IYNC 2008
Interlaken, Switzerland, 20-26 September 2008
Paper No. 226

ADVANCED LIGHT WATER REACTOR PLANT

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ABSTRACT

For nuclear power to be competitive with the other methods of electrical power generation the economic performance should be significantly improved by increasing the time spent on –line generating electricity relative to time spent off-line conducting maintenance and refueling. Maintenance includes planned actions (surveillances) and unplanned actions (corrective maintenance) to respond to component degradation or failure. A methodology is described which is used to resolve maintenance related operating cycle length barriers. Advanced light water nuclear power plant is designed with the purpose to maximize online generating time by increasing operating cycle length.

1 INTRODUCTION

Nuclear power plants have an advantage over all major electric power production competitors: significantly lower fuel costs. However, a nuclear power plant's lower fuel costs can only offset the higher capital costs if the amount of time spent on-line producing electricity at full capacity significantly exceeds the number of days spent shutdown. The term typically used to measure the economic performance of a nuclear power plant is unit capability factor. Unit capability factor is the percentage of maximum electricity generation that a plant is capable of supplying to the electric grid. Unit capability factor is directly related to the ratio of on-line days to on –line plus off-line days during any given period. Clearly, to improve the unit capability factor the on-line days must increase, the off-line days must decrease, or both.

A renewed interest in new power generation has spurred interest in developing advanced reactors with features which will address the public's concerns regarding nuclear generation. Economic performances, to great extent, improved by maximizing the time that the plant is on-line generating electricity relative to the time spent off-line conducting maintenance and refuelling.

Methodology was developed for injecting component and system maintainability issues into the reactor plant design process to overcome maintenance related barriers. There was determined the types of operating cycle length barriers. According to evaluation preventing from achieving 48 month cycle, there are 54 known IRIS operating length barriers. The methodology is presented in order to narrow the design space enabling a desired operating cycle length. This can be accomplished by focusing on three general areas:

- increasing the cycle length between refuelling
- minimizing refuelling and planned maintenance outage times, and
- reducing the frequency and duration of forced outages

This paper describes the methodology in order to overcome the operating cycle length barriers for advanced light water reactor plant. The advanced light water reactor plant to which this design methodology is applied is the International Reactor, Innovative & Secure (IRIS). IRIS is currently being developed by an international consortium, led by Westinghouse, the aim is:

- Enhance safety systems-utilization of a single, integrated, self-pressurized vessel and enhanced safety systems will passive safety features making severe damages leading to core damage impossible. The integral configuration eliminates the possibility of loss of coolant accidents of significant entity, and reactor is designed for a very high level of natural circulation, thus eliminating the loss of flow accident.
- Proliferation resistance-the core lifetime is projected in order of eight years without fuel shuffling or refuelling. Maintenance of the nuclear system is minimized.
- Simple and economic, the capital cost is reduced because of the elimination of entire system such as refuelling, soluble neutron absorber, and emergency core cooling, the use of a single, integrated, self-pressurized vessel, and simplifications through the plant, e.g. reduction in piping and valves. The operation and maintenance costs are substantially reduced by the condition-based maintenance strategy, no partial refuelling, and the use of modular, easy replicable components.
- Environmentally friendly, because of the very long life of the core the amount of radioactive waste spent fuel is drastically reduced (of the order of five times less than current reactors for the same power output).

2 ADVANCED WATER REACTORS

2.1 Examples

Water Reactors are nuclear power plants that use water to control and remove the heat from the nuclear fuel in order to convert heat to electricity.

There are two basic types of water reactors: those cooled by ordinary water, called the light water type, and the heavy water type. The majority of the world's water reactors are Light Water Reactors (LWRs), including both Pressurized Water Reactors (PWRs) and Boiling Water Reactors (BWRs).

