Shift Manager Carol Lenestour (right) announces the synchronization of Bruce-4 to the Ontario electricity grid on October 7, 2003, ending an outage that lasted more than five years. (Photo: Bruce Power)

# The Canadian comeback

BY E. MICHAEL BLAKE

*Even as installed nuclear capacity has come to be seen as an asset worth maintaining and upgrading in the United States, the long-idled Bruce A and Pickering A reactors in Canada are being given another chance to prove their value on line.*

FOR MORE THAN five years, roughly one-third of Canada's operable nuclear generating capacity was idled. As troubled as the situation was for the United States nuclear community in the late 1990s, the situation in Canada at the same time appeared utterly bleak. Eight of the nation's 22 power reactors were out of service, with the understanding that the work needed to refurbish them fully and ensure smooth operation for years to come was simply too expensive to justify the effort. Because all of Canada's power reactors are CANDU units, it was easy to surmise that even the 14 reactors still running would eventually succumb to the same equipment and operational problems that had halted Bruce A and Pickering A, and that all Canadian reactors would be retired long before the end of their once-expected operational careers.

Yet look at Canada today. Two of the four Bruce A units are back on line, and an agreement to restart the other two has been negotiated and is working its way through the approval process in the Ontario provincial government. Pickering-1 —with the longest tenure of any power reactor in Canadian history, dating back 34 years—has received approval for restart from the Canadian Nuclear Safety Commission (CNSC). The rest of the Canadian fleet has been less troubled by the kind of systemic problems that plagued Bruce A and Pickering A. It is now widely accepted in official circles in Canada, and evidently supported by the majority of the populace, that a major step in curbing greenhouse gas emissions from fossil-fueled power plants is the restart of the nation's idled power reactors.

So what happened? How were the oldest CANDUs transformed from balky, unmaintainable money pits to valuable assets? Following is the story not of a renaissance—at least, not in the sense the word is used these days in the United States, because there is no expectation that Canada will move immediately from the restart of all idled reactors to the construction of new ones—but what may be called, given the end of the slumber of several power reactors, a reawakening.

## Enriched U vs. heavy water

About 50 years ago, the nations considering nuclear energy as a potential electricity source made decisions that influenced their embryonic nuclear programs for decades to come. The United States, with a nuclear weapons infrastructure already in place and experience with submarine reactors growing, decided that its existing capability in uranium enrichment would allow for practical power reactor designs in

Pickering-1, fourth from left, went critical in August, and will soon join Unit 4 (left) and Pickering B (the four units at right) in power production. (Photo: Ontario Power Generation)

which light water would both cool and moderate reactions from low-enriched fuel. Canada, with no weapons program but abundant uranium resources, decided to use natural uranium fuel with heavy water as a moderator. Not only was it easier and cheaper to produce heavy water than to enrich uranium, but at the height of the Cold War, enrichment technology wasn't readily available from those who already possessed it.

The results of these decisions were the commercialization of light-water reactors in the United States and of the Canadian Deuterium-Uranium (CANDU) reactor in Canada. The CANDU, with features such as on-load refueling to avert the most common cause of routine reactor downtime, is in many ways a great success, not only in Canada but also in Argentina, China, Romania, and South Korea. Among the 22 CANDUs commissioned since 1980, 17 have lifetime load factors of 80 percent or more, and the other five have factors in the 70s.

For the eight operable CANDUs commissioned before 1980, however, it has been a different story.

Atomic Energy of Canada Limited (AECL) developed the CANDU reactor, operating the 22-MWe NPD demonstration reactor with Ontario Hydro (OH) starting in 1962, and then providing its first commercial pressurized heavy-water reactor (PHWR), the 216-MWe Douglas Point, to the OH grid starting in 1968. (The NPD reactor closed in 1987, and Douglas Point in 1984, with both reactors considered to have completed their missions.) The next step in the CANDU scale-up was the ordering of four reactors in the 500-MWe range for a site on the north shore of Lake Ontario, near the town of Pickering. They entered commercial operation from mid-1971 to mid-1973.

In June 1972, less than a year after the first unit went commercial, Pickering was idled for more than five months for a purely nontechnical reason: a strike by plant workers. (Other strikes in 1985 added to outage times at Pickering reactors.) Once the strike ended and operation resumed, the reactors generally performed well, with downtime either fully scheduled or attributable to shakedown. The first serious problem arose in April 1975 at Unit 4, less than two years after its startup: pressure tube leakage. By the time the problem was analyzed fully, remedial actions considered, repairs completed, and the reactor restarted, 11 months had passed. This was the longest outage that any CANDU reactor would experience for the next seven years—indeed, the only one lasting more than three months—but in 1983, pressure tube leakage again was the cause of downtime that not only lasted longer than the Pickering-4 outage, but affected more than one reactor.

