MAINTENANCE BASED DESIGN AND EQUIPMENT RELIABILITY FOR AECL'S ADVANCED CANDU REACTOR®*

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1.0 Introduction

In order to consistently achieve high capacity factors in any power station a number of things must be done well. The design, initial equipment procurement, construction and commissioning must obviously be of high quality but to sustain high performance over the life of the station the quality of the operation and maintenance are the more important factors. The nuclear industry has learned that good operation and maintenance (O&M) programs are best achieved if they are included up front as an integral part of the initial design process. AECL is doing this in the design of the ADVANCED CANDU REACTOR (ACR)® through a series of processes referred to as Maintenance Based Design that are described in this paper.

2.0 The ACR-1000® Background

The ACR-1000® is an evolutionary design with advancements and enhanced features relative to previous CANDU®** designs. The design will produce a gross output of approximately 1150 MWe, depending on siting. The design emphasizes customer driven improvements in safety margins, capital cost, operating performance, reliability and O&M costs. The targets for some of these, over the 60-year design life of the plant are,

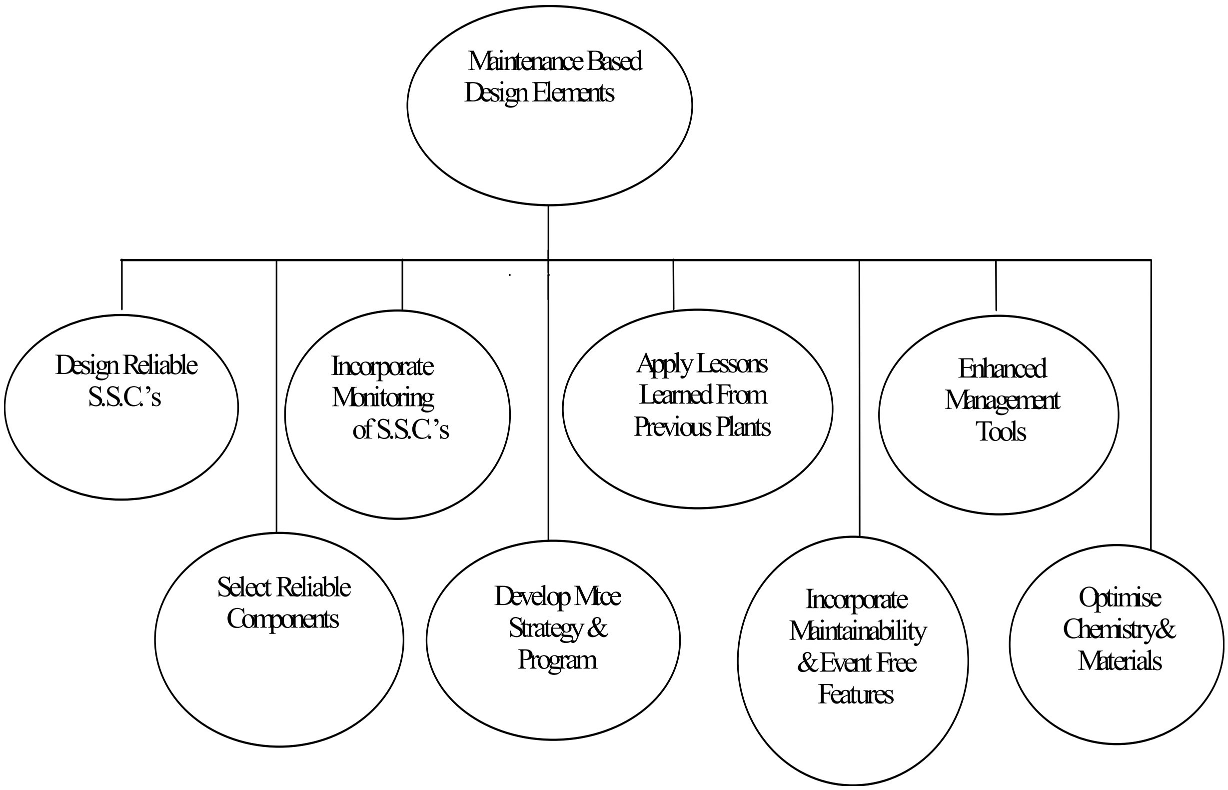
- Lifetime Capacity Factor > 90%
- Annual Year-to-Year Capacity Factor > 95%
  - Planned Outages of 21 days every 3 years (nominal)
  - Forced Outage Rate < 1.5%
- Reduced Staff (at least 10% less than previous CANDU® designs)

A major contributor to achieving these ambitious targets is Maintenance Based Design (MBD)

3.0 Maintenance Based Design (MBD)

The elements that make up MBD are shown in Figure 1 along with a brief description of each. While all equipment in the plant is important, MBD focuses on improving the reliability of systems, structures and components (SSCs) that are important to production. Such a production focus does not exclude safety systems. In fact safety systems are crucial to reliable production. This focus is also customer driven, as utilities require production improvements in order to justify a reasonable financial return on the significant capital costs associated with new nuclear plants.

