shown by this analysis that the methodology KEPCO used for KNGR design optimization could be used as a useful tool for risk management in a global competitive nuclear industry.

ANNEX 8

MANAGEMENT OF CHANGE, BRITISH ENERGY, UK

Summary:

The Company's Management of Change document sets out the procedures and controls for managing organizational change with a potential impact on nuclear safety such that all changes are properly considered, justified and auditable. Its aim is to manage the risks to safety management associated with changes of organizational structure, personnel, responsibilities and resources or loss of corporate knowledge.

Impacts:

This activity was primarily initiated because of safety issues. The principal impacts of implementing this activity were in the safety, operational, commercial and external factors areas.

Detailed description of the Activity/Example:

Between re-licensing in 1996 and April 2000, changes in British Energy Generation to organizational structures and resources that may affect nuclear safety have been made under Management of Change controls defined in Company procedures. These procedures, which existed before 1996, have been reviewed in the light of user feedback and NII Audit recommendations, and a revision was issued in March 2000. The previous procedure required that change proposals were assessed, validated, had implementation plans and were periodically reviewed and monitored. The procedures also involved a degree of third party assessment, depending on the significance of the potential impact on nuclear safety. These principles have been retained and strengthened in the revision.

The purpose of the procedure is to set out the procedures and controls for managing change such that all changes are properly considered, justified and auditable. Its scope covers changes to organizational: structures; resources; responsibilities, or loss of corporate knowledge. Responsibilities are defined for change Proposers, Assessors, and Approvers, and for the Head of Quality.

A process flow chart is provided which includes:

- Early judgement of the significance of the potential nuclear safety impact of the proposed change, and hence its grading (see below);
- For the most significant changes, early approval to a 'paper of principle' by a sub-committee of the Company Board (the Management of Change Board);
- Appropriate assessment and approval of the proposed change prior to implementation;
- Review of the effectiveness of the change and its controls, during and after implementation.

Grading for changes relevant to nuclear safety

Grade A. A change to organizational structure or resources which, if inadequately conceived or executed, may seriously reduce the capability of the organization to maintain safe operation and compliance with the Site License.

Grade B. A change to organizational structure or resources which, if inadequately conceived or executed, may lead to a significant but not serious reduction in the capability of the organization to maintain safe operation and compliance with the Site License.

Grade C. All changes within the scope of this document for which a change proposal is judged necessary to demonstrate that it has no significant impact on nuclear safety.

All other low level changes do not require justification under this procedure as they are considered to be normal business.

Assessment and approval routes for changes relevant to nuclear safety

Nuclear Safety Critical Area	**Grade**	**Assessor**	**Approver**
Maintenance of safe operation or compliance with the site license	A	Director, Health Safety and Environment.	Line Director and Executive Director Operations (after Management of Change Board consideration and advice)
	B	Director, Health Safety and Environment or his/her nominee	Line Director or Head of Function
	C	Not applicable	Line Manager

The document has a number of Appendices providing additional guidance and requirements, including:

- Proposals and validation statements to describe activities to be completed prior to change (enablers), the risks to nuclear safety, and countermeasures available to be deployed if needed.
- Implementation plans to include adequate review points and performance measures, such that changes are implemented only if enablers have been delivered and nuclear safety has been adequately addressed.
- Specific nuclear safety requirements (criteria) to be met by the change and considered in the risk assessment.
- Specific process requirements for changes involving staff release with loss of nuclear safety related posts or key skills.

ANNEX 9

DECISION MAKING PROCESS, ATOMIC ENERGY OF CANADA, LTD (AECL)

Summary:

AECL, a nuclear vendor company, is an engineering-design-project management type organization, which markets and supplies pressurized heavy water reactors (PHWRs) on a worldwide scale. As such, it deals with complex engineering, commercial, safety, construction and project management related issues that need to be addressed and resolved in an efficient, responsible and timely manner. This example contains the description of AECL's internal Decision Making Process, applied in phases of design, construction, configuration management, proposal preparation, or project implementation.

