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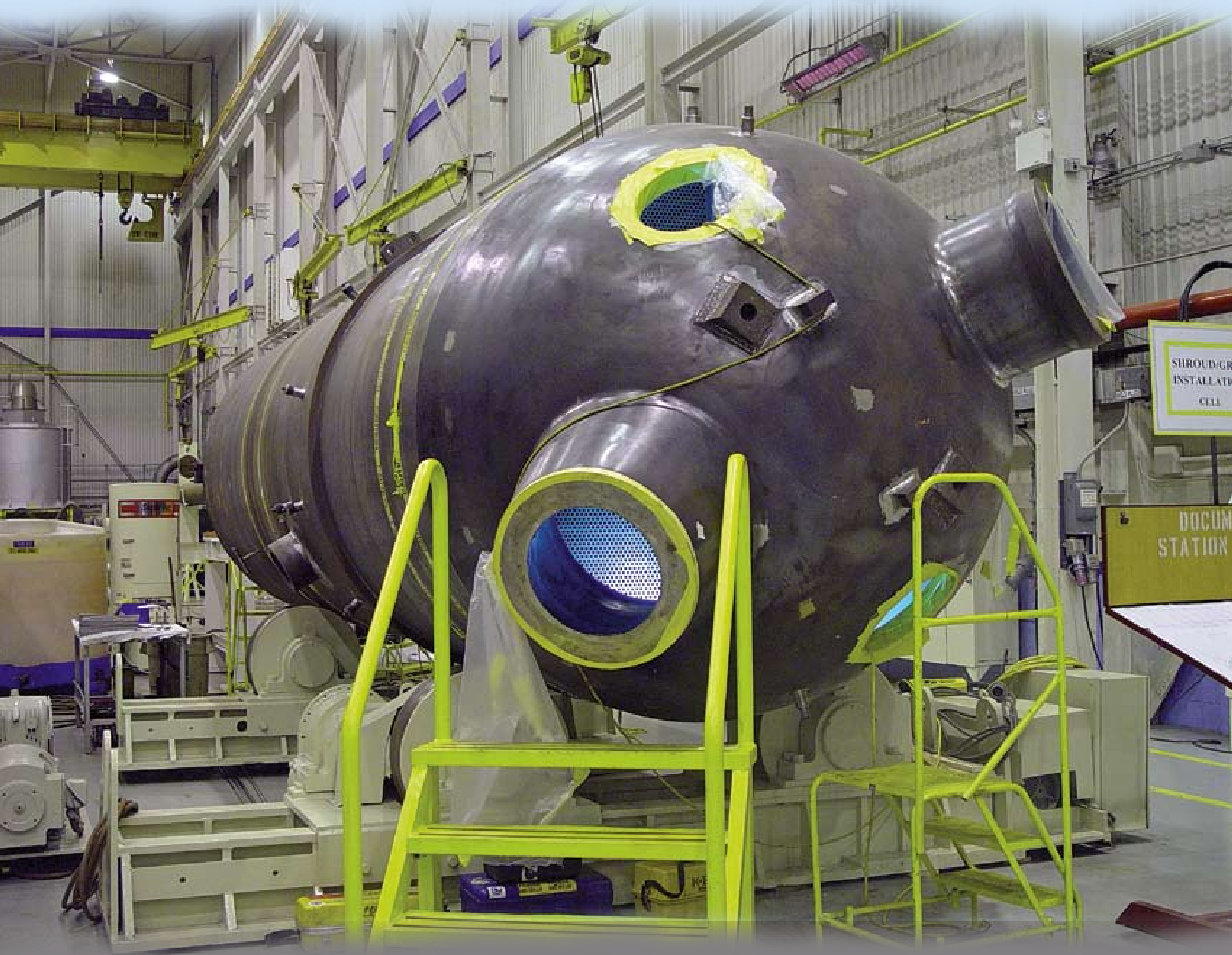

• Special Focus on Nuclear Steam Generators

• 5th CNS Steam Generator Conference • 30 Years of Operation and R & D

• Replacement of Bruce A Steam Generators • Experience at Point Lepreau

Uncertainty

Uncertainty seems to characterize the current state of the nuclear program in Canada. Admittedly there is much action related to nuclear power. The "Bruce A Renewal" is well underway; the organization for the refurbishment of Point Lepreau is in place; Bruce Power has identified the scope of their "new build" project.

Yet there is uncertainty. Ontario Power Generation is waiting for a decision on the scope of the environmental assessment for the refurbishment of Pickering B; the design of ACR 1000, Canada's contender in the "Generation III" class, is still two years off; and, the Ontario government continues to dither about its plans for the future of the electricity system in the province.

In the non-power arena, work on MAPLE and the associated New Processing Facility continues to plod along, now seven years behind schedule, continuing the apprehension of the many users of medical radioisotopes for whom MDS Nordion has been the supplier. Although old faithful, NRU, continues to operate (with great credit to the operations team) alternative radioisotope suppliers are springing up around the world in response to this uncertainty.

The future of the Chalk River Laboratories continues to be unclear. Once a major national laboratory with a strong international reputation, CRL has, because of the drastic cuts to its funding from the government, become primarily a support laboratory for the nuclear power industry. AECL has to use some of its commercial revenue to cover about half the cost of running the laboratory. CRL is not alone. The National Research Council, and other national laboratories have suffered from this shortsighted government policy, with the result that Canada has lost stature in the international research community.

Finally, there is the uncertainty about the regulation of nuclear power plants. The Canadian Nuclear Safety Commission has stated (and restated) that it will apply "international standards" without defining what those are. Although CNSC president Linda Keen complained, at the very recent 2007 Nuclear Industry Seminar, that there are many "misconceptions" she failed to clarify any. The new document issued the day of her talk, titled *Supplementary Information on Design Review Process for New Build,* expands on the process but gives no insight into technical requirements. And, worse, the lack of clarity of requirements for the refurbishment of existing plants continues.

With that environment it was sad to hear the entrepreneur from Alberta speak optimistically about having nuclear plants in service in the tar sands by 2016. The ACR design, which Atomic Energy of Canada Limited is proposing, is still more than a year from completion, and the CNSC has pointed out that the environmental assessment alone could take three years.

There was a time when our leaders made sound and timely decisions. Apparently that time has passed.

Fred Boyd

In This Issue

This issue has two editorials, the one above and a second, subtitled "a history lesson" on the next page. Then, on page 3, we have a letter commenting on a letter in the September 2006 issue, which, in turn, referred to a paper in the June 2006 issue.

The technical content draws heavily on the **5th CNS International Steam Generator Conference** held in Toronto at the end of November 2006, beginning with a report on that event.

That is followed by reprints of three of the papers presented that give overviews from different perspectives. The first is s review from an expert in that field, Robert Tapping, on **Steam Generator Aging in CANDUs: 30 years of Operation and R & D.** Next is an extensively illustrated explanation of how the steam generators at Bruce units 1 and 2 are going to be replaced, by veteran Ralph Hart, **Steam Generator Replacement at Bruce A Unit 1 and Unit 2.** The third is the history of the steam generators at one of the first CANDU 6 units, **Evolution of Management Activities and Performance of the Point Lepreau Steam Generators,** which was presented by one of the several women at the conference, Janice Keating.

Ernest Siddall, a Chalk River Laboratory pioneer, offers an interesting opinion in **The Greenhouse Problem – Let's Get Serious.** And, there is another "history" item, on **The Rutherford Museum at McGill University.**

Then we have reports on the 4th annual meeting of **Women in Nuclear,** held in Ottawa, February 28 and the Canadian Nuclear Association's **Nuclear Industry Seminar 2007,** held March 1, just days before publication.

Our typical eclectic selection of **General News** contains a number of, hopefully, interesting items.

CNS News presents a partial insight into the many activities of the Society, including some news of individual members, a feature we have been wanting to include

We close with a **Book Review** of a new biography of the earliest nuclear researcher in Canada, Ernest Rutherford, the updated **Calendar,** and, of course, Jeremy Whitlock's particular view in **Endpoint.**

Again, we hope you find something of interest and invite your comments.

A History Lesson

Evolution of Canadian Reactor Safety Principles and Requirements

A major problem facing the Canadian nuclear power program is the loss of "institutional memory", exacerbated by the fact that no new nuclear power plant has been built for two decades. This note deals with one aspect of that problem, the development of the safety principles and requirements that were applied to all of the existing nuclear power plants in Canada

Safety was a concern from the beginning of the Canadian nuclear program. Those at the Montreal Laboratory who conceived the design of the NRX reactor at the end of the Second World War were very aware of the potential danger and ensured numerous safety devices were included in the design. Nevertheless, NRX suffered a "runaway" accident, a power excursion, in 1952, just four years after it had begun operation.

It was decided to refurbish NRX but the accident led to much introspection, not only for needed changes to NRX, but also for safety objectives for the nuclear power reactors then being proposed. Two people at the Chalk River Laboratory, Ernie Siddall and George Laurence, wrote several papers on the topic in the 1950s. Both proposed a "probabilistic" or "risk" objective derived from what society appeared to accept from other major industrial activities.

In 1956, with the design of the Nuclear Power Demonstration (NPD) plant already underway, the Atomic Energy Control Board (AECB), the regulatory body of the day (which had only one scientific staff at the time), created the Reactor Safety Advisory Committee (RSAC) with very experienced enginers and scientists as members and appointed Laurence as chairman. For the next two decades the RSAC (with the support of a growing support staff) made the major licensing decisions on behalf of the AECB. (Laurence was appointed as the first full-time president of the AECB in 1962.)

Laurence led the RSAC in pursuing the risk objective. An early proposal was that the likelihood of a serious accident, which could result in significant release of radioactive fission products, should be less that 10-5 per year. Over the next few years this was lowered to 10-6 per year (which the international nuclear community adopted years later).

The challenge was how to achieve this (at the time probabilistic analyses had not been developed.) Laurence proposed separating the design of the plant into three parts: the operating systems; the safety (e.g. shutdown) systems; and the containment. The concept was that it would take a major failure of the operating system combined with failure of both safety systems and containment to result in a significant release of radioactive material.

Laurence argued that if the three divisions of the plant were sufficiently separate and independent the low target probability could be achieved with practical designs. His initial proposal was to presume that the design of the operating systems could ensure the likelihood of a severe failure (leading to fuel damage) would be less than 10-1 per year and the "unavailability" (the likelihood that the safety systems or containment would not work) could be less than 10-2.5, giving an overall result of 10-6.

After further consideration the concept was modified to consider the plant having operating systems and a set of separate and independent safety systems (including containment)

To have a significant release of radioactive fission products, a major failure of the operating systems (one that could potentially lead to disruption of the fuel) combined with complete failure of two of the safety systems would be required. The target for the operating systems was relaxed to 1/3 per year and that for any safety system was increased to 10-3 per year. Limits for the calculated dose to a person at the boundary of the plant were prescribed for a "single" failure (of the operating system) and a "dual" failure of any operating system failure combined with failure of any safety system.

For the Bruce A station, the designers, having the sad experience of Douglas Point where the occupational radiation dose of the operators was very high, proposed a much smaller containment. However, with that design they could not show that the containment would withstand a "runaway" accident. The designers proposed a partial second shutdown system. After much agonizing the RSAC (supported by a modest staff) accepted the concept of a second shutdown system, but only if it was different and completely separate from the first shutdown system.

These concepts augmented the several safety attributes of the CANDU design, such as: the large heat–sink capability of the moderator and shield tank; relatively long neutron lifetime; low fuel rating.

All of this evolved in closed meetings between the RSAC and designers and operators. These concepts were formally presented in a paper by D. G. Hurst, then president of the AECB, and the writer, in 1972. It remained the basic standard of the AECB for over two decades. A number of associated requirements evolved, such as: number of "trip" parameters; basis for pressure relief of the primary system; size of the exclusion zone; etc.

This Canadian "risk" approach was pursued through positive interaction between designers, operators and regulators. It predated similar developments in other countries by many years. As a result existing Canadian nuclear power plants are as safe as any in the world of the same generation.

Fred Boyd

1 "Reactor Licensing and Safety Requirements" by D. G. Hurst and F. C. Boyd, AECB 1059, June 1972

Re: Paper Ignored Thorium – Acclerator Breeding

The Editor

J.A.L. Robertson's point *[Letter to Editor in Vol. 27, No. 3 September 2006 issue]* that we ignored thorium in the paper "Nuclear Fuel Can be Considered as Inexhaustible" *[Vol. 27, No. 2 June 2007]* is well taken by H. Douglas Lightfoot in the September issue.

I have long been intrigued by another strategy contemplated by AECL to produce fissile fuel from fertile uranium or thorium. Dan Meneley mentions this accelerator driven concept in his article "Transition to Large Scale Nuclear Energy Supply" in the September issue. It seems we have almost forgotten that any of this work involving thorium and other fuel cycle concepts was ever done. We need to be reminded of the feasibility and practicality of paths to inexhaustible nuclear energy.

As a memory jog, I list some published reports I've encountered over the years.

Bartholomew, G.A., J. S. Fraser, and P.M. Garvey, Accelerator Breeder Concept, AECL 6363, INFCE/WG.8/CNA/DOC1, October 1978, 39 pp.

Fraser, J. S., C.R. Hoffman, S.O. Schriber, P.M. Garvey and B.M. Townes, A Review of Prospects for an Accelerator Breeder,† AECL-7260, Atomic Energy of Canada Limited, December 1981, 40 pp.

Schriber, S.O., ZEBRA, The First Stage of an Accelerator Breeder Program, ISSN 0227-1907, Proceedings, 4th Annual Conference, CNS, Queen Elizabeth Hotel, Montreal, Canada, June 15, 1983, 19pp.

The decline of petroleum and the need for replacement energy is becoming a fashionable topic again. Perhaps scientists and engineers involved with accelerator breeders and other alternative fuel cycles would be interested in sharing their knowledge and experience. If the nuclear industry has forgotten the enormous potential of nuclear fission energy, we can be sure the rest of the world has hardly heard of it.

Duane Pendergast
Lethbridge, AB

Errata

On page 3 of the December 2006 issue, near the top, in the article on the PBNC 2006 Conference, there was a photograph with a caption reading "Ian MacFarlane, Australian Minister of Industry" but actually was of Paul Fehrenbach, a vice-prsident at Atomic Energy of Canada Limited. We apologize to Paul for transforming him into a politician.

Canadian Nuclear Achievement Awards

Each year, the Canadian Nuclear Society joins with the Canadian Nuclear Association to present awards to individuals and groups that have contributed significantly to the Canadian nuclear program.

Mailed out with the December 2006 issue of the *CNS Bulletin* was a booklet describing the various awards and their criteria.

Although the deadline for nominations has nominally passed there is still the possibility that a nomination can be made

Read the booklet or go to the CNS website: *www.cns-snc.ca* for a description of the various categories and criteria.

Then contact Charles Gordon, Chair of the CNS / CNA Honours and Awards Committee at: *charles.gordon@nuclearsafetysolutions.com* to see if your nominaton can still be accepted.

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~ Cover Photo ~

The photograph on the cover shows the shell of one of the replacement steam generators for Bruce A Unit 1 under construction at the shops of Babcock & Wilcox Canada.

– Photograph courtesy of Babcock & Wilcox Canada, with permission of Bruce Power.

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*La SNC procure aux Canadiens intéressés à l'énergie nucléaire un forum où ilf peuvent participer à des discussions de nature technique. Pour tous renseignements concerant les inscriptions, veuillez bein entrer en contact avec le bureau de la SNC, les membres du Counseil ou les responsables locaux.
Les frais annuels d'adhésion pour nouveaux membres sont 75$, 44$ pour les retraites, et sans frais pour les étudiants.*

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5th CNS International Steam Generator Conference

Large attendance reflects importance **of key NPP component**

Despite its specialized focus, over 200 delegates assembled at the Marriott Eaton Centre Hotel in downtown Toronto, 26 – 29 November 2006 for the 5th International CNS Steam Generator Conference.

The organizers chose a relatively lengthy theme for the conference – *Management of Real-Life Equipment Conditions and Solutions for the Future* – to embrace a wide-ranging forum on nuclear steam generator technology, from life-cycle management to inspection, maintenance, performance and design. They noted that the nuclear power industry is in a time of transition, with existing plants working to optimize their performance while plans are made for new steam generators.

A pre-conference reception on the Sunday evening provided an opportunity for delegates to renew acquaintances and meet with others facing similar challenges in their work related to nuclear steam generators.


Ken Ellis

On the Monday morning, **Ken Ellis**, Chief Engineer and V.P. Engineering at Bruce Power, welcomed everyone as Honorary Chair of the conference. Then, following an introduction by **Revi Kizhatil**, of Babcock & Wilcox Canada, conference chair, Ellis gave the first presentation in the opening plenary session on the topic *"The Equipment – An Owner's Perspective"*.


Revi Kizhatil

He began by noting his first introduction to nuclear steam generators was at the Douglas Point demonstration plant in 1982. Bruce Power's main objectives related to steam generators are, he said:

- safe and reliable operation
- simple and effective maintenance strategies
- efficient and cost effective inspection techniques
- plant longevity

He mentioned some specific problems, such as the degradation, discovered through eddy current examination, of the broach plates in 2002. Support of the steam generator industry is essential, he stated in closing. To a question he said actual replacement of the steam generators in units 1 and 2 at the Bruce A plant is scheduled for January 2007 and that for unit 4 in 2009.


Andrei Blahoianu

Andrei Blahoiau, of the Canadian Nuclear Safety Commission, followed with a presentation titled, *"Regulations and Proactive Management of Ageing Steam Generators in Canada"*. Degradation of steam generator tubing has occurred at a number of plants, he noted, which can be attributed to a number of factors. Licensees have responded to this challenge, he acknowledged, with extensive inspection and maintenance programs. He then outlined the CNSC regulatory framework for steam generators. A proactive approach is being promoted. Several regulatory documents have been issued:

- Regulatory Standard S-334 – Ageing Management Program
- Regulatory Standard S-335 – Regulations for Pressure Retaining Components
- Regulatory Guide G-360 – Life Extension

In closing he noted the SMiRT Conference (19th International Conference on Structural Mechanics in Reactor Technology) to be held in Toronto,12-17 August 2007.


Roger Staehle

The last speaker of the short plenary session was **Roger Staehle,** an independent consultant, who chose the title, *Serious Concerns and Actions for Mitigating Future Degradation on Modern Steam Generators*. To predict degradation it is essential to understand the mechanism, he asserted, and noted the importance of the "environment". There is a serious problem of lack of institutional memory, he noted. Turning to specific problems he pointed out the importance of totally eliminating lead and sulphur. He said his full paper included a long list of recommended work needed.

After a break the technical program began with the first of two technical sessions on *Life Management Strategies*. It opened with an interesting and informative review of the experience at

Janice Keating

Bob Tapping

Point Lepreau with its steam generators over the life of the plant, *Evolution of Management Activities and Performance of the Point Lepreau Steam Generators,* presented by **Janice Keating.** *(That paper is reprinted in this issue of the* CNS Bulletin.). That session concluded with a paper on, *Predicting and Managing Steam Generator Performance* by Carl Turner et al, of AECL – CRL.

Another brief plenary session was held on the Tuesday morning, this time with just two presentations.

The first was a retrospective review, *Steam Generator Ageing in CANDU – 30 Years of Operation and R & D,* by **Robert Tapping** of the Chalk River Laboratories of Atomic Energy of Canada Limited. He began with describing his talk as a "high-level overview" and apologized in advance for any work not mentioned. Then he gave an outline of his presentation as: evolution of design; operating experience; research and development; the next ten years.

Noting that several alloys had been used for tubing he commented that alloy 600 had some stress corrosion cracking problems but there has been good experience with alloy 800, so far. One factor affecting the design of steam generators for CANDU compared to those for LWRs was the cost of heavy water, leading to the choice of 1/2 inch diameter tubes for CANDU compared to 3/4 or 7/8 inch in LWRs. This, in turn, required development of our own inspection techniques.

