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North American Policies and Technologies
ELECTRICITY
Transmission & Distribution
THE ELECTRICITY FORUM
TODAY

Where Utilities are Turning for New Generation

Dispelling Myths Associated with Spread Spectrum Radio in SCADA Networks
Page 8

Fall Transformer Report
Study and Design of Power Plant Transformer Explosion and Fire Prevention
Page 38

Controlling Coal Combustion and Emissions - Page 20

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AECL LOOKS TO THE FUTURE WITH THE ACR-1000

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In North America and around the world, the demand for clean, safe and reliable baseload electricity will grow dramatically over the next decades and nuclear power technology — with newer, safer, more economically competitive designs — is poised to play a major role.

Atomic Energy of Canada Limited (AECL) is the designer/developer of the CANDU® nuclear reactor and has been building nuclear plants for more than 40 years. CANDU units are operating successfully in Canada (Ontario, Québec and New Brunswick), South America, Asia and Europe. AECL's recent plant construction has been focused on its 700-MWe-class CANDU 6 plant — with projects ongoing from the late 1970s to now.

To meet upcoming needs, AECL has now designed a Generation III+ plant — the Advanced CANDU Reactor®, ACR-1000® — adapting the successful features of the CANDU reactor and incorporating innovations. The basic design is complete and the ACR-1000 is already in full project mode.

The ACR-1000 was chosen this year for generic design assessment in the United Kingdom. Additionally, there are active ACR-1000 new-build initiatives in Canada — in Ontario, Alberta and New Brunswick. Energy Alberta Corporation has recently applied to Canada's nuclear regulator, the Canadian Nuclear Safety Commission (CNSC), for a site licence for up to two ACR-1000 units.

CANDU technology is inherently amenable to localization because the key components of the CANDU reactor core comprise a large number of small, identical fuel channel components. For Canadian ACR-1000 projects, for example, 90% of equipment, supplies and services can be sourced domestically.

Figure 1: ACR-1000 twin-unit plant

EVOLUTIONARY PRODUCT

The ACR-1000 is a 1200-MWe-class nuclear power plant with a 60-year design life. It is a light-water-cooled, heavy-water-moderated pressure-tube reactor which has evolved from the well-established CANDU line. It retains basic, proven CANDU design features while incorporating innovations and state-of-the-art technologies to further enhance safety, operation, performance and economics. Many of the innovations were developed using experience and feedback gained in the design, construction and operation of top-performing CANDU 6 reactors operated by utilities around the world.

Key CANDU strengths retained:

- modular, horizontal fuel channel core;
- simple fuel bundle design;
- separate low-temperature and low-pressure heavy water moderator;
- passive safety features including reactor vault filled with light water surrounding the core and two independent, passively driven, safety shutdown systems;
- on-power refueling;
- reactor building access for on-power maintenance.

ACR-1000 innovations:

- more compact core design;
- steel-lined, 1.8-metre-thick containment building, to withstand aircraft strike;
- light water reactor coolant, reducing heavy water inventory and resulting in lower costs and reduced emissions;
- thicker pressure tubes and thicker and larger calandria tubes;
- stainless steel feeders and headers;
- mechanical zone control rods, solid-rod guaranteed shutdown state, no adjusters;
- use of low-enriched uranium (LEU) fuel, in advanced CANFLEX®-ACR® fuel bundles, to help achieve negative void reactivity;
- option to efficiently burn other fuel types such as mixed oxides (MOX), thorium and actinides;
- improved plant thermal efficiency through use of higher pressures and temperatures in the coolant and steam supply systems;
- enhanced accident resistance and core damage prevention features;
- further enhanced passive safety;
- customer-driven improvements in operability and maintainability, with designed-in maintenance features;
- distributed control system/plant display system; modern control centre incorporating human factors;
- improved plant performance through SMART CANDU™ advanced on-line diagnostic systems;
- four-quadrant design: essential operating and safety systems separated into four divisions; permits on-line maintenance, flexibility during outages.

These technical improvements, along with system simplifications and advancements in project engineering, manufacturing, and construction, result in a reduced capital cost and construction schedule, while enhancing the inherent safety and operating performance of the ACR-1000 design.

All innovative features of the ACR-1000 have been or will be fully tested and proven before the first project. Because of this — and because 80% of plant features, equipment and specifications, are based on the successful CANDU 6 reference plant — the initial ACR-1000 build project will be executed with a high degree of confidence.

