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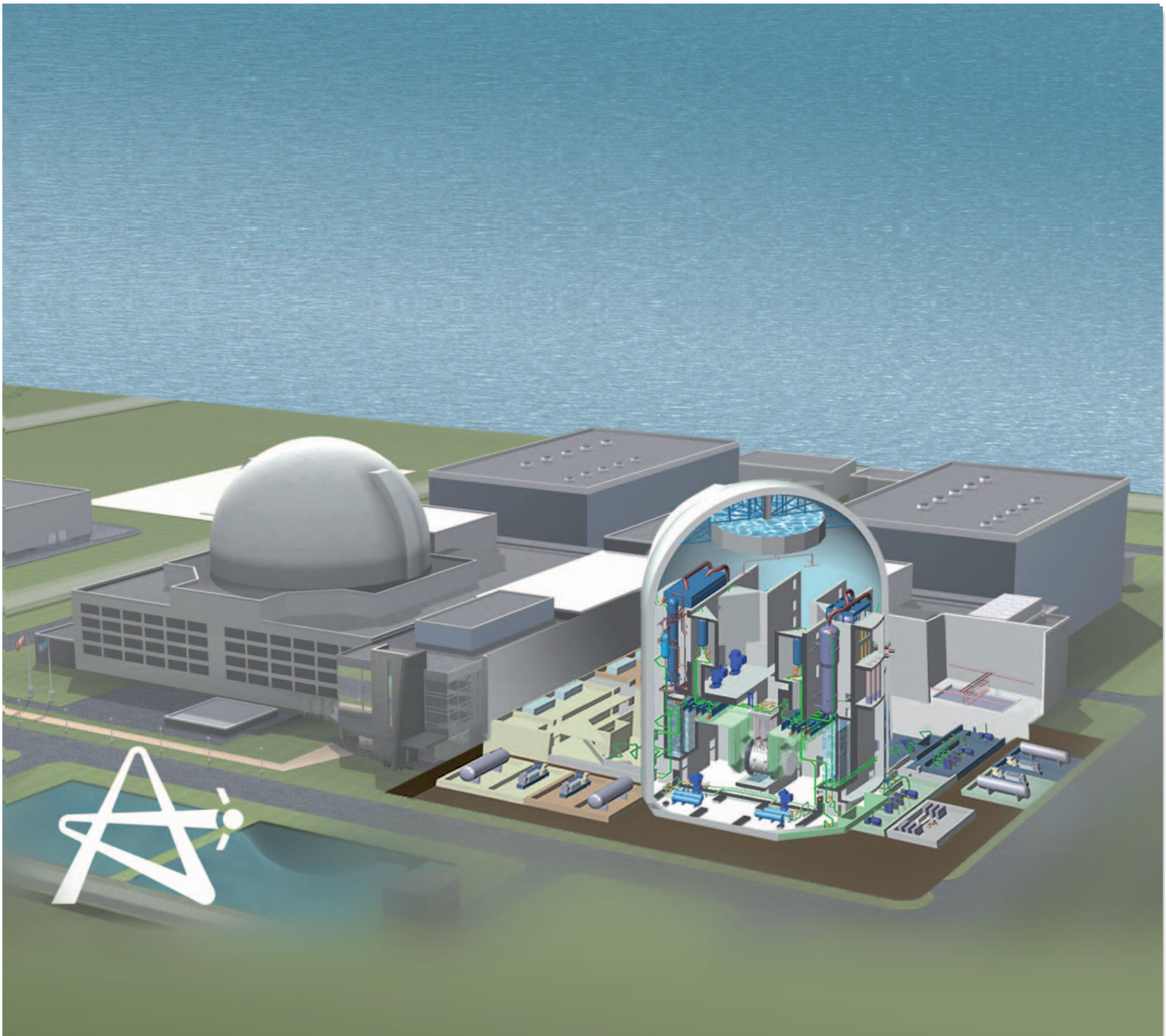
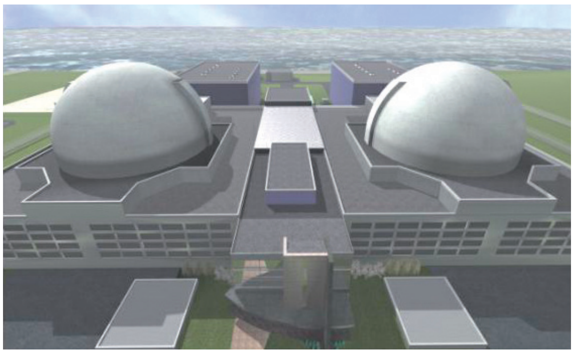


ACR-1000
READY FOR THE MARKET

Ready for the market



AECL has adapted the features of its Candu reactors in designing a Generation III+ plant – the Advanced Candu Reactor – to meet upcoming marketplace needs. ***By Ken Petrunik***

The basic design of AECL's Advanced Candu Reactor, the ACR-1000, has been chosen for generic design assessment in the UK, and there are active ACR-1000 new-build initiatives in Canada – in Ontario, Alberta and New Brunswick.