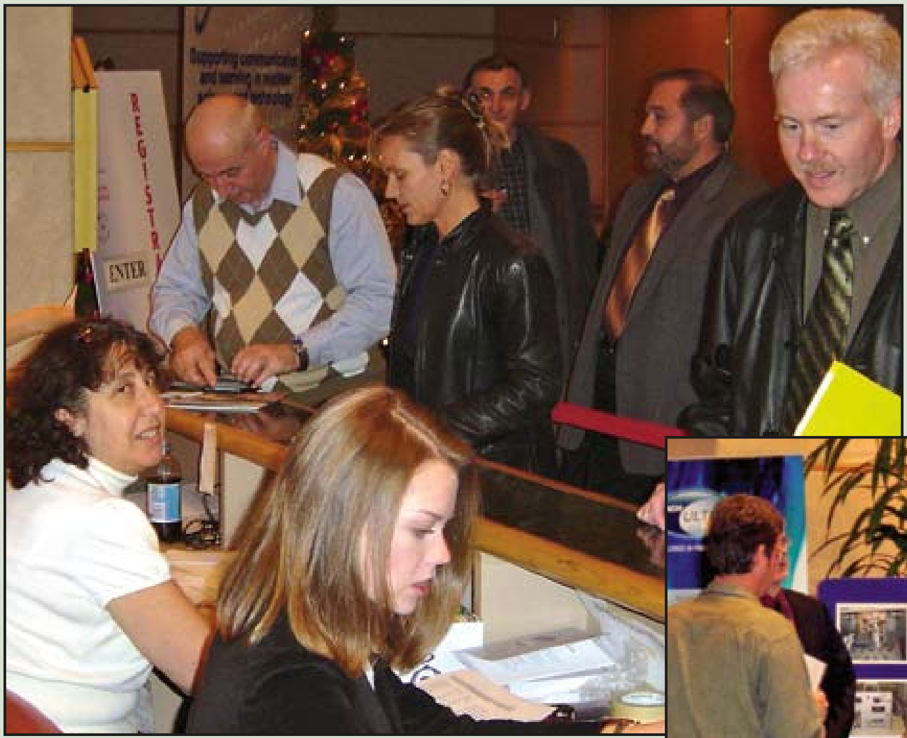
Operating experience was good for the first decade or two but problems developed in the 1990s, which led to increased R & D. There is now a good understanding of chemistry, thermal-hydraulics, vibration, fretting, he stated, which gives excellent prospects for a 60-year life.

(Tapping's full paper is reprinted in this issue of the CNS Bulletin.)

Rounding out the plenary sessions, **Todd Mintz,** of the Office of Regulatory research of the US Nuclear Regulatory Commission, presented a paper, co-authored by Joseph Muscara of the same office, on *Steam Generator Integrity Assessment and Proactive Actions.*

Managing degradation can be separated into a few key concepts, he said. It is important to know, after an in-service inspection, what flaws have been left in service and also what type of flaws may initiate during an operating cycle, he continued. The use of crack growth rates can be used to deter-

Scenes from 5th International Steam Generator Conference



mine how degradation will proceed. Once it is known what flaws are present and how they will progress during an operating cycle, the integrity of flawed steam generator tubes can be calculated. The USNRC Office of Nuclear Regulatory Research is currently funding a program that has been examining these topics, he stated, which is studying: inspection reliability; tube integrity and integrity predictions; degradation; and corrosion.

The balance of the three-day conference was devoted to a series of sessions focussed on various topics related to nuclear steam generator performance. The titles of the sessions indicate the scope of the conference.

- Life Cycle Strategies
- Fouling, Cleaning and Chemistry
- Replacement Strategies & New Build Design
- Materials Degradation
- Condition Assessment / Fitness for Service
- Inspection Advancements & Experience
- Thermal Hydraulic Performance

Most of the papers were specific to the particular topic covered. One that had broad appeal was by **Ralph Hart,** now with SNC Lavalin Nuclear, on *Steam Generator Replacement at Bruce A Units 1 and 2,* in which, with a number of photos and drawings, he described the elaborate procedure to replace the steam generator sections of the boilers in those two units. *(Hart's paper is reprinted in this issue of the* CNS Bulletin.*)*

In addition to the presented papers there was a poster session on the Monday evening, combined with a wine and cheese reception, at which 19 papers were presented in poster format.

Although there was no conference dinner, there was an extended "networking reception" on the Tuesday evening, which was well attended with, apparently, considerable "networking".

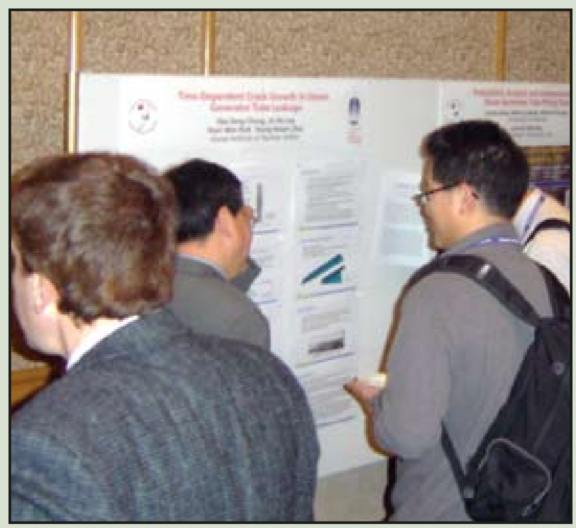
The conference was organized by a committee under the chairmanship of Revi Kizhatil of Babcock & Wilcox Canada. Members were: Ken Belfall, OPG; Ben Rouben, AECL; Denise Rouben, CNS; Michael Schneider, Intech Int'l.; Heather Smith, AECL; Pam Sprague, AECL; Jerry Harnadek, AECL; Jamie Goodfellow, B & W; William Schneider, B & W.

The program committee was headed by Graham MacDonald of Areva NP Canada, with Peter Angell, AECL, as co-chair. Members were: Steve Fluit, B & W; John Roberts, JGR Chem.; Sridhar Ramamurthy, UWO; Carmina Maruska, OPG; Roger Newman U of T; Jim Nickerson, AECL.

Sponsoring companies were: AECL CANDU Services; Areva; Babcock & Wilcox Canada; Bruce Power; Hydro Quebec; Intech International; New Brunswick Power Nuclear; Zetec Inc.

Several companies also had exhibits: AECL CANDU Services; Areva; Babcock & Wilcox Canada; Curtis Wright; Jamko Nuclear Services; Kinectrics; ZETEC.

A CD with all of the presentations and most of the full papers, together with photos from the conference is available from the CNS office. The full program is still available on the CNS website.



Steam Generator Aging in CANDUS: 30 Years of Operation and R&D

by Robert Tapping[1]

Ed. Note: The following paper was presented at the 5th CNS International Steam Generator Conference held in Toronto, Ontario, November 2006.

Introduction

The early years of operation of CANDU reactors, with the exception of the Douglas Point reactor, was characterized by relatively few operational problems associated with steam generators. During the same period PWR reactor steam generators (SGs) were experiencing tubing degradation associated with denting of tubes at intersections with drilled hole support plates; that of degradation of SGs tubed with Alloy 600.

CANDU SG degradation experience with SGs tubed with Alloy 600 (Bruce A and B) has followed this PWR experience, although with much lesser impact at Bruce B to date and, to date, longer times to crack initiation at Bruce B in the absence of accelerants such as Pb. No cracking has been detected at Bruce B after approximately 20 years of operation, although there has been some localized intergranular attack (IGA) detected. For PWRs SG degradation has accounted for about 0.3% of in-service tubes being plugged per year, on average, and for significant incapability factors until recently. In addition to improved SG management practices, many of the high

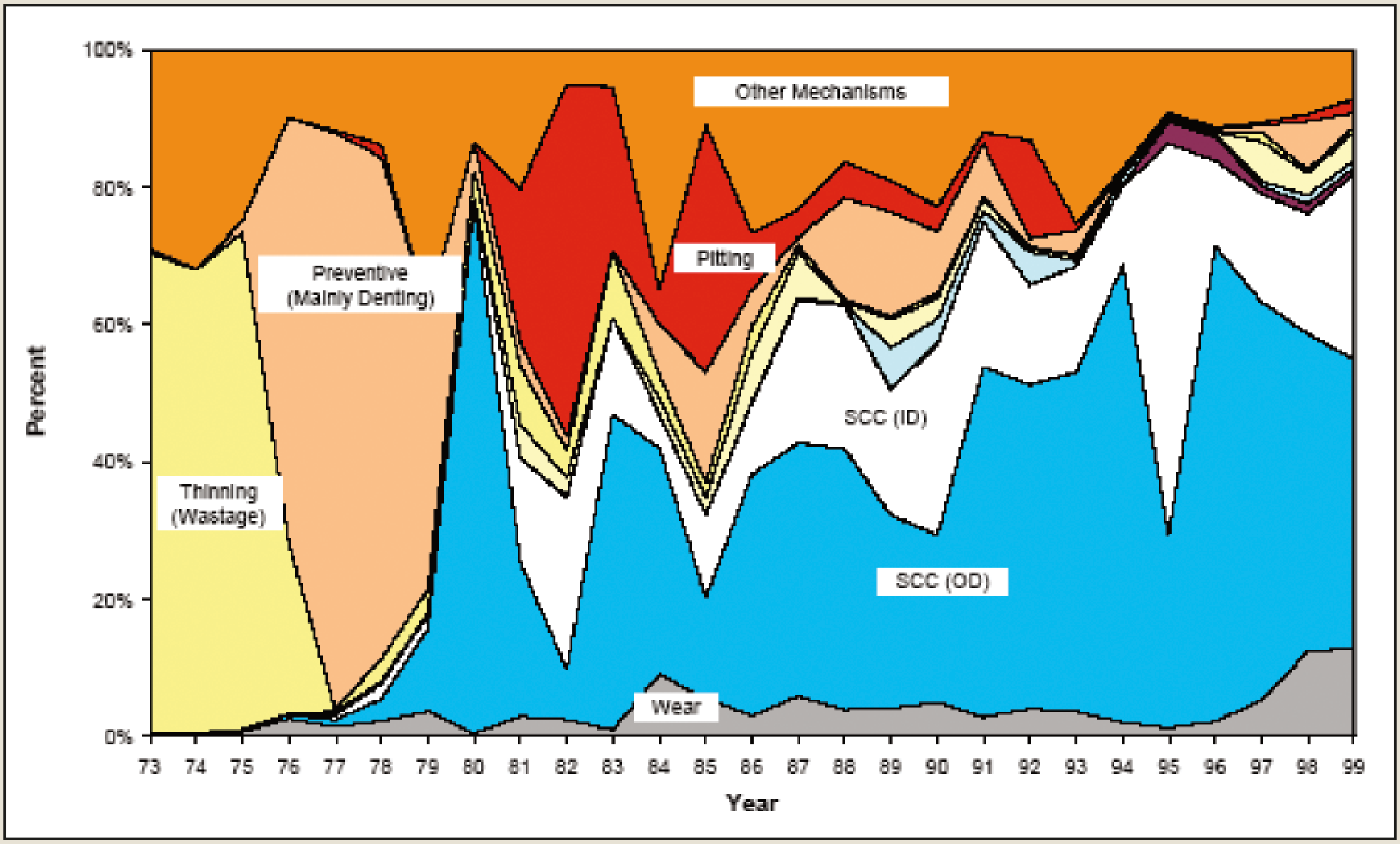


Figure 1: Evolution of Causes of SG Tube Degradation with Time [1]

these types of degradation were followed by other forms of corrosion-related degradation. *Figure 1* shows the evolution of the various SG degradation mechanisms observed to date with time for the first 30 years of operation, with stress corrosion cracking (SCC), either primary side SCC (ID SCC) or secondary side SCC (ODSCC) dominating the degradation. This history is essentially risk SGs have been replaced, thus taking these degraded Alloy 600-tubed SGs out of the database. The impact of SG degradation on Canadian CANDU plant incapability factors has been significant at some stations, notably Bruce A and Pickering B. The contributions

1 Atomic Energy of Canada Limited, Chalk River, Ontario K0J 1J0

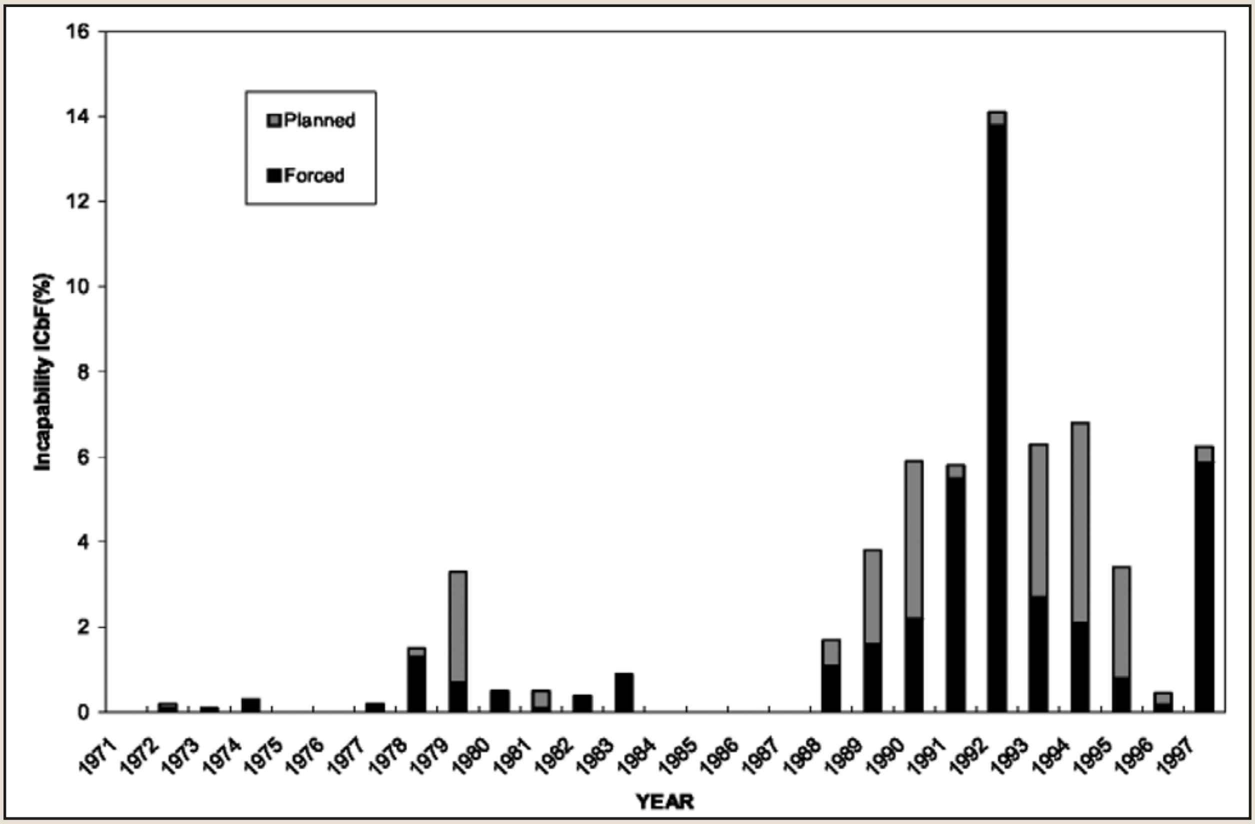


Figure 2: Incapability Factor Associated with Ontario Hydro SGs up to 1998 [2]

of SG degradation on Ontario Hydro reactors (now OPG and Bruce Power reactors) until the late 1990's is illustrated in *Figure 2*.

Thus, there has been a history or legacy of SG degradation, dominated by Alloy 600 issues, that has affected operation of all types of SGs, and has impacted regulatory and design decisions, as well as operational practices.

CANDU SG design has evolved differently from that of PWRs. Typically, PWRs employed a small number of large SGs per reactor, one for each loop. The early days of CANDU reactor design and construction emphasized a "made in Canada" approach, where feasible, and for SGs this resulted in a larger number of small SGs, compared to typical PWRs, for Pickering and Bruce; 12 for Pickering and 8 for each Bruce reactor. The Douglas Point and Pickering sizing and tube material selection were based on experience with fossil-fuelled plant feedwater heaters, and cost [3]. All CANDU SGs have had preheaters, all integral preheaters except Bruce A and B, which have external preheaters. Despite PWR experience to the contrary, CANDU experience is that there has been relatively little negative impact of the integral preheaters on SG performance; in fact, the preheaters permit more efficient design and operation of the SGs. Each evolution of CANDU reactors was marked by a decrease in the number of SGs per reactor, and an increase in size. Figure 3 illustrates this trend. Current CANDU 6 and Darlington reactors each have four SGs with stainless steel supports and Alloy 800 tubing, with relatively little history of corrosion-related degradation. For the Advanced CANDU Reactor (ACR), the SG size is comparable with the larger PWR SG designs.

As reactors age, decisions are being made about extended plant life (long term operation), which is usually associated with a refurbishment plan (following a condition assessment and remaining life assessment of major components) and outage, and, for CANDU reactors, an extended life of 25 to 30 years. The refurbishment decision is an economic one. For CANDU reactors the minimum requirement is to retube the calandria vessel (new pressure tubes and calandria tubes). Refurbishment of other major components, which include the feeders and steam generators, is based on remaining life decisions and projected future maintenance costs. SG replacement is a major cost item, and in some cases, SG degradation has resulted in premature permanent reactor shutdown (for instance Trojan in the USA; Bruce Unit 2 in Canada) because of escalating SG maintenance and downtime costs. For CANDU 6 reactors planning retubing or refurbishment (Point Lepreau, Gentilly-2, Wolsong-1), the steam generators are currently in good condition and should perform well for the extended life period. Other CANDU reactors undergoing retubing are replacing steam generators (Bruce Units 1 and 2), and other potential Bruce Power and OPG refurbishments may also replace the SGs.

The R&D emphasis in support of CANDU SGs has evolved in line with the operating experience and life extension decisions, and typically has evolved in parallel with (but complementary to) R&D carried out elsewhere. Initially R&D focussed on denting, SG chemistry (especially crevice chemistry) and SCC, then moved to an integrated SG program that included all aspects of SG technology (thermalhydraulics, inspection, repair, cleaning, vibration and fretting), and has now evolved to consider possible future long term degradation mechanisms (Pb cracking, for

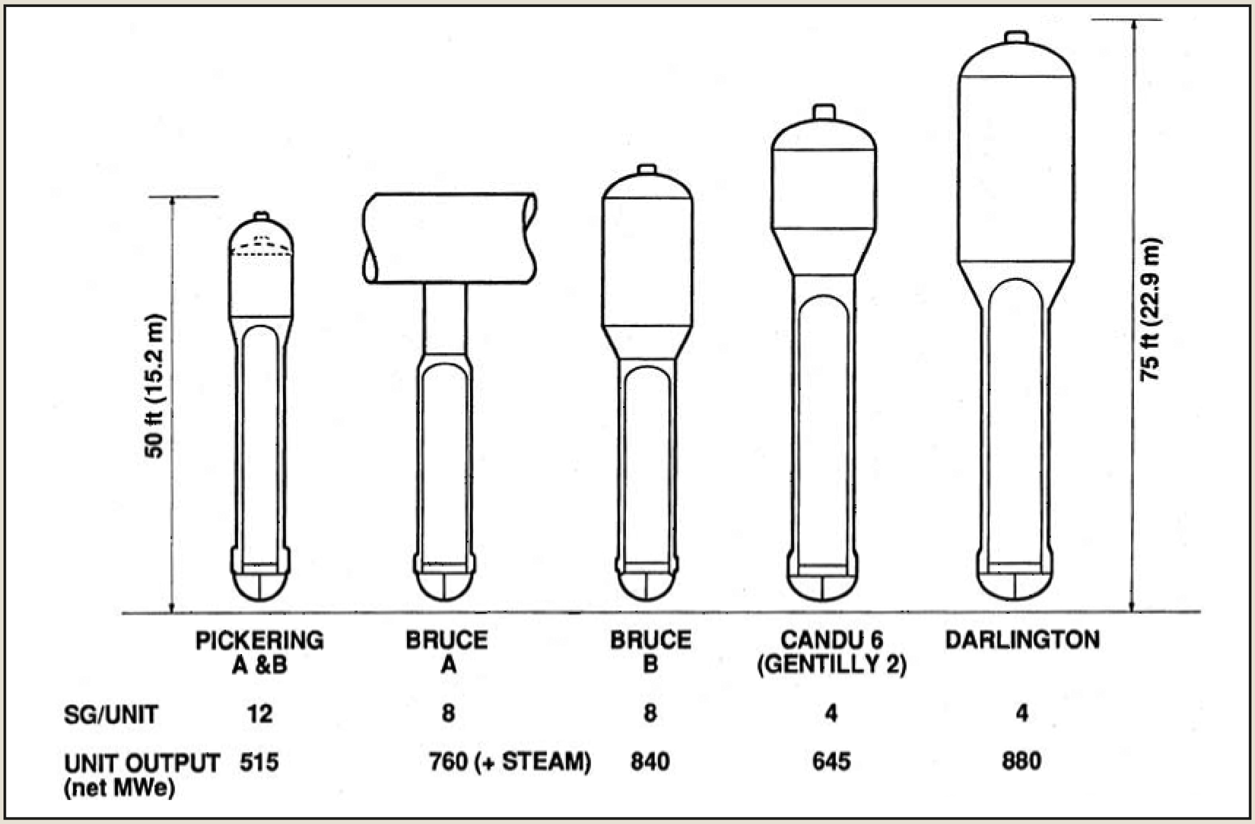


Figure 3: Size Evolution of CANDU SGs

instance) and remaining life estimation. For SGs tubed with Alloy 800, very little degradation has been observed to date with up to 30 years' service, and thus there is no large operational database upon which to base a deterministic remaining life prediction, although it is generally assumed that a further 30 years' service is a reasonable expectation if appropriate life management practices are followed [for instance, see references 4 and 5]. Similar considerations apply to new SGs, which are required to operate economically and without replacement for up to 60 years, regardless of whether they are tubed with Alloy 800 or with Alloy 690.

