STEAM GENERATOR ASSET MANAGEMENT: INTEGRATING TECHNOLOGY AND ASSET MANAGEMENT

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1.0 Introduction

Asset Management is an established but often misunderstood discipline that is gaining momentum within the nuclear generation industry. The global impetus behind the movement toward asset management is sustainability. However regional drivers are somewhat varied to include competition, privatization, regulation, workforce management, equipment replacement, equipment obsolescence, and new nuclear generation development.

The discipline of asset management is based upon three fundamental aspects: key performance indicators (KPI), activity-based cost accounting, and cost benefits/risk analysis. The technology associated with these three aspects is fairly well-developed in all but the most critical area; cost benefits/risk analysis. There are software programs that calculate, trend, and display key-performance indicators to ensure high-level visibility. Activity-based costing is a little more difficult, requiring a consensus on the definition of what comprises an activity and then adjusting cost accounting systems to track. In the United States, the Nuclear Energy Institute launched a Nuclear Asset Management task force several years ago for the purpose of developing a Standard Nuclear Process Model (SNPM) to serve as the basis for activity-based costing. Additionally, several utilities participated in the project, resulting in the development of an industry baseline collected by the Electric Utility Costing Group. As a result, the software industry has quickly adapted to develop tracking systems that include the SNPM structure.

Both the KPI's and the activity-based cost accounting feed the cost benefits/risk analysis to allow for continuous improvement and task optimization; the goal of asset management. In the case where the benefits and risks are clearly understood and defined, there has been much progress in applying technology for continuous improvement. This is especially true in the electrical transmission and distribution industry, where asset management practices have improved grid reliability while considerably lowering life-cycle costs. Within the nuclear generation industry, more specialized and unique software systems have been developed for active components, such as pumps and motors. Active components lend themselves well to the application of asset management techniques because failure rates can be established, which serves as the basis to quantify risk in the cost-benefits/risk analysis. To date, these systems and/or the enabling sensor technology are not fully developed, but the technological hurdles are understood and can quickly keep pace with the market demand.

A key issue with respect to asset management technologies is only now being understood and addressed, that is how to manage passive components. Passive components, such as nuclear steam generators, reactor vessels, and nuclear fuel, are the most costly components within a nuclear steam supply system, yet they do not lend themselves well to asset management practices. However, application of asset management principles to these components represents the largest potential return for asset management within nuclear generation and sustaining continued plant operation to include life extensions. Recognizing this critical gap, AREVA NP launched a Steam Generator Asset Management Program (SG AMP) to develop advanced technologies for the management of nuclear steam generators. These technologies include advanced mitigation techniques, to include non-invasive techniques, new inspection techniques, predictive modeling and expert systems aimed at minimizing and managing steam generator corrosion and risks.

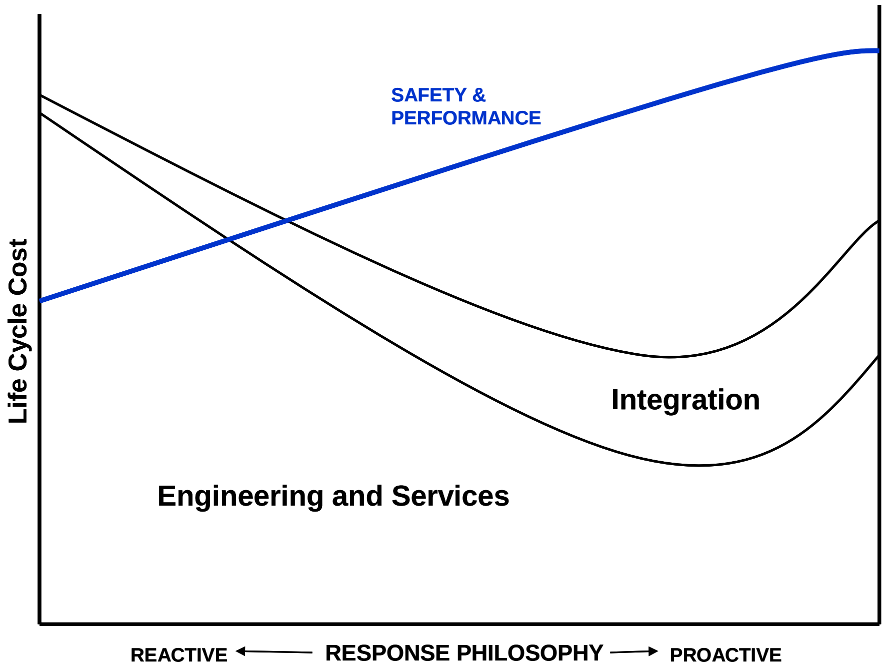
2.0 Challenges of Asset Management

Fundamentally asset management is the practice of managing physical assets in an optimal manner so as to achieve the desired results. This basic definition is reflected in the INPO Equipment Reliability Process (API-913), definition of life-cycle management as follows:

". . . the integration of aging management and economic planning to optimize the operation, maintenance, and service life of SSC's (Systems, Structures, and Components); maintain an acceptable level of performance and safety, and maximize return of investment over the service life of the plant."

