VENDOR PROVISION FOR OPERATIONS AND MAINTENANCE

A Route to Nuclear Excellence

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ABSTRACT

The CANDU ® pressurized heavy water design has been established over three decades of operation. Historically CANDU has been developed by a successful partnership between AECL, the designer and developer, and the operating utilities.

Maintaining good performance of a nuclear power plant is primarily the responsibility of the owner operator; but there is a common interest between the design organization and the operator in achieving good performance. AECL is emphasizing activities and partnerships to provide engineering and Research and Development (R and D) to reduce operating costs for new plants and support existing plants. Among these are: a comprehensive, structured process to deal with project, operations and other feedback; teams to study issues with impact on capacity factor and OM&A cost and identify initiatives in response; an integrated plant life management program in conjunction with CANDU 6 utilities; and strategic information technology products installed at the plants in support of improved station operation, sponsored by the CANDU Owner's Group.

The breadth of these programs gives AECL a unique ability to link between support to operating plants, and the development of improved Nuclear Power Plant (NPP) designs for the future.

1. INTRODUCTION

As many nuclear plants approach mid- and later life today, increasing attention focuses on the need for effective Operations and Maintenance (O and M) practices for good plant performance and life assurance. Much of the initiative lies with the owner-operator; but effective vendor partnership with plant owners can provide important benefits to operating units. Attention by designers to O and M issues, and feedback of operating experience to design, is a source of valuable improvements for future projects. Historically, the CANDU Pressurized Heavy Water Reactor (PHWR) line has evolved by a successful partnership between AECL, the designer and developer, and the operating utilities. Now that the CANDU family of nuclear plants is a broad-based, diverse group, AECL is emphasizing activities and partnerships through engineering and R and D both to reduce operating costs for new plants, and to support existing plants. This paper describes these activities, with examples of how these will add provision for excellence in Operations and Maintenance.

The most recent generation of CANDUs, which entered service in the mid to late 1980s, have achieved consistently good capacity factors and similar measures of operational health (scram frequency, reportable events, etc.). The earliest generation of CANDUs from the 1970s has encountered more difficulties, reflecting to some degree the earlier stage of development of the technology. As with other classes of nuclear units, there are many examples of operating impacts which demonstrate the exacting demands placed on operations and maintenance, if excellent performance is to be achieved.

The latest CANDU 6 projects at Wolsong 2,3 and 4 (Korea) and Qinshan Phase 3 Units 1 and 2 (China)

incorporate lessons learned from the increasing body of operating CANDU experience. AECL follows the continuous improvement approach to its designs, and future design development will continue to adapt to such experience feedback. To give future customers assurance of excellent performance over full plant lifetime, much of this design emphasis is on improved provision for operations and maintenance.

Programs which contribute to this include: a comprehensive, structured process to deal with project, operations and other feedback; study of issues with impact on capacity factor and O and M cost, identifying initiatives in response; an integrated plant life management program in conjunction with CANDU 6 utilities; and strategic information technology applications installed at operating plants to improve support to station staff, sponsored by the CANDU Owners Group (COG).

2. EXPERIENCE FEEDBACK TO DESIGN

The fleet of operating CANDUs extends from the original commercial power plants which entered into service in the 1970s (Pickering A and Bruce A) to the second-generation CANDUs which entered service in the 1980s (Pickering B, Bruce B, Darlington and the 4 original CANDU 6 units). Updated CANDU 6 units have recently entered service at Wolsong 2 (1997), and Cernavoda 1 (1996). Further CANDU 6 units continue under construction at Wolsong 3 and 4, Cernavoda 2, and the two-unit Qinshan Phase 3 plant in China.

Since the initial years of operation of the first CANDU plants, AECL has reorganized the role of operational feedback and has participated in programs to respond to nuclear operating experience, both in R and D, and in engineering activities. These feedback and support programs are organized both as AECL-led activities and as activities sponsored by the CANDU Owners Group. COG is a cooperative group of AECL and the CANDU utilities which operates to facilitate cooperative information exchange, R and D, and joint projects.

The CANDU Owners Group has been operating since 1984. The COG information exchange program includes the CANNET station messaging network, which links AECL and all operating CANDU plants. CANNET provides a forum for stations to publish operating information and experience. This provides direct feedback to other stations, and also feedback to AECL, for analysis and recommendations, and also for input to future product improvements (see below for details of AECL's experience feedback program).