This paper provides an overview of the CANDU SG operating experience (OPEX), the R&D response and a projection of the next 30 years' operating experience and requirements.

What Was Not Forseen By Early SG R&D

As Figure 1 illustrates, a number of different SG degradation mechanisms has been experienced, many of which were neither anticipated by designers nor expected by operators. This paper will not discuss these mechanisms in detail; there are a number of publications that do so [for instance references 6 and 7 and references therein], but a brief overview of the historical evolution of the degradation mechanisms serves to highlight the key factors responsible for the degradation. The first point to note is that although it was recognized that stainless steels would not provide adequate service if chloride contamination could occur, and thus was used for SG tubing in only a few early SG designs, the successor material in PWR SGs, Alloy 600, was shown by the early 1960s to be susceptible to SCC in pure water if stressed sufficiently [for instance, see reference 8], and in contaminated caustic solutions which were believed to be possible in secondary side crevices [9]. Thus it perhaps should not have been surprising that after a few years' service, SCC of Alloy 600 SG tubes was detected in areas with high residual stress (dented areas, rolled joints at the tubesheet, tight radius U-bends, etc.), starting in the late 1970's.

Wastage is usually associated with concentration of phosphates in crevices, especially tube-to-tubesheet and tube-support crevices, and with off-specification application of the Na/PO_4 ratio. Phosphate chemistry, derived from fossil boiler use, was designed to complex and suspend impurities in the SG to facilitate their removal by blowdown. Some wastage, typically in cold leg portions, was associated with acidic chloride or sulphate buildup under deposits. Most stations converted to a volatile amine chemistry, called all-volatile treatment (AVT) using ammonia, and then morpholine and other amines, to eliminate phosphate wastage as a concern. In Canada, the only station to use phosphate SG chemistry, PLGS, remained on phosphate chemistry until 2000, when it converted to AVT [4].

Denting, which was not anticipated at the time reactor SGs were designed, is typically associated with acidic (chloride or sulphate) chemistry in tight crevices between carbon steel supports and the SG tubing, and was originally primarily associated with seawater ingress into the feedwater. The corrosion of the carbon steel supports resulted in the expanding corrosion product crushing the tube in the confined spaces between the tubes and supports and,

Table 1: Geometric and Material Data and Operational Parameters for PWR and CANDU Steam Generators

Reactor Design	AP600	AP1000	ACR 1000	System 80	N4	CANDU 6	Darlington
	Westinghouse	AECL		CE	Framatome	AECL	AECL
Electrical output MWe gross/net	619/600	/1090	1165/1085	1389/1350	1450	680/650	881
No of SGs	2	2	4	2	4	4	4
Thermal MW transfer/SG	970	1707.5	802	1957	1065	516	664
Heat transfer area, m²/SG	**6986**	**11477**	**8454**	**14660**	**7300**	**3205**	**4830**
No of tubes	6307	10025	7234	12580	5599	3550	4663
Tube pitch, mm	24.9	24.9	24.79	25.4	27.4	24.13	24.5
Tube diameter/wall, mm	17.5/1.00	17.5/1.00	17.4/1.07	19.05/1.07	19.05/1.09	16/1.13	16/1.13
Pitch/Diameter for tube	1.42	1.42	1.42	1.337	1.44	1.52	1.54
Max outer dia, mm	4500.8	5842	4650	5890	4780	3862	4730
Total height, mm	21051	22536	24000	23000	21940	19333	22211
Weight (tonnes)	480	422	748			215	334
Tube material	I690 TT	I690 TT	I800M	Inconel 600	I690TT	1800M	1800M
Steam flow rate, kg/s/SG	531.5	943.73	430	1100	600	258.25	329.2
Steam temperature, °C	272.7	275.5		289.7	288.5	260	264.75
Steam pressure, MPa (abs)	5.74	5.764	6	7.38	7.3	4.7	5.07
Feedwater temp, °C	226.6	226.6	217	232C	229.5	187	176.5
Tube support design	broached trefoil	broached	lattice grid	egg crate	broached hole	lattice grid	lattice grid
Tube suppport material	405 SS	405 SS	410 SS	409 SS	13% chrom steel	410 SS	410 SS
Primary flow rate, Mg/s/SG		3.26		10.33	4.17	1.925	2.48
Primary inlet pressure, MPa (abs)	15.5	15.5	11.1	15.5	15.5	9.89	9.88
Primary SG inlet temp, nom/max, °C	315.6	322/325	318.6	327.3	329	309	309.2
Primary SG outlet temp, °C	279.5	279.72	274	296	292	266	265
Primary quality, %	0	0	0	0	0	4.4	3.4
Integral preheater	no	no	yes	yes	yes	yes	yes
Design fouling factor, hr-sqft-F/Btu		0.00011	0.00015			0.0002	0.0002
Circulation ratio			6.2			6	5

occasionally, the tubesheet. The stresses induced by this tube crushing action were sufficient to initiate IDSCC of the tubing. This has been seen only with Alloy 600 SG tubes and carbon steel support plates. Early CANDU 6 SGs were designed with stainless steel supports, and broached-type flow holes, to eliminate this concern.

Over the next decades, SCC became more prevalent in SGs tubed with Alloy 600. As noted above, this was perhaps predictable based on some early R&D results, but what was probably not anticipated was the extensive nature of the SCC, and some pitting, that was observed on the secondary side, and the wide range of environments found to cause this degradation, including reduced sulphates (thiosulphates and tetrathionates, for example), copper compounds, oxidants, chlorides and Pb. These contaminants can concentrate in heat transfer crevices at factors up to 10_6 [7]. Included in this concern is the need to reduce fouling associated with ingress of corrosion products from the feedwater system; such ingress has been reduced with improved amine selection and improved feedwater piping materials. These concerns have resulted in the need for stringent chemistry control requirements such that the impurity levels of key corrosive or fouling contaminants must be maintained at the low ppb level or below. Related to this was the need to eliminate copper-containing materials from the feedtrain and any auxiliary system that feeds into it, the need for much improved water treatment plant operation, exclusion of oxygen from the feedwater prior to startup, maintaining the SG in a deoxygenated state during shutdowns, and the need for improved condenser designs and materials such that leak tightness can be assured.

Finally, for some PWR and CANDU SGs, another unexpected degradation has been flow-accelerated corrosion (FAC) of some carbon steel secondary side internal components. This has included steam separator components, support plates (U-bend and straight leg) and

Table 2: Qualitative Comparison of Support From a Fouling Perspective [6]

A Fouling-Resistant Design Will Have:	Bruce Broached Plate	CANDU 6 Broached Plate	Darlington Lattice Bars		Wolsong-1 Formed Bars
			High	Low	
Low flow resistance	X	0	X	~	~
Low potential for particle trapping upstream	X	X	0	~	~
Low potential for particle deposition downstream	X	X	0	~	~
Uniformity in subchannel size	~	~	X	~	0
Design asymmetry for flow mixing	X	X	~	~	X
NET ASSESSMENT	XXX	XX	~ ~		~ ~

legend: X = bad; 0 = o.k; ~ = good

feedwater inlet components. Although FAC of carbon steel is now a well-known phenomenon, it was not as well-understood 40 years ago when early SGs were designed, and even today, the FAC experience is highly variable, with frequent observations of variability between otherwise identical SGs and within a given SG. This variability may be a consequence of small variations in the Cr content of the carbon steel, and thus is difficult to predict, although the use of stainless steels for supports and other susceptible areas eliminates this concern.

Evolution of CANDU SG Designs and Materials

As Figure 3 shows, the most obvious design evolution for CANDU SGs has been size; the size increasing as the manufacturing capability has increased, to the stage where the ACR (Advanced CANDU Reactor) SGs are of similar size to the larger PWR designs. However there has also been an evolution in other key areas, which include tube material, support material, support design and feedwater/steam cycle piping design and materials.

Tube material evolution was from Monel 400 (Alloy 400) used for Douglas Point, Kanupp, early Indian PHWRs and Pickering SGs, through Alloy 600 selected for Bruce, to Alloy 800 selected for CANDU 6 and Darlington SGs, as well as for replacement SGs for Bruce A. As noted earlier, the selection of Alloy 400 was based on available Canadian technology derived from fossil plant feedwater heaters, where the material has had an excellent service record. In CANDU-type reactors the early Alloy 400 used at Douglas Point and in some Indian SGs experienced fatigue cracking at the very tight radius bends ("hairpins") of the early designs, but has given excellent service at Kanupp, Pickering A and several other Indian SGs. The slightly modified Alloy 400 (change in Ni to Cu ratio to improve inspectability with eddy current [3]) used at Pickering B has been shown to be susceptible to under-deposit corrosion in the presence of oxidizing impurities [10]. AECL and Ontario Hydro moved away from Alloy 400 because of operating experience at Douglas Point, and because of the activity transport issues there associated with Cu-64 following oxidizing transients[1 1]. Ontario Hydro elected to use Alloy 600 at Bruce A and B, based on early PWR experience at the time design decisions were made and because of concerns with early experiments with Alloy 800 which showed that the material was susceptible to cracking in concentrated hydroxide solutions, especially if not made with carefully controlled Ti/C ratio (nuclear grade or "modified" Alloy 800) to prevent sensitization. These early decisions were based on the assumption that SG crevices could become highly alkaline under certain chemistry upset conditions [12].

For CANDU-6 SGs, AECL, after careful review of early Alloy 600 laboratory data showing the susceptibility to PWSCC, and in consultation with developments elsewhere that led to the modified Alloy 800 tubing specification, specified Alloy 800M with a Ti/C ratio >12. This ratio has changed slightly since the late 1970's, but Alloy 800M is used in current CANDU 6 SGs, as well as at Darlington.

CANDU SG support plates, including U-bend supports, were fabricated from carbon steel in early SGs, but all CANDU-6 SGs, except Embalse, have stainless steel supports (Wolsong-1 has Alloy 600 supports). The move away from carbon steel was driven by the early experiences with denting in PWRs, but has also provided an additional benefit with the resistance to FAC. Table 1, which shows various operating parameter comparisons for some PWR and PHWR SG designs, includes this information.

Similarly, certain secondary side components which may be susceptible to FAC are now specified to be made from either Cr-enriched carbon steel (Cr > 0.2 wt. %) or stainless steel. Steam cycle piping sections and components that are susceptible to FAC in single phase flow or two-phase flow, and thus which may contribute to high feedwater iron and particulate ingress to the SG, are now also specified to be stainless steel. Early BOP piping was fabricated entirely from carbon steels, and much of the high-energy portions of this have been replaced over the years because of FAC.

As noted earlier, current CANDU designs have eliminated the use of copper components that might contribute Cu contamination to the feedwater; this has led to the elimination of copper-alloy condensers and feedwater heaters, which were the primary sources of copper. This is to eliminate the risk of copper-induced corrosion of the SG tubing, but provides an additional benefit of improved chemistry control by eliminating mixed-metal systems. Support designs have also evolved, from "solid" U-bend support structures at Bruce A to a more open design at Bruce B, and the early CANDU 6 units, to lattice bars at recent CANDU 6 units and at Darlington. R&D has also shown that the flat bar designs are more open to flow than broach plate (or drilled hole) designs, and thus are the appropriate choice for optimal thermalhydraulic performance (Table 2).

CANDU SG Operational Drivers

Over the past 30 years, the SG-related operational drivers affecting CANDU stations have evolved from initial optimism, in the

Table 3: Summary of CANDU SG Degradation Experience

PERIOD WHEN FIRST NOTED	DEGRADATION ON TYPE	COMMENTS
1970's and 1980's	Fatigue cracking	Found only in a few outer row tubes at Bruce A; early in life.
	Fouling	Primary side fouling generic to all SGs and resulted in contribution to RIHT increase and less efficient operation/reduced margins. Secondary side fouling varies with chemistry management practices; Pickering A and Bruce A units experienced significant fouling. In both cases, lack of inspection up to late 1980's to quantify rate and extent; in late 1980's fouling began to impact SG operation/ thermalhydraulics.
	Pitting	A few tubes affected at Point Lepreau at first support plate location; phosphate wastage may also have been involved.
	Carbon steel corrosion	Bruce A U-bend supports (attributed to crevice corrosion, unprotective chemistry and flow accelerated corrosion)
1990's	Cracking (SCC)	Bruce A U-bends Bruce A top-of-tubesheet
	Phosphate wastage	Limited to Point Lepreau (arrested after switch to AVT); approximately 40 tubes directly affected. Some pitting also as a consequence of condenser leaks
	Denting	Bruce A U-bends (cause of some of the SCC there); resulted in U-bend support damage Pickering A: a few hundred tubes affected at lower supports (carbon steel lattice bar supports)
	Fretting wear	Bruce B U-bends Darlington U-bends and hot leg supports Minimal impact at CANDU-6 SGs, Bruce A, Pickering A/B
	Pitting	Bruce Units 3 and 4; significant numbers of tubes affected (approximately 2000 tubes plugged); attributed to inappropriate layup practice. Pitting in other SGs may be a consequence of oxidizing conditions during shutdowns.
	Flow accelerated corrosion (FAC) of carbon steel primary side components	Primarily associated with segmented divider plates; FAC of bolts, plates and channel supports led to divider plate bypass and loss of thermal efficiency. Mitigated by replacement with solid plates fabricated from FAC-resistant materials, or by application of a stainless steel "skin"
Late 1990's and 2000's	Flow accelerated corrosion of secondary side components	Major impact has been on upper supports; Bruce B and Embalse. Feedwater component wall loss at Pickering. Separator wall loss at Bruce B (variable extent). Monel 400 SG tube wall thinning in upper broaches at Pickering B SGs

absence of inspection (especially of the secondary side) that the SGs were performing well and were thus not significantly impacting operation and maintenance, to the realization that SG management is a core component of safe and economic plant operation. The major impacts of SG degradation on plant operation began to be seen in the 1990's and primarily at Bruce A with cracking of the Alloy 600 SG tubing, and at Pickering B, with Alloy 400 SG tubing. Table 3 provides a summary of this history.

This experience has led to SG life management plans that include extensive inspections, and the need to develop disposition arguments that can ensure economic plant operating intervals. Currently fretting wear rates and SCC crack growth rates can have a significant impact on the length of the operating interval that can be justified before tube integrity is compromised. Thus, R&D has been carried out to improve inspection capability (sizing and probability of detection), and to better understand the root causes of the observed degradation. Corrosion-related degradation is best managed by improvements in chemistry control, in particular to ensure no deposit buildup and to ensure non-oxidizing conditions are maintained, especially during shutdowns and startups. Examples of the effectiveness of this approach are the arresting of FAC degradation of carbon steel supports by improving at-temperature pH control [for instance see 13], and the minimization of top-of-tubesheet pitting at Bruce Units 3 and 4 by eliminating oxidants and the likelihood of generating corrosive species such as reduced sulphate compounds.

The R&D has had to evolve to address this progression of degradation, and because much of the CANDU SG degradation is specific to CANDU SG tube materials, and CANDU SG tubing is smaller in diameter than PWR tubing, it has not been possible to simply apply R&D results or operational experience generated outside Canada. However external OPEX and R&D results have been incorporated where possible, including those related to feedwater chemistry specifications, shutdown chemistry guidelines, etc..

The R&D Response

Early R&D, before significant degradation was observed in CANDU SGs, followed PWR R&D that was co-ordinated by EPRI, and R&D carried out in Europe. Thus, the early focus was on crevice chemistry and denting, and corrosion-related degradation of SG tubing in secondary-side faulted feedwater and under off-specification HTS conditions. This work included studies of Alloy 800 (nuclear grade) as well as comparisons with Alloy 600. Much of the work was related to specifications for SGs, especially the heat treatments of tubing materials, vibration and fretting wear requirements, and tube-to-tubesheet expansion joint studies. Table 4 summarizes the major components of the CANDU SG-related R&D carried out over the past 30 years.

This paper will not address in detail what has been covered by the R&D outlined in Table 4 [see, for instance, Reference 13], but examination of the table reveals that, after the early R&D carried out before the late 1960s, the R&D has tended to follow, rather than predict, the SG operational issues experienced by the stations, and that "themes" or paradigms have evolved and been replaced as the issues changed. Thus in the 1 960s and into the early 1970s the major R&D activities were driven by design-related needs [for instance, see Reference [14]. The initial PWR experience with Alloy 600 degradation (denting, phosphate chemistry), which led to R&D in these areas in Canada [15], was followed in the 1980's by a growing impact of fouling on SG function, especially in Canada. However, inspections of CANDU SGs, especially of the secondary side, were not extensive and thus the growing fouling, and associated corrosion, problem was not fully realised until the late 1980's (for instance thermalhydraulic instabilities, under-deposit corrosion, denting). In fact it was widely assumed that SG designs would prevent SG fouling because blowdown would be effective in removing suspended particulate (hence the initial applications of phosphate chemistry). By the late 1980's and early 1990's fouling and corrosion-related degradation, particularly at Bruce A, had had a major operational impact on reactor operation, in common with the PWR experience with Alloy 600.

This was to continue through the 1990's. Unique to CANDU was the "wastage" or "pitting" of the Alloy 400 SG tubing at Pickering B, along with "erosion" of the Monel 400 tubing in the upper broach plate flow holes [9]. During this time, it was recognized that SG fouling was the major contributor to the corrosion-related degradation and thermalhydraulic instabilities, and significant cleaning development, qualification and field campaigns took place. Also critical during this period was the development of CANDU-specific inspection technologies that provided the operators and regulators with confidence that the degradation could be confidently detected and operating intervals defended. During this time Ontario Hydro removed more than 100 tubes from Bruce A for detailed examination, and this database enabled development of good probability of detection (POD) curves for the C3-4 and C3-8 eddy current probes, which provided the dispositions for maintaining the units in service. The inspection technologies for the small diameter Bruce A SGs and the large Alloy 600 cracked tube database for Bruce A were not available from the PWR industry, and thus was addressed by CANDU industry. Similarly, inspection technology for other small diameter SG tubing (compared to PWR tubing), and the need to understand the degradation of Alloy 400 and Alloy 800 SG tubing, required a CANDU-specific R&D activity.