To simplify, asset management is the balance of safety and performance while optimizing the return on investment. Figure 1 illustrates the key objective of asset management in the optimization of the total life-cycle costs associated with effective asset management.

Figure 1: AREVA Asset Management



The challenge is the ability to optimize the returns, while ensuring both safety and performance. The classic approach to asset management, regardless of industry, has three fundamental concepts:

Activity-Based Costing
Key Performance Indicators
Cost Benefit/Risk Analysis

Activity-based costing allows for a true accounting of all the costs associated with the management of the asset and is the foundation of the Nuclear Asset Management Community of Practice's (NAMCop) Standard Nuclear Performance Model. Key performance indicators provide metrics upon which to monitor the overall progress to plan and to support continuous improvement. The SNPM is an extremely valuable tool, which not only supports the fundamental concepts of asset management, but which provides a level of standardization that supports benchmarking against industry data and the cost benefit/risk analysis requirement of asset management. To be sure, the industry has a great opportunity to improve by the application of both activity-based costing and KPI's. The groundwork has been laid and it is a matter of applying the solution. This is not so in the area of cost benefits/risk analysis.

Cost benefit/risk analysis has two basic components: comprehension of the life-cycle cost and quantification of the risk. The industry has a good handle on the cost benefits aspect, both through the application of the SNPM and/or through site-specific standard cost benefits (e.g. the cost/manrem). However in the area of risk analysis, the required inputs are the meantime between failure (MTBF) for a particular component and/or system and the effectiveness of the mitigation technique. MTBF allows for a fairly accurate determination of the risk of failure, which can then be applied to the cost of failure to support the performance of the cost benefits analysis. The effectiveness of the mitigation technique is generally assumed to be near 100% and, as such, is not typically even recognized as an input.

For active components, such as pumps, valves, and motors the data is reasonably available (or can be reasonably interpolated from similar components) so as to allow for an effective cost benefit/risk analysis. Furthermore, sensor technology and solutions are available that can greatly enhance the ability to manage these assets should the utility invest in these technologies. Therefore, the current tools for asset management are well within reach for active components, yet the same statement is not true for passive components.

Passive components, such as the reactor vessel, nuclear fuel, and steam generators (for PWR's), do not lend themselves well to asset management principles. However, they represent the most expensive components within the nuclear steam supply system. Therefore the successful application of asset management principles will bring about the greatest benefit. Furthermore, it has been erroneously assumed that regulatory requirements are, in effect, asset management programs for these components. This assumption is only partially valid in that regulatory requirements are to ensure public safety but do not require specific levels of performance nor do they require the optimal return on investment. Therefore the challenge to the industry is to be able to apply asset management principles to large components. Specifically to:

- Quantify the risk
- Optimize the Life-Cycle Plan
- Develop Meaningful Metrics

Large, passive components do not lend themselves well to cost benefits/risk analysis as the risk is very difficult to quantify. For example, what is the risk of not water lancing the steam generators during the next outage? Can it be quantified? The answer lies in understanding the damage mechanisms, which are primarily corrosion related and which requires specific expertise in the areas of materials and water chemistry. Furthermore, because of varied plant design, materials selection, operating cycle performance, and plant chemistry regimes the nature and severity of the damage mechanism are somewhat plant specific, further complicating the ability to quantify the risk. Therefore, what is required is a combination of materials/chemistry research to better understand damage mechanisms, an understanding of the life-cycle process for the component, and data collection/mining to support benchmarking. In short, expertise and technology needs to be developed so as to better quantify the risks associated with passive components so as to provide the scientific basis behind the life-cycle planning.