Three large advanced PWRs called Convoy were recently completed in Germany. The United Kingdom's first commercial water reactor the Sizewell B PWR: Two mid-sized about 600 MWe advanced LWRs are under development in the United States, with the major focus on plant simplification. For example, the advanced PWR has 32 per cent fewer valves, 35 per cent fewer pumps, and 45 per cent less pipe than a traditional PWR of comparable rating. These simplifications are expected to greatly enhance the safety and reliability of plant operation. Significant reductions in the cost and schedule of plant construction are expected both from the plant simplification and from the application of modular construction techniques and a greater scope for factory assembly. Major emphasis is also placed on passive safety features which put less reliance on human intervention for accident management. . for example , emergency core cooling systems will not rely on pumping systems requiring diesel generated electrical power, and containments can be cooled using using natural rather than forced circulation. The PIUS (Process Inherent Ultimate Safety) reactor is under development in Sweden. Because this reactor system has marked departures from existing water reactor systems in areas such as reactivity control and primary coolant system configuration, a large scale prototype system (or demonstration plant) should probably be constructed to confirm the reliability of the system. A primary design goal of the system and a similar system in Japan, the Intrinsically Safe Economical Rector (ISER), is enhanced protection of the core during postulated accidents. The goal is for core degradation accidents to be prevented by passive means without reliance on the function of active components and7or operator action following conceivable accidents. [1]

The AP100 is the safest and most economical nuclear power plant available in the worldwide commercial marketplace, and is the only Generation III+ reactor to receive Design Certification from U.S. Nuclear Regulatory Commission (NRC). Generation III+ is the Department of Energy's nomenclature for Generation III Advanced Light water Reactors with improved economics and safety. The established design of the AP1000 offers there distinct advantages over other designs:

- unequalled safety
- economic competitiveness
- improved and more efficient operations [2]

2.2 Extension Maintenance Cycles

A distinguished characteristic of IRIS is its capability of operating with long cycles. IRIS is designed to extend the need for scheduled maintenance outages to act at least 48 months. There was performed the study by MIT for an operating PWR to identify required actions for the extending the maintenance period from 18 to 48 months or to perform maintenance testing on line. There were identified 3743 maintenance items. 2537 of them off-line and the remaining 1206 on-line. It was discovered that 1858 of the off-line items could be extended from 18 to 48 months, while 625 could be re-categorized from off-line items to on-line.

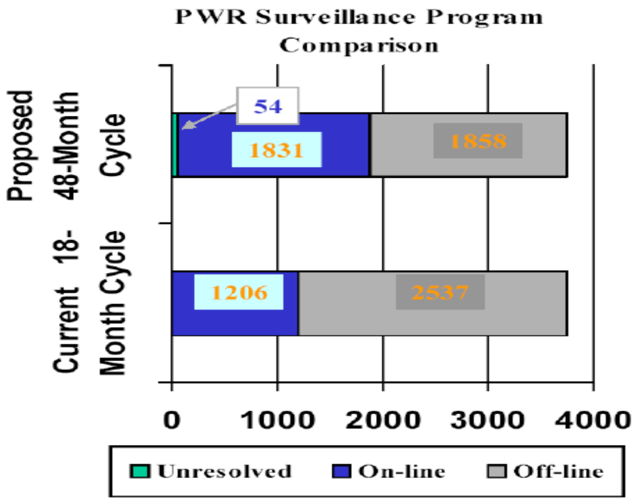

Fig.1 Possible re-categorization of maintenance items to enable 48-month maintenance cycle [3]

As illustrated in Fig. 1, only 54 items which still need to be performed off-line on a schedule shorter than 48 months. There is no need to change reactor primary coolant pumps oil lubricant, since the IRIS spool type pumps are lubricated by the reactor coolant only 7 items are left as obstacles to a 48-month cycle. These items were addressed and either resolved or a plan of action was identified.

Because of the four-year maintenance cycle capability, and extended cycle design, the capability factor of IRIS is expected to satisfy and exceed 95% target. [3]

The idea is to develop a methodology for injecting component and system maintainability issues into the reactor plant design process. Methodology is intended simply to focus on creative design effort on those factors which are relevant to the process. The first step is the synthesis of the general requirements that the component must satisfy, which is non-trivial task based on both experience and judgement. The second step is the synthesis of design objectives with the design requirements. The third step is bound the solution source by application of suitable and relevant constraints. The final step is to develop design alternatives which meet the specifications of the synthesized design requirements, objectives and constraints. To meet the specified cycle length objective, the component must either require no maintenance for the entire cycle or be maintainable during the cycle.

New materials may provide solutions where the original component is retained but fabricated from a ‘better ‘material. New materials may allow the component to operate in an environment that the original material could not, saving considerable design effort and simplifying the integration of the component into the overall design.