On August 2, 1983, a pressure tube ruptured at Pickering-2, forcing a shutdown. This time, the examination of the situation in Unit 2 prompted close inspection of Unit 1 as well. The condition of the reactors, after only a dozen years of operation, was such that Ontario Hydro decided that it would be necessary to replace all of the pressure tubes—a costly, unprecedented task that kept Pickering-1 off line until September 1987 and Unit 2 down until October 1988.

During the rest of the 1980s, the other CANDUs managed to avoid fuel channel ruptures, but Bruce-1 and -2 both underwent six-month outages that included a pressure-tube repositioning procedure that

With half of Bruce A back on line, Bruce Power is in negotiations with the Ontario government on a plan to bring back the other half. (Photo: Bruce Power)

was intended to avert ruptures. Even though Pickering-3 had no ruptures, it and Unit 4 were both put through their own fuel channel replacement outages, each lasting more than two years, between 1989 and 1993.

### More than tube troubles

Starting in the 1970s, steam generator tubes in pressurized light-water reactors in the United States and elsewhere began experiencing a variety of corrosion-related failures, but while these are both radiation hazards and costly nuisances, PWR operators learned to live with the problem through a variety of measures, ranging from plugging to steam generator replacement. In a CANDU reactor, however, each pressure tube is also a fuel channel in the reactor itself. (CANDUs also use steam generators the same way that pressurized light-water reactors do.) Corrosion in a CANDU pressure tube can have a much more direct effect on the reactor than corrosion in a steam generator tube would.

In the reactors at Pickering A (as the first four units are known collectively), Zircaloy-2 was used in the pressure tubes, in part because it was available in sufficient quantity to allow the completion of the reactors in time to meet rising power demand. The first four Bruce units (Bruce A) were not only larger and more powerful than those at Pickering A, but incorporated some design modifications intended to prevent a generic problem with one design from influencing all reactors on the OH system. One important change was the use in the pressure tubes of Zr-2.5% Nb, an alloy that proved to be less prone to failure under long-term operation.

By the time the severe pressure-tube failures began at Pickering A, Ontario Hydro was also involved with the commissioning of Bruce B and Pickering B (Units 5 through 8 at each plant) and the construction of the four-unit Darlington plant. These extra projects spread thin the utility's resources, leading to delays on all fronts and deterring OH from plans to add four more four-unit plants. Interest rates during the construction projects ran as high as 21 percent, and capital limitations forced cutbacks in the operations and maintenance budgets at all plants. Rapid growth meant the addition of many inexperienced workers, which had an adverse effect on day-to-day operations. As a state-owned Crown corporation, OH was limited in its ability to obtain the funding necessary to continue its new projects and also ensure operability at its existing reactors. Desperate to cut costs, OH set up an early retirement plan in 1993, which had the effect of removing about 10 000 employees, many of them highly experienced operators and technical support staffers. From this point, maintenance performance declined.

A 10-ton flask is positioned at Pickering-1 as part of the shutdown system enhancement. (Photo: Ontario Power Generation)

While organizational, political, financial, and regulatory factors combined to put OH in a downward spiral, plant staff managed to keep the older reactors running through much of the 1990s—with one significant exception. After inservice radiographic inspection of a steam generator head at Bruce-2, a lead shielding blanket was mistakenly left in place. The prolonged presence of the lead caused chemistry changes that severely damaged the steam generator tubing and forced a shutdown in 1995. Bruce-2 was still down in 1997 when OH ordered that the rest of the Pickering A and Bruce A reactors be shut down indefinitely, in part because of a decision to focus its abilities on the steady operation of its 12 newer reactors. Bruce-3 and -4 ran until early 1998 and were the last of the eight reactors to leave service and enter what is referred to as the guaranteed shutdown state (GSS).

### Reorganization and remotivation

Arguably, the situation for the idled reactors could never change as long as Ontario Hydro continued to exist as it was. Shortly after the shutdowns, however, steps were taken to address OH's problems (which were not limited to the nuclear side). Ontario Power Generation (OPG) came into existence in April 1999 as part of a reorganization of OH, and while this did not change the utility's basic legal status (OPG is wholly owned by the province of Ontario), it sharpened the focus to power plants and their operation and maintenance.