COG also sponsors frequent specialist meetings on topics of interest to CANDU station operators, and publishes regular bulletins collecting up to date information on station operating practices and experience.

In addition to the information exchange role, COG also sponsors an extensive R and D, program addressing topics of concern to station owners. This program addresses many operations and maintenance issues, such as improvements to steam generator inspection and cleaning; improvements to elastomer seal components, etc.

In addition to its participation in COG information exchange and R and D, AECL has established a comprehensive in-house experience feedback program. This is intended both to support operations and maintenance at operating plants and to provide input to design improvements for future plants. In this sense product "proveness" is something which is continuously re-established, by ensuring lessons learned from operations are systematically applied to design.

Feedback from CANDU and other nuclear plant operations is one part of AECL’s systematic process of feedback review. AECL’s feedback process incorporates regular, formal review of lessons learned from the following areas:

- NPP Operations;
- Both CANDU and non-CANDU plants construction and commissioning;

- Regulatory input (both Canadian and international);
- Results of R and D programs;
- Suppliers' input.

In addition, suppliers' input from other stakeholders, in particular utilities (both currently operating CANDUs, and utilities considering future NPPs) is sought to maintain a design which reflects customer requirements. This formal feedback process has been established with a broad mandate, covering all aspects affecting nuclear power plant design. Operations and maintenance implications are addressed, as well as impacts on the functional performance of the design. This design feedback process is closely linked to similar CANDU utility operations experience (OPEX) review processes. Design feedback is also an input to, and is closely linked to, initiatives to support CANDU plant life management and plant life extension (see below).

The formal process to review feedback, and incorporate lessons learned into design, is as follows:

- Feedback teams identify, review and perform first-cut evaluations. Teams evaluate feedback from operations, construction, commissioning, supply of equipment, regulatory agencies, research and development, and designers' experiences on ongoing projects.
- Design Feedback Managers and staff ensure that all feedback is entered in the CANDU feedback database for follow-up. All affected projects are informed and feedback is dispositioned, (i.e. implemented or rejected) with documented reasons.
- Each project reviews the feedback and develops strategies for implementation. The CANDU feedback database is available to all design staff, as an on-line resource via the AECL Intranet.
- When AECL's assessment of feedback information indicates that it is appropriate to forward this assessment to operating plants for action, this is done by preparing Station Information Bulletins or Advisory Notices with analysis and/or recommendations. This, in-depth feedback assessment complements the at-the-time direct information exchange through the COG CANNET system.

Recent examples of operations input to design which have proceeded through the feedback process to design improvements include:

- Steam generator operational improvements such as provision of additional access parts for chemical cleaning and improved divider plates for long life performance;
- ECC simplifications and performance improvements including strainer design for long term circulation of cooling water;
- Control room improvements to display annunciation organization and overall human factors as per feedback from operations staff;
- Reduced plant emissions by optimization of reactor building airflow including addition of inlet dryer;
- Improved safety system signal monitoring with updated digital displays, increased computerized testing for reduced operation burden and increased system reliability;
- Improvements to liquid relief valve component and system design for heat transport pressure and inventory control, based on operational experience;
- Updated equipment technical specifications, based on manufacturers and ongoing project feedback, to reflect up-to-date materials, manufacturing processes and standards, including adoption of international standards such as ISO);
- Improvements in construction sequencing and detailed equipment layout to assist project schedule reduction;
- Increased reactor overpower trip margins via improved instrumentation accuracy and optimized fuel management schemes.
- The feedback process generates a stream of minor change recommendations each of which will

improve either manufacturing, installation, operations, or maintenance, for the standard CANDU designs.

3. CAPACITY FACTOR IMPROVEMENT STUDIES

AECL is carrying out a systematic review of the various causes of plant incapacity, to determine implications for design, and also to support utilities in their activities to improve operations and maintenance effectiveness. This review complements and strengthens reviews carried out by the various CANDU owners. The work will identify areas of the plant where increased attention to preventive maintenance, or improved equipment calibration, will reduce downtime or reduced-power operation durations. It will also provide a framework to evaluate design improvements aimed at increasing capacity factor.

Major items of equipment such as steam generators and fuel channels, which can be a source of specific problems affecting capacity factor, are addressed through their own R and D programs, sponsored by COG. Results from these and other joint programs lead to specific recommendations regarding monitoring and surveillance inspection for equipment, and to recommendations for improved maintenance techniques.