During this period, there was also emphasis on fouling, on both the primary and secondary sides for CANDU SGs, and for the secondary side at EPRI. This work led to an improved understanding of fouling mechanisms and predictability, and to the development of dispersants and alternative amines for SG application [13]. This work was linked with R&D activities oriented at improving SG secondary side cleaning, including a better understanding of deposit consolidation that enables

Table 4: Overview of Major SG R&D Activities Carried out by the Canadian Nuclear Industry

TIME PERIOD OF CANDU R&D EMPHASIS	PRIMARY CANDU R&D AREAS INVESTIGATED
1970's	Denting and crevice chemistry/hideout
	Primary side cracking
	Phosphate chemistry
	Vibration and fretting wear
	Rolled joint technology
1980's	Primary and secondary side cracking
	Crevice chemistry/hideout
	Fouling
	Vibration and fretting wear
	Inspection technology
	Thermalhydraulics (THIRST code development)
1990's	Secondary side cracking
	Secondary side corrosion (pitting, IGA)
	Crevice chemistry
	SG chemistry/chemistry mitigation strategies, alternative amines and dispersants
	Inspection technology (eddy current and UT)
	Vibration and fretting
	Thermalhydraulics (THIRST code development)
	Fatigue
	Cleaning (primary and secondary side technologies)
	Tooling for SG inspection, repair/mitigation strategies
	Lead (Pb) chemistry
2000's	Crevice chemistry (including effects of crevice geometry)
	Lead (Pb) cracking and Pb chemistry
	Inspection technologies (eddy current and UT)
	Cleaning of hard deposits (secondary side)
	Secondary side cracking, IGA and pitting (susceptibility mapping)
	Fatigue
	SG chemistry (hydrazine chemistry)

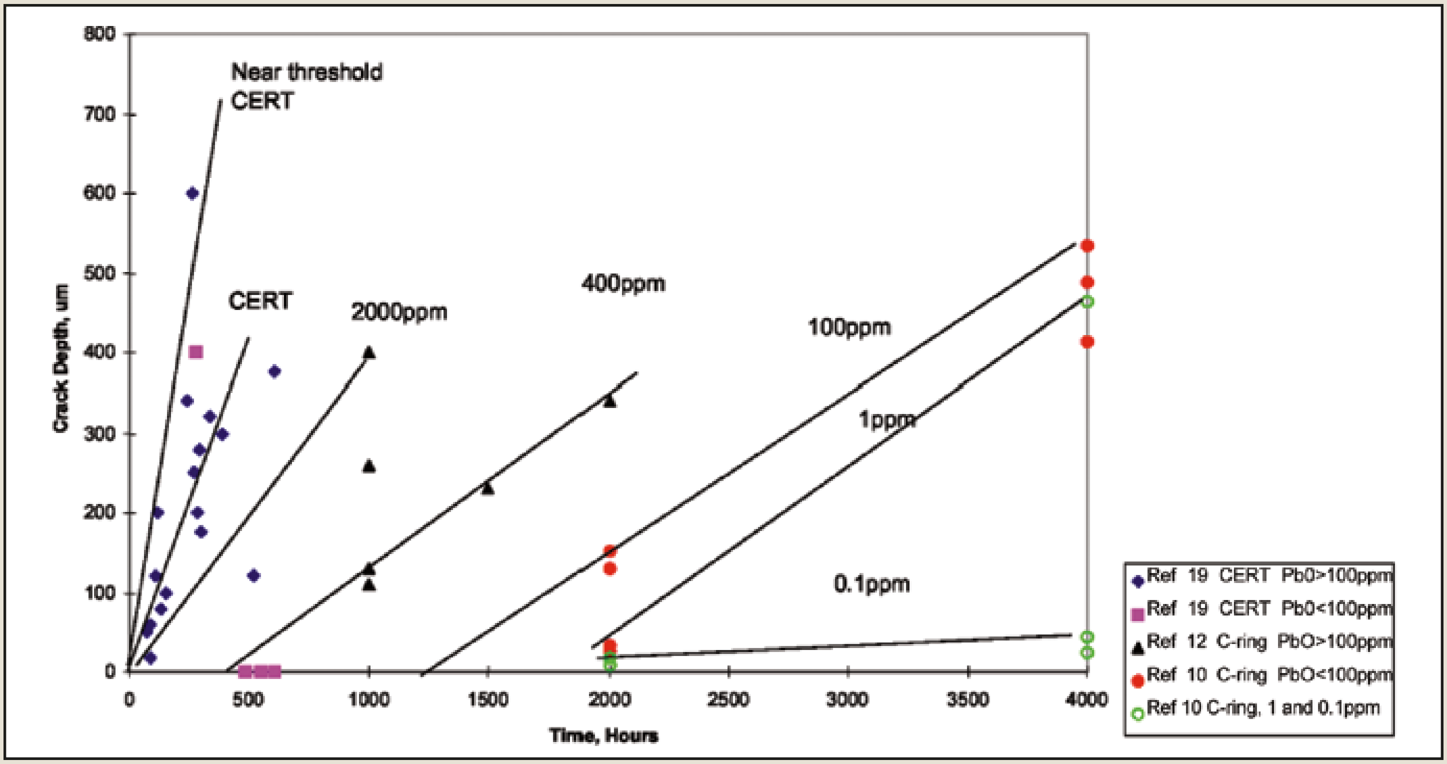


Figure 4: Effect of Varying Pb Concentrations on Stress Corrosion Cracking of Alloy 600 SG Tubing [17].

operators to better schedule cleaning activities, and the application of ultrasonic energy to improve tubesheet cleaning,

It is also important to note that the Bruce A SG tubing cracking was complicated in the mid-1980s by the inadvertent introduction of a lead blanket into an operating Bruce Unit 2 SG, which resulted in severe SCC of that SG and significant contamination of the other SGs in that unit, and eventually, in 1995, in shutdown of the Unit (Unit 2 is to be restarted with new SGs and other components). This event drove some significant R&D activity in Pb transport and Pb-assisted cracking, with the realization that not only does Pb accelerate SCC of Alloy 600 SG tubing, and that most, if not all SGs are contaminated with Pb, but also that very low levels of Pb may impact Alloy 600 SCC. This is illustrated by Figure 4. Recently, the realization that Pb may be responsuible for much of the Alloy 600 SG tube cracking detected to date, and that most, if not all, SGs are contaminated with Pb, has begun to cause some concern in the SG community, in particular with respect to the possible susceptibility of Alloy 690 SG tubing to Pb-assisted SCC [7, 16], with EPRI, AECL and COG all initiating studies of the effects of Pb on SG chemistry and corrosion. Thus, for the 2000's there are several collaborations by CANDU industry with SG technology and R&D with EPRI related to Pb. This is currently a major R&D activity, focussed on ensuring that Alloy 800 will not be susceptible to Pb-assisted cracking over the next 30 years, or for a total of 60 years in-service. The other R&D activities are complementary to this goal, and there continues to be interest in cleaning of primary side deposits (now a mature technology) and in the removal of remaining hard tubesheet deposits using new solvent-based approaches. The major industry focus is now moving towards more effective life management and preventive maintenance, and the integration of the past 30 years of knowledge, both R&D and operational, to achieve this and hence meet retubed/refurbished and new reactor requirements.

The R&D activities, whilst still addressing new or as-yet still difficult issues, are indeed starting to consider the needs for the next 30 years. Typically, the R&D data are being incorporated into tools that are more readily available to SG operators, and more clearly address their needs. For instance, "smart" SG monitoring technologies can link corrosion susceptibility data with operating chemistry parameters to provide a tool that advises when chemistry is out-of-specification and could impact SG integrity if not corrected. Figure 5 illustrates this approach [18]. Although it is recognized that the accelerated tests used to create these types of diagrams may not accurately reflect actual field corrosion susceptibility, especially for SCC susceptibility, they provide a useful operating guide.

Past experience has shown that laboratory data may be a better predictor of qualitative susceptibility than often thought, even if this realization has been in hindsight.

The Next Thirty Years

Over the next 30 years, a number of CANDU (and PWR) SGs will achieve a 60-year life if they are able to remain in economic service, and if plant operation is also economic and safe. New SGs are promised to have a 60-year life, largely based on knowledge from nearly 30 years of service and R&D. The first 30 years of service has been obtained with the knowledge and expertise of a generation of engineers and scientists who are now retiring. Thus the path forward, and especially the integration of the past knowledge with that required for the future, requires a knowledge transfer to the

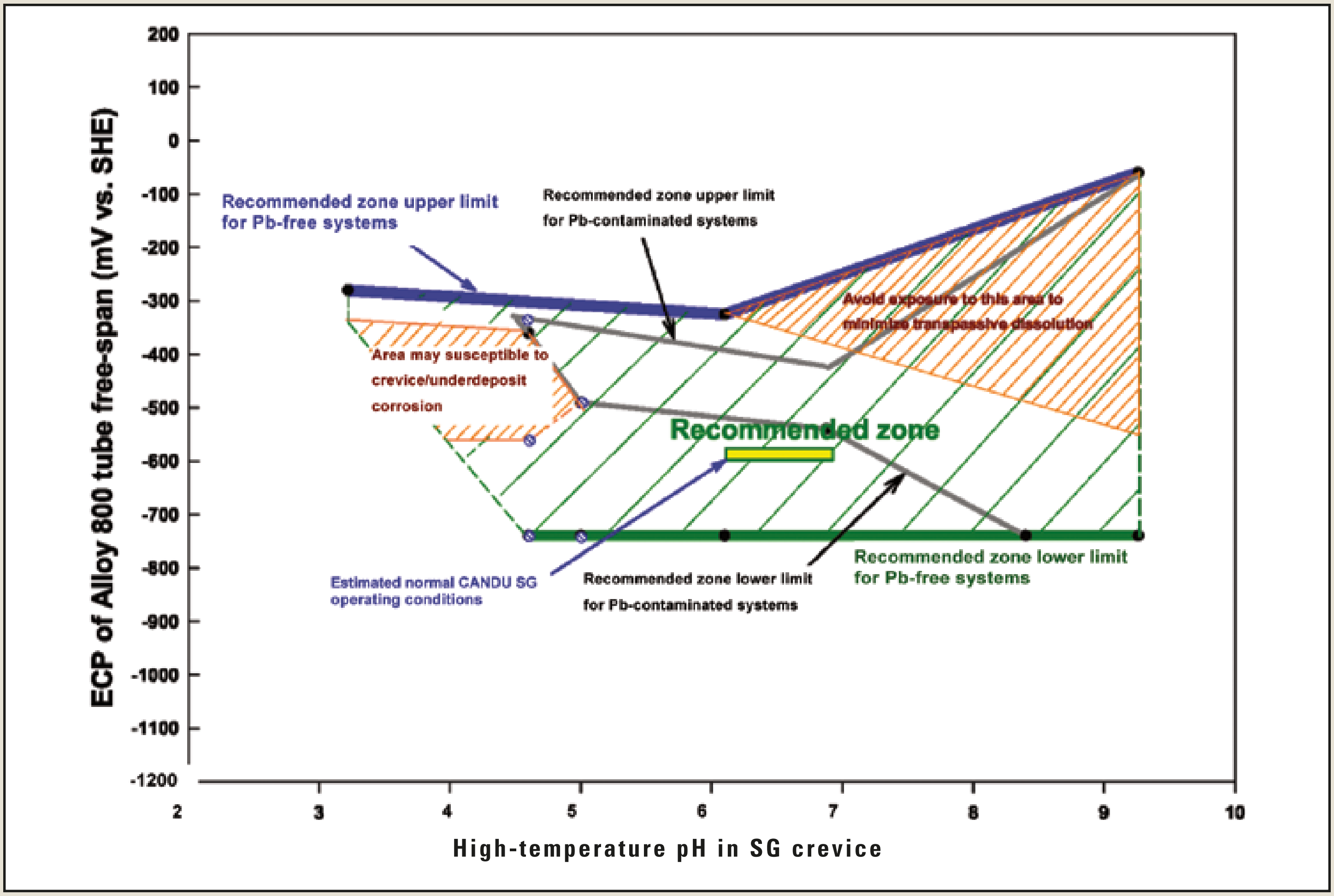


Figure 5: Schematic Showing Recommended Operating Zones for Alloy 800 SG Tubing [18]

operators, the R&D community, and the service providers of the current state-of-the-art. Within the CANDU community much of that knowledge has been transferred into improved technologies for predicting, monitoring and diagnosing SG performance, improved inspection probes and data analysis, improved chemistry monitoring, diagnostics and control, an integrated heat transport system aging management perspective and improved technical and operating specifications designed to ensure the possibility of 60-year life.

There is insufficient scope in this paper to fully address all the key advances R&D has made that, if appropriately implemented, should ensure that steam generators can achieve these extended, compared to the original "design life", service lives. Compared to 30 years ago, the existing OPEX and the following advances (not in any particular order) derived from CANDU-related R&D, including international collaborations, are providing, or have provided, the technologies that have increased 30 year life to confidence that 60 years is achievable:

- Continued confirmation that Alloy 800M is the appropriate choice for SG tubing and identification of the optimal operating conditions to ensure SG tube life, and identification that shutdowns, layups and startups may constitute the times of greatest risk to SG integrity. It is also clear that minor surface imperfections, such as scratches, weld spatter (for instance see [4]), etc., can initiate degradation of any SG tube material, including SCC degradation;
- Development of a versatile chemistry codes (such as AECL's ChemSolv [19]) to predict SG/feedwater/steam cycle chemistry, including evaluation and prioritization of dispersants and alternative amines to improve SG chemistry control;
- Identification of the design, chemistry and materials requirements to eliminate FAC in the SG secondary side and in the feedwater system;
- Development of a thorough understanding of SG fouling, and its impact on SG thermalhydraulic function, fouling margins, alternative amines and dispersants, support plate fouling and contributions to CANDU reactor inlet header diagnostics;
- Development of fast multi-purpose eddy current probes for SG tube inspection (X-probe), and of high resolution UT probes (TRUSTIE);
- Identification of the design requirements needed to minimize vibration and fretting wear and to optimize SG thermalhydraulic function (support design requirements);
- Development and application of the THIRST code [20] for 3-d thermalhydraulic analysis of SGs, including chemistry predictions, applications of CFD codes to analyse localized corrosion problems at supports, and application of EPRI's CHECWORKS code to evaluate SG FAC susceptibility;
- Development and qualification of cleaning technologies for

the primary and secondary sides of the SG tube bundle, in particular for hard tubesheet deposits;

- Development and application of operator-friendly prediction and diagnostic codes, and fitness for service guidelines, to aid in-service decision making.

However, the CANDU industry is not stopping at this stage, but is continuing to maintain key capabilities such as inspection, which is essential to all plant management strategies, chemistry control, tubing corrosion, and thermalhydraulics. Key areas of interest in inspection are to improve the speed of analysis of the increased data stream that is a consequence of using faster and more comprehensive probes. This may include new approaches to applications of probabilistic methods for handling data, and to innovative approaches that may involve combinations of NDE techniques. In the chemistry area, future challenges include the continued drive to reduce hydrazine additions and the use of alternative amines (compared to ammonia and morpholine). There will be a continuing challenge to assure operators and regulators that there are no unforeseen degradation mechanisms that could significantly impact Alloy 800 SG life, especially in light of concerns about the role of Pb in accelerating SG tube corrosion.

In this light, it is important to continue the move away from focussing on the latest problem towards a proactive approach. There has been a tendency to assume that R&D knowledge and plant experience is sufficient to address any future problems that might occur; this has led to the cessation of R&D in vibration and fretting wear, for instance. Even if there are no issues related to SG vibration and fretting wear anticipated for the next few years, there is a need to invest in capability maintenance should an issue arise, and to provide expert assistance for new designs that will be required should the new reactor build plans become a reality.

Overall however, the primary issue is that further operating life of SGs in refurbished plants, and the expectation of a 60 year life of new SGs, will require a very proactive chemistry control program, including regular cleaning of both the primary and secondary sides to ensure that deposit buildups are always maintained at the minimal acceptable level to prevent unacceptable crevice chemistries. In the opinion of this author, this will likely require more stringent SG chemistry management than is usually practised, especially during periods of shutdown or layup, and during startups.

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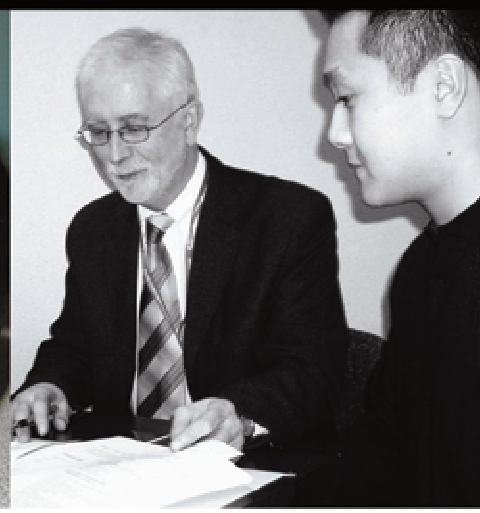

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Steam Generator Replacement in Bruce A Unit 1 and Unit 2

by Ralph S. Hart[1]

Ed. Note: The following paper was presented at the 5th CNS International Steam Generator Conference held in Toronto, Ontario, November 2006.

Abstract

The Bruce A Generating Station consists of four 900 MW class CANDU units. The reactor and Primary Heat Transport System for each Unit are housed within a reinforced concrete reactor vault. A large duct running below the reactor vaults accommodates the shared fuel handling system, and connects the four reactor vaults to the vacuum building. The reactor vaults, fuelling system duct and the vacuum building constitute the station vacuum containment system.

Bruce A Unit 2 was shut down in 1995 and Bruce A Units 1, 3 and 4 were shutdown in 1997. Bruce A Units 3 and 4 were returned to service in late 2003 and are currently operating. Units 1 and 2 remain out of service. Bruce Power is currently undertaking a major rehabilitation of Bruce A Unit 1 and Unit 2 that will extend the in-service life of these units by at least 25 years. Replacement of the Steam Generators (eight in each unit) is required; this work was awarded to SNC-Lavalin Nuclear (SLN). The existing steam drums (which house the steam separation and drying equipment) will be retained. Unit 2 is scheduled to be synchronized with the grid in 2009, followed by Unit 1 in 2009.

Each Bruce A unit has two steam generating assemblies, one located above and to each end of the reactor. Each steam generating assembly consists of a horizontal cylindrical steam drum and four vertical Steam Generators. The vertical Steam Generators connect to individual nozzles that are located on the underside of the Steam Drum (SD). The steam drums are located in concrete shielding structures (steam drum enclosures). The lower sections of the Steam Generators penetrate the top of the reactor vaults: the containment pressure boundary is established by bellows assemblies that connect between the reactor vault roof slab and the Steam Generators. Each Steam Generators is supported from the bottom by a trapeze that is suspended from the reactor vault top structure.

The Steam Generator Replacement (SGR) methodology developed by SLN for Unit 1 and Unit 2 SGR employs a Medium Lift Crane (MLC) located at ground elevation north of the powerhouse to perform all heavy lifts within the reactor buildings, including relocation of the steam drums and removal and replacement of the Steam Generators, through openings created in the reactor building roof structures. Following the removal of components and systems that interfere with SG replacement activities, the connections between the Steam Generators and the steam drums are severed, the roof of the concrete SD enclosure and the steam drum cooling system are removed, and the steam drums are lifted from the steam drum enclosures and placed on temporary supports to the reactor side of the steam drum enclosures by the MLC. The old Steam Generators are then removed and the replacement Steam Generators are installed through the reactor building roof openings by the MLC. The steam drums and all piping connections and equipment will be reinstalled following the installation of the Replacement Steam Generators to establish the "as found" condition.