Figure 2: Cutaway of ACR-1000 showing four-quadrant design

ENHANCED SAFETY AND SECURITY

The ACR-1000 is laid out to provide separation by distance, elevations and the use of barriers for safety-related structures, systems and components. Each corner of the reactor auxiliary building houses redundant safety equipment in a four-quadrant design, with quadrants separated by three-hour fire barriers.

The ACR-1000 design takes advantage of both passive and engineered safety characteristics, including distinctive features that arise from CANDU design principles. The core is designed for a small negative reactivity coefficient. This feature provides inherent protection against transients with any inadvertent increase of reactor power, while limiting complexity in engineered systems and operating procedures that deal with large reactivity swings.

Central to ACR-1000 safety are two fast-acting, fully capable, diverse and separate shutdown systems, physically and functionally independent of each other and also from the reactor regulating system. Based on proven CANDU technology, each shutdown system is designed to cover the whole spectrum of design-basis events and to perform its safety functions with a high degree of reliability. Additional defence-in-depth is derived from the inherent passive-safety features of the CANDU fuel channel core, including extra heat sink redundancy for potential accident conditions.

Security and physical protection have been addressed to ensure that the response to potential common and abnormal events meets latest criteria. The ACR-1000 containment is designed to withstand external events such as earthquakes, tornadoes, floods, aircraft crashes and malevolent acts. The plant is designed for an exclusion zone of 500 metres.

Figure 3: ACR-1000 advanced control room

IMPROVED OPERABILITY AND MAINTAINABILITY

The design-basis lifetime capacity factor for the ACR-1000, over the operating life of 60 years, is greater than 90%, and the operating year-to-year capacity factor is greater than 95%. The high average annual output is achieved by a low forced loss rate of less than 1.5%.

AECL-designed and -built CANDU 6 units are already achieving a lifetime capacity factor of 88.1%, and the combined average for 2006 was 92.4%. Also, the newer Ontario Power Generation and Bruce Power multi-unit CANDU stations are operating well, with annual capacity factors well in excess of 90%.

Key to meeting or exceeding performance targets has been direct feedback provided by CANDU plant operators on how to enhance operability and facilitate maintenance. This has allowed new features to be designed into the plant to reduce operating risk. Use of data on CANDU operating experience provided by the CANDU Owners' Group network (COG) has also been applied.

Designed-in, on-line inspection and maintenance has revolutionized the ACR-1000 outage strategy. The traditional outage of up to one month has been improved for the ACR-1000 to one planned outage every three years, with a standard duration of 21 days. For Plant Life Management (PliM) purposes, the reactor design supports a planned, mid-life, extended outage for replacing the pressure tubes.

The ACR-1000's outage philosophy is based on replacement and not repair, with the requirement for a significant inventory of spare parts. Removed parts will be repaired after the outage in preparation for the next outage. The use of a solid rod Guaranteed Shutdown State (GSS) enables rapid entry into outage work conditions and provides faster return to power following the outage.

Load following and daily load cycling capability are facilitated by enhanced control schemes - due to the use of solid control rods - and CANDU's ability to refuel on power. On-power refuelling minimizes excess reactivity in the core and provides an inherent ability to manage load changes and provide better reactor control. These changes in operation are subject to further design work as well as to Canadian Nuclear Safety Commission agreement in Canada.

The ACR-1000 also has station blackout capability, ensuring a rapid return to full power on restoration of electrical grid. It can supply the unit's services from the grid or the turbine generator and also has two independent, on-site standby power generation facilities.

Other important aspects of the ACR-1000 that enhance operation and facilitate or minimize maintenance include:

- improved, long-life materials and experience-based plant chemistry specifications;
- advanced control room based on human factors engineering allowing "control from the console", with restricted traffic flow and clear sight-lines to Large Screen Displays;
- computerized testing of major safety systems and automatic calibration of in-core detector control systems;
- improved plant performance through integrated SMART CANDU modules, which provide on-line health monitoring and diagnostics for plant chemistry, predict future performance of components, determine maintenance requirements and optimal

operating conditions and ensure maximum power output;

• on-power maintenance strategy, maximizing component life and minimizing component replacement time, thus reducing radiation exposure, maintenance costs and staff requirements;

• improved plant layout, with a permanent elevator, walkways and platforms and provision for electrical, water and air supplies built in for on-power and normal shutdown maintenance;

• increased shielding in radiologically controlled areas, reducing worker exposure and occupational dose.

