STRATEGY FOR COMPETITIVENESS AND RISK REDUCTION IN CANDU PROJECTS

S.K.W. Yu, J.M. Hopwood, K. Singh
Atomic Energy of Canada Limited
Canada

ABSTRACT

Future CANDU design will continue to meet emerging design and performance requirements as expected by the operating utilities, and will integrate new technologies into both the product features and work processes. This paper summarizes the strategy used to enhance competitiveness of the CANDU products and the measures introduced to minimize risk during project implementation. This strategy provides a balance between innovation and proven designs; and between the desire for safety and operational improvements and the cost to achieve the improvements.

Elements of this risk reduction strategy include feedback of lessons learned from operating plants, project experiences from previous projects, and replication of successful systems and equipment. Project implementation risk is minimized by up-front engineering and licensing prior to contract start.. Enhanced competitiveness of the CANDU products is ensured by incorporating improvements based on updated technology.

INTRODUCTION

Future CANDU design will continue to meet emerging design and performance requirements as expected by the operating utilities, and will integrate new technologies into both the product features and work processes. This paper summarizes the strategy used to enhance competitiveness of the CANDU products and the measures introduced to minimize risk during project implementation. This strategy provides a balance between innovation and proven designs, and between the desire for safety and operational improvements and the cost to achieve the improvements.

Most of the requirements for design improvements are based on a systematic review of current operating CANDU stations in the areas of design and reliability, operability, maintainability, and licensability. In addition, there is a continuing pressure to improve safety. This is partly in recognition of the greater risk associated with the increasing number of plants, but also to help reduce the public concern of risk associated with nuclear power plants.

One key factor that will ensure product competitiveness is to address issues that confront the operating utilities. Hence AECL applies a process to incorporate lessons learned from operating plants, and project experiences from the implementation or construction phase of previous projects. Due to the risk averse attitude of operating utilities, the strategy of evolutionary improvements, including the replication of successful systems and equipment will be a winning combination. Enhanced competitiveness of the CANDU product is assured by incorporating improvements based on updated technologies, including safety technology, the rapidly advancing information technology and the modern construction technology. Reduced project implementation risk is assured by up-front engineering and licensing prior to contract start.

EXPERIENCE FROM PLANT OPERATION AND PROJECT IMPLEMENTATION

Feedback System

AECL has taken an evolutionary approach in developing its current designs and has implemented a formal process of gathering and responding to feedback from operation, construction, commissioning, and from regulatory activities(1). The design feedback team ensures that all feedback is entered in the CANDU feedback database for follow-up. This CANDU feedback database is available to all design staff, online via the AECL Intranet.

Feedback from plant operations is being increasingly evaluated and collected in a systematic way. The lessons learned can be used as input to both the design process and the design features of the CANDU product. This build-up of knowledge and insights from operating experience will ensure that AECL is more effective in responding to future stations issues.

At the product development stage, AECL is working closely with its partners in the CANDU industry such as equipment manufacturers and construction companies. This will result in improved equipment specification and hence equipment performance, and provide a streamlined engineering and procurement interface.

Use of Proven Products

The approach adopted for the derivation of a single unit CANDU 9 from a multi-unit configuration is based on the successful experience acquired in the derivation of the single unit CANDU 6 from the multi-unit Pickering plant. A high level of standardization has always been a feature of CANDU reactors and all CANDU 9 key NSSS components (steam generators, coolant pumps, pressure tubes, etc.) are of the same design as those proven in service. The CANDU 9 control systems are designed with standardized equipment, thus reducing spare parts inventories and enhancing interchangeability. These features ease maintenance, reduce operating and maintenance costs, reduce occupational exposure and facilitate repair and replacement of equipment.

The CANDU 6 for Qinshan, China is based on the latest design being built in Wolsong, and includes improvements appropriate to the project.

UPDATED TECHNOLOGY IMPROVEMENTS

Safety Technology Improvements

CANDU 9 also features a simplified emergency core cooling system with improved reliability by the use of one way rupture discs and a floating ball inside the high pressure injection water tanks. This reduces the number of injection valves that are required to operate during accident conditions. A result of this design simplification is a drastic reduction in the operator time required to carry out the reactor header injection valve testing to demonstrate safety system reliability. The downtime resulting from rupture disc failure or heavy water leakage from ECC valves will be eliminated by the use of the reliable one-way rupture discs.