Figure 1. Maintenance Based Design Elements



Each element of MBD is reviewed in detail with each system designer by the O&M group in order to ensure completeness and compliance.

3.1 Design Reliable SSCs

In order to achieve high reliability each system's design features must contribute. No weak links are allowed. Since there are many systems in a station that can each cause outages and deratings, each must have a reliability significantly better than the overall reliability target for the station. A review of CANDU® operating experience, examining contributors to forced outages and deratings in the past and that could be applicable to the ACR-1000® in the future identified the systems shown in Table 1. To improve the reliability of these systems a number of improvements must be made in the design.

In normally poised systems (e.g. Safety Systems) additional redundancy has been added in the ACR®, to eliminate many Single Points of Vulnerability (SPV) defined as any single component whose failure could directly cause a unit trip, outage or derating, even during routine testing. The design incorporates 4 divisions of safety system and safety support system equipment each with a dedicated channel of instrumentation in a 2 out of 4 configuration. This allows a complete division/channel to be by-passed and taken out of service for testing or maintenance at full power, without incurring the risk of a spurious failure on another division/channel and a resultant loss of production. Allowing all regular maintenance on these systems to be done at full power significantly simplifies and reduces the amount of work traditionally done during planned outages

For the normally operating systems a reliability review of each is being done as part of the ACR® design process to identify all SPVs and eliminate or mitigate them as far as practical.

Table 1 Systems Applicable to ACR-1000® That Have Caused Past Production Losses

Nuclear Systems	Balance of Plant Systems
Bldgs & Structures (Steam Barriers)	Turbine
Airlocks	Moisture Separator Reheater
Fuel Channel Assemblies	Turbine Speed Control System
Reactivity Control Units	T/G Supervisory Systems
Moderator System	Main Generator
Moderator Cover Gas System	Generator Potential Transformer
Liquid Poison Systems	Generator Excitation
Steam Generators	Generator Hydrogen Cooling
Main HTS Equipment	Generator Stator Cooling
Feeder Cabinets & Cooling System	Generator Neutral Grounding
HTS Pressure Control System	Main Condensate & Make Up
HTS Purification Circuit	Turbine Governor Oil System (FRF)
HTS Shutdown Cooling System	Seal Oil System
Shield Cooling System	Main Condensing System
Containment Spray System	Feedwater Heating System
Emergency Core Cooling System	Main Feedwater Circuit
Emergency Water Supply System	Turbine Bypass System
Liquid Injection Shutdown System	Pumphouse Common Systems
Annulus Gas	Circulating Water System
Fuel Handling Systems	Service Water Systems
Main Steam Supply	Recirc Cooling Water
Steam Generator Pressure Relief	Water Treatment Plant
Steam Generator Level Control	Demineralized Water System
Digital Control System	Instrument Air
Shutdown System No. 1	HVAC Systems
Shutdown System No. 2	Containment Isolation System
Delayed Neutron Monitoring	Chilled Water Systems
Switchyard Equipment & Structures	
Main Output Power Transformers	
Class I,II,III &IV Electrical Systems	

3.2 Select Reliable Components

The reliability of any system depends on the reliability of each component. While all components require maintenance throughout their design lives there is an intrinsic maximum reliability that cannot be exceeded no matter how much maintenance is performed. This intrinsic reliability can only be increased by selecting the best components such as those that have previously demonstrated high quality through reliable service in previous power plants or industry. For example the valve applications shown in Table 2 were reviewed using operating experience data from the CANDU Owners Group. These valves had a history of past performance sufficiently poor as to cause lost production for the typical intervals shown. As part of the ACR® design process the application, selection and quality of these valves will be specifically targeted in conjunction with the manufacturers, to address this poor performance.

Note: Other valves not listed but with significant problems were Liquid Zone Control Valves (not applicable to the ACR®) and Turbine valves which are unique to each manufacturer.

Table 2- Valve Impacts on CANDU® Capacity Factors (2004-2006)

Application	Full Power Days Lost
1. Heat Transport System Valves	38 days
2. Shut Down Cooling Valves	19 days
3. Condensor Steam Discharge Valves	17 days
4. Boiler/Deaereator Level Control	7.2 days
5. Liquid Injection System	6.3 days
6. Emergency Core Cooling	3.3 days

3.3 Incorporate Monitoring of SSCs

In order to confirm that components and systems continue to operate reliably it is important to be able to monitor their performance. It is also preferable to do this monitoring with the components in-service. This usually requires special instrumentation and facilities such as, vibration probes on rotating equipment and viewing windows on electrical buses and switchgear for thermography.