Detailed Description:

Once a specific change, modification, or requirement is identified, it gets documented in a Change Request form. This document provides a systemic checklist of impact on design, material or equipment supply, and construction activities. A structured process defines its preparation and sign-off format, on the basis of which the document package is submitted to the next level of approval process, as follows:

- The Change Control Board is the first level decision making body, consisting of representatives from design, QA, Chief Engineer's (including Safety) office, and Cost Engineering. On a regular basis, the Board reviews and seeks consensus on the submitted case from aspects of design requirements, necessity, safety and economic considerations. Pending the outcome, and the need for higher-level approval, the case is then forwarded to the next level.

- The Executive Committee, consisting of Vice President level representatives (Finance, Commercial operations, Research & Product Development, Marketing & Sales, Strategic Planning, Administration), reviews the suggested recommendation from the Change Control Board, and (in a positive case) requests a preparation of a more formal document, the Request for Authorization. This document carries a Risk Assessment appendix, defining the risks or opportunities associated with the task on hand. The complete package is submitted for review and approval.

- The company's Board of Directors reviews the previous assessment and makes a decision, based on the request for authorization process results.

The overall process is efficient, and usually completed within a month. All aspect of risk impact, as well as opportunities, are identified, reviewed and considered. The individual cases presented must be of a nature justifying the purpose, otherwise they are dealt with on lower management levels.

Impact:

This activity normally covers issues impacting safety, operational nature, commercial or other external issues, design aspects.

Lessons Learned with respect to risk management:

The requirement of the Decision Making Process necessitates that each Request for Authorization submission carries a specific Risk Assessment appendix, which identifies all known risks and opportunities, on quantitative and qualitative level. Most of the management decisions are related to, or affected by, the risk identified issues. The process is efficient, and ensures that all facets of the organization are aware of potential impact of the change.

ANNEX 10

ENVIRONMENTAL, SOCIAL AND ECONOMIC IMPACTS/RISKS — FORTUM, FINLAND

Fortum, is a major Nordic energy company, providing electricity, heat and fuels. It is the operator of the Loviisa Nuclear Power Plant, a relatively small part of its overall portfolio. It publishes an annual report entitled, Fortum in Society, A Report on Fortum as a Corporate Citizen. The information in this annex is taken from its most recent (1999) report. In this report, Fortum has committed to take environmental, social and economic impacts into account in all of its operations, and has outlined three aims that it needs in order to have the trust of customers, employees and society:

- to be a forerunner in safety and environmental competitiveness in our different markets
- to offer superior products and services which are safe and environmentally preferred over their life cycle
- to act responsibly in society and in use of natural resources.

Among the mechanisms identified to achieve these aims are the use of risk management tools to assess the environmental, health and safety aspects of all projects. Essential measures include systematic identification of risk, applying the best practices in risk management and continuous comparison with international high performing companies. Fortum has integrated environmental, health and safety (EHS) issues into its business strategy to the extent that it views this as a competitive advantage through reducing the commercial and financial risks related to environmental, safety and health impacts.

A six-member Board of Directors is responsible for managing Fortum. Large scale investment projects are discussed by an Investment Committee which ensure that the projects meet economic, environmental and social requirements (e.g., that risks in all these areas are properly identified and managed). Integration of EHS issues into management also means that in order to monitor progress and carry out corrective measures, the various business units must have clear goals and indicators. A summary report on occupational injuries, accidental spills, fires and other accidents is drawn up quarterly and discussed in the meetings of the Corporate Executive Committee. Fortum also reports annually in the Fortum in Society report and on its website regarding progress made in implementing its EHS programme.

Fortum operates in business sectors that involve risks of increasing environmental expenditures and liabilities, thus it continuously assesses the environmental impacts of its operations. From this assessment environmental liabilities are determined and the appropriate provisions for future environmental remediation costs are determined in accordance with good accounting practice. The liabilities and provisions section of Fortums report discusses the details of these provisions including the extent and limitations of its insurance against unexpected environmental damages.

The complete report, Fortum in Society 1999, A Report on Fortum as a Corporate Citizen, is available at the following internet address: www.fortum.com.

REFERENCES

[1] "Government Strategy Seeks Independence, Low Emission", Business Korea (1999).

[2] "Achieving an Effective Living Maintenance Process: A Handbook to Optimize the Process and Keep It That Way", EPRI Report TR-108774 (1997).