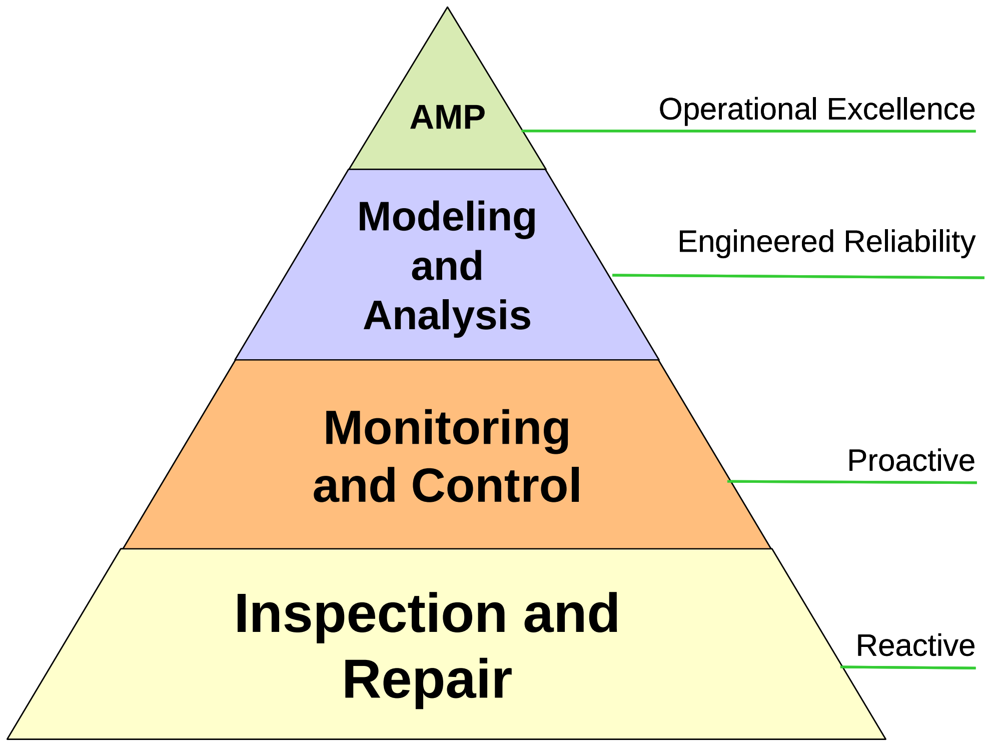
Unlike active components, mitigation techniques have limited effectiveness and do not restore a passive component to at or near its original condition. Therefore, the effectiveness of the mitigation techniques needs to be quantified so as to optimize the life-cycle plan. Understanding this effectiveness will have two benefits: to ensure the most effective maintenance regime, and to provide a basis for continuous improvement to enhance the effectiveness of the maintenance regime. The efficiency of a particular mitigation technique will allow asset managers to provide a high quality life-cycle plan at the optimal cost, by scheduling the required maintenance within the life cycle so as to achieve the desired results. Without understanding the efficiency, the result is a shot in the dark. Secondly, to further optimize life-cycle planning the mitigation technique has to be as effective as reasonably possible so as to minimize the cost of mitigation and/or return the asset closer to its original condition.

Quality metrics will not only ensure performance to plan, but will be able to provide foresight (e.g. leading metrics) so as to optimize the maintenance regime. While there are many metrics that serve the industry well, such as availability, capacity factor, INPO ratings, etc, they don't provide a good long-term, asset management focus. For example, new materials in replacement steam generators will ensure, with compliance to manufacture's specifications, the component design life with respect to corrosion. However, what metrics ensure optimal performance with respect to loose parts damage and steam generator fouling? What is required are metrics that can help predict long-term performance, so as to support proactive maintenance planning. The metrics of the past, regulated business environment, will need to be adjusted to respond to a more competitive market place and to support sustainable operation.

3.0 Advanced Technology for Today's Challenges

Quite simply, if the industry wants different results for the next thirty years of operation, they will need different materials, tools, and technology. While replacement components included advancements, particularly in the area of materials, there have been few advancements to support proactive asset management of large components in the nuclear island. In the past, the focus was on regulatory compliance and reacting to aggressive degradation mechanisms. Today these issues remain, but are complicated by the need for profitability, a retiring workforce, and equipment that is near the end-of-life. These dynamics necessitate a new paradigm. However to achieve any goal, it is necessary to understand the past so as to manage the future. The Asset Management Pyramid, Figure 2, answers that basic question.

Figure 2: Asset Management Pyramid



Inspection and Repair

Management of large components, up to now, has been primarily a reactive approach, mostly by necessity. As the industry matured, many issues, both programmatic and technical emerged. As a result, the industry found itself reacting to the many new regulations and technical issues by addressing the symptoms as shown in the Inspection and Repair area of the Pyramid. For large components, this has meant long and costly outages. Competition has forever changed the playing field. The drive for profitability meant that operators could no longer afford the cost of extended outages or increased scope. Therefore, the emphasis shifted to outage optimization resulting in significant reduction in outage duration. This focus led to the development, largely by the vendors, of advanced inspection and repair technologies, resulting in shorter outages, lower dose rates, and increased profitability.

Monitoring and Control

As the industry managed technical issues and regulations better, an opportunity to more proactively address the management of its assets emerged. Rather than merely perform Inspection and Repair, the industry turned to Monitoring and Control to reduce the need for repairs. A better understanding of chemistry control and implementation of Foreign Materials Exclusion (FME) programs have greatly reduced the impact of damage mechanisms in steam generators. While much has been accomplished in this area, there are plenty more opportunities for improvement.

Engineered Reliability

Component replacements, through the selection of more corrosion resistant materials and new features, provide the opportunity to engineer reliability into the new component. However, once the new component is installed, a new focus for engineered reliability is required; that is in the Modeling and Analysis area of the Pyramid. The effort expended in the development of advanced, sophisticated inspection and repair technologies to optimize outages has to be applied to Modeling and Analysis. The best approach is to manage the cycle of Inspection and Repair to further reduce outage duration, cost, and dose while adding value. For example, more utilities are increasing steam generator inspection cycles (within the allowed regulatory limits with respect to materials of construction) due to the positive effect on profitability. However, what is being done to ensure that these longer inspection cycles can be maintained in the future? How many primary-to-secondary leaks are going to be tolerated due to loose parts on a generator that has skipped an outage? What is the impact of unplanned outages or increased scope of an outage based on emergent issues?