ACR-1000 DESIGN STATUS

The successful CANDU 6 fleet is the foundation for the ACR-1000 design. The ACR-1000 program focus is to plan and execute work based on risk analysis, assessment and mitigation, ensuring licensability and addressing customer input, to achieve an in-service date of 2016. The program plan is project-based and will ensure that all required documentation is available to support the Environmental Assessment and Site Preparation and Construction Licence applications. All design documentation will be completed prior to construction.

The ACR-1000 program is being managed as a full-scale project, under AECL's Commercial Operations group. New technology input has been confirmed and the licensing basis has been established. All elements of the detailed engineering program are in progress and project risk management processes and procedures are in place. The Preliminary Safety Case Package (PSCP) will be submitted in 2008 and the Preliminary Safety Analysis Report (PSAR) for a site construction licence is scheduled for 2010.

The Level 3 production schedule — covering the detailed engineering program together with completion of the remaining R&D work and licensing activities, and comprising more than 10,000 activities — has been issued and is being carefully tracked.

Figure 4: Very-heavy-lift crane and open-top, modular construction at Qinshan Phase III, China

LICENSING BASIS

The design of the ACR-1000 systems, structures and components is based on the CANDU 6 and Darlington nuclear steam plants (NSPs). Minimal manufacturing and supply changes are anticipated due to the similarities of major NSP equipment and components for the ACR-1000 and CANDU 6. Major equipment and components have been proven through many years of continuous operation of 10 CANDU 6 plants. A proven licensing and safety basis builds on 40 years of CANDU licensing experience in Canada and around the world. The Balance of Plant (BOP), comprising 40% of total plant equipment, is a scale-up of the proven CANDU 6 BOP.

The ACR-1000 is designed to meet regulatory requirements in Canada and other countries. Its design:

• is developed to meet the Canadian Nuclear Safety Commission's new requirements for new reactors;

• fully complies with the IAEA's NS-R-1, which is the International Atomic Energy Agency's (IAEA) Safety Standard for the Design of Nuclear Power Plants;

• meets Canadian and international requirements for international nuclear plant siting;

• incorporates international codes and standards, as they apply;

• has benefited from pre-licensing review by the US Nuclear Regulatory Commission.

ONGOING TECHNOLOGY AND PLANT SUPPORT

The ACR-1000 is an evolutionary design and enhancements have resulted from extensive AECL efforts in code validation and R&D on reactor and fuel design and materials properties, as well as operations and maintenance input provided through COG. Comprehensive R&D facilities at AECL's Chalk River Laboratories in Ontario remain instrumental to the success of the new Generation III+ ACR-1000 and continue to assure ongoing support to operating CANDU reactors worldwide.

CONSTRUCTABILITY AND PROJECT IMPLEMENTATION

Maximum use of modularization and "open-top", parallel, construction — which have already been demonstrated at the Qinshan Phase III units in China, both delivered under budget and ahead of schedule — are key to AECL's ACR-1000 project model.

The plant layout is also designed to achieve the shortest practical construction schedule while facilitating maintenance. Buildings are arranged to minimize interferences during construction, with allowance for on-site fabrication of module assemblies. The footprint of the two-unit plant is minimized with the adoption of common areas for the main control room and service and maintenance buildings.

Advanced integrated project management tools have also contributed significantly to AECL's successful project performance. These include:

• Intergraph 3-D plant modeling and design;

• TRAK electronic document management systems;

• CANDU Materials Management System (CMMS) supply chain management system;

• IntEC wiring design and management system.

AECL has assessed and qualified internationally renowned manufacturers and suppliers of nuclear and conventional equipment and materials. These form the foundation of the supply base for new-build projects, enabling AECL to obtain highly competitive pricing and delivery terms from a variety of sources.

SUMMARY

AECL's CANDU reactor has evolved to the next generation. The new ACR-1000 design retains basic, proven, CANDU features while incorporating key innovations and state-of-the-art technologies. Safety has been further enhanced and AECL has placed a major focus on constructability, operability and maintainability, to ensure that the plant's performance and economics are optimized.

With the basic design complete, first site construction licence scheduled for 2010, a target in-service date of 2016 and real interest from customers in Canada and abroad, the ACR-1000 gives AECL a challenging and exciting future.

Canadian-made CANDU® nuclear technology is lighting up the world—and brightening Canada's future.

A $5 billion per year industry, CANDU technology provides employment for thousands of Canadians in more than 92 companies. And the building of new CANDU technology in Canada could contribute $30 billion to our GDP over the next 20 years.

Together, Team CANDU®—a consortium of five leading nuclear companies—can help Canadians meet our power needs.

Emissions-free electricity. Brighter employment prospects. An energized economy.

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