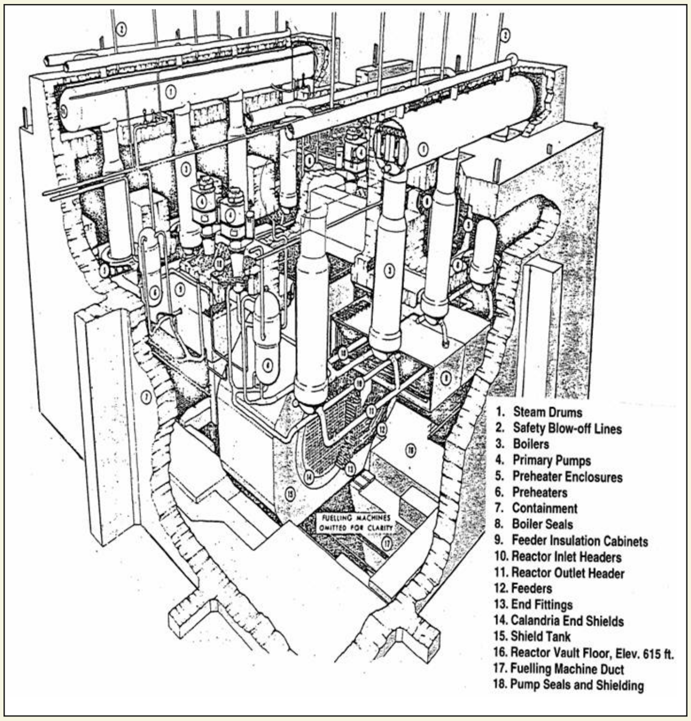


Figure 1-1: General Steam Generator Assembly Arrangement

1. Introduction

The Steam Generator Replacement work at Bruce A presents many "first-of-a-kind" challenges. The vacuum containment system employed by the Bruce, Pickering and Darlington stations, and the horizontal steam drum configuration utilized by Bruce A are unique in the world. In the vacuum containment system, the containment structure of each unit in the station connects to a vacuum building. In the event of a loss of coolant accident in a unit, valves connecting the unit containment to the vacuum building open to allow the discharge of steam into the vacuum building where it is condensed. While the Pickering units have cylindrical reactor buildings that house most of the Nuclear Steam Supply System, the Bruce and Darlington units have compact rectangular containment structures that house the reactor and the high pressure reactor coolant system (Heat

1 SNC-LAVALIN Nuclear Inc, Mississauga, ON, Canada, L5K 2P8

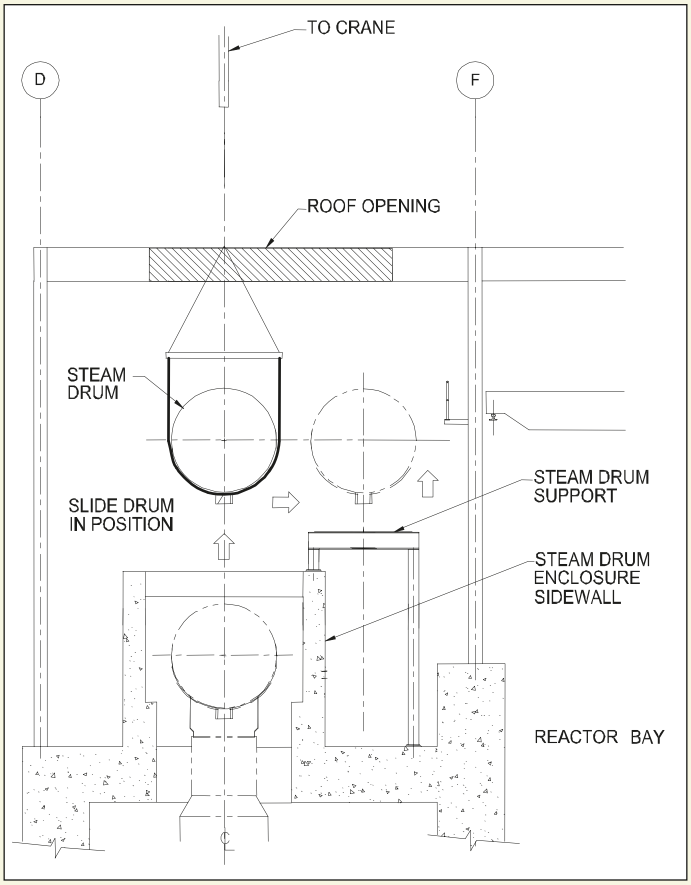


Figure 4-1: Steam Drum Repositioning – End View

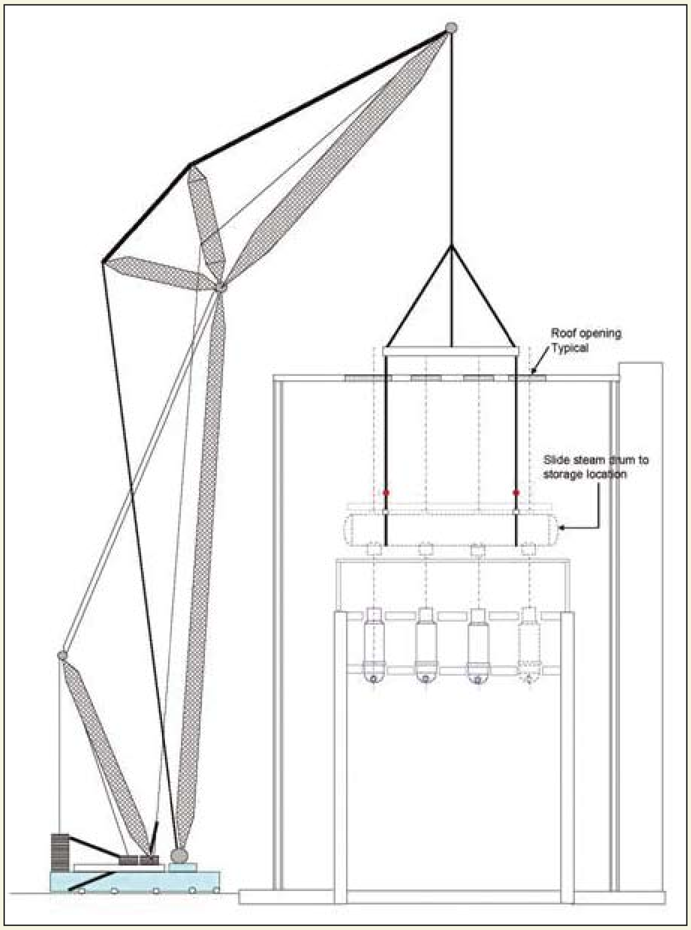


Figure 4-2: Steam Drum Repositioning – Side View

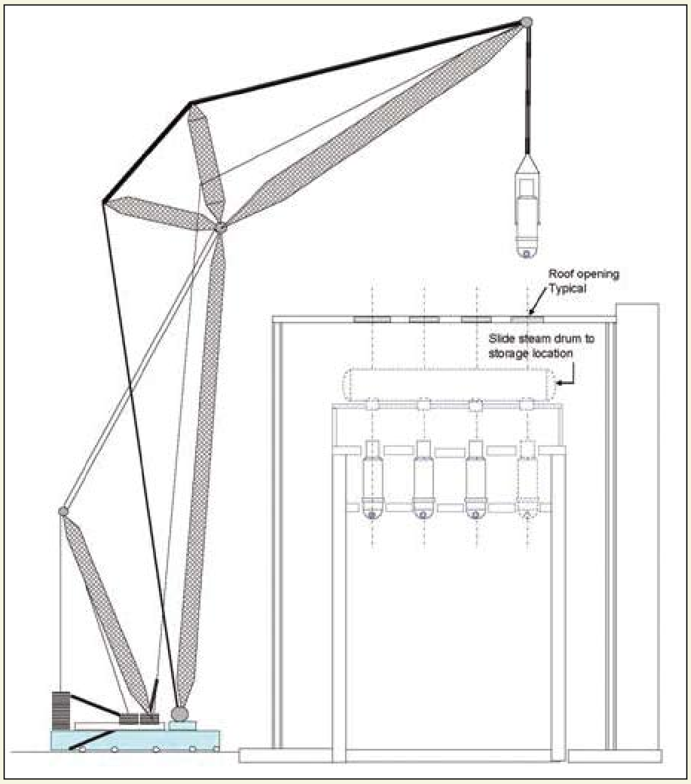


Figure 4-3: Steam Generator Removal/Replacement

Transport System): a single vacuum building serves four units. At these plants, the lower portions of the Steam Generators penetrate the top of the rectangular containment structures, which are referred to as the reactor vaults. Another feature that is unique to the Bruce A units is the use of eight vertical Steam Generators, four of which connect to a cylindrical horizontal steam drum at and above each end of the reactor assembly.

Although Steam Generators have been replaced in many Pressurized Water Reactors (PWRs) world wide, this experience is not directly applicable to the Steam Generator replacements at Bruce A, as all PWRs, except the early models designed in Russia, have cylindrical full pressure containment systems. The Bruce A Unit 1 and Unit 2 Steam Generator replacements require novel Steam Generator replacement methodologies due to the unique design features.

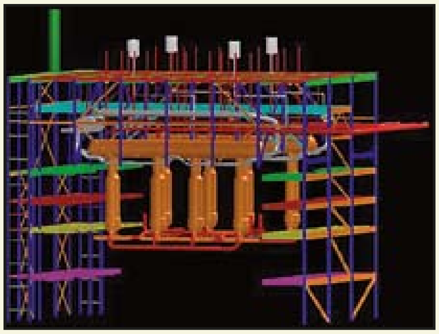
Bruce A Unit 1 and Unit 2 are de-fueled and the Primary Heat Transport Systems are drained and dried. The Unit 1 and Unit 2 reactor vaults are isolated from the station vacuum containment system, thereby facilitating reactor vault access and allowing openings between the reactor vaults and the reactor building environment.

2. Steam Generator Configuration at Bruce A

Each Bruce A Unit has two Steam Generation Assemblies, each consisting of a horizontal cylindrical steam drum (30m/96 feet long, and 3m/114 inches OD and weighing approximately

300 tons/270,000 kg) and four vertical Steam Generators (each 12m/39 feet tall and weighing about 120 tons/109,000 kg.)

The vertical Steam Generators connect to individual nozzles (5'-10"/1.8m OD) that are located on the underside of the steam drum. The steam drums are located in reinforced concrete shielding structures (steam drum enclosures). The Steam Generators span the reinforced concrete boiler rooms (located between the reactor vaults and the steam drum enclosures) vertically, with their lower sections penetrating the top of the reactor vault, where the containment pressure boundary is established by cylindrical bellows assemblies that connect between the reactor vault roof slab and the Steam Generators secondary shells. Each Steam Generator is supported from the bottom by a trapeze that is suspended from the reactor vault top structure. The general arrangement of the Steam Generator assemblies is shown in Figure 1-1.



▲ Figure 5-1: 3D Model of the Steam Generators and Steam Drum Assembly

3. Steam Generator Replacement Methodology

The Steam Generator replacement methodology developed by SLN resulted from a thorough evaluation of potential methodology options. These evaluations included an in-depth review of the Bruce A layout, arrangement and structural drawings covering the areas of the station affected by the Steam Generator replacement activities. Several ëwalk throughs' of the areas in the vicinity of the steam generation equipment were completed, and discussions were held with specialist in heavy lifting and material handling. High resolution laser scans of the areas that house the steam generation equipment (steam drum enclosure, areas in the vicinity of the steam drum enclosure, boiler rooms and reactor vault below the Steam Generators) were completed and ëintelligent' 3-D images were produced. Data from the laser scans facilitated the production of the drawings required to support the identification and assessment of Steam Generator replacement concepts.

▲ Figure 5-2: Boiler Room, top of the Containments Seal Assembly & Seismic Restraint

Four basic Steam Generator replacement concepts were selected by SLN from the identified potential Steam Generator replacement concepts for detailed evaluation. The evaluation of the selected Steam Generator concepts, based on technical merit, risk, cost, and schedule, resulted in the selection of the reference Steam Generator replacement concept described in this paper. This concept utilizes a robust Medium Lift Crane (MLC), located north of the reactor building to lift the steam drum and Steam Generators through openings in the reactor building roof.

▲ Figure 5-3: Boiler Room, Supporting Rods Closure

4. Steam Generator Replacement Overview

Many activities must be completed prior to lifting and moving the steam drum and removing the old Steam Generators. These activities include the removal of systems and components that interfere with the Steam Generator replacement activities in the reactor vaults, boiler rooms, steam drum enclosures, and in the areas above and to the reactor bay side of the steam drum enclosures, cutting of the heat transport system connections to the primary nozzles of the Steam Generators, removing the steam mains that are located above the steam drum, cutting the feedwater connections to the steam drum, and the cutting of temporary openings in the reactor building roof above each Steam Generator.

▲ Figure 5-4: View Inside Boiler Room Above Vault Showing Containment Expansion Joint & Blow Down Lines

Following the completion of interference removal, the MLC is utilized to lift the steam drum clear of the steam drum enclosure (refer to Figure 4-1 and Figure 4-2) and place it on temporary supports located to the reactor bay side of the steam drum enclosure. The old Steam Generators, after being sealed, are then lifted from the reactor building by the MLC through the temporary openings in the reactor building roof. The MLC then moves the old Steam Generators to a position north of the reactor building and lowers them to ground elevation, placing them on a transporter. The MLC then lifts the replacement generators from their horizontal position at ground elevation, and places them in position (vertical) in the boiler rooms, supported by the Steam Generator trapeze supports. The MLC is positioned north of the reactor building such that it can lift all eight Steam

▲ **Figure 5-5: View Inside Boiler Room Showing Bank of Steam Generators**

▲ **Figure 5-6: Top of Reactor Building, Crane Bay & Steam Drum Closure**

▲ **Figure 5-7: View Above Steam Drum Enclosure Roof**

▲ **Figure 5-8: View of Top of Steam Drum Enclosure Showing MSSVs & Cooling Fan**

▲ **Figure 5-9: Steam Generator to Steam Drum Connection**

▲ **Figure 5-10: Steam Drum Face Showing Cooling Ducts**

Generators from one unit from a single MLC location.

Following their placement in the boiler room, the replacement Steam Generators are positioned precisely to align with the Heat Transport System (HTS) piping based on accurate measurements utilizing the adjustment devices provided in the boiler rooms. After aligning the Steam Generator primary nozzles within the Heat Transport System, the HTS pipes are welded to the Steam Generator primary nozzles (inlet and outlet), and the welds are then inspected and heat treated. The steam drum is moved into position above the Steam Generators by the MLC and lowered into position for welding the steam drum nozzles to the Steam Generator connections following the placement of all four Steam Generators of one Steam Generator assembly. The auxiliary components and systems (i.e., bellows containment seal, steam relief valves, steam mains, ASDVs, instrumentation, steam drum cooling, system, etc.) are then reinstalled. Inspection of the systems is then completed to assure that all components and systems are in the "as-found" condition and in compliance with Code requirements.

5. Interference Removal Activities and Physical Preparations

Replacement of the Steam Generators at Bruce Unit 1 and Unit 2 requires the removal of all systems, components and structures that interfere with or impede the removal of the Steam Generators. Although this is technically interference removal, the removal and repositioning of the steam drum is considered, as in conjunction with the removal of the Steam Generators, an integral part of the Steam Generator assembly. The interferences to be removed include sections of the reactor building roof structure, steam lines, Steam Relief Valves and Atmospheric Steam Relief Valves (ASDVs), the concrete top of the steam drum enclosures, a large portion of the steam drum cooling system, blowdown lines and Steam Generator hydraulic restraints, the top seal plates of the containment bellows assemblies and a substantial amount of wiring and instrumentation.

In addition, restraints must be installed to maintain the heat transport system piping position following the severance of the connections to the Steam Generators. Temporary supports must also be installed, the largest of which supports the steam drum when relocated from above the Steam Generators. Adequate physical protection must also be provided for critical components such as the containment bellows seal.

The removal of interferences and the physical preparations in the boiler rooms and the reactor vaults is further complicated by the limited space available and difficult access. The following images give an indication of the working conditions in these areas.

6. Project Status

SLN mobilized at the Bruce site in 2006 May, and Steam Generator activities are well underway, with a focus on Unit 2. Comstock is the principal sub-contractor to SLN, undertaking most of the Steam Generator replacement activities, and B&W

▲ **Figure 5-12: Vault Showing Limited Head Room between Top of Support (Trapeze) & Vault Ceiling**

▲ **Figure 5-13: Vault PHT Piping & Support Arrangement**

▲ **Figure 5-14: Vault PHT Inlet & Supporting (Trapeze) Arrangement**

Canada is supplying the replacement Steam Generators. As of 2006 September 01, three (3) replacement Steam Generators were delivered to site. The replacement Steam Generators are being temporarily stored in a building provided by SLN where the new Steam Generators are prepared for installation. This work includes the detailed inspection and mapping of each new Steam Generator to permit, matching to a specific location. The closure covers on the replacement Steam Generators are removed and a work platform above the tube bundle is installed. PHT nozzle weld end preparation is then made and the shell section that will be enclosed within the containment bellows assembly following installation is insulated.

The following photos show some of the work completed as of 2006 September 25. This includes the MLC and the storage building with the Replacement Steam Generators.

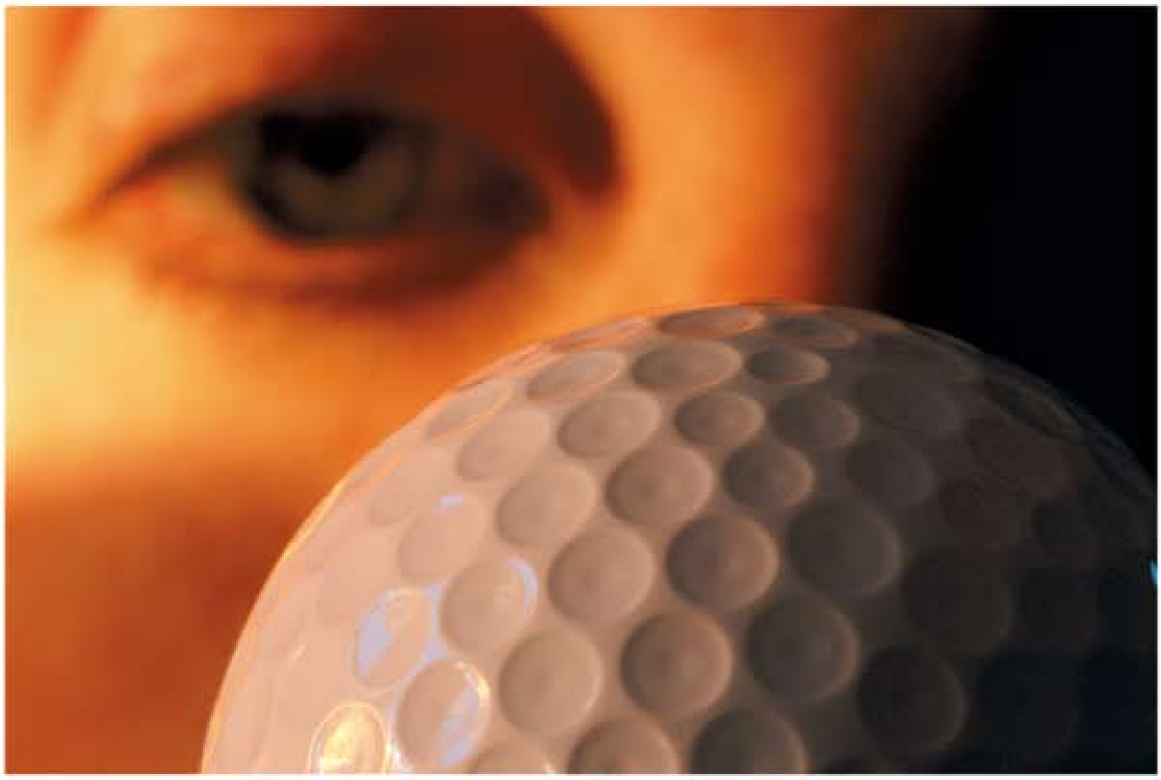
▲ **Figure 5-15: HTS Inlet Piping**

7. Summary

The replacement of all 16 Steam Generators for Bruce A Unit 1 and Unit 2 represents a major portion of the Bruce A rehabilitation program for the above units. SLN developed and is implementing a first-of-a-kind Steam Generator replacement methodology that minimizes risk, cost, and schedule. This project will contribute to the successful return-to-service of Bruce A Unit 1 and Unit 2, and establish the technical basis for the replacement of Steam Generators in other CANDU plants, with applicability in particular to the Ontario Bruce and Darlington plants.

▲ **Figure 6-1: Medium Lift Crane (MLC)**

◄ **Figure 6-2: Temporary Storage Provided for Replacement Steam Generatorsw**



Evolution of Management Activities and Performance of The Point Lepreau Steam Generators

by John Slade, Janice Keating1 and Tracy Gendron2

Ed. Note: The following paper was presented at the 5th CNS International Steam Generator Conference, Toronto, Ontario 26-29 November 2006.

Abstract

The Point Lepreau steam generators have been in service since 1983 when the plant was commissioned. During the first thirteen years of operation, Point Lepreau steam generator maintenance issues led to 3-4% unplanned plant incapability. Steam generator fouling, corrosion, and the introduction of foreign materials during maintenance led to six tube leaks, two unplanned outages, two lengthy extended outages, and degraded thermal performance during this period.

In recognition of the link between steam generator maintenance activities and plant performance, improvements to steam generator management activities have been continuously implemented since 1987. This paper reviews the evolution of steam generator management activities at Point Lepreau and the resulting improved trends in performance. Plant incapability from unplanned steam generator maintenance has been close to zero since 1996. The positive trends have provided a strong basis for the management strategies developed for post-refurbishment operation.

1.0 Introduction

The steam generators at the Point Lepreau Generating Station (PLGS) have been in service since 1983 when the plant was commissioned. During the first thirteen years of operation, steam generator degradation and maintenance issues led to 3-4% unplanned plant incapability. Steam generator fouling, corrosion, and the introduction of foreign materials during maintenance led to six tube leaks, two unplanned outages, two lengthy extended outages, and degraded thermal performance during this period.