In the ACR® design the use of on-line monitoring facilities and the associated software applications to collect, store and analyse this data will be extensively employed on electrical equipment, rotating equipment, power operated valves and instrumentation and control devices

3.4 Develop A Maintenance Strategy and Program

Equipment degradation begins as soon as it is manufactured and accelerates during construction, commissioning and eventual operation. For this reason the ACR-1000 will include a complete “cradle-to-grave” maintenance strategy which will include preservation during construction, preventive maintenance during commissioning and operation, and/or end of life replacement. Once such a maintenance strategy has been developed it must be implemented in detailed maintenance programs which include a supply of spare parts. Historically this has fallen on the utility to meet. A better approach is to be ready to implement this prior to the start of commissioning. To do this the strategy and program must be developed during the design phase. These strategies and programs must also be based on best industry practices and data (i.e., INPO/EPRI).

As part of the ACR® design the INPO AP-913 Equipment Reliability Process is being used to analyse all the systems important to production, identify all the critical components and specify a maintenance strategy (i.e. preventive maintenance tasks and schedule) for each. These strategies can then be implemented as equipment is installed during construction and commissioned.

3.5 Apply Lessons Learned From Previous Plants

The best predictor of system or of a component’s reliability is its past performance. Past performance problems and applicable lessons learned must be used in the design process to improve reliability. AECL has a formal process (Feedback Monitoring System) for gathering relevant operating experience from its previous designed plants and from external sources such as COG. All of these issues have been reviewed and addressed if applicable by the ACR® design team. For more information on this process see the other paper presented at this conference entitled “Use of Operating Experience to Improve Performance of the ACR-1000” by Dennis McQuade.

An example of how this feedback process is being used is in the area of shutdown heat sinks. All previous stations have significant constraints in managing heat sinks during outages. The ACR® will have 4 completely independent shutdown cooling heat sink loops. This will remove the need for reliance on other heat sinks such as the steam generators during outages.

3.6 Incorporate Maintainability and Event Free Tools

"Maintainability" and "Event Free" are defined as,

Maintainability - A designed-in characteristic of a system or component that provides an inherent ability to be safely maintained using fewer resources, exposing staff to less radiation and achieving improved reliability.

Event Free - The result of doing maintenance (or operations) in such a manner so as to minimize human error that could result in consequential events (e.g., injury, outages, etc.).

The incorporation of human factor design guidelines to the layout and design of equipment and the provision of supporting maintenance facilities and tooling can significantly enable improvement in these areas.

Some examples as to how these are being addressed in the ACR® can be seen in the design of the reactor building (RB) facilities. The layout of the RB has been reviewed to ensure good access for O&M staff to equipment during operation and outages. This will significantly reduce the need for temporary scaffolding and will include additional platforms, additional cranes and slinging facilities for all heavy equipment, an elevator inside the RB for moving staff and small tools and equipment, etc. In the ACR® access for staff will also be facilitated by the elimination of heat transport D_2O and the resulting tritium hazards present in previous CANDU® Heat Transport Systems. The Fuelling Machines will also contain light water and will incorporate the loading of new fuel without staff needing to enter the RB.

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3.7 Enhanced Management Tools

The management of maintenance is centred on having quick and easy access for all staff to all the right information (both initial design and on-going operation and maintenance information). The management of maintenance is also best served by reducing the burden of information gathering to enable decision-making. In order to manage the large amounts of information and data involved in maintenance, a number of sophisticated electronic tools (e.g., wiring program, equipment status monitoring, etc) are required. In addition, special procedures, vendor training and tools are required in order to properly equip staff to work on some of the unique and complicated equipment in the station (e.g., turbine-generator controls).

In new stations all data associated with the plant design will be produced electronically. During commissioning and operation it is also expected that all new information will be generated and stored electronically. The ACR® station will therefore have an extensive information management network installed (i.e. fibre optic backbone with interface connections) in all areas of the site to help the O&M staff to access all this data, both real time and historic. This network will also support the widespread ability to wirelessly collect and transmit visual and voice data to all areas needed by the staff.

3.8 Optimise Chemistry and Materials

One of the largest factors in being able to achieve a 60 year plus design life of a station and minimize radiation exposure levels to staff will be the selection of the best materials and the maintenance of optimum chemistry conditions of all the working fluids.

Examples of improvements in this area on the ACR® include the extensive use of stainless steels in the heat transport feeders and headers to eliminate erosion/corrosion degradation and the strict minimization of cobalt in all piping alloys and fuelling machine parts to reduce radiation exposures. The heat transport purification circuit will utilize 0.1 micron filters with a very short (1 hour) purification half life. Stainless steels are also selectively used in areas of the conventional side of the plant (e.g. steam generator internals, screenhouse, etc) that have been susceptible to corrosion and erosion.

4.0 Conclusions

The capacity factor and cost targets for the ACR-1000® are very challenging. In-order to consistently achieve these an owner will require world-class operations and maintenance but even the best O&M programs cannot salvage a poor design. The ACR® Maintenance Based Design process described above will get the utility off to a good start and act as an enabler for sustained success over the design life of the station.

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