The ACR-1000 is a 1200MWe-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 optimise safety, operation, performance and economics (see Panel).

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. 80% of plant features, equipment and specifications are based on the Candu 6 reference plant.

ENHANCED SAFETY

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.

Enhanced defence in depth is derived from the inherent passive safety design features of the Candu fuel channel core, including:

- Feedwater makeup, providing passive gravity driven makeup to the steam generators *via* the large volume reserve water tank (RWT) located at the top of the reactor building to prevent failure of fuel and fuel channels and delay or prevent progression to severe accidents.
- Heat transport system (HTS) makeup supplied from emergency core injection system water tanks and from the RWT to prevent progress to a severe accident state; cools the fuel and keeps the HTS full.
- Moderator thermal capacity, absorbing heat and delaying accident from progressing beyond a severe accident state; conducts heat directly to the moderator if the pressure tubes make contact with the calandria tubes.
- Moderator makeup and thermosyphoning, designed to prevent a severe accident from progressing, for as long as there is water in the RWT.
- Water-filled reactor vault, designed to mitigate a severe accident (if all the above fail) by absorbing heat and preventing failure of the calandria vessel until reactor makeup or active cooling is re-established.
- Reactor vault makeup and thermosyphoning, designed to mitigate the consequences of a severe accident; this involves manually initiating reactor vault makeup from the RWT to establish and sustain thermosyphoning.
- Containment spray, initiated automatically to suppress the pressures and temperatures to within design limits.

PLANT LAYOUT

Designed for efficient operation, increased safety and easier and faster maintenance, 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 reac-

ACR-1000 features

Key Candu strengths retained

- Modular, horizontal fuel channel core.
- Simple fuel bundle design.
- Separate low temperature and 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 refuelling.
- Reactor building access for on-power maintenance.

ACR-1000 innovations

- More compact core design.
- Steel-lined, 1.8m-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 shut-down 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 oxide (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 online diagnostic systems.
- Four-quadrant design: essential operating and safety systems separated into four divisions; permits online maintenance, flexibility during outages.

ACR-1000 data

Containment structure

	CANDU 6	ACR-1000
Type	Pre-stressed concrete/epoxy liner	Pre-stressed concrete/steel liner
Reactor building inside diameter (m)	41.4	56.5
Containment wall thickness (m)	1.07	1.8
Building height (base slab to top of dome) (m)	51.2	74.0

Fuel

	CANDU 6	Darlington	ACR-1000
Material	Natural UO_2	Natural UO_2	Low enriched UO_2
Burnup (MWd/kgU)	7.5	7.8	>20 (reference)
Fuel bundle assembly	37-element	37-element	43-element Canflex-ACR
Bundles per channel	12	13	12

Heavy water inventory

	CANDU 6	Darlington	ACR-1000
Moderator system (Mg D_2O)	265	312	250
Heat transport system (Mg D_2O)	192	280	0
Total (Mg D_2O)	457	592	250

Heat transport pumps

	CANDU 6	Darlington	ACR-1000
Number	4	4	4
Rated flow (l/s)	2228	3240	4320
Motor rating (MWe)	6.7	9.6	11.5

Reactor core

	CANDU 6	Darlington	ACR-1000
Output (MWt)	2064	2657	3187
Coolant	Pressurised D_2O	Pressurised D_2O	Pressurised H_2O
Moderator	D_2O	D_2O	D_2O
Calandria diameter (m)	7.6	8.5	7.5
Fuel channel	Horizontal Zr 2.5wt%Nb alloy pressure tubes with modified 403 SS end-fittings	Horizontal Zr 2.5wt%Nb alloy pressure tubes with modified 403 SS end-fittings	Horizontal Zr 2.5wt%Nb alloy pressure tubes with modified 403 SS end-fittings
Fuel channels	380	480	520
Lattice pitch (mm)	286	286	240

Steam generators

	CANDU 6	Darlington	ACR-1000
Number	4	4	4
Type	Vertical U-tube/ integral preheater	Vertical U-tube/ integral preheater	Vertical U-tube/ integral preheater
Nominal tube diameter (mm)	15.9 (5/8")	15.9 (5/8")	17.5 (11/16")
Steam temp (nominal) (°C)	260	265	275.5
Steam quality	0.9975	0.9975	0.999
Steam pressure (MPa)	4.6	5.0	5.9