Operational Excellence

Technology alone does not ensure long-term asset management. A team effort in which everyone’s goals and measurements are integrated ensures operational excellence. Not only will the benefits of the base of the Pyramid be realized, continuous performance improvements will result from the team’s performance. This is the area where the traditional asset management techniques, of KPI, activity-based costing, and cost benefit/risk analysis will pay dividends, but only with the strong foundation of the Asset Management Pyramid.

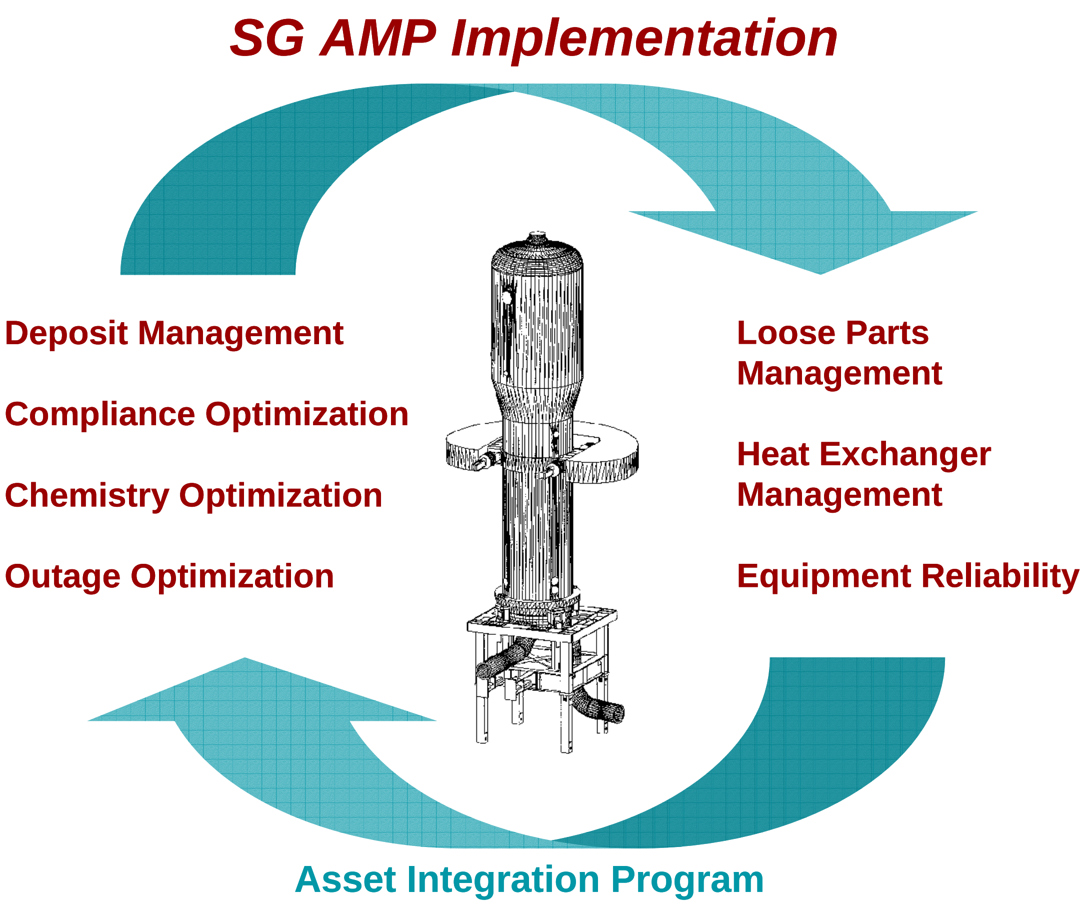
While the technology associated with the Inspection and Repair area of the Pyramid is well-developed and advanced, the technology associated with the Monitoring and Control area and the Modeling and Analysis area needs to be more fully developed. This advanced technology has to provide the scientific **basis** behind high-quality life-cycle planning, increase the **effectiveness** of the mitigation techniques to improve return on investment, and to develop meaningful and predictive **metrics** to measure performance to plan and ensure optimal maintenance regimes. The combination of these technologies fully supports the Asset Management Pyramid in laying the foundation for operational excellence.

3.1 Technological Basis

Steam generator asset management is not a simple task. Multiple sources of information, scientific and engineering disciplines, and experience must be analyzed to adequately understand steam generator performance. Tube integrity, that is tube damage, is relatively easy to measure and quantify the risks associated with that damage. Driven by regulation, the assessments and corrective actions required are very prescriptive. However, what about secondary side cleanliness? What is an acceptable level of fouling? What is the risk of delaying or not performing a particular maintenance activity, such as top-of-tubesheet water lancing? These are the types of questions today's steam generator asset manager must answer in order to optimize the maintenance regime in response to competitive and/or cost control pressures. However, the answers do not come easy and are the focus of a new area of research that supports effective asset management.