4. PLANT LIFE MANAGEMENT

As described in a companion paper (1) AECL has formulated an integrated program, to be carried out jointly with CANDU utilities, to address plant life issues. This integrated program will cover safety, performance, and economic aspects.

Current maintenance programs at CANDU plants are a combination of corrective and preventive maintenance practices. As plants age, a shift in maintenance strategy is need to move to predominantly preventive maintenance, in order to prevent a trend to declining performance. To do this effectively and at reasonable cost, maintenance of critical equipment needs to be planned based on a detailed assessment of equipment needs.

In the early 1990s, plant life management considerations for CANDU 6 led to the development of a joint utility program focusing initially on 12 major critical components. These components were selected on the basis of their high cost of replacement and/or extended outage requirements for repair or refurbishment. These studies are currently underway and while the degradation mechanisms and analysis results may be common to all CANDU plants, the mitigating strategies are in some cases plant-specific, based on the environment and service conditions. So far, two assessments have been completed, covering the reactor itself and the containment building structures.

The plant life management program is now being expanded in cooperation with the CANDU 6 utilities to carry out a more comprehensive assessment of the critical systems, structures and components (SSCs). The capacity factor review identified the lack of a comprehensive maintenance program as a contributor to declining performance at some of the early CANDU units. The objective is to develop an integrated plant aging management program which optimizes the plant inspection and maintenance program for critical systems. This program is intended to anticipate and mitigate aging effects which could impact on plant safety and economic viability. It is also intended to identify new methods and technologies which can be used to maintain good equipment performance through maintenance. Existing utilities will benefit from this program through sharing of the development cost and sharing the lessons learned from CANDU plant studies. This cooperation also provides an opportunity for the adoption of common mitigating programs as well. Lessons learned will then be transferred to new design through the experience feedback process.

5. INFORMATION TECHNOLOGY TO SUPPORT OPERATIONS

The introduction of increased use of information technology to design and project delivery activities, is also

generating opportunities to improve the support to plant operations and maintenance, by improving ability to manage the as-built and as-maintained plant, by improving ability to manage the as-built and as-maintained configuration of the plant. Information technology can also greatly improve the ability of the station staff to assess equipment status information and make appropriate O and M decisions.

5.1 Plant Configuration and Maintenance Systems

AECL is developing methods and tools to integrate existing electronic systems, such as the 3-D CADDS and linked databases, electronic documents used in design, and the real-time plant human-machine interface information systems at the operating plant, to create an integrated plant configuration and maintenance support system. Existing information technologies for new CANDU projects consist of two technology groups:

a) An extensive compliment of integrated 3-D CADDS design tools, electronic documents and automated design processes, and

b) Real-time computer systems that provide the plant controls, the human-machine interface and a portion of the plant protection system.

The technology group being developed from these existing groups consists of information technology modules under joint development by AECL and operating Canadian utilities (sponsored by the CANDU Owners Group) and R&D programs funded by AECL, to create plant configuration and maintenance systems. Development is in three parts:

5.1.1 Design Configuration Control

This includes adaptation, for use during operations, of the CADDS and other electronic tools and automated processes used during design. This enables the utility to maintain precise control of the design and design basis. Instead of attempting to control the design configuration by controlling documents, the utility can control the baseline data from which the documents are constructed. This provides the opportunity for much more precise, error free definition of the plant hardware, and its design basis, than could be achieved using traditional document systems.

5.1.2 Real Time Computerized Information System

This includes development of a comprehensive set of real-time computer products that provide the operators and maintainers with on-line functions that include:

- Condition-based maintenance
- Critical safety parameter monitoring
- Control room alarm analysis and diagnostics
- Automated chemistry control, monitoring and diagnostics
- Component signature analysis
- Vibration and loose parts analysis
- Dynamic VDU graphical procedures using hand held computers
- Diagnostics based on frequency domain signal noise analysis
- Semi automated transmitter accuracy analysis and calibration

5.1.3 Operational Configuration Control

Successful management of the plant operational configuration is a key component of safe, reliable station operations. CANDU nuclear plants include a significant number of manually-operated devices not connected to the computer control and reactor protection systems. The operation of these devices on a

daily basis requires strict controls and procedures for safe operation and for provision of correct up-to-date status information. Efficient yet comprehensive work processes and information flow are needed for planning, tracking, and recording changes to the plant configuration. The status of each operable device must be immediately available to plan and execute future changes to the plant.