Perhaps more significant, however, was the formation of a company called Bruce Power, which by Canadian electricity standards was almost brash in its enterprising approach. Bruce Power is a partnership among Cameco Corporation, TransCanada Corporation, and BPC Generation Infrastructure Trust (representing the Ontario Municipal Employees Retirement System, the Power Workers' Union, and the Society of Energy Professionals). British Energy had originally been involved, but sold

## OPG halts restart plans for Pickering-2 and -3

At the time this feature article was written, Ontario Power Generation (OPG) was keeping open the possibility of following the restarts of Pickering-4 and -1 with a similar recovery effort on Units 2 and 3. On August 12, however, OPG announced that its board of directors had accepted a management decision not to refurbish Units 2 and 3 (although the work would be technically feasible), and to focus OPG's resources on its other 10 power reactors, perhaps through life extension at Pickering B and Darlington. OPG has stated that over the next two years, fuel and heavy water are to be removed from the two reactors, which will then be put in what is called "a long-term layup state." OPG has not stated specifically that the two units will be decommissioned.

its stake to Cameco in 2003. Canada and Ontario have not embraced electricity deregulation and privatization to the point of allowing Bruce Power to buy an entire province-owned power plant, but in July 2000, OPG and Bruce Power announced plans for Bruce Power to lease all eight Bruce reactors from OPG, and the deal was closed in May 2001. The lease gives Bruce Power control of the licenses and the authority to make operational and planning decisions.

Very soon after the lease went into effect, Bruce Power sought approval from the CNSC for the restart of Bruce-3 and -4. Work on the reactors—entailing the replacement and refurbishment of virtually all major components—began while the CNSC deliberated. The idled reactors were still licensed, so much of the regulatory scrutiny was on the environmental effects of resumed operation and the quality of the upgrade work (including post-9/11 security enhancements, mandated by the CNSC at all Canadian power reactors).

To meet or exceed current regulatory standards, Bruce Power reviewed and upgraded safety, fire, and seismic systems. Contracted for much of the work were ASLF (a joint venture of Acres, Sargent & Lundy, and Fox) and RCM Technologies, which focused on environmental qualification. Electrical work alone required 60 kilometers of new cable and 200 000 circuitry connections. Among the major tasks carried out by Bruce Power were:

- Spacer location and repositioning of the pressure tubes.
- Reactor coolant feeder inspection.
- Fueling power track repair.
- Aligning the Unit 3 pressure tubes in a westerly direction to accommodate radiation-induced creep.
- Replacement of the horizontal flux detectors.

Bruce-4 was reconnected to the grid on October 7, 2003, and Unit 3 followed on January 9, 2004. The cost of the completed project is listed as Can$700 million ($575 million). Bruce Power has also developed a plan for the restart of Units 1 and 2, and an agreement on the plan was announced in March by a negotiator for the provincial government. The Ontario Energy Ministry is now considering the plan, which would also need the same sort of federal-level approvals (from the CNSC, for example) that the Bruce-3 and -4 restart required.

Meanwhile, OPG—which, like OH before it, had always intended to bring the idled reactors back, but did not always have the resources—was able to get through basic environmental approvals for the restart of Pickering A in 2001 and began its own refurbishment project. The work has cost more and taken longer than was initially expected—one report had projected that all four reactors would be back up by the end of 2002, and another had them all up by about now—but OPG itself has stated that it would bring the reactors back on line on whatever schedule would allow for all issues to be addressed properly and not interfere with performance at operating reactors. Pickering-4 was the first to reach power production, on August 22, 2003. Pickering-1 passed its reactor building pressure test on June 24 of this year, and on July 28, the CNSC lifted the GSS order on the reactor, which achieved criticality on August 2. Power operation is currently expected in September or October, and full-power operation by November.

The work recently completed on Pickering-1 is estimated to have cost Can$975 million (about $800 million), and it affected virtually every part of the reactor—the moderator system, the cooling water system, the heat transport system, the fueling machines, the shutdown systems, all 12 boilers, the turbine-generators, and the fire protection and ventilation systems. At this writing, OPG had made no commitment on whether to seek the restart of Units 2 and 3 and had no plans to do so until after Unit 1 is fully back in service.

With the entrepreneurial Bruce Power and the state-owned OPG both at work on much the same tasks at the same time, there are sure to be comparisons made on costs and schedules as to whether private or public ownership is preferable for the electricity industry in Ontario (and perhaps in Canada generally). Because the restarts of Bruce A and Pickering A both remain works in progress, it would be premature for anyone to pass judgment now, but one point seems clear: Two organizations sharing the operation and refurbishment of 20 reactors bring to bear more resources and motivation than were available to the bygone Ontario Hydro.