For CANDU 9, safety system computer functions are also enhanced. The CANDU 9 design uses and builds on the application of safety software verification established by the Wolsong 2,3,4 project. Improvements to the automated testing capability successfully introduced in the Darlington power plant are incorporated, to reduce the operator's burden in the on-line testing of safety system availability. The safety system monitor computer is provided with safety system signal monitoring and automated safety system testing functionality resulting in shorter test duration and a significant reduction in the potential for operator error.

AECL has been enhancing the performance of CANDU reactors under postulated severe accident conditions that go well beyond the normal design basis for nuclear power plants. The presence of the heavy water moderator surrounding the fuel channels effectively mitigates the consequences of postulated severe accidents. The reason for this is that, if primary and emergency coolant is lost from the system, heat is transferred out of the fuel channel and into the moderator water. From the moderator, heat can be transferred to the environment via the moderator water cooling system. This means that CANDU fuel does not melt even if both normal and emergency cooling are unavailable. In addition, the moderator is surrounded by a shield tank containing light water for biological and thermal shielding. In severe core damage accidents, where moderator cooling has also failed, the shield tank can absorb decay heat either from the moderator or from debris inside the calandria vessel, and would prevent the core from melting through to containment for tens of hours, until the water had boiled away. Therefore, in addition to the usual engineered safety systems in plants that meet international safety standards, CANDU reactors contain passive safety features that result from the inherent design of the reactor.

The CANDU 9 design has built strongly on these inherent passive safety features. For example, a large reserve water tank is located high in the reactor building and supplies water by gravity to various systems in the event of a severe accident. In particular, the tank provides severe accident prevention/mitigation by supplying water to the secondary side of the steam generators and to the primary system (in addition to the ECC), and makeup water to the moderator and shield tanks. Thus, even if the primary coolant, emergency core cooling system, and the moderator cooling system are all lost, water can be supplied from the reserve water tank to the moderator, removing decay heat for about three days via boil-off, and the severe accident would not progress to fuel melting during that time. If makeup water to the moderator and the moderator cooling system are both unavailable, then the moderator water would boil off over several hours, and the core would eventually collapse into the bottom of the calandria vessel. The shield tank water, supplied by the reserve water tank, would ensure that the debris is contained, again for about three days. Thus severe core damage accidents in CANDU 9 would progress very slowly, giving ample time for accident management and preparation of countermeasures.

Information Technology Improvements

The information technology advances which have revolutionized the business world have also created opportunities to improve operations and safety for future CANDU, and will provide the vehicle for reducing operation and maintenance costs.

The next generation CANDU control centre will provide improved operability capabilities(2). The use of advanced information technology in the nuclear control system design and in the control centre display, separate from the control system computers, will improve operational simplicity. The advanced CANDU control centre design will provide accurate, timely information and advice to station operators, enabling them to make correct, timely decisions, which is crucial to the safe and reliable operation of a nuclear power plant. In addition to providing a powerful plant wide database for monitoring purposes, these data can be processed using calculation capabilities in the computers to provide recognizable and readable output data on plant state information and plant state change information.

The CANDU 9 computer systems for control, plant display, testing and communications are provided with a “system health” display for the operator so that the location of a faulted instrument or device can be readily indicated and confirmed.

Improvement of the man-machine interface is a key factor in reducing the probability of operator or maintainer induced accidents. Human factors engineering practices are being followed in the plant design process. The systematic analytical approach to system design consists of requirement definition, function analysis, function allocation and task analysis to define operator information and information presentation requirements.

The CANDU 9 control centre design, incorporating the full set of advancements to the man-machine interface and the above advanced computer systems, is being proof-tested in a mock-up at AECL. This mock-up includes detailed event simulation, and will allow operator response procedures to be developed and tested during the up-front engineering of the CANDU 9.

Safety system monitor computers will provide automated safety system testing, resulting in shorter test duration with reduced opportunity for human error. All aspects of plant design for which there is an interface with plant personnel will incorporate consistent human factor considerations.