[3] BERG, H.P., "Approach for Risk-Based Regulation and Risk Management of Nuclear Power", The 1996 Annual Meeting of the Society for Risk Analysis—Europe.

[4] "Survey on the Use of Configuration Risk and Safety Management Tools at Nuclear Power Plants", EPRI Report TR-102975 (1998).

[5] FOURCADE, F., JOHNSON, E., BARA, M., CORTEY-DUMONT, P., "Optimizing Nuclear Power Plant Refueling with Mixed-integer Programming", European Journal of Operational Research (1997).

[6] "Development of Shutdown Probabilistic Safety Analysis (PSA)/Shutdown Equipment Out of Service (EOOS) for River Bend Station", EPRI Report TR-113084 (1999).

[7] "An Approach for Plant-Specific, Risk-Informed Decision Making: Inservice Inspection of Piping", US Nuclear Regulatory Commission Regulatory Guide 1.178 (1998).

[8] ZINK, J.C., "Competition Dictates Maintenance Decisions", Power Engineering (1998). (a)

[9] "Inventory Optimization in Support of the EPRI Work Control Process Module", EPRI Report TR-109648 (1998).

[10] "Revised Reactor Oversight Process", United States Nuclear Regulatory Commission, (1999). http://www.nrc.gov/NRR/OVERSIGHT/index.html Downloaded December 1999.

[11] "An Approach for Plant-Specific, Risk-Informed Decision Making: Technical Specifications (TS)", US Nuclear Regulatory Commission Regulatory Guide 1.177 (1998).

[12] "Adjusting to Mother Nature", Mechanical Engineering (1999).

[13] JORION, P., Value at Risk: The New Benchmark for Controlling Derivatives Risk, McGraw Hill (1997).

[14] BENGTSON, C.S., "Value at Risk Calculation for a Major U.S. Utility Company", Personal Interview with GASPER, J.-A. (2000).

[15] RiskSpectrum® PSA. http://www.relcon.se/default.htm Downloaded January 2000.

[16] SCHIMMOLLER, B.K., "Plant Equipment Adapts to Changing Market", Power Engineering (1999). (a)

[17] "Inspection and Repair Database", Power Engineering (1999).

[18] GARWATOSKI, F., "How to Cut Rewind Times by 15 Days or More", Modern Power Systems (1999).

[19] "EPRI ORAM-SENTINEL™ Code – All Modes Maintenance and Safety Function Advisor", Version 3.3, Software AP-112894 Version 3.3, EPRI (1999).

[20] CHAMBERS, A., "TVA Boosts Efficiency at Nuclear Sites", Power Engineering (1999).

[21] ZINK, J.C., "Find the Competitive Edge with Maintenance", Power Engineering (1997). (b)

[22] Cimage Information Solutions for Industry, http://www.cimage.com Downloaded January 2000.

[23] ZINK, J.C., "Information and Control Merge in New Environment", Power Engineering (1999). (c)

[24] PLANTFORMA, http://www.erineng.com/plantforma.html, downloaded June 2000.

[25] "Work Management Process Benchmarking Report", Nuclear Energy Institute (1997).

[26] "Integration of Probabilistic Risk Assessment in Operations Training Programs at Monticello Nuclear Generating Plant", The Nuclear Exchange NX-1003 (1997).