In recognition of the link between steam generator maintenance activities and plant performance, improvements to steam generator management activities have been continuously implemented since 1987. This paper reviews the evolution of steam generator management activities at Point Lepreau and the resulting improved trends in performance. Plant incapability from unplanned steam generator maintenance has been close to zero since 1996. The positive performance trends provide support for the decision not to replace steam generators during the eighteen-month plant refurbishment outage beginning in 2008. The post refurbishment design life is 30 years at 80% capacity factor.

PLGS has four recirculating steam generators configured in a two-loop heat transport system with two steam generators in each loop. The steam generators are a Babcock and Wilcox Canada design with an integral steam drum and preheater. The design features that have most relevance to the steam generator management at PLGS are:

- Alloy 800 tube material
- Stainless steel (type 410) tube supports (tube support plates, U-Bend scallop bars, preheater upper baffle plates)
- Carbon steel components in the feedwater box/preheater section (e.g. thermal sleeve, plates, lower baffle plates)
- Emergency Water Supply (EWS) header (with J-tubes) is also used for reheater drains return flow and is made of a combination of carbon steel and Co-Mo
- Seawater cooled condensers

Additional details of the PLGS steam generator design and operating conditions are provided in Figure 1.

2.0 Degradation Mechanisms And Potentially Affected Locations At PLGS

Numerous components of the steam generators can be susceptible to different degradation, by mechanisms that are interrelated. This section briefly describes these degradation mechanisms and the locations potentially affected, according to their likelihood of occurrence. For the PLGS design, there is no anticipated degradation with unmanageable failure rate or safety significance. The characteristics of each degradation mechanism require different management strategies and maintenance activities that are discussed later in this paper. Table 1 provides a summary of this information.

2.1 Expected Degradation under Normal Operating Conditions

Based on the PLGS steam generator design and external operating experience, flow accelerated corrosion (FAC) and fouling are expected to occur to various degrees on some components during normal operating conditions. Mitigation activities can be performed to minimize the severity of these mechanisms, but it is not economical to completely prevent them.

2.1.1 Flow Accelerated Corrosion

Carbon and low alloy steel components can be susceptible to flow accelerated corrosion under normal steam generator chemistry and operating conditions in locations of high coolant flow rate and turbulence and under-saturation in dissolved iron. Steels with very low chromium content (0.0 1%) are particularly

1 NB Power Nuclear, Lepreau, NB, E5J 2S6
2 Atomic Energy of Canada Ltd., Chalk River, ON, K0J 1J0

Babcock & Wilcox Steam Generators

Design:

- 4 Steam Generators, 2 per reactor loop
- Vertical U-tube
- Integral steam drum and preheater
- 18.9m high
- 4.01m Steam Drum OD
- 3550 tubes, triangular pitch (0.950”)
- Alloy 800 Tubes (5/8” OD, 0.0445” WT)
- 410 SS broached hole support plates
- 410 SS U-bend scallop bar supports
- 410 SS preheater upper baffles
- Carbon steel preheater section
- Carbon steel shell, drum, internals
- Inconel clad tubesheet
- Heat Transfer Area: 31 77m2
- Heat Transfer: 515MW
- Design T and P (Primary/Secondary side):
    - 318/266°C
    - 11MPa/5.07 MPa

Operational Data:

- Coolant Information:
    - Volume – 10.8m3
    - Inlet T - 309°C
    - Outlet T - 266°C
    - Inlet P – 9.89MPa
    - Outlet P – 9.61MPa
    - Inlet Quality – 4.4%
    - Flow – 1.9Mg/s
- Steam Information:
    - Output – 262kg/s
    - Exit P - 4.55MPa (original)
    - Exit T - 260°C
    - Exit Quality – 99.75%
- Feedwater Information:
    - Flow – 258kg/s
    - T (Full Power) - 187°C
- Reheat Information:
    - Flow ~ 20kg/s
    - Temp - 242°C

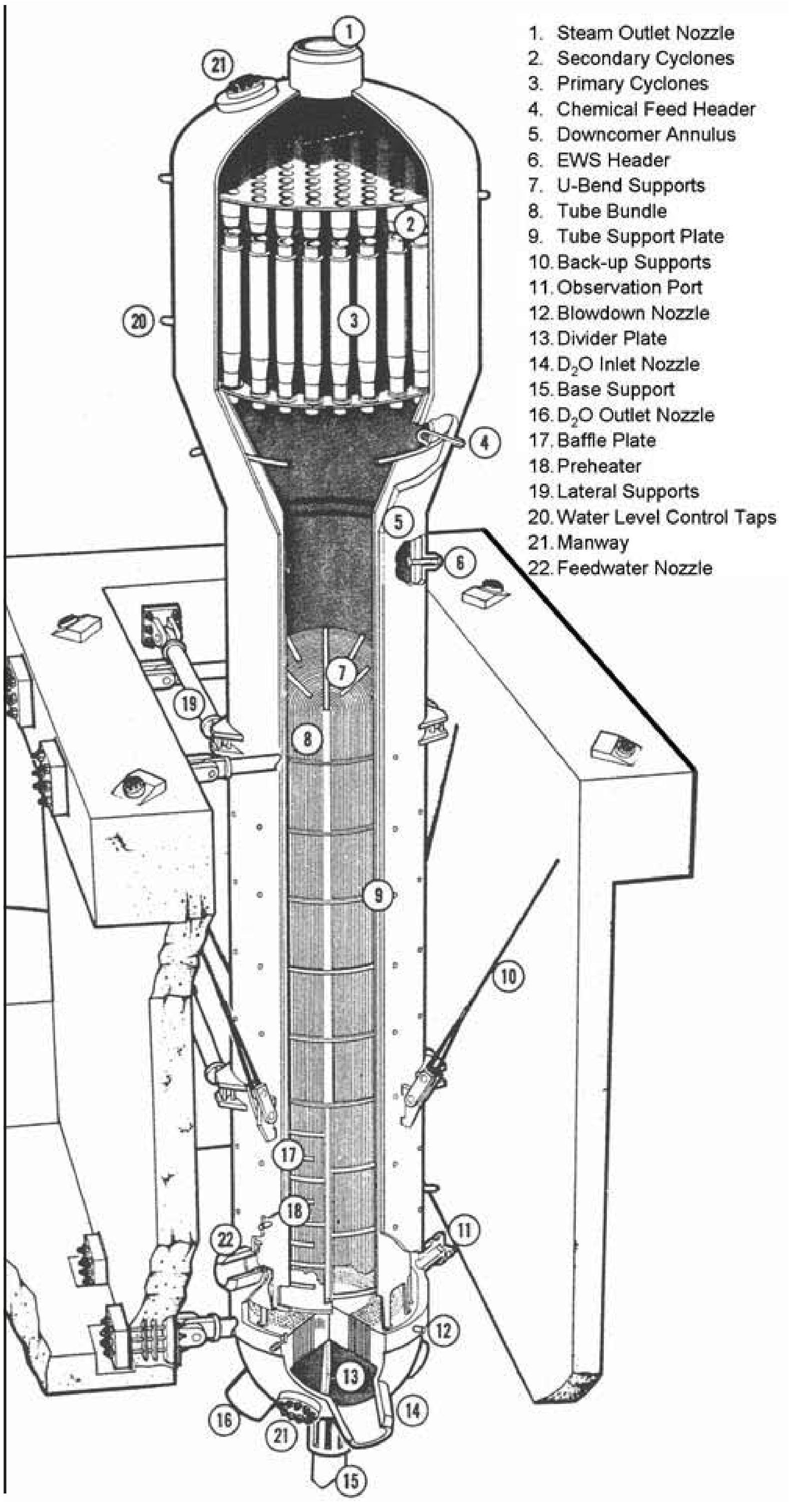


Figure 1: PLGS Steam Generator Design and Operating Conditions

susceptible. The components considered most susceptible to FAC, based on operating experience and knowledge of operating conditions are listed in Table 1.

2.1.2 Fouling

The primary side of the steam generator tube bundle is susceptible to magnetite fouling, increasing from just beyond the entrance of the hot leg to the preheater. Primary side tube fouling is caused by the precipitation of dissolved iron generated by FAC of outlet feeders.

Secondary side fouling is caused by deposition of solid particles entrained in the coolant during normal operation and from crud

Table 1: Summary of Management Plan Elements for Credible Degradation

Potentially Affected Components	Primary Strategy to Manage Degradation	
	Plan Elements	Management Activities
Expected Degradaton Under Normal Operating Conditions		
Flow Acceleerated Corrosion		
EWS header and J-tubes, Bolted divider plate, bowl ear gap, Secondary and primary separator vanes, Feedwater box, head, nozzle, and lower baffle supports	Inspection	Wall thickness, Eddy current of tubes (adjacent to baffle plates), Visual inspection
	Repair & Replace	Repair/Replace thinned components
	Chemistry conrol	Control alkalinity
Fouling		
Tubing inside surface, particularly hot leg side, Secondary side horizontal surfaces, particularly the hot leg of the tube sheet, also tube supports, separator decks, Tubing outside surface	Deposit Removal	PHT: Mechanical cleaning Secondary: Waterlancing, Chemical Cleaning
	Chemistry control	PHT: Control alkalinity Secondary: Alkalinity, impurities and particulate, oxidizing potential during shutdown and startup
Credible Degradation Under Common Operating Conditions		
Fretting		
Debris fretting of tube outside surface at the tubesheet, mainly at the bundle periphery, along the tube-free lane & near the feedwater inlet. Support fretting of tube outside surface at U-bend scallop bar supports	Configuration Management	Foreign materials exclusion program Loose parts detection and retrieval
	Deposit Removal	Waterlancing
	Inspection	Volumetric
	Repair	Tube plugging
Localized Corrosion		
Wastage and pitting of tubing outside surface, primarily under deposits Wastage of tie rods under the sludge pile	Deposit Removal	Waterlancing
	Chemistry Control	Impurities, oxidizing potential
	Inspection	Volumetric inspection Visual inspection
	Repair	Tube plugging
Credible Degradation Under Rare Conditions		
Fatigue, Tube Denting, Plugged Tube Failure, Environmental Cracking		
Fatigue of feedwater nozzles and distribution box, seismic restraint lugs, and tie rods. Tube denting under heavy deposits. Failure of tube plugs. Environmental cracking of tubing in locations of residual stress and fouling.	Deposit Removal	Waterlancing
	Chemistry Control	Impurities, oxidizing potential
	Inspection	Volumetric inspection Visual inspection Material surveillance
	Operating Guideline	Heat up and cool down limits

bursts during reactor startup. The (mainly magnetite) particles are generated from corrosion of feedtrain materials under normal operating conditions as well as impurities that enter the secondary system under off-design conditions (condenser leakage, resin ingress, contaminated make-up). On the secondary side, horizontal surfaces and locations with a high local heat flux are most susceptible to deposit buildup, the hot leg side of the tube sheet, in particular.

2.2 Credible Degradation Under Common Operating Conditions

Fretting and localized corrosion are degradation mechanisms that have been known to occur in materials used in the PLGS steam generator design, as a result of common operating conditions that are not optimal.

2.2.1 Fretting

Debris fretting of tubing can occur from damage by loose parts that have inadvertently entered the system as a consequence of manufacture and installation, maintenance activities or degradation of steam generator internals. Fretting is most likely at the tubesheet, in tubes on the bundle periphery, along the tube-free lane and near the feedwater inlet.

External operating experience indicates that fretting of tubing at supports can sometimes occur under design conditions. The incidence and severity is known to increase if tube supports become degraded or flow patterns change because of deposit buildup.

2.2.2 Localized Corrosion

The outside surface of alloy 800 tubing is susceptible to localized corrosion if aggressive local chemistry is permitted to develop. Crevice regions or locations under deposits are most susceptible. Oxidizing chloride conditions from air ingress and condenser leaks can lead to tube pitting whereas acidic-sulfate or -phosphate from aggressive hideout conditions or incorrect phosphate-to-sodium ratios during phosphate treatment can lead to wastage. External operating experience indicates that carbon steel tie rods can also suffer wastage under deposits if aggressive local chemistries develop.

2.3 Credible Degradation Under Rare Conditions

Plugged tube failure and other degradation mechanisms of specific components have been identified as less likely but credible either based on rare external operating experience, laboratory data under abnormal operating chemistries, or other postulated operating conditions.

2.3.1 Fatigue

Low cycle or thermal fatigue has been postulated at defects in the seismic restraint lug-toshell weld heat affected zone during heat up and cool down transients and at the feedwater pipe to nozzle weld, feedwater distribution box, and at the tie rods at the thermal plate due to thermal stratification when cold water is added during zero power hot conditions. The most likely susceptible locations for high cycle fatigue would be at defects in the upper tube bundle if subjected to flow induced vibration because of inadequate support or tube lockup from heavy fouling.

2.3.2 Tube Denting

The outside surface of tubing can be mechanically deformed (dented) if it is physically restrained and subject to forces caused by the volume expansion of magnetite from the rapid oxidation of iron, usually under acidic conditions. Heavily fouled tubing adjacent to carbon steel components (tie rods, supports) is most susceptible; denting in the hard sludge pile region has also been reported.

2.3.3 Environmental Cracking

PLGS steam generator materials are not considered susceptible to environmental cracking under normal operating and anticipated transient conditions. Cracking would require high tensile stresses from mechanical damage or sub-optimal fabrication practices and the development of a highly aggressive environment (highly caustic or acidic, particularly when Pb present) most likely within an occluded region (e.g. beneath heavy fouling, within a tubesheet crevice) and/or from a severe chemistry transient. The likelihood of cracking will be reassessed once the cause of crack-like indications observed within the tubesheet crevice below the upper expansion in four German plants has been identified.

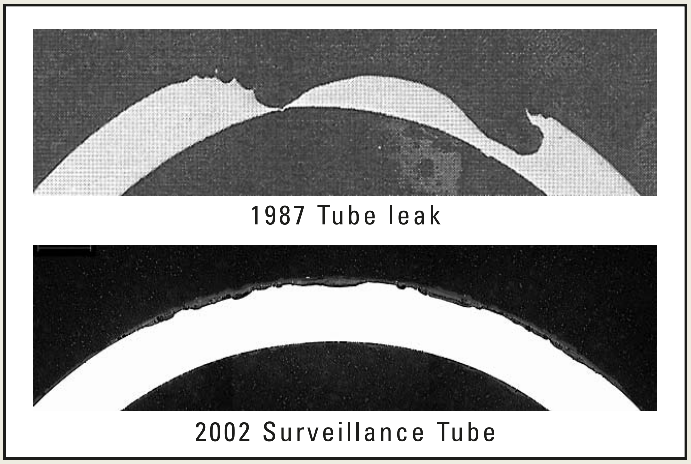


Figure 2: Tube Pitting at Fouled First Support Plate that Led to 1987 Leak (top) and Tube Removed for Surveillance in 2002 showing an Indication of Arrested Phosphate Wastage (bottom)

3.0 PLGS Steam Generator Degradation – Operating Experience

This section briefly describes the degradation observed in the PLGS steam generators that has had the greatest influence on the evolution of management activities. The most significant degradation has been fretting and localized corrosion of tubing, FAC of internal components, and fouling.

3.1 Fouling

During the first decade of PLGS operation, secondary side deposits accumulated to a degree that promoted localized corrosion of tubing, some broach-hole blockage, and decreased thermal efficiency of the steam generators. All surfaces were covered with deposits, including the primary and secondary separator decks and steam generator tubing. Deposits grew about 5cm high on the hot leg lower support plates, blocking some of the trefoil broached holes of the first and second tube support plates and beginning to block some of the holes in the top support plates.

Accumulation of sludge in the center of the hot leg tubesheet covered about 10% of tubes in each steam generator to a maximum height of about 15cm with a 5cm hard core.

Magnetite has deposited on the tube inside surfaces at a rate of about 50kg per steam generator per year. Deposits can reach about 1 50•m in thickness on the cold leg. These deposits interfere with tube inspection (damage probe heads and create signal noise), reduce heat transfer efficiency, and increase local radiation fields.

3.2 Tube Degradation

In the early years of operation, there was a significant amount of unplanned maintenance resulting from steam generator tube degradation. Fretting and localized corrosion has led to six tube leaks (1985, 1987, 1992, 1994, two in 1996), two unplanned outages (1994, 1996), and plugging of about eighty tubes. Pitting or phosphate wastage has occurred in thirty-one tubes caused by aggressive chemistries developing beneath fouling deposits and exacerbated by aggressive impurities introduced during condenser leaks. Figure 2 (top) shows a metallographic cross section through the pitted region that caused the tube leak in 1987. This pit was under fouling at the hot leg first support plate and was associated with mechanical damage on the tube surface. PLGS pitting has often shown undercutting as in Figure 2, and has been attributed to the local presence of copper and chloride ion.

Thirty-seven tubes have been plugged because of debris from foreign materials left in the secondary system during maintenance or by the generation of loose parts from degradation of internal components. Some of these tubes had debris-frets and other tubes surrounding irretrievable debris were plugged in case of debris-fretting. The two leaks in 1996 were attributed to debris fretting. Seven tubes have also been plugged because of U-bend fretting at Anti-Vibration Bars. These are randomly distributed across the tube bundle above row 50.

3.3 Flow Accelerated Corrosion

Severe FAC degradation of the EWS header and J-tubes led to their replacement with more resistant Cr-Mo steel in 1996. FAC from the inside surface caused perforation at the T-joint and several J-tubes to break off. FAC on the outside surface at the low clearance gap with the thermal sleeve also led to perforation. Figure 3 shows this FAC damage to the original header in 1996 and the good condition of the same locations of the replacement header in 2002.

In 1994, FAC damage of some divider plates was observed due to leakage between the plates and some bolts holding the divider plates to the upper seat bar were found sheared. As a result, the primary side divider plate panels and bolts were replaced with a more resistant one-piece floating design in 1995. This design included FAC-resistant materials for the tubesheet seat bar, liner welded directly to the SG head seat bar, and material buildup on the sealing faces of the divider plate rim.

FAC that is not currently life-limiting has been observed at other locations. Visual inspection of the primary head at the intersection with the divider plate and the seat bar has shown some minor indications of FAC in what is known as the "ear

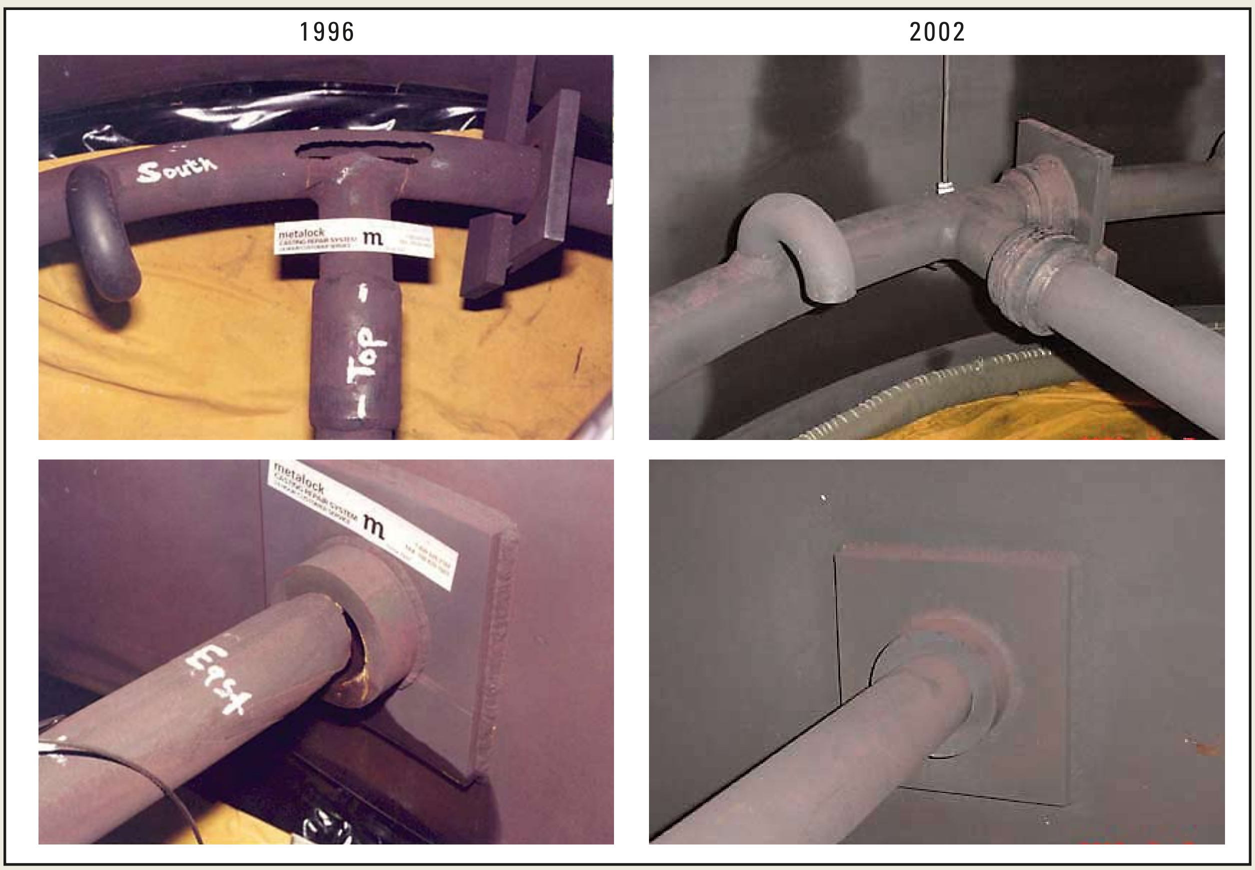


Figure 3: FAC Damage to the EWS Header T-joint (top) and Thermal Sleeve Connection (bottom) in 1996 and the Good Condition of the Replacement Header in 2002

Figure 4: Hot Leg Tubesheet Deposits Before and After Water Lancing in 2004

gap". FAC is also occurring at a low rate in the PLGS removable secondary separators at the vane edges and in shallow circular patterns on the inside of the top surface of the base plate. Wall thickness measurements in 2006 on the baseplates from B02 and B04 indicated maximum wall losses of between 0.002 to 0.022" from a nominal thickness of 0.125". B02 and B04 inspections in 2006 indicated that FAC is not active in the primary separators. Locations considered susceptible (vanes and scoops) showed no signs of FAC degradation. Limited inspection of the PLGS feedwater boxes and inlet locations has indicated some FAC of the stay bolts around the feedwater inlet, the feedwater box top plate, and the thermal sleeve. FAC has not been observed at the friction-fit retaining ring location.