Steam generator management is often the result of compromise among many competing goals and objectives. Optimization of the management protocol requires the integration of all available relevant information and experience with the appropriate weighting or significance. Among some of the most important information sources are the total plant design, plant operating performance, chemistry analysis of the environment (sludge chemistry, corrosion product transport (CPT), correlation with degradation), the materials science of the generator components, tube degradation mechanisms, eddy current assessment of the degradation and deposit condition, related past experience, operating performance and the context of the regulatory and economic environment. The challenge is to understand and manage this large, diverse, yet interrelated information and phenomenon. Therefore, to separate the sources of information into manageable groups, we have established seven separate initiatives: Regulatory Compliance Optimization, Chemistry Programs Optimization, Deposit Management, Heat Exchanger Management, Foreign Object Management, Equipment Reliability Programs and Outage Optimization. These individual initiatives will be combined with software that utilizes data input from all the available relevant plant information and experience to support the analysis of the changing parameters for effective life-cycle management. The Asset Integration Program will support both short and long-term predications in the optimization process for each initiative. Integrating the seven initiative programs together forms our overall Asset Integration Program, Figure 3, that allows for computer executed evaluations that make comprehensive predictions on recommended optimized inspection, maintenance and remediation activities to support long range budget planning and outage activity scheduling. An additional benefit of the Asset Integration Program is that it is a dynamic package that can be easily utilized for changes in any of the seven initiatives (plant excursions, emergent issues, equipment failures or changing outage schedules) to identify resultant impacts and revise/optimize the future long-term predictions.

Figure 3: Asset Integration Program



Narrowing down on one initiative, Deposit Management shows the benefits of this approach. The Deposit Management initiative's primary objective is to determine what is the required life-cycle maintenance so as to best manage the secondary side deposits over the remaining life of the asset consistent with station goals. One strategy is to avoid a chemical cleaning during the life of the steam generator and adopt an aggressive campaign of mechanical cleaning using water lancing, hard deposit lancing, and upper bundle flushes. Another strategy is to perform as little secondary side maintenance as possible and opt for a chemical cleaning, or several, over the life of the plant. Which strategy is correct? It has been largely a matter of station culture and opinion. The Asset Integration Program, Deposit Management initiative, seeks to answer this question with facts. Facts with respect to the risks of tube damage due to sludge composition and hard deposit formation, the risk of steam generator outlet pressure loss and resultant thermal performance reduction, and the schedule, dose, and cost impact of a particular maintenance strategy. Developing and running multiple scenarios and tuning the preferred scenario is a complex, costly, and time consuming endeavor that rarely is performed past two to three outages much less through the end of plant life. The Asset Integration Program's overall objective is to incorporate Information Technologies (IT) to assist the steam generator asset manager in establishing the technological basis and the optimal maintenance regime to support the goal of asset management: the balancing of safety and performance at the maximum return-on-investment.

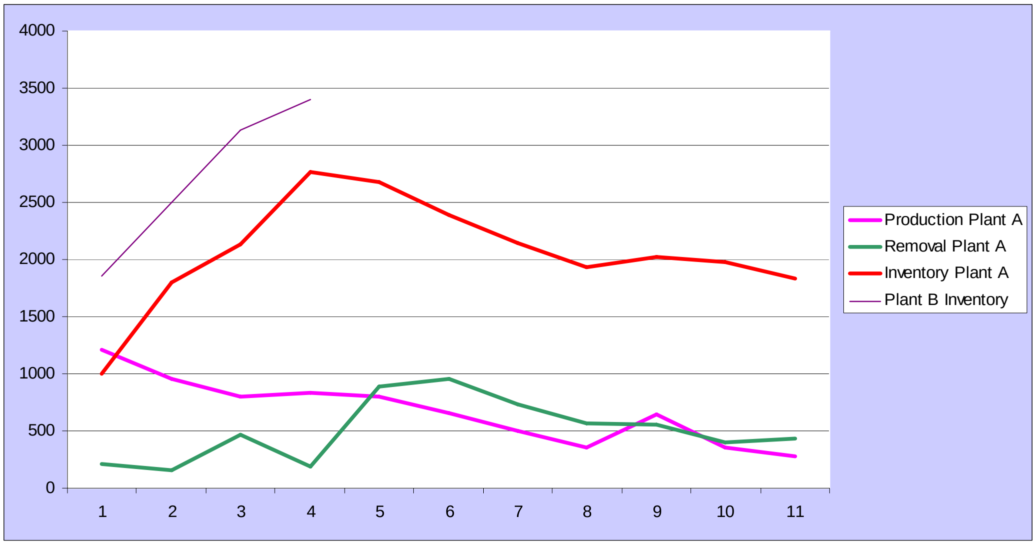
3.2 Technological Effectiveness

The process of cost-optimizing SG operation and maintenance activities is the essence of SG AMP. Technology comes into play through the continuous improvement of existing technology and the development of new technology - tools for the toolbox - and through the asset management decision making process. An under appreciated reality is that the replacement of steam generators with more corrosive resistant materials will result less frequent inspection intervals, which equates to less frequent maintenance. Furthermore, as utilities drive to shorten their outage windows, the types of maintenance activities will be severely constrained. As a result the asset manager will be challenged to ensure the most effective maintenance techniques and/ or combination of these techniques will have to be deployed.