The resolution process begins with the functional requirements to be satisfied and the component currently used to satisfy that requirement. Successive iterations evaluate the design against the next performance requirement in an external process until all requirements have been satisfied. If the current state of design does not meet a particular requirement, then the design is either modified or a new design is generated by external process.

- The following questions are addressed:
- Does existing component meet requirements?
- Can exist component be modified to meet requirements?
- Does design meet operating cycle length requirements?
- Can component be isolated for maintenance?

The designer can either improve the current component by modifying component (evolutionary design) or by finding a completely different method to meet the design requirements (revolutionary design). The designer must always evaluate whether a revolutionary design would better accomplish the prescribed function than an evolutionary design in order to ensure the most cost-effective and best engineered solution obtained.

The implicit goal of IRIS, then, is to utilize revolutionary design solutions where necessary and evolutionary design solutions where practical. The output from the methodology consists of a set of design alternatives, all of which meet the specified requirements, ranked by maintainability. [4]

2.3 Surveillance Strategy to Overcome

Surveillances are performed in order to ensure safety or because they are prudent to protect capital investment. A typical commercial nuclear power plant performs thousands of surveillance activities including system testing, equipment inspections, and preventive maintenance. These surveillances may be imposed by a regulatory body, or either may be initiated at the level of investment protection or economically significant components. The surveillances can be further divided by their mode of performance. On-line surveillances can be accomplished with the reactor at power, while off-line surveillances require the unit be shutdown. on-line surveillances are generally independent of operating cycle length, but the off-line surveillance program must be coordinated with refuelling outages to ensure that the periodic testing and maintenance is completed within the time frame set forth by regulatory and protection guidelines. Any proposed operating cycle extension, therefore, must analyse each off-line surveillance activity currently performed at the plant and reconcile it with the increased planned outage interval to maintain regulatory and economic compliance. In order to achieve the stated objectives and complete systematic surveillance reconciliation to a four year operating cycle, a general surveillance reconciliation methodology was developed.

For IRIS, maximizing the on-line surveillance performance will be the key enabler for the eight year operating cycle length objective. The idea is not to resolve all the cycle lengthy barriers, but rather use the methodology which will assist the reactor plant designer in designing systems which are not cycle length limiting. This methodology was designed to analyse pertinent characteristics of the surveillance procedures and to categorize each individual surveillance activity according to its potential for on-line performance or performance off-line at extended intervals:

- Regulatory based: surveillances performed to meet technical specification requirements
- Investment protection: non-technical –specification-based surveillances, including surveillances performed as a result of commitments to agencies. The investment protection surveillances can be further broken down into reactor and supporting components and systems, referred to as the nuclear steam supply system (NSSS), and all other, referred to as balance of plant (BOP):

In 1996, Thomas Moore developed a surveillance strategy for a 48 months operating cycle in a commercial PWR: Moore analyzed the existing surveillance program at a candidate PWR plant to assess the impact of an operating cycle change from 18 months to 48 months. After appropriate justification, surveillances were placed in one of the categories: candidates for on-line performance (category A), candidates for off-line performance interval extension to 48 months (category B); and barriers to a 48 month cycle (category C).

There was determined the following categories:

- 2673 in Category A (on-line)
- 381 in Category B (extended to 48 months)
- 54 in category C (incompatible with 48 months cycle)

Assessment of operating PWR surveillance program relative to the IRIS eight-year operating cycle length objective requires, in part, resolution of 435 surveillances (54 category C and 381 Category B) identified by Moore. The technical justification Moore provided to extend the category B surveillances to 48 months may not necessary apply to an interval extension to eight years, resulting in IRIS cycle length barriers. However, development of methodology which will resolve the identified category C barriers will likely provide a solution to the unidentified Category B barriers as well.

One of the most significant results from the theoretical development of the surveillance reconciliation methodology was the introduction of the concept of limiting plant event frequency (LPEF) to make rigorous surveillance modifications decisions. The LPEF is the frequency of any events that limits the ability of the plant to generate full electrical capacity.