Heat transport system

	CANDU 6	Darlington	ACR-1000
Reactor outlet header pressure (MPa)	9.9	9.9	11.1
Reactor outlet header temp (°C)	310	310	319
Reactor inlet header pressure (MPa)	11.2	11.3	12.6
Reactor inlet header temp (°C)	260	267	275
Single channel flow (max) (kg/s)	28	27.4	28

Turbine generator

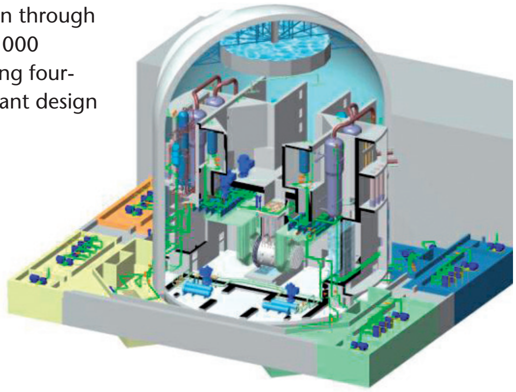
	CANDU 6	Darlington	ACR-1000
Type	Hitachi impulse-type, tandem-compound	Tandem-compound	Impulse-type, tandem compound
Composition	One double-flow high pressure cylinder	One double-flow high pressure cylinder	One double-flow high pressure cylinder
Net to turbine (MWt)	2060	2650	3180
Gross/net electrical output (nominal) (MWe)	728/666	935/881	1165/1085
Efficiency	35.3%	35.3%	~36.6%
Steam temp at main stop valve (°C)	258	263	273
Final feedwater temp (°C)	187	177	217
Condenser vacuum (kPa)	4.9	4.2	4.9

tor auxiliary building houses redundant safety equipment in a four-quadrant design.

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 layout is also designed to achieve the shortest practical construction schedule while facilitating maintenance. Buildings are arranged to minimise interferences during construction, with allowance for onsite fabrication of module assemblies.

The footprint of the two-unit plant is minimised with the adoption of common areas for the main control room and service and maintenance buildings. The plant is designed for an exclusion zone of 500m.



Section through ACR-1000 showing four-quadrant design

IMPROVED O&M

The design basis lifetime capacity factor for the ACR-1000, over the operating life of 60 years, is greater than 90%, and the design basis 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 in excess of 90%.

Direct feedback provided by Candu plant operators on how to enhance operability and facilitate maintenance 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 (COG) network has also been applied.

Designed-in online inspection and maintenance has improved the traditional outage of up to one month to one planned outage every three years, with a standard duration of 21 days. For plant life management purposes, the reactor design supports a planned, mid-life, extended outage for retubing.

Operability-enhancing features in the ACR-1000 include:

- Advanced computer control and interaction systems based on human factors engineering.
- Enhanced power manoeuvring capability to simplify reactor operation and make the ACR-1000 inherently more responsive; this includes load following and daily load cycling capability and lower xenon load following reactor power reduction.
- Station blackout capability, ensuring a rapid return to full power on restoration of electrical grid.

Other important aspects of the ACR-1000 operations and maintenance-based design include:

- Improved, long-life materials and experience-based plant chemistry specifications.
- Improved plant performance through integrated Smart Candu modules, which provide online 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, maximising component life and minimising 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.
- Computerised testing of major safety systems and automatic calibration of in-core detector control systems.
- Increased shielding in radiologically controlled areas, reducing worker exposure and occupational dose.

DESIGN STATUS

The successful Candu 6 fleet is the foundation for the ACR-1000. The ACR-1000 programme 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 programme will have all design documentation completed prior to construction.

The ACR-1000 programme 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 programme 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 programme 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.

LICENSING BASIS

The design of the ACR-1000 systems, structures and components is based on the successful Candu 6 and Darlington nuclear plants. Minimal manufacturing and supply changes are anticipated due to the similarities of major plant equipment and components for the ACR-1000 and Candu 6. Major equipment and components have been proven through many years of continuous operation of ten 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. It 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 remain instrumental to the success to the new Generation III+ ACR-1000 and continue to assure ongoing support to operating Candu reactors worldwide.

PROJECT IMPLEMENTATION

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

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

- Intergraph 3-D plant modelling 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 international manufacturers and suppliers of nuclear and conventional equipment and materials and these form the foundation of the AECL supply base for international projects.

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