PROJECT IMPLEMENTATION RISK REDUCTION

Use of Advanced Engineering Tools

The design engineering for Qinshan project and for the basic engineering program for CANDU 9 utilizes advanced engineering tools such as 3-Dimensional Computer Aided Design (CADDS) tools, intelligent flowsheets and linked equipment databases, for better design quality. The 3-D CADDS model is used to decide the layout configuration and space allocations; to optimize the fabrication construction sequences; and to determine the use of prefabricated assemblies depending on the layout and complexities of the systems. The ability to thoroughly check the design, before construction starts, using powerful interference checking routines will avoid costly rework and delays. The enhanced presentation of the construction packages by CADDS will improve information transfer to construction and operating staff.

The design of components and reactor layout has been improved to allow many construction activities to proceed in parallel, or independently of each other. The 3D CADDS model allows us to extensively animate the assembly process to optimize the sequence and eliminate potential interferences. The model is also being used to establish improved material delivery requirements and to enhance the efficient use of site personnel.

Design and other engineering document production is another area where the implementation of advanced information technology will result in a enhanced document production process. A program has been developed that allows designers access to a common data catalog containing all the key design data values used for the technical documents. This not only allows better control of design changes, but also assists in providing consistent plant design data through document text linking, avoiding transcription errors.

For project management of the Qinshan project, AECL has implemented new systems that use a computerized engineering design and document management system to keep track of the engineering outputs and deliverables to suppliers and site construction groups, as well as project correspondences. The drawings for the construction of the Qinshan project are also managed by the same system. This is the first time that the construction aspect of a CANDU project has been computerized using AIM and TRAK application software. AIM is an electronic document storage system and TRAK, developed by AECL, is an electronic document package production system.

Use of Improved Construction Methods

The incentive to shorten the construction duration is substantial and many tools and techniques are available to the constructor to allow selection of the optimum combination. The shortening of the schedule is balanced against overall project cost, while improving product quality. There has been considerable success with reduced schedules using new construction methods in recent power plant constructions.

In order to shorten the construction period compared to previous projects, use of many proven tools and techniques, and construction methods such as "Open Top" construction, Prefabrication, Parallel Construction Techniques and use of 3D CADDS are incorporated. For the Qinshan project, the 3D CADDS system has been established for use in the project design engineering work that includes generating plant design and layout as well as producing engineering packages for construction. In addition, open top construction method has been adopted in order to reduce construction schedule risk and to achieve the short project schedule.

The constructor can visualize and animate various construction scenarios, and evaluate conflicts, risks and critical path events using the 3D models. This is invaluable in developing the optimum construction scheme and schedule. Use of this tool for up front planning for detailed construction sequences in specific areas improves material delivery and ensures the most efficient use of manpower and resources.

As a result of these activities, the construction period for CANDU 6 has been shortened by at least 7 months compared to conventional construction methodology. For CANDU 9 we expect to continue to optimize constructability of the plants through component simplification, advanced materials, increased use of computer applications, increased modularization, and optimization of the human resources.

Special features related to constructability are incorporated in the CANDU 9. The design includes a site and building layout that promotes efficient construction, and the application of design approaches that facilitates modern construction methods and techniques. In addition to full implementation of open top construction, prefabrication of structures and assemblies are used.

"Open Top" Construction

The "Open Top" method of construction allows access to the entire interior of the reactor building from outside the perimeter walls. Equipment is moved through the top of the reactor building, rather than the traditional horizontal technique, by using a large, very heavy lift crane. This easy access saves considerable time in the schedule. For example, a steam generator can be installed in one or two days as compared to two weeks for the traditional access method. The CANDU 9 construction sequence is shown in Figure 1.

Open-Top construction significantly shortens the construction schedule. Work sequences are more efficient because activities which previously had to be conducted sequentially can now be carried out independent of one another. The construction schedule for the CANDU 9 utilizes the open top construction technique using a very heavy lift (VHL) crane. Major lifts of equipment for open top installation will result in a significant reduction in the construction schedule by eliminating or minimizing the duration of activities that are on the critical path, and will maximize the efficient use of the VHL. The benefits of this methodology in reducing the construction schedule were exemplified during the construction of many nuclear power plants around the world and the Darlington generating station.