Examples of new and improved technology include the development of a high pressure inner bundle lance for the removal of residual sludge collars, and the use of chemical enhancements to the field proven Upper Bundle Flush process to maintain steam generator outlet pressure. Application of this technology early in the life cycle of the new component eliminates the potential for corrosive material build up that historically has contributed to tube degradation. This point cannot be overstressed – *the application of proven mitigation technology as early in the life-cycle as possible will have a dramatic effect on the optimization of the overall return on investment*. A recent, real-world example illustrates the benefits of this approach.

Plant B, SG Engineering personnel, made a request for AREVA NP's recommendation concerning water lancing for their next outage. In addressing this issue, AREVA NP benchmarked Plant B's deposit management performance to a similar plant design with a successful deposit management track record. This benchmarking is summarized in Figure 4, Plant Benchmarking Comparison.

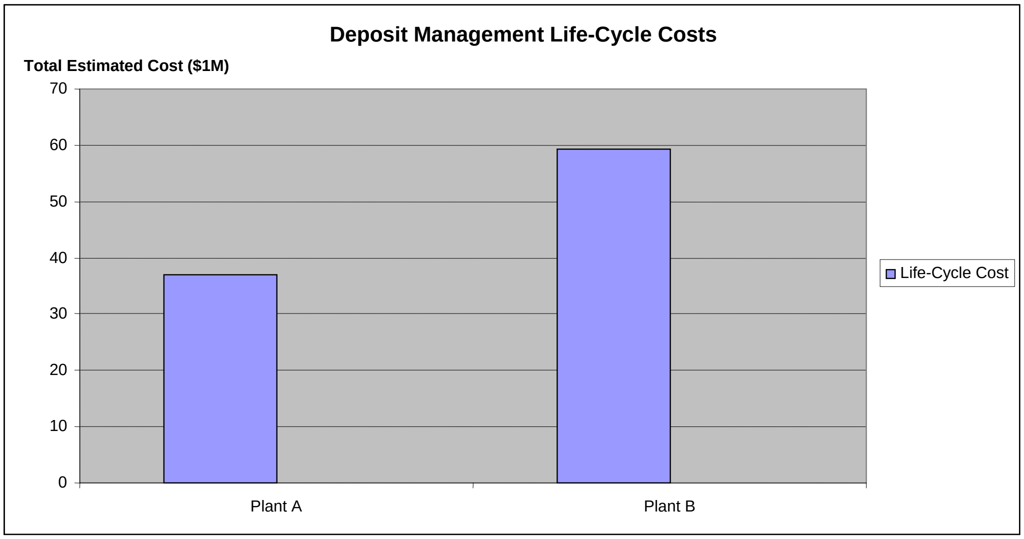
Figure 4: Plant Benchmarking Comparison



Plant A, at the end 11-cycles of operation, had accumulated a total deposit inventory of less than one-third that of Plant B in four cycles. This was accomplished through aggressive management of iron transport and incorporation of (then) new maintenance technique (Upper Bundle Flush).

AREVA NP further evaluated the total life-cycle cost for both plants with respect to their respective steam generator maintenance plans. In the case of Plant B, the life-cycle costs are significantly higher than Plant A, as shown in Figure 5 - Deposit Management Life-Cycle Costs. This is primarily due to the inescapable conclusion that Plant B will have to perform multiple chemical cleanings over the life of the generators in order to avoid steam generator pressure loss and a reduction in thermal performance, Despite the fact that Plant B’s stated strategy was to avoid chemical cleanings altogether!

Figure 5: Deposit Management Life-Cycle Costs



The significance of this analysis is that if Plant B had **timely** instituted an aggressive deposit removal regime, using AREVA NP's Upper Bundle Flush technology, their optimal life-cycle cost would be on par with Plant A's life-cycle cost. This is without managing a difficult iron transport issue!

The real story of this analysis is that Plant A was an early adopter of AREVA NP's Upper Bundle Flush technique in the early 1990's, whereas Plant B began seriously evaluating the use of the UBF technology for the first time for deployment in 2005! The point being, regardless of the service vendor, the asset manager has to aggressively evaluate new (and existing) technology for incorporation into the life-cycle plan as early as possible. This is not without risk; primarily commercial risks as the technical risks are well-evaluated, but it is a risk worth considering.

3.3. Advanced Metrics

Metrics and their continued monitoring is an essential element for the success of any dynamic program. The metrics provide a feedback loop that trends performance and supports decision making for program optimization. Additionally, forward looking metrics can predict future performance allowing for adjustment of the life-cycle plan to take the appropriate corrective action and optimizing the response.