The surveillance reconciliation methodology and its application to the case study plants favoured on-line surveillance performance over performance interval extension. There are several advantages to on-line surveillance completion. Any surveillance moved to the online work scope ultimately shortens the refuelling outage length. Reduced refuelling outages translate directly into improved capacity factors and increased revenue. On-line surveillances tend to levelize the plant workload which means that the plants can utilize full time employees conduct surveillances in that level of on-site knowledge and familiarity with plant components will be improved through increased work experience. There, of course, some advantages to on-line surveillances such as increased performance complexity requiring grater personnel training and possible increased plant trip risk. [4]

2.4 Methodologies to Resolve the Maintenance Related Barriers

To validate the surveillance reconciliation methodology and to evaluate the ability of typical commercial nuclear power plant to coordinate its surveillance program to an extended operating cycle up to 48 months, two operational BWR and PWR plants were selected as case studies. Methods which may lead to on-line performance or complete elimination of these surveillances are presented.

With respect to IRIS, the operating PWR surveillances can be placed into one of four categories:

- Category 1: On-line surveillances which will be performed on –line in IRIS
- Category 2: Candidate surveillances for design resolution to create on-line performance mode in IRIS
- Category 3: Surveillances requiring further analysis to determine performance mode in IRIS
- Category 4: Off-line surveillances likely to have performance interval extended to at least eight years in IRIS.

The remaining 435 operating PWR surveillances (54 categories C plus 381 categories B) which are currently performed off-line and do not have an on-line performance mode are the potential IRIS cycle length barriers. [4]

From these 435 surveillances a quantitative assessment will be made as to whether the surveillance plausibility could have an on-line performance mode in IRIS, based on IRIS design goals and objectives.

NRC Generic letter 91-04, “Changes in Technical Specification Surveillance Intervals to Accommodate a 24 Month Fuel Cycle” is used as a model for a 48 month cycle, the first step in reconciling each surveillance was to examine the governing procedure to determine what actual plant mode restrictions existed.

For those surveillances that could not be moved into on-line work scope, an analysis was conducted to evaluate their potential for performance interval extension to 48 months or more. Plant surveillance and material history records were reviewed to identify testing intervals, during those reviews, it was common to find components that had never failed their corresponding surveillances and those material histories raised no doubts about the ability of testing interval to be extended. For the less obvious cases, plant specific and industry failure histories, applicable testing codes, and expert experience were all combined to form a judgement about the potential for interval extension.

Any surveillance that did not fall into the categories of on-line performance interval extension was left as unresolved and requires further study. In the cases, a broader survey of state of art testing technologies and alternative testing used within the nuclear industry was conducted. The final reconciliation of these surveillances was left as future work for the MIT research project and the nuclear industry. In all cases, expert's reviews of the surveillance categorizations by plant system engineers and department heads were conducted. These interviews were conducted to incorporate the operational experience of plant personnel and to identify idiosyncrasies not apparent in the surveillance procedures. [5]

Figure 2 shows the proposed 48 month cycle surveillance programs compared to the current plant programs.

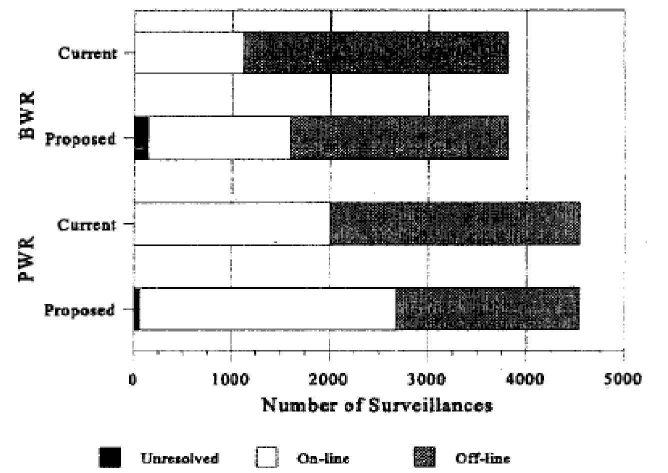

Figure 2
Proposed Surveillance Programs

Figure 2: 48 month cycle surveillance programs compared to the current plant [5]

The BWR plant currently conducts 1115 (29%) on-line surveillances and 2694 (71%) off-line surveillances at twenty-four month intervals. Under the proposed program there would be 1457 (38%) on-line surveillances and 2210 (58%) surveillances performed off-line to a 48 month intervals. there are 140 (4%) surveillances that remain unresolved to the extended cycle. The PWR plant currently performs approximately 2000 (44%) on-line surveillances, and 2537 (56%) surveillances off-line during refuelling outages every eighteen months. The proposed surveillance program consists of 2625 (585) on-line surveillances, 1858 (41%) performed off-line at 48 months interval, and 54 (1%) surveillances that remain unresolved.