The Darlington nuclear generating station experience indicated that VHL cranes can be also utilized for additional lifts in order to facilitate installation of many components and equipment. These lifts are determined during the detailed construction planning of the project. For example, it was originally planned to use the VHL crane at Darlington for only lifting the steam generators but as the benefits of using the VHL crane became apparent during construction, more than 60 lifts of other pieces of equipment and components that had not been originally part of the construction plan, were installed using the open top method.

Prefabricated Assemblies

CANDU 9 has been designed to make extensive use of pre-fabricated assemblies, that can be manufactured off site, and assembled into larger units on or off site. This reduces the amount of work and congestion within the plant, which is particularly important within the critical path areas. Many systems are designed to be incorporated into skid mounted assemblies which can be installed in rooms during the civil program thus saving costly time in the schedule.

With parallel construction techniques, the mechanical program is integrated in concurrent work areas with the civil program. Work progresses in three key reactor building areas at the same time. These techniques significantly reduce the mechanical work needed after the civil program is completed.

Up-front basic engineering and licensing approval

Even with the cumulative experience in previous CANDU 6 projects, a pre-project team was put together before and during contract negotiations to reduce project implementation risks for Qinshan. The pre-project team tasks included: standardization of document production and control tools, demonstration and documentation of the process for generating construction documents, and definition and agreement of common project tools and interfaces between main contractors and sub-contractors. In addition, the design documentation was updated for new project requirements and or new site conditions.

For CANDU 9, an up-front engineering and licensing review program was initiated to reduce project risks(3). A three year basic engineering program was started in 1995 after completing the design definition. The CANDU 9 basic engineering program objective is to perform sufficient up-front design engineering so that the detailed design is sufficiently defined that the systems can be adequately modelled in safety analysis. Hence the basic engineering program has a comprehensive work schedule to prepare design requirements and design descriptions for key systems, design methods (e.g., for safety critical software), safety analyses, probabilistic safety analysis, and other program documents such as quality assurance, decommissioning, safeguards, and security requirements. This CANDU 9 basic engineering program started in 1995 January is scheduled to be completed by 1998 March.

In addition to improvements highlighted in earlier sections on technology improvement, additional changes were made to meet the evolving licensing requirements:

- a more rigorous application of the basic safety philosophy,
- the steady development of knowledge about the accident behaviour of CANDU plants,
- resolution of outstanding safety and licensing issues, and
- introduction of human factors considerations during design of the plant

A key element of the basic engineering program was the 2 year CANDU 9 licensability review by the Canadian regulatory authority, AECB, completed in January 1997. The concluding statement of CANDU 9 licensability review stated that "AECB staff conclude that there are no fundamental barriers to CANDU 9 licensability in Canada." Although the CANDU 9 design is based on that of operating CANDU plants, AECL expected that both domestic and foreign potential customers would require evidence of current licensability in the country of origin (Canada). Such evidence would dramatically reduce the risk of licensing-induced design changes once a project had been committed. It would also assure customers that the CANDU 9 had had thorough independent review. An intensive "up-front" licensing process was therefore established to give this assurance.

Thus, in reaching the conclusion that there are no fundamental barriers to licensability in Canada, and in the acceptance that the CANDU 9 design complies with the most recent regulatory requirements in Canada, the CANDU 9 designers can point to the successful application of "up-front licensing", and prospective owners can take comfort in the consequential reduction of licensing risk to the project.

CONCLUSION

The evolutionary improvement approach adopted for CANDU product development ensures updated design to meet customers' requirements. This includes feedback from lessons learned from operating plants and incorporation of new enhanced design features based on new technologies. The use of advanced engineering tools and modem construction methods will reduce project implementation risk on project costs and schedules. The up-front attention to details through pre-project engineering and licensing ensures product quality and licensability.