## Cutback on coal power

Pickering-4 was already back in service, and Bruce-3 and -4 were being prepared for restart, when a political development occurred that added to the pronuclear momentum. In October 2003, the Liberal Party won the Ontario provincial election, ousting the incumbent Progressive Conservative government. The Liberals had pledged to have the province's coal-fired electric generating capacity shut down in order to reduce greenhouse gas emissions (and, also important in southern Canada, acid rain). While the Liberals have edged back their ambitions slightly since taking office—they had originally sought to close all coal-fired capacity by 2007, but now concede that at least some coal plants may run until 2009, or later—the restart of Pickering A and Bruce A can take Ontario most of the way to coal-free power, if they operate as other CANDUs have.

In much of the United States, the idea of shutting down all coal plants would be almost unthinkable. Ontario's nuclear output, however—even without Bruce A and Pickering A—exceeded that from all other

Pickering-1 modifications team leader John Ieraci (right) and Dale Renouf, of contractor Black & McDonald, examine work in progress on the cooling water system. (Photo: Ontario Power Generation)

sources, providing 37 percent of Ontario's electricity in 2003, versus 29 percent from coal and 26 percent from the region's bountiful (but already completely exploited) hydroelectricity.

Unfortunately, restarting all of the old CANDU reactors wouldn't completely fulfill the provincial government's coal-free hopes. Working essentially at full power, Bruce A and Pickering A could boost nuclear's share to about 58 percent and allow coal to drop to about 8 percent. As yet, Ontario's officialdom has not grown so eager for nuclear as to agitate for new reactor construction, but neither is there a definite plan in place to obviate the need for coal power through renewables and efficiency improvements.

As it is, the provincial government has never explicitly established a policy in favor of restarting all of the idled CANDUs. Bruce Power's plan to bring back Bruce-1 and -2 has met no opposition in the ministry thus far, but nothing can be assumed when one is dealing with a new government (as defined in the parliamentary system used at both the provincial and federal levels in Canada). The Progressive Conservatives, generally identified as pro-business, decided in favor of all of the restart plans over which it had jurisdiction. So far, the Liberal government has decided in favor of the requests it has received, including the continuation of Pickering-1's refurbishment.

## A longer license

The restart process has not been an unbroken string of triumphs. Pickering-4 was off line from April 2 to July 19 because of the discovery of thinning feeder pipes. In 2004, capacity factors of the restarted units were 72.2 percent for Pickering-4, 76.1 percent for Bruce-3 (which was connected to the grid in January), and 81.9 percent for Bruce-4—certainly good enough to encourage more restarts, but not yet up to the level of most other CANDUs. Also, the OH experience should be enough to remind OPG and Bruce Power that they should commit to operating more units only once the resources and personnel are in place to ensure that the reactors will be operated and maintained safely and smoothly for the next several years.

Even so, the restarted units are seen as good prospects. On June 29, the CNSC issued a five-year operating license renewal to OPG for Pickering A. Canadian reactors are licensed for specific short terms, rather than the 40-year terms granted in the United States, and previously Pickering A had been on a two-year license. OPG Senior Vice President John Coleby said that the five-year renewal "reflects positively on OPG's safety culture and our ability to sustain our safety programs, procedures, and training efforts beyond a two-year time horizon."

Canada in general may also have to face what U.S. utilities and ratepayers learned a few years ago: A power reactor can be made into a valuable long-term asset, but perhaps at greater ongoing cost than planners might have hoped for when the reactors were first being built. New Brunswick Power Corporation has announced that it will have its 650-MWe Point Lepreau CANDU refurbished and has signed AECL to do the work, intended to take place during an 18-month shutdown planned to start in 2008 (see page 38, this issue). Even with AECL making concessions to get the bid (beating out Bruce Power), provincial officials in New Brunswick were still concerned about the cost of the work and potential financial risk. But in the end, they chose refurbishment over closure of the plant, in part because Canada has relatively few options for power sources while it attempts to curb its use of coal.

If Ontario eventually gets all 20 CANDUs back on line as steady performers, and if Canada is still facing either a further need to reduce greenhouse gas emissions or rising power demand, there might emerge an opportunity for AECL to market its new ACR-700, or another advanced PHWR design, in the nation that first developed the CANDU. NN