4.0 Improvements To Steam Generator Management

Improvements to steam generator management activities have been continuously implemented since 1987 to minimize degradation of system components, optimize plant performance, and prolong steam generator life. These activities form part of the formal Steam Generator Life Management Plan issued in 2006. The major improvements are briefly described below under the management plan elements shown in Table 1:

4.1 Chemistry Control

The control of secondary side chemistry has been continually improving since early operation. The objectives are to minimize fouling, corrosion, and the development of aggressive crevice or underdeposit chemistries. Many of these improvements are described in an Optimization Plan for the Steam Cycle and are summarized below:

- 1986 – A full flow condensate polishing plant was put into service to remove impurities in the feedwater that are introduced as a result of condenser tube failures.
- 1988 - Switched from ammonia to morpholine as the pH control agent to increase the pH in the steam condensate regions throughout the turbine. The purpose was to reduce FAC and iron transport from carbon steel surfaces wetted by steam condensate.
- Early 1990's - The sodium/phosphate ratio was optimized to minimize the development of the aggressive underdeposit environment that was considered to be the primary cause of the observed tube wastage.
- 2000 - Changed from congruent phosphate treatment to all-volatile treatment (AVT) due to concerns over continuing phosphate wastage.
- 2000- Full flow condensate polishing was suspended and only put in service during full power operation in the event of condenser leakage. Condensate polishing is still performed during start-up to remove feedwater impurities and to reduce iron transport.
- 2000 – A recirculation loop was retrofitted to permit the feedwater to by-pass the steam generators and return to the condenser for the purpose of conditioning the feedwater during preparations for start-up. During recirculation of the feedwater, the pH is brought into specification, the condensate polisher removes corrosion products, and hydrazine is added to remove dissolved oxygen.
- 2004 – Minor modifications to the blowdown system were completed to achieve maximum design blowdown flowrate (OM36310 states a maximum of 6.2 kg/s or 1.55 kg/s per boiler) when impurity levels in the steam generator are unusually high. This can occur during shutdown when hideout return occurs (release of species from occluded sites where they accumulated during operation), periods of startup, or after condenser leaks. Boilers are drained and refilled prior to startup to remove hideout return impurities. Boiler blowdown is not utilized for this purpose prior to warmup.
- 2004 – Improvements to condensate polisher resin reduced feedwater contaminants from resin slippage during startups (e.g. a two stage regeneration process was implemented to reduce chloride loading on regenerated anion resin).

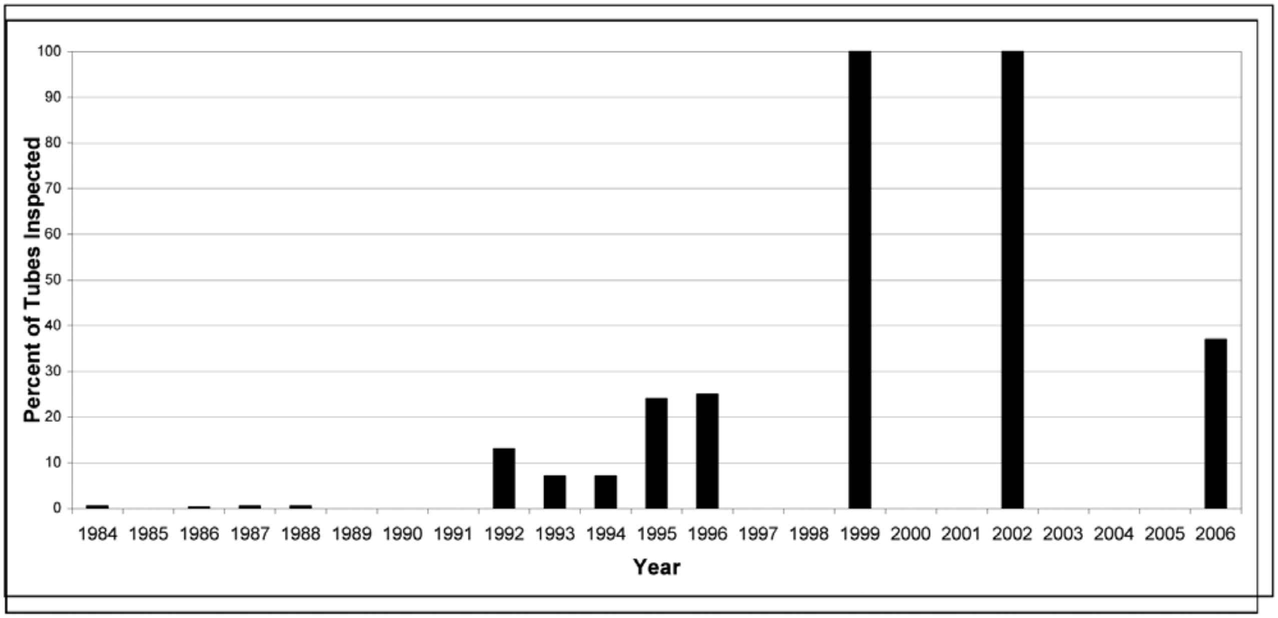


Figure 5: PLGS Steam Generator Tube Inspection History

4.2 Deposit Removal

In recognition of the need to minimize the development of aggressive underdeposit chemistries, prevent tube lockup and flow instabilitlies, maintain tube inspection tool passage, and restore loss of thermal efficiency, deposit removal activities have been implemented since 1987.

- Secondary side tubesheet water lancing has been performed on one or more steam generators during outages in 1987, 1991, 1992, 1993, 1995, 1999, and 2004. Figure 4 shows an the deposit removed from the steam generator 3 tube sheet hot leg by water lancing in 2004, after five years accumulation. Water lancing of all four steam generators is planned every four years in future.
- n 1995, a primary side mechanical clean of ~60% of tubes (8209) in all four steam generators removed a total deposit mass of 789kg. A second primary side clean of all four steam generators is planned during the 200 8-09 refurbishment outage.
- In 1995, a secondary side high temperature chemical cleaning of all four steam generators was performed. Deposits were effectively removed from all surfaces; tubes were cleaned, almost all broached holes were completely cleaned, and only a small amount of hard sludge remained on the tubesheet. A total of 123 6kg material was removed, including 70kg of phosphates and 54kg of other salt impurities. It should be noted that a copper step was not performed so residual copper may remain, particularly on carbon steel surfaces.

4.3 Repair and Replace

Repair or replacement of components is performed primarily to prevent tube failure (tube plugging), replace degraded components with a more corrosion resistant material or design, and to maintain component design function. The examples below have the added benefits of restoring lost thermal efficiency (divider plate), preventing loose parts (EWS header), and reducing corrosion product transport to the steam generators (secondary side piping).

- As discussed in section 3.3, steam generator internals that have experienced severe FAC (EWS header and primary side divider plate) have been replaced with a more corrosion resistant design. Subsequent inspections have shown no significant degradation of the replaced components.
- Between 1986 and 1990, secondary side carbon steel piping significantly affected by FAC was replaced. Those components with the highest FAC rates in the extraction steam, heater drains and vents, reheater steam, and steam drain systems were replaced with austenitic stainless steel or in a few cases, Cr-Mo steel.

4.4 Configuration Management

Configuration management of components is generally performed to identify and prevent its own damage and to maintain its own design function. The three examples given below also improve the protection of steam generator components against environmental cracking, debris fretting, and localized corrosion.

- Early 1990's – Restricted use of Pb-containing leak suppressants by selecting products low in Pb and also by controlling the use of excess leak suppressant.
- 1996 – Implemented steam generator foreign materials exclusion processes to monitor for loose parts and control foreign objects. The main elements are:
  - Increased visual inspection of secondary side internal components. Loose parts or foreign objects are removed unless it is shown by evaluation that these objects will not cause unacceptable tube damage or the tubes are removed from service.
  - A plant-wide foreign materials exclusion (FME) program was implemented. This program includes procedures to preclude the introduction of foreign objects into the pri-

Figure 6: Visual Inspection Images Showing Lack of Fouling in the Upper Bundle. Left: hot leg broached holes in support 9 in steam generator 3 in 2004. Right: U-bend scallop bar supports in steam generator 4 in 2006

mary or secondary side of the steam generators. The main elements of the program are increased awareness of maintenance staff, formal procedures to control access to open systems and equipment, cleanliness requirements, accountability of all materials and tooling used for maintenance inside the system, and accountability for components and parts removed from internals of systems.

- 1999 - Preventative maintenance on the condensers was increased to reduce the risk of seawater impurities and air ingress into the condensate water. This included:
  - Increased frequency and extent of condenser tube inspection and repair
  - Improved the condenser tubesheet coating (SPECOAT) to protect it from corrosion and galvanic attack at the tube/tubesheet rolled joint
  - Located and sealed likely sources of air leaks
  - Increased frequency of condenser tube cleaning
  - Upgraded condenser leak detection system to indicate condenser hotwell contamination
  - Replacement of condensate extraction pump restriction bushings with lead free material

At PLGS, condenser leak searches and maintenance can be performed on-line by isolating condenser half shells. No significant condenser leaks have occurred since these improvements were implemented with the exception of occasional leakage in condenser CD01B from July 2005 until it was repaired January 2006.

4.5 Inspection

Figure 5 shows history of tube inspections. In response to the tube fretting and localized corrosion observed in the first decade of operation, tube inspection was substantially increased. 100% of tubes were inspected in 1999 and 2002. In 2006, a risk-based inspection program was introduced which focuses on regular inspection of highest risk tubes. These tubes were identified based on an understanding of the steam generator operating conditions and key factors driving degradation, and also from internal and external operating experience. At the same time, a risk-based inspection scope for the internal components was also implemented. As a result, for example, after 2006, inspection of the EWS header will decrease to levels that satisfy the minimum requirements of CSA N285.4-05, whereas inspection of the feedwater box and nozzles is raised in priority in upcoming outages.

5.0 Relationship Between Steam Generator Management Activities And Materials Degradation

This section reviews the expected and credible steam generator degradation identified in section 2 and discusses how the incidence of observed degradation (section 3) has changed as a result of the management activities introduced at PLGS (section 4).

Flow accelerated corrosion of some carbon steel components is expected during normal operating conditions. Replacement of those with life-limiting degradation (EWS header, primary divider plate) with more resistant materials and design has been effective at preventing further FAC. For example, figure 3 shows the degraded condition of the original EWS header in 1996 after 13 years service. Inspection of the replaced headers in steam generators 2 and 4 in 2006 after 10 years service, showed no appreciable degradation. The condition of other steam generator components identified as susceptible to FAC is being monitored.

Fouling is also expected during normal operating conditions but several management activities have been successful at minimizing and removing secondary side deposit accumulation. Since 1995 when chemical cleaning practically restored the secondary side to its original condition (with the exception of a ~5cm hard core within the tubesheet sludge pile), several activities have been successful in preventing corrosion products from entering

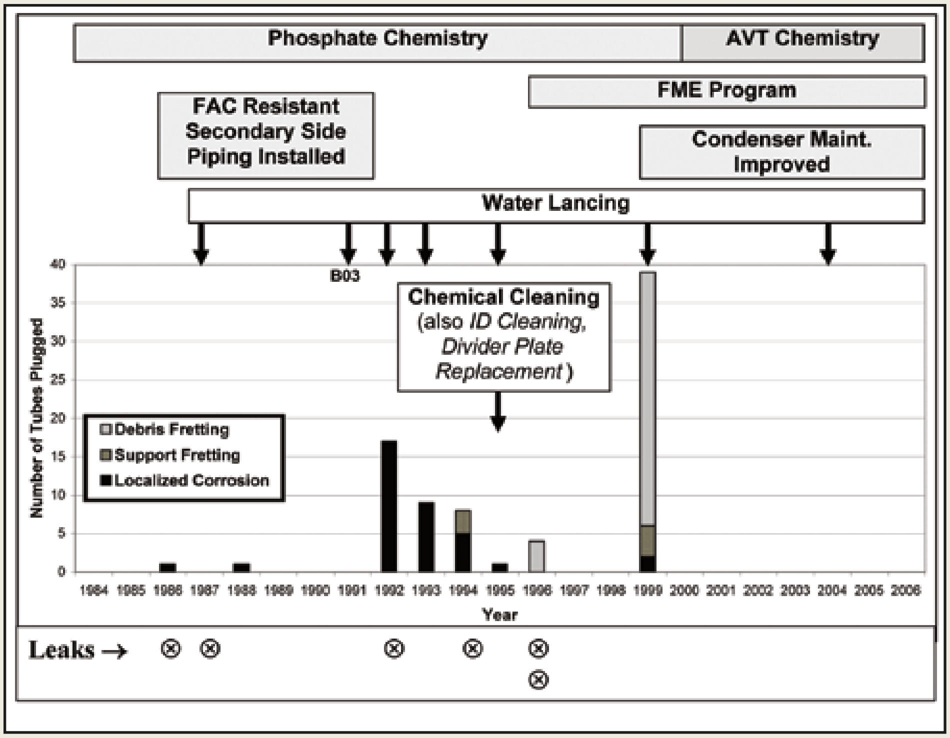


Figure 7: PLGS Steam Generator Tube Plugging and Management Activity History

the steam generator and water lancing has been used to regularly remove those that have accumulated on the tubesheet.

The replacement of secondary carbon steel piping that was undergoing high FAC rates with corrosion resistant materials; improvements in pH control, and improved processes to prevent crud bursts and remove corrosion products from the feedwater have been effective at minimizing corrosion products entering the steam generators. Corrosion product sampling indicates that the concentration of iron in the final feedwater is about 2µg/kg under full power operating conditions and 40-60 µg/kg in blowdown. The mass of deposits removed during water lancing indicates that these activities have been effective at minimizing accumulation of deposits on the tubesheet. In 1995, ~1 0 kg was removed whereas in 1999 a total of only 1.1kg was removed from all four steam generators. In 2002, the total mass removed was even lower, 0.7kg. The sludge pile height is currently 40-50mm high, reduced from a maximum height of 200mm in 1987 prior to water lancing, and 80mm in 1995 prior to deposit removal activities.

Eddy current inspections of tubing and secondary side visual inspections indicate that the fouling rate of upper tube supports has also been reduced by these activities. Tube inspections in 2006 continue to show that broached hole blockage has not reoccurred. The visual inspection images in Figure 6 shows how clean the hot leg broached holes and upper tube supports were in 2004 and 2006, respectively, a decade after chemical cleaning.

As a result of the 1995 divider plate replacement and the primary and secondary side cleaning, the reactor inlet header temperature (RIHT) was reduced from 267.6°C to 264°C (4.4MPa boiler pressure). In the decade of operation since that time, the RIHT has only risen about 1°C.

The tube plugging history illustrated in Figure 7 indicates a clear reduction in tube degradation since 1999. Pitting and phosphate-wastage has been practically arrested. There have been no tubes plugged because of localized corrosion since 1999 and eddy current results show for existing defects indicate minimal growth (~1% through-wall per year). This good performance is attributed mainly to the significant reduction in deposit loading since 1995, reductions in impurity ingress to the steam generators by elimination of condenser leaks, and suspension of phosphate chemistry. Condensate polishing and improved blowdown are also believed to contribute.

Following the debris-fret leaks in 1996, the risk associated with debris was reduced by implementing improvements to the steam generator foreign material exclusion program in 1996, by inspecting 100% of tubing in 1999 and plugging those at high risk of debris fretting, implementing a plant wide foreign material exclusion program and a more rigorous secondary side inspection and loose parts/foreign object removal program. Since 1999, there have been no additional tubes plugged because of debris. Figure 6 (right image) illustrates the effectiveness of video inspection to identify locations with foreign material.

6.0 Concluding Remarks

Selected maintenance activities have significantly reduced PLGS steam generator degradation and unplanned shutdowns. Localized corrosion and fretting of tubing has been practically arrested. Existing defects are growing at only ~1% through-wall per year and no new indications have been found. The management activities considered to have made the greatest improvements are feedwater impurity control (including condenser maintenance and chemistry control), suspension of phosphate chemistry, rigorous deposit management (including chemistry control, deposit removal, and replacing piping that generated corrosion products), and risk-based inspection of tubing and internal components.

Currently, the PLGS steam generators are in good condition. Good performance is expected to continue during post refurbishment operation with continued attention to the management activities described above and effective layup during refurbishment. As a result of external operating experience, NBPN is also paying attention to possibility of FAC of secondary separators and feedwater inlet/boxes, wastage of tie rods, and environmental cracking of tubing in tubesheet crevices.

Opinion

The Greenhouse Problem – Let's Get Serious

by Ernest Siddall[1]

Summary

The most readily available sources of the energy that is essential for human advancement involve the emission of enormous quantities of carbon dioxide to the atmosphere as waste, and there is concern that these may cause harmful changes in the world's climate. This article shows that most of the energy that is needed can, to the extent that is judged to be necessary, be provided without emission of carbon dioxide by ensuring abundance of grid electricity from nuclear and other CO2 free sources and by a combination of other measures that are discussed.

Introduction

The "greenhouse" problem is the discharge to the atmosphere of gases that have the potential to raise the earth's temperature. If the most optimistic views of climatic scientists prevail, the effect will not greatly exceed past "natural" climate variations. On the other hand, extreme pessimistic views predict that they will cause catastrophic changes. This article does not contribute to this climate debate except to be based on the simple premise that these great emissions are a bad thing, and that it would be of value to formulate realistic measures for their reduction.

About 61% of the total calculated greenhouse effect is due to carbon dioxide [CO2] resulting from mankind's use of carbon-containing fuels. This article puts forward measures that could virtually eliminate these emissions by about 2060 AD, which may be enough to stabilize the existing CO2 content of the atmosphere indefinitely. To the extent that optimism about the climate prevails, the proposals could be adopted to a lesser degree. Changes on a very large scale would be needed, but, on the time scale proposed, these would not be more disruptive than technological and industrial changes that have occurred in the past.

Human advancement

Abundance of energy, that is, when a user can readily obtain as much as is needed at a price that keeps producers in business, has been an integral and universal feature of our industrial civilization. Energy use is essential to prosperity and good living. It uplifts society by eliminating menial and repetitious work and creating leisure. Greenhouse reduction must not be achieved by a reduction of energy use, which would create an impediment to human advancement. What is needed is a changeover from energy involving CO2 emission to other sources. This article shows that it would be possible in this way to greatly reduce the greenhouse problem without harmful curtailment of energy use and without undue disruption of our world political-industrial system that, despite many faults and weaknesses, has been outstandingly beneficial to mankind in the overall

The cause-and-effect relationship between human advancement and increased energy use is brought out in Table 1

Today, in 2007, perhaps a billion people live towards each of these extremes, with four billion others occupying a "spectrum" in between. Any solution of the greenhouse problem by, say 2060, to be considered seriously, must apply to perhaps 10 billion people, the expected world population by then, all wishing, given any freedom of choice, to move from left to right in Table 1 as they have done since the dawn of industrial civilization.