REFERENCES

1. Allen, P.J., J. M. Hopwood and G. P. Rousseau "Learning From Experience Feedback to CANDU Design", CNA 1997
2. MacBeth, M.J. and N.M. Ichiyen. "Advanced CANDU Control Centre", NUTHOS Conference 1997
3. Snell, V.G. and J.R. Webb. "CANDU 9 - The CANDU® Product to Meet Customer and Regulator Requirements Now and In the Future" PBNC 1998

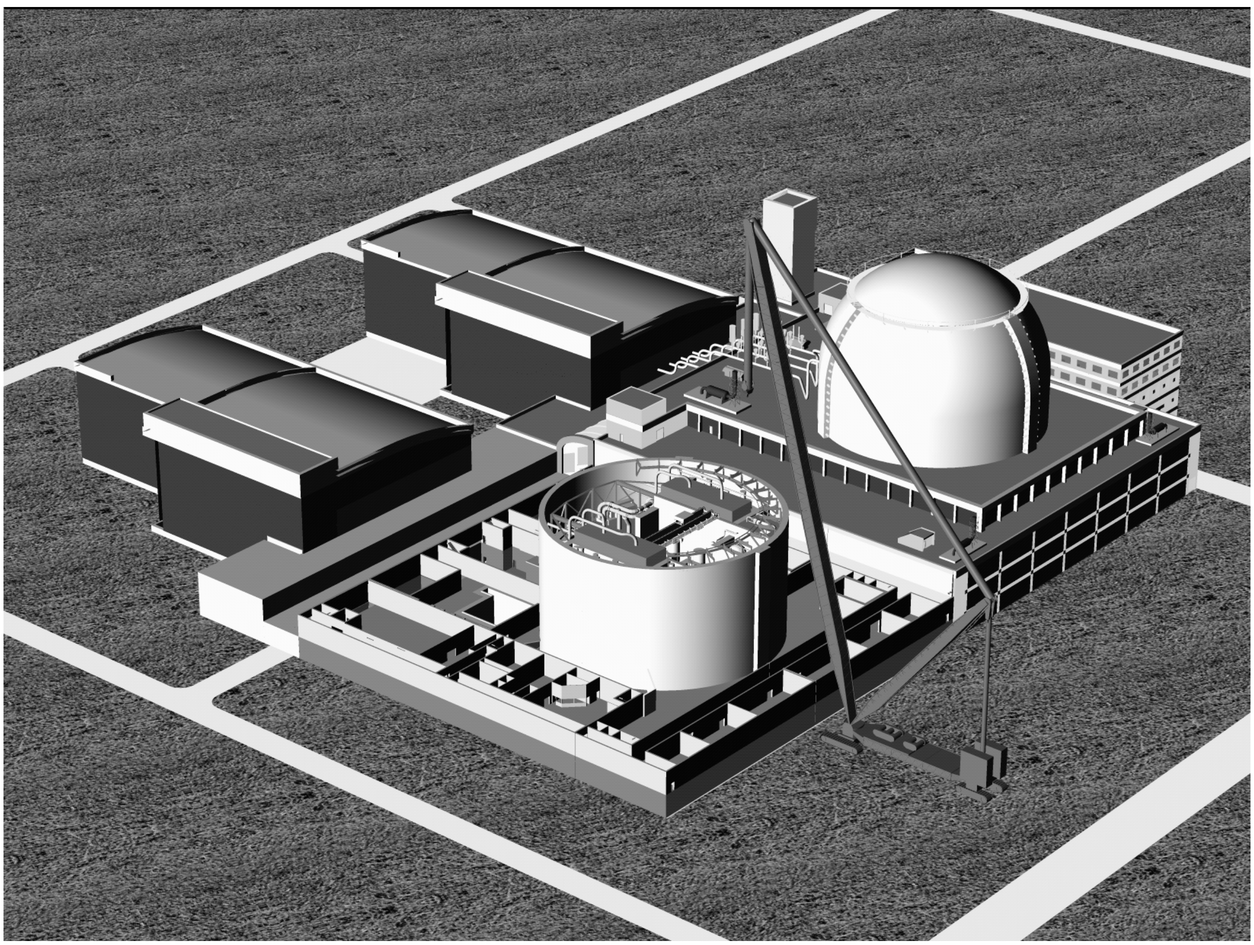

Figure 1 3D CADDS model of the construction of a 2 unit CANDU 9 station