[27] "Risk Informed Performance Based Fire Protection at Nuclear Power Plants", EPRI Report TR-108799 (1997).
[28] "An Approach to Risk-Informed Changes to Physical Security", EPRI Report TR-113787 (1999).
[29] RODE, D.M., ANDERSON, F.C., "Avoid piping pitfalls", Power Engineering (1997).
[30] BANHAM, R., "Two for the Money", Journal of Accountancy (1999). (a)
[31] BANHAM, R., "Double Whammy", Treasury & Risk Management Magazine (1999). (b)
[32] BANHAM, R., "They're Singin' in the Rain", CFO Magazine (1999). (c)
[33] AMRAM, M., KULATILAKA, N., Real Options (1998).
[34] "A Risk-Informed Flaw Tolerance Approach for Increasing ASME Section XI, Annex G PT Limits", EPRI Report TR-107451 (1997).
[35] "An Approach for Plant-Specific, Risk-Informed Decision Making: Graded Quality Assurance", US Nuclear Regulatory Commission Regulatory Guide 1.176, 1.174.
[36] "Guidelines for Preparing Risk-Informed Graded Quality Assurance Program Implementation Request Submittals", EPRI Report TR-109646 (1998).
[37] "Quality Assurance Grading Criteria for Plant Systems and Components: Results from a Pilot Plant Project at Grand Gulf Nuclear Station", EPRI Report TR-105868 (1995).
[38] ZINK, J.C., "Open Systems Revolutionize Plant Automation", Power Engineering (1998). (d)
[39] "Calvert Cliffs Nuclear Power Plant Life Cycle Management/License Renewal Program: Nuclear Plant Asset Management Case Study", EPRI Report TR-104615 (1995).
[40] "Nuclear Plant Life Cycle Management Implementation Guide", EPRI Report TR-106109 (1998).
[41] "OM Technology Announces Online Power Risk Management Solution" (1999). http://www.omtechnology.com, downloaded December 1999.
[42] "Optimizing Asset Value (OAV) – A Decision Tool" (2000). http://www.tenera.com/risk/ serv-rmm.htm, downloaded January 2000.
[43] MAIDMENT, J., ROTHWELL, G., "All Nuclear Power Plants are not Created Equal", Public Utilities Fortnightly (1998).
[44] FOX, M.R., "Nuke Plant Staffing: How Low Can You Go?", Public Utilities Fortnightly (1999).
[45] POOL, R., "When Failure is Not an Option", Technology Review (1997).
[46] TULER, S., MACHLIS, G.E., KASPERSON, R.E., "Mountain Goat Removal in Olympic National Park: A Case Study of the Role of Organizational Culture in Individual Risk Decisions and Behavior", National Park Service Northwest Region CA-9000-8-E005. Risk (1992).
[47] "Perceived Nuclear Risk, Organizational Commitment, and Appraisals of Management: A Study of Nuclear Power Plant Personnel", Risk Analysis (1995).
[48] SIMONS, R., "How Risky is your Company?" Harvard Business Review (1999).
[49] SCHIMMOLLER, B.K., "Capitalizing on the Renewed U.S. Power Generation Market", Power Engineering (1999). (b)
[50] GARVEY, M.J., "Energy Suppliers and Customers Get Wired", Information Week Online (1999).
[51] ROTHWELL, G., "Electricity Deregulation Risky", Engineering News-Record (1997).
[52] DONDE, S., FOX, B., "Risk Management Savvy Vital Under Deregulation", Power Engineering (1999).
[53] "Nuclear Know-how Becomes Exportable", Business Korea (1998).
[54] HULL, J.C., Options, Futures, & Other Derivatives (2000).

CONTRIBUTORS TO DRAFTING AND REVIEW

De Castro Silva, L.E.M.	Electronuclear, Brazil
Gasper, J.-A.	Creighton University, United States of America
Gasper, J. K.	Omaha Public Power District, United States of America
Gessler, A.	Kernkraftwerke Gundremminen, Germany
Gomez-Cobo, A.	International Atomic Energy Agency
Labroille, S.	Technicatome, France
Langlois, L.	International Atomic Energy Agency
Lawrence, G.	British Energy, United Kingdom
Mazour, T.	International Atomic Energy Agency
Nettleship, D.	British Energy, United Kingdom
Pakan, M.	AECL, Canada
Na, J.-H.	KEPRI, Republic of Korea
Surendar, Ch.	Nuclear Power Corporation, India

Advisory Group Meeting
Vienna, Austria, 10—13 April 2000

Consultants Meeting
Vienna, Austria, 4—7 July 2000

RELATED IAEA PUBLICATIONS ON RISK MANAGEMENT

Application and Development of Probabilistic Safety Assessment (PSA) for Nuclear Power Plant Operations, IAEA-TECDOC-873 (1996).

Living Probabilistic Safety Assessment (PSA) IAEA-TECDOC-1106 (1999).

Advances in Safety Related Maintenance, IAEA-TECDOC-1138 (2000).

Applications of Probabilistic Safety Assessment (PSA) for Nuclear Power Plants, IAEA-TECDOC-1200 (2001).