One example of the SG AMP metrics is in the case of the Deposit Management initiative where technology is being coupled with existing historical information, operating performance information and inspection information to establish a metrics program; "Deposit Mapping". The Deposit Mapping program currently uses bobbin coil Eddy

Current Testing (ECT) data to extract deposit information within the SG Secondary Side. This is a very valuable tool in SG AMP by helping understand the deposition rate and spatial distribution of deposit within the SG Secondary Side. By integrating this with the CPT information and established thermal hydraulic models, we can better understand the effect of this deposit information on SG efficiency, on planning corrective maintenance actions such as upper bundle flush, and in evaluating the effectiveness of such maintenance actions. The Deposit Mapping initiative provides a non-invasive technique to establish a metrics in deposit formation and removal techniques that were previously obtained through invasive techniques such as SG Secondary Side tele-visual inspections. These tele-visual inspections require additional time to execute within the outage schedule, contributes to additional radiation exposure and additional maintenance costs. Through a better understanding and quantification of the value of this technique, one could better determine the value of future development work or improvements in the technique.

The Deposit Mapping program utilizes an automated analysis program and calibration standard that accurately simulates the steam generator secondary side deposits through a range of different thickness, Figure 6. This calibration standard is coupled with the routine ECT program to obtain thickness measurement data over the length of the tube inspection area in conjunction with the standard inspection technique. The obtained Deposit Mapping data is analyzed automatically by the Deposit Mapping software to provide accurate thickness measurements, deposit volume calculations and location of deposits within the steam generator secondary side, Table 1. This Deposit Mapping software data output was validated through testing, use at multiple steam generators locations and by comparison between different ECT probes. The results all provided high accuracy and repeatability of the measurements with a maximum thickness error of 0.127 mm and thickness error standard deviation of 0.0254 mm. The Deposit Mapping program has been applied to inspection data obtained from prior operating cycles to initiate actual historical trending of the deposit build up as a metric to deposit formation rate to support long-term mitigation technique application planning. The Deposit Mapping program provides an extremely valuable metric tool to the asset manager by providing a non-intrusive technique to support life-cycle planning decisions