Historically, these activities are controlled using manual and administrative methods. The status of all operable devices is maintained on operational flow sheets located in the work control area of the main control room. Coloured pins, dots, labels, and other mark-ups are used to indicate the current operational status—including device and equipment status, jumpers, and work protection tags. Traditionally, the operational flow sheets are used to plan and develop Operating Orders (OOs) or Orders-to-Operate (OTOs) and the control centre work processes are used to manage their execution. After performing each OO procedure, the operational flow sheets are updated to reflect the new plant configuration. Overall, this process can be very time consuming, and due to the manual processes, can lead to the potential for time lags and errors in the recording of the current plant configuration.

Canadian CANDU utilities (COG) and Atomic Energy of Canada Limited, have applied modern information technologies to develop a prototype computer-based Equipment Status Monitor (ESM) to address processes and information flow for efficient operational configuration management. The prototype is undergoing trials and further development in operating CANDU stations.

The ESM integrates electronic operational flow sheets, equipment databases, engineering and work management systems, and computerized procedures to assess, plan, execute, track, and record changes to the plant's operational configuration. Figure 1 illustrates some of the key functions performed by this system in six different operational areas of a CANDU plant.

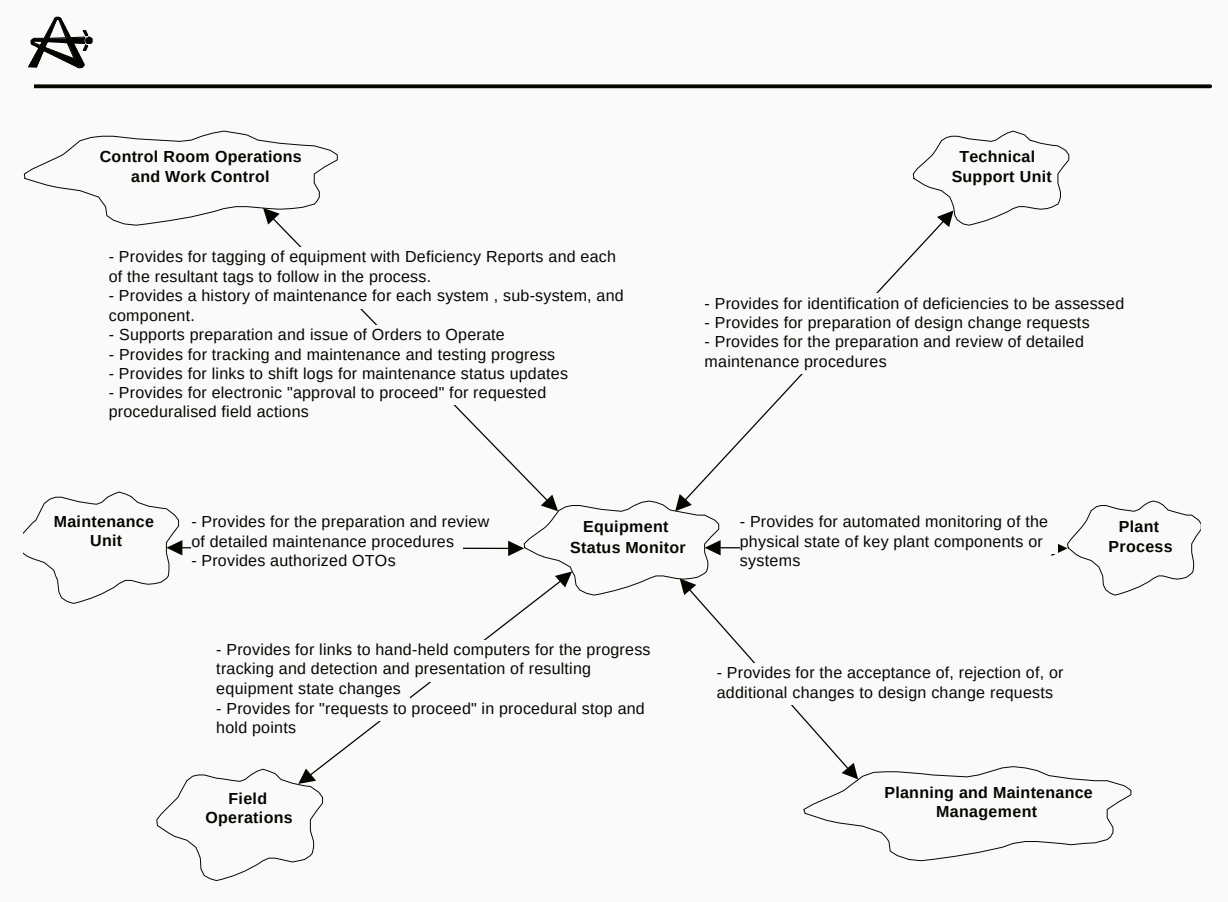

Figure 1 Equipment Status Monitor - Operational Context

6. EXAMPLES OF IMPROVED O AND M PROVISION

The various programs described above, complemented by the extensive COG-supported CANDU R and D program, are leading to numerous improvements in O and M technology for existing CANDUs, and to design features in future CANDU projects which will further support O and M effectiveness. In addition to examples noted above, some further improvements to operations and maintenance arising from these programs, include:

6.1 Support For Existing Plants

- Fitness for service guidelines have now been established for fuel channels and steam generators, to guide utilities in long-term management of these components. In addition, through the CANDU Owners Group, numerous NDE, inspection and maintenance techniques have been established to guide the operators.
- AECL has identified more precise chemistry control specifications for the primary and secondary coolant circuits which minimize the potential for equipment corrosion or crud buildup. This will support long-life operation of steam generators.
- Through R and D carried out at AECL's Chalk River Laboratories, improved longer-lasting elastomer seal materials have been developed for components such as airlock seals. This reduces the equipment maintenance burden for seal inspection and change-out.

6.2 Improvements For Future Projects