Figures 3 and 4 shows the detailed breakdown of these modified surveillances to the respective plant surveillances organizational structure.

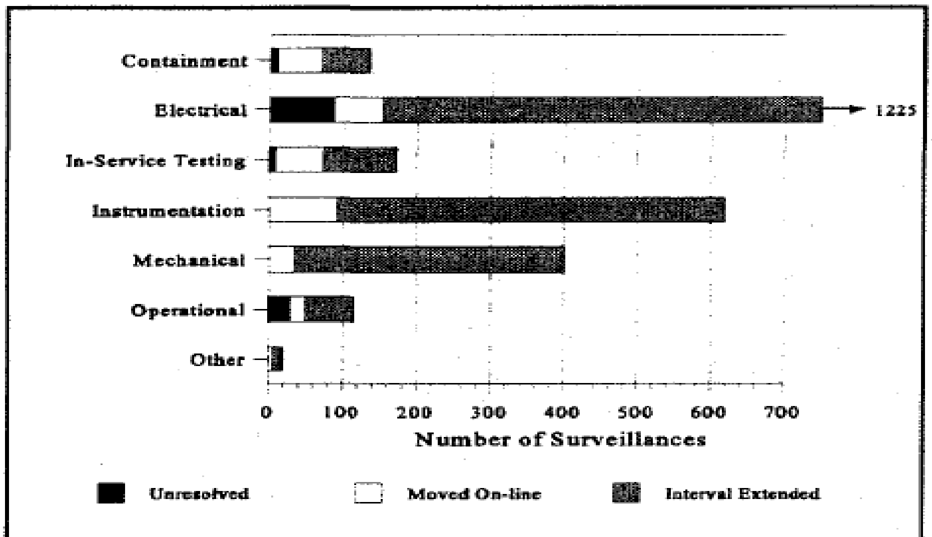

Figure 3
BWR Modified Surveillances

Figure 3 Breakdown of modified surveillances to the respective plant surveillances organizational structure: [5]

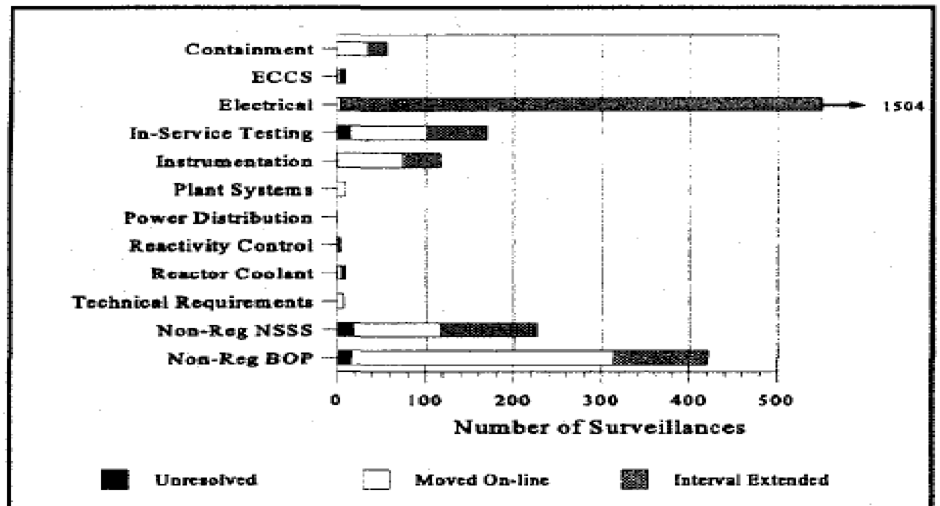

Figure 4
PWR Modified Surveillances

Figure 4 Breakdown of modified surveillances to the respective plant surveillances organizational structure: [5]

Table 1. Unresolved plant surveillance activities [5]

Table 1
Potential Barriers to Extended Cycles

Common	BWR	PWR
• Relief Valve Testing • MOV Testing • In-Service Testing • Battery Discharge Testing • Condenser Waterbox Maintenance • Engineered Safety Feature Testing	• Automatic Depressurization System Testing • Main Steam Isolation Valve and Feedwater Valve Testing • Drywell Equipment Lubrication	• Steam Generator Eddy Current Testing • Reactor Coolant Pump Maintenance

All of the BWR and PWR plant surveillance activities unresolved in the case studies are compiled in Table 1.