Figure 6: Automated Calibration Analysis Setup

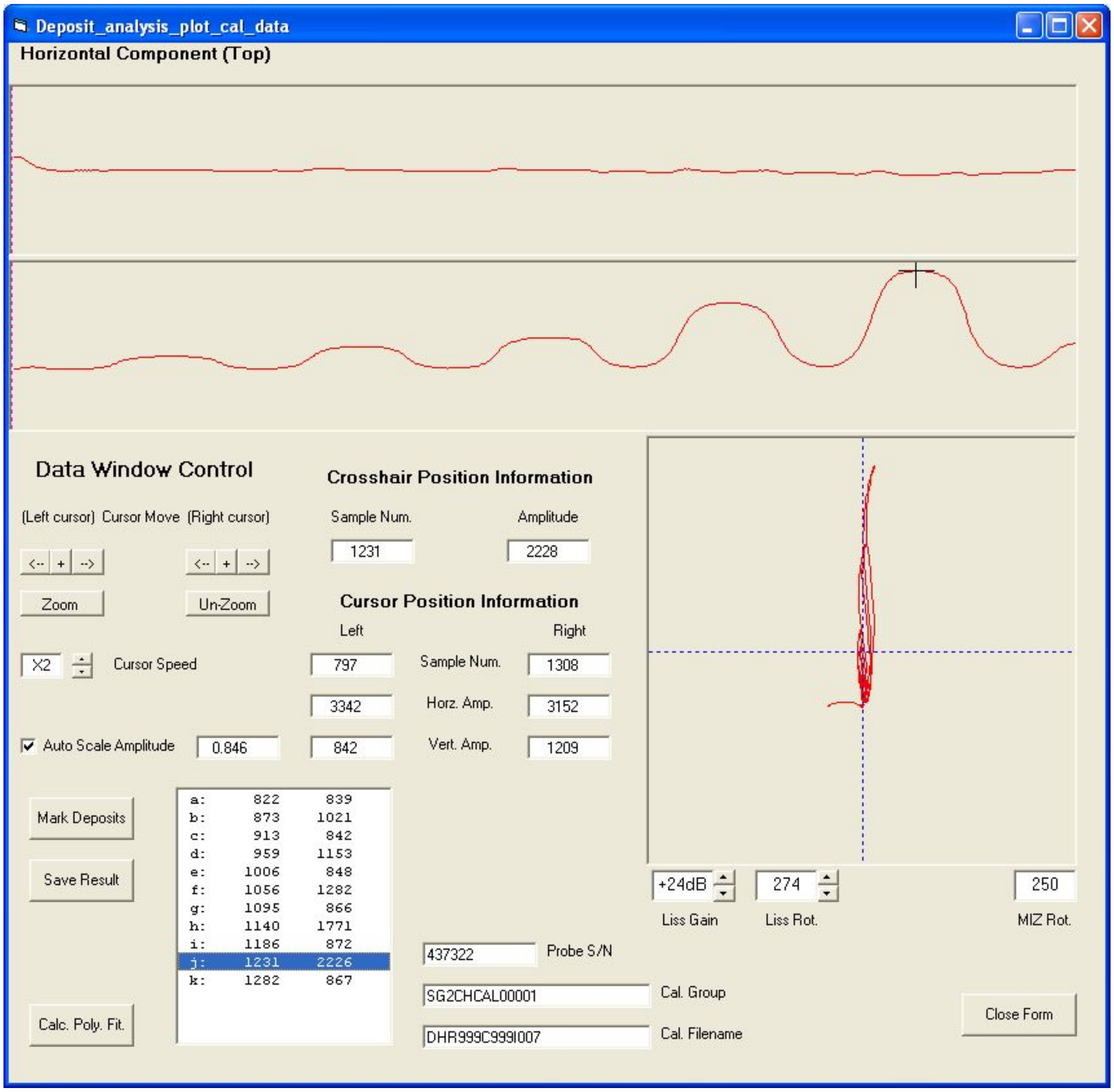


Table 1: Example, Deposit Tabular Output by Span and Location

Span	Cold Leg (Kilograms)	Hot Leg (Kilograms)
1	19	22
2	32	11
3	48	12
4	50	30
5	40	55
6	36	61

4.0 Deploying Technology

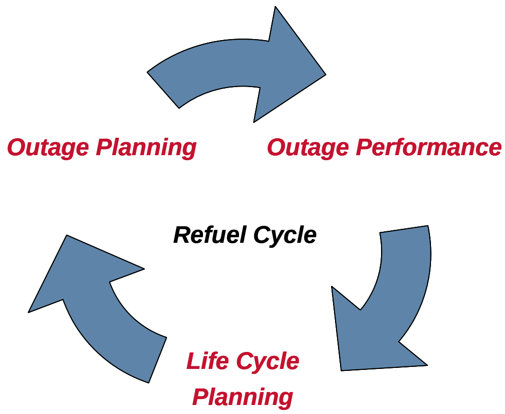
As illustrated in Figure 2.0, the AREVA Asset Management Pyramid, to achieve the goal of Asset Management requires a foundation built upon advanced technology that is sub sequentially integrated to ensure operational excellence. The basic premise is that a high-quality input will only yield a high-quality output when applied in a high-quality process. The advanced technologies associated with large component asset management serve to enhance both the quality of the input and the process.

The quality of the input is enhanced by understanding of the phenomenon associated with the component, which is typically related to an understanding of the component design, materials behaviour, and the related chemistry; in other words the technological basis.

The quality of the process is enhanced through the application of advanced mitigation techniques and evaluation of the associated performance metrics that allow for continuous improvement, or tuning, of the life-cycle plan.

The expertise to achieve operational excellence is rarely found in one individual. Therefore an asset manager needs to be assigned that can focus and integrate the various expertises to the benefit of the component. The asset manager must be supported by a team of experts to include the OEM (or equivalent), who can provide the insight and recommendations in their area of expertise. Furthermore, the asset manager will have to have a greater reliance on the service vendor in order to better understanding the efficiencies of the required mitigation techniques and their applications. The service vendor and OEM have to add more value to the process, so as to help ensure the quality of the output. Figure7, Refueling Cycle, demonstrates the major process leading up to and including the outage.

Figure 7: Refueling Cycle



The first step is life-cycle planning to validated results from the most current outage, assess the impact on the life-cycle plan, and to determine the scope of the next outage. The second step is to plan the outage so as to ensure the most efficient delivery of services in the optimal timeframe so as to protect revenues. The last step, which is traditionally considered the only step in the utility/service vendor relationship, is the actual performance of the services. As is obvious, a close cooperation between all stakeholders early in the process will yield higher quality results. This represents a new paradigm in the delivery of outage services. In an asset management model the utility customer, the service vendor, and the OEM (or equivalent) have to work well in advance of the outage so as to ensure the optimal maintenance regime and life-cycle planning.

5.0 Summary

While some of this technology and data has been available in the past, the relative significance and level of action required was not obvious. Continued improvement in the Asset Integration Program will improve the identification and collection of these information sources with design modeling technology and economic modeling necessary to provide a better understanding of the interrelation and impact of asset management decisions. Through use of the new technology developed, a better understanding of the significance of each information source and the impact they have on the component performance allows for the continued development of new technology that can be more directed and effective.

An asset management approach is based upon developing a sustainable strategy to support the maximum utilization of the existing nuclear assets while expanding the world-wide fleet to meet the growing electrical demands and minimizing the emissions of harmful greenhouse gases. To respond to this challenge, energy-intensive industries as a whole are retooling and providing advanced technological solutions, such as fuel cell technology, investments in hydrogen technology, and hybrid automobiles. The response in the management of the existing nuclear fleet calls for similar approach in the development and application of advanced technologies so as to best manage the resources. This technological response needs to establish a basis for sound and high-quality life-cycle planning, to provide for as effective mitigation techniques as practical, and it requires advanced metrics that not only measure performance to plan, but predict future performance. An asset management program without a sound and advanced technological basis will provide better returns through the implementation of best practices, but a technology-based asset management program, focused on high-value components or processes, will provide a far better and sustainable return.