AECL's targets for future CANDU designs (for example, the state-of-the-art CANDU 9 design) include achieving a 60-year plant life with 85% capacity factor. In support of this, AECL's product development emphasizes improvements which improve O and M effectiveness. These improvements are based on the evolutionary approach; by this means, individual items can be incorporated into the next CANDU project, once the rigorous demands of proof-testing are completed.

6.2.1 Improved Equipment Monitoring

Improved accessibility of information to the operators and maintainers will greatly improve their effectiveness. For example, expanded surveillance information monitoring equipment health, available both in the main control room and via plant-wide LAN to systems support engineers, allows maintenance intervention before equipment malfunctions.

Added to such improvements as instrumentation noise analysis will be detailed trend records on rotating equipment, and detailed, on-line monitoring of chemistry parameters. Information will be collected on a historical data analysis system, available on the plant LAN.

6.2.2 Advanced CANDU Control Centre

The Advanced CANDU Control Centre includes a state-of-the-art human-machine interface which permits plant operation by a single operator from a neutral console, supported by intelligent VDU displays. This control centre is supported by an Advanced CANDU Control and Information Display System, allowing improved maintenance information, as noted above, and also permitting on-line procedures for operations, maintenance and abnormal events.

This control centre and software support has been fully developed and proof-tested, using a full-scale, full-function control room mockup. It is now incorporated into both CANDU 6 and CANDU 9 designs for future projects.

6.2.3 Improved Fuel Handling

Improvements in layout allow automatic remote new fuel loading, from the service building through to the fuelling machines. This eliminates the need for any assistance to fuel handling inside the reactor building.

6.2.4 Improved Radiation Control

Numerous improvements to minimize (already low) heavy water leakage, contribute to both reduced heavy water upkeep losses, reduced occupational exposure, and reduced off-site emissions. These include leakage collection via fuelling machines for each refuelling operation; collection of all transient heavy water associated with spent fuel discharge; introduction of welded fuel channel-to-feeder piping connections; improvements to heavy water vapour recovery equipment and operating procedures**.**

7. SUMMARY

The AECL CANDU development program, supporting both CANDU 6 and CANDU 9 plant designs, includes a strong emphasis on enhancing operations and maintenance. Input from operations feedback, from plant life management and from ongoing R and D is all integrated into evolutionary design development. This input also provides a strong vendor capability to support operating CANDU plants, and results from these programs are being applied in many instances to existing plants. In addition, the programs will lead to a much improved operator and maintainer interface for future plants, built around an Advanced Control Centre and associated information technology applications.

REFERENCES

1. Shalaby, B.A, and P. Charlebois, "CANDU Plant Life Management Safeguarding the Investment", Pacific Basin Nuclear Conference, Banff, May 1997.