Rather than an indication that the surveillance programs will inhibit a cycle extension effort, the fact that relatively few surveillances (4% for the BWR and 1% for the PWR) remain unresolved after this initial survey is an encouraging result. These types of surveillance activities can receive more focussed attention to develop engineering solutions that will enable on-line performance or performance interval extension. [5]

2.5 Data Availability and Resolution Categorization Considerations

The basic issues taken into consideration while eliminating the maintenance –related barriers and the following resolutions are assigned:

- On-line or eliminated surveillances
- Advanced monitoring techniques: advances in remote and on-line monitoring techniques now allow for conducting many inspections at power in locations which are, due either to environment or radiation, inaccessible by personnel. Examples of these techniques include robot assisted ultrasonic inspection, on-line motion and vibration monitoring, and radiation hardener infrared imaging. Benefits are that the investment is better protected by more frequent (or even continuous) assessment of component condition without requiring an outage. Secondly, these techniques are generally passive and no testing-included failures (which can occur with a time –based surveillance program) are expected.
- Improved technologies: new generation of highly reliable and more easily maintained components have emerged from manufacturers. New design and construction, however, affords the opportunity to take advantage of these component improvements. For example switchboard and breaker technology has improved significantly. Fully enclosed switchboards are now available which do not require frequent cleaning.

Redundant capabilities-many investments protection calibrations and alignments can have their periodicity extended by installation of diverse reliable and redundant monitoring capability.

- Regulatory change
- Surveillances requiring design resolution

Above are indicated the methods available to the designer which can be used to resolve identified operating cycle length barriers. The strategy for eliminating these barriers

Evaluating surveillances for deferral requires in-depth analysis of the surveillances basis and the component's maintenance history. [4]

The technical justifications for surveillance interval extension will certainly require historical performance data when considering a 48 month operating cycle. Previous cycle extension efforts to 18 and 24 months have been based primarily on expert judgements and some material conditional histories. Due to changing regulatory expectations, it is not likely that the expert judgement alone will be sufficient to justify the interval extension of surveillances from 24 to 48 months. Unfortunately, there is a general deficiency in the quality and the availability of the data needed to complete such rigorous technical evaluations. In many plants, the data has been collected for years but it is not compiled in any accessible format. New plants tend to have more efficient computer-based data systems, but the breadth and depth of these programmes are still only marginally adequate.

Ultimately, the lack of data availability and trending is a problem that can be resolved if it is given a high enough priority of management. Continuing economic pressure to optimize the plant operations will drive some resolution of this problem, but for the short term, data availability may pose a significant obstacle to any extended operating cycle effort. [5]

3 CONCLUSIONS

This paper presented a surveillance reconciliation methodology which is applied to two case study plants, an operational BWR and PWR to evaluate the methodology and gauge the ability of current surveillance programs to conform to extended cycle. Results show that the majority of surveillances can be moved on-line or can be performed at extended cycle intervals. Finally, the resolution methodology was applied to the barriers and feasible design alternatives were proposed which enable the achievement of the eight year IRIS operating cycle length

REFERENCES

[1] Advanced water Reactor Technology, NEA Issue Brief: An analysis of principal nuclear issues, Nuclear Energy Agency, June

[2] AP 1000 Westinghouse http:77ap1000.Westinghousenuclear.com/index.html March 2008-03-10

[3] M.D. Crelli and B. Petrovic, Recent Developments of the IRIS project of interest for Latin America, Westinghouse Electric Co. LLC, USA 2004

[4] Mark Robert Galvin, Maintenance Cycle Extension in advanced Light Water Reactor Plant Design, Oregon State University, June 2001

[5] R.S. McHenry, T.J. Moore, J.H. Mauer, N.E. Todreas, Surveillance Strategy for an extended cycle in commercial nuclear reactors, Massachusetts Institute of Technology, June 1997