Remedial action

To the extent that the greenhouse concern that is now being engendered is judged to be rational, it would be necessary for an anti-CO2 program to work down the scale of Table 2., which is rough because it has been difficult to decide from readily available data how much CO2 emission resulted from each part of the "mixed bag" that each row represents. This scale is intended to progress from the easier and more profitable to the more difficult, and certainly includes some "wishful thinking".

[1] Hydroelectricity is technologically and economically nearly perfect and CO2 free, but unfortunately the undeveloped amount available is relatively small. In some cases, dams could be rebuilt higher and further downstream, to yield more energy output and storage at higher cost. At the margin, hydroelectricity often involves the exchange of hectares of residential and fertile land for megawatts of grid electricity, and this comparison tends to be emotionally biased.

[2] Nuclear energy is the established non-CO2 emitting energy source that would permit the most effective and immediate remediation of the greenhouse problem. At present, about 18 % of the world's grid electricity is generated by 450 reactors in 25 different countries, with another 29 reactors in course of construction. France has 59 reactors generating 78% of its electricity and Japan has 56 generating 29%. The safety of nuclear energy has caused concern. This issue can be considered rationally by starting from

1 Ernie Siddall is a Canadian nuclear pioneer. He was a member of the original CANDU design concept team and contributed greatly to the establishment of safety objectives for nuclear plants. He was awarded the W.B.Lewis Medal in 1982 and made a Fellow of the Canadian Academy of Engineering in 1987. He now lives in Victoria, B.C. His e-mail address is: richsidd@telus.net

Table 1: The human advancement spectrum

People unfortunate enough to be condemned, through no obvious fault of their own, to a backward way of life:-	People in advanced societies, like the author:-
live in mud hut or shanty	live in 100 square metre 2 bedroom + bathroom + kitchen home with 5 appliances
use open ditch as toilet	use flush toilet inside
carry water in jar from communal well	have piped hot and cold water
wash dish by hand	put all meal dishes into electric dishwasher
wash clothes in nearby river	use electric clothes washer & dryer
shiver in winter	set furnace thermostat
swelter in summer	run air conditioner
eat tough and unappetizing food quickly, before it goes bad	keep several day's wholesome food in the refrigerator
whole family pull ploughs or hoe little patches of land for subsistence	one or more breadwinners are in sustainable well paid employment in office, factory or store, using much energy
have no conveyance, no good roads life spent tied to one locality by need to survive	use their car or take taxi or bus to travel thousands of kilometres per year for business and pleasure
work hard most of the time just to survive	enjoy much leisure to pursue cultural and intellectual advance
family income $50 per month	family income $4,000 per month
life expectancy 50 years	life expectancy 80 years
Energy is very effectively conserved	Every element depends upon or uses energy

Table 1 above. Advanced countries typically achieve a life expectancy of 80 years. In energy poor countries, about 50 years is typical. This difference amounts to an immense saving of human life. When a rational attempt is made to decide the relationship between this and energy use, it becomes clear that the share of this due to nuclear energy greatly exceeds the mortality from the single serious accident at Chernobyl to a primitive reactor primitively operated. Nuclear waste has been dealt with without serious difficulty for over 60 years.

[3] "Green" energy; windmills, biomass etc.. The attractiveness of these "green" sources increases the further the viewpoint moves from the realities of the electricity industry. Windmills are unsightly, a detriment which could become dominant if the necessary vast "forests" of millions of very large windmills come to be planned, in contrast to the few thousands that have been scattered around so far, heavily subsidized and sited mainly to win votes for politicians. Biomass is discussed below; it is perhaps too valuable to be used for grid electricity. However, there is no need to exclude almost any of these measures. If an anti-greenhouse campaign is judged to be necessary, the right course is to pursue any or all of these technologies as energetically as possible. Whether or not they will be found to be feasible or effective will soon become apparent.

[4] The possible trapping of CO2 is a technology in its infancy and may never mature. However, if the most pessimistic concerns about the greenhouse problem come to be accepted, it is the only way that the world's immense resources of carbonaceous fuels can retain their great value.

[5] Biomass. The carbon contained in biomass has recently been extracted from the atmosphere so that the energy ranks as net-non-CO2 emitting. Ethanol and methanol, useful fuels for road transport, are already being produced from biomass. Unfortunately their energy content per unit of volume or weight is low and both the quantity and the source of the energy needed to produce them are under question. An attractive prospect is to use grid electricity to hydrogenate the cellulose and lignin biomass to eliminate the oxygen and to combine all the carbon into paraffins such as dodecane, that is, diesel. This excellent liquid fuel would then contain all the energy of the biomass but would also be a "carrier" of the added hydrogen. To achieve much reduction in the very great CO2 emissions from road transport, the scale of biomass development would need to be correspondingly enormous. Very large land areas of genetically engineered monocultures with extensive use of fertilizers and pesticides would probably be necessary,

[6] Hydrogen. As a fuel at the point of use, hydrogen, generated from grid electricity, is excellent, but unfortunately it

Table 2: Sequence of feasible actions.

Technology field	% of total present greenhouse	Possible remedies
Grid-electric power stations burning coal, oil or natural gas	25%	Changeover to hydroelectric [1], nuclear [2], "green" windmills, biomass, solar, etc.[3], CO2 trapping [4]
[Greatly expand non-CO2 grid electricity production to permit changeovers from CO2 producing processes –Table 3. below]	—	– same –
Residential, commercial, industrial heating, lighting, air conditioning	7%	Change to grid electricity & some direct solar
Industry general	7%	Change to grid electricity & some direct solar
Railways	2%	100% electrification
Urban buses	1%	Change to trolley buses
Subtotal – the easier ones!	42%	
Trucks, other buses	2%	Compressed hydrogen, Biomass liquids [5]
Automobiles	8%	Batteries [7], compressed hydrogen, biomass liquids [5]
Major air transport	2%	Liquid hydrogen
Minor aviation	1%	?
Ships	2%	?
Iron smelting	2%	Grid electricity & reduction by hydrogen?
Cement production	2%	Grid electricity & silicate ore?
Subtotal – all energy related sources	61%	
Non-energy related human greenhouse sources, deforestation, farming, CO2 equivalent	39%	
Total 2006 human greenhouse, CO2 equivalent	100%	

can only be stored and transported either in large and heavy tanks or as a liquid in tanks that are also large and from which the contents continually evaporate despite elaborate insulation. Much research and development is taking place and should of course be actively continued. Liquid hydrogen seems to be very suitable for air transport, starting with its high energy-to-weight content, though considerable changes in the layout of aircraft would be needed.

Road Transport

This is the most important transport medium for people and materials but it presents a difficult problem in reducing CO2 emissions. The automobile is widely deprecated by the "green" minded but most people who have any choice love their cars – an important case where free choice lacks "virtue". In 2007 there are more than 500 million automobiles, about 10 million heavy trucks and about 5 million buses of various kinds in use. This enormous fleet grew from almost nothing, starting mainly from the appearance of the Model T Ford, relegating more energy-virtuous railways to second place and bankruptcy, in only about 40 years. Unfortunately in the present context, road transport is almost totally dependent on liquid carbon based fuels and accounts for about 11 % of the overall greenhouse problem. If it is judged that this contribution must be eliminated, four technologies; trolley systems, batteries, compressed hydrogen and biomass liquids, can be considered.

Batteries charged from grid electricity, CO2 free as above, can drive road vehicles. Batteries now available use nickel and lithium in sealed enclosures and are thus 100% recyclable, though after a rather short life. They store about 200 Watt-hours per kilogram of weight, which can give a range of 200 kilometres of travel in a typical automobile, but they then need a recharge that takes several hours. It seems probable that cars with both large batteries and liquid fuelled engines, a combination already in use, could derive half their total energy from grid electricity.

Only a few trolley bus systems remain in business because of the excellence of the modern diesel bus and the low cost of oil, but the changeover could readily be made. It seems likely that liquid fuels will still be needed to provide about half the total energy needed for road transport. The most promising eventual source for these is biomass, as discussed above.

Table 3: World energy use

Year --->	2007	gt CO2 per year	2020	gt CO2 per year	2060	gt CO2 per year
Coal,oil,natural gas	9.4 tW	30	10.4 tW	36	0.0 tW	0
Hydroelectricity	1.0 tW	0	1.2 tW	0	2.0 tW	0
"Green" energy	1.6 tW	0	1.8 tW	0	5.6 tW	0
Nuclear	0.5 tW	0	0.7 tW	0	11.0 tW	0
Total	12.5 tW	30	14.1 tW	36	18.6 tW	0

The scale of action needed

An earlier study by the author and others estimated that the world usage of energy in 2060, a date chosen here to give enough time for necessary changes, would be roughly 18.6 teraWatts. To allow, optimistically, for a greater effort to develop "green" energy, that is, windmills, biomass, CO2 trapping etc., the 2.8 teraWatts previously estimated under that heading is now increased by a factor of 2 to 5.6 teraWatts, so that if the maximum anti-greenhouse effort is made on the lines here discussed, the make up could be, roughly as shown in Table 3.

Grid electricity can be conveniently and economically transmitted over long distances and is universally distributed in the advanced and advancing world. It therefore offers the prospect of being the source or carrier for supplying almost all human energy needs. It can be generated without emission of CO2 as outlined above. Realistically, the total nuclear generating capacity that would be needed in 2060 would be 11 teraWatts. To bring about this change, starting in 2020, a world total of about 68 nuclear power stations of 4 gigaWatts capacity would have to be manufactured and installed per year. It is difficult to be more precise, particularly since the change over to electrical energy source in the past has almost always resulted in greater energy efficiency. This enormous industrial effort would include the replacement of existing generation stations at the end of their useful lives, which would be needed in any case.

If all static uses of energy had been converted to non-CO2 emitting grid electricity, the reduction in total greenhouse effect would be about 42% of the "business as usual" level, leaving perhaps 58 % still uncorrected – a brutal reality!. If all energy for road transport had been converted to non-CO2 emitting sources, a further 10 % reduction of the total could be achieved. The totality of these steps would almost eliminate CO2 emissions resulting from energy use.

There do not appear to be any realistic alternatives to these measures. If nuclear stations are assumed to cost 3,000 $[US,2007] per kW, instead of perhaps 2,000 per kW for coal stations, they would represent a shift of about 2 % of the world's spending and, perhaps, also a cost increase of about 1/2 % in world GFP. In a world with a GFP of which 70% is listed as "services" and where unemployment in advanced countries has usually been around 7%, these changes in 40 years would be relatively minor.

Implementation

The process of moving down Table 2 is the only realistic plan to achieve the elimination or major reduction of CO2 emissions in a reasonably short time with proper regard for human welfare. In the past, major changes in technological industry, such as the elimination of the coal-fired steam railway locomotive and the creation of an immense jet-aircraft transport industry, have been achieved very smoothly. In 5 years of WW2, after a decade of depression, the USA and the British Commonwealth alone built 45 million tons of shipping, in addition to an immensely expanded production of aircraft, tanks, road vehicles and munitions.

These developments involved both government and private industrial effort and investment. The changeovers here indicated would be about comparable to these, but they would be spread out over 40 years instead of 5, so that the disruptions involved would be much less and easily accommodated. The major energy industries, coal, oil and natural gas, would be profoundly affected, but the total industrial effort would remain on about the same scale. Economic measures such as emission trading schemes and carbon taxes are often proposed to bring about the intended changes. However, in economic terms, energy is a good that is highly regarded in relation to what has been its usual price, and its price is extensively manipulated, often by governments very dependent on energy revenues.

Most kinds of anti-greenhouse measures, if effective, will necessarily reduce demand for fuels, which will greatly reduce their market price, particularly the political component. This reaction, normally beneficial, will tend in this case to defeat economic and taxation measures. But in most advanced countries it would only be necessary for CO2 to be decreed to be noxious, and this would enable the necessary prohibitions for progress down Table 2 to be achieved simply as needed. This approach has been very successfully used in the advanced democratic nations to achieve a big reduction in the emission of smog-causing and health-threatening fumes from hundreds of millions of automobiles and from the burning of bituminous coal. These successive prohibitions, following ample advance notice, would merely be an addition to the mass of natural laws, man-made laws, government regulations, acceptable practices and planning approvals under which industry has developed. These restraints have had no adverse economic effects discernible at least to the layman. An international protocol -- "Kyoto N Real" -- in which the signatory nations would agree to legislate these co-ordinated actions would be needed.

Research and development

Nuclear energy, the most effective remedy to the greenhouse problem if such remedy is judged to be needed, is the product of an immense research and development program of the last century. Clearly, corresponding efforts on a similar scale would be justified in the following areas at least:-

[1] technologies for CO2 trapping as mentioned above.

[2] the production of high-quality liquid fuels by hydrogenation of biomass

[3] the advancement of nuclear breeder technology to full economic viability. This may be necessary if the effectiveness of the nuclear solution leads the demand for uranium to exceed new discoveries earlier rather than later

[4] spallation-neutron nuclear energy and fusion energy.

[5] any and all "green" energy sources that show economic or political promise.

Needless to say, mankind's restless efforts to do better things in the full variety of possible activities should not be restricted by adherence to any single list such as this.

Conclusion

This article is not deeply researched but it reflects current experience and know-how in the energy field and points to the course of action that may become necessary to manage the greenhouse problem for greatest human net benefit. Worldwide, it is unlikely that mankind will accept restrictions of energy use, and they should not. Serious efforts to curtail the human-caused greenhouse gases without restricting energy use are feasible, technically and economically. However, they will only be practicable if broad worldwide scientific and political agreement as to their necessity can be secured. There is a need to work now towards this goal.

The Rutherford Museum at McGill University

(The following note is based on a visit by Jim Arsenault and Fred Boyd to the Rutherford Museum at McGill University, 22 December 2006.)

Nuclear science in Canada began over a hundred years ago, with the studies of Ernest Rutherford at McGill University in Montreal. Rutherford was a professor at McGill from 1989 to 1907. During that period he published 69 papers on all aspects of radioactivity that led to his being awarded the Nobel Prize in Chemistry in 1908.

Much of Rutherford's early work at McGill has been preserved in an excellent collection of the experiments he conducted over the nine years he was there.

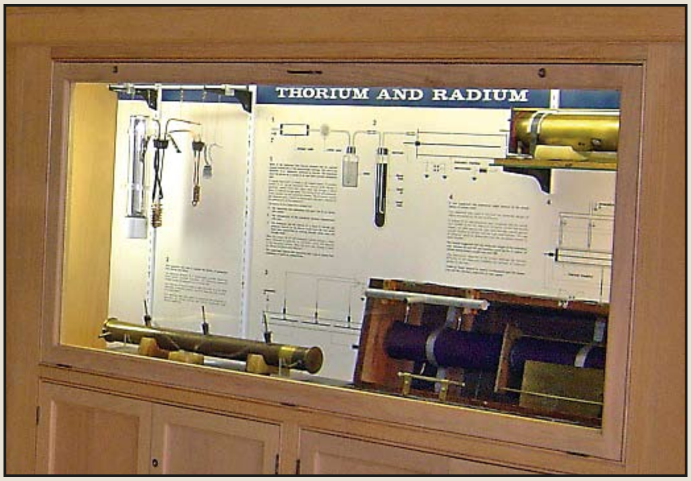
In 1898 Ernest Rutherford, at the age of 27, was appointed Macdonald Professor of Experimental Physics. He had just completed two years of study under a scholarship at the famous Cavendish Laboratory of Cambridge University in England where he had been encouraged by the laboratory director, J. J. Thompson, to study X-rays that had been discovered by Wilhelm Roentgen in 1895. Shortly before coming to Canada he had identified two components of the rays emitted by uranium, a non-penetrating one he called "alpha" rays and a more penetrating one he named "beta rays".

Rutherford's research at McGill covered every aspect of radioactivity, including the nature and properties of the 'emanation' (radon) produced by radium and thorium, the heating and ionization proper ties of the radiations, the charge and nature of the , and rays, excited radioactivity, and elucidation of the three natural radioactive series (uranium-radium, actinium and thorium).

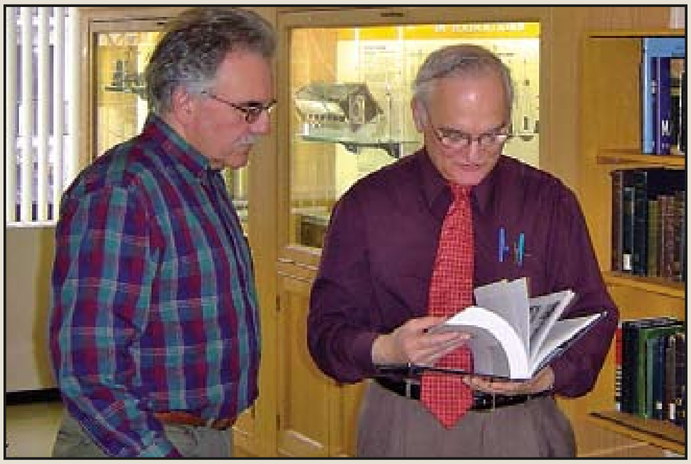
The apparatus displayed in the Rutherford Museum is simple in design and construction. However, the concepts underlying the apparatus were highly sophisticated and enabled Rutherford to obtain direct answers to specific questions. At that time a scientist would design the apparatus for an experiment and it would then be constructed in the machine shop. Usually at the conclusion of an experiment the apparatus would be dismantled, so that some of the components (such as brass plates, blocks of wax, glass tubing, etc.) could be re-used in later equipment. Fortunately, a colleague of Rutherford, Howard Barnes, recognized that Rutherford was a pioneer in a new field of science and arranged for his experimental equipment to be put away in a cupboard, where it remained, undisturbed, until the late 1930s.

After Rutherford's death, in 1937, his friend and former colleague, Arthur Stewart Eve, was asked by the Royal Society to write the "official" biography. Eve wrote to his former colleagues at McGill and requested them to take photographs of the apparatus for the book. This was done and three photos were included in Eve's book, published in 1939. The apparatus was subsequently brought out of storage from time to time for inspection by visitors. In 1950 the construction of a "Rutherford Museum and Conference Room." was proposed. However, no progress was made until 1964, when the Chairman of the Physics Department, Dr. Norman Shaw, bequeathed $2,000 to establish the Museum. An additional sum was provided by the McGill Graduates' Society and a room was allocated on the second floor of the Macdonald Physics Building. The Museum was officially opened in October 1967. The current curator is Professor Jean Barrette. *(To visit the museum contact Prof. Barrette at 514-398-7030; e-mail: Jean.Barrette@mcgill.ca)*

See the Book Review of: "Rutherford – Scientist Supreme" *for more background.*



A view of one of the displays of Rutherford's original experimental apparatus, in this case that for studying emanations from thorium and radium.



Prof. Jean Barrette, curator of the Rutherford Museum at McGill University, (R) shows an early book from the collection to Jim Arsenault of the CNS during a visit to the museum in December 2006.

WiN meeting draws capacity attendance

The organizers of the 4th Annual Meeting of Women in Nuclear Canada had to close off registration at 130 when they reached the limit of the space they had reserved at the National Arts Centre in Ottawa for February 28, 2007.

As for the past three annual WiN meetings, this one was scheduled to be the day before the Nuclear Industry Seminar of the Canadian Nuclear Association *(see separate article)*.

Immediately after the continental breakfast, WiN Canada president **Susan Brissette** welcomed delegates and introduced **Linda Keen**, president of the Canadian Nuclear Safety Commission, as a strong supporter of WiN Canada and a "role model" for women.

Susan Brissett

Christiane Bergevin

In a somewhat rambling talk Keen noted the renaissance of the nuclear industry underway in Canada but then turned to the topic of how to get women involved in science and technology. She spoke of a conference in Korea in 2005 where she was impressed by the number of women participating. There is a need to communicate better with the public about nuclear energy, she stated, and commented that the CNSC is demanding that licensees engage better the people in their area.

After a short break there were four presentations in what was termed a "mini seminar". The first speaker was **Jad Popovic** of Atomic Energy of Canada Limited who addressed the topic "Writing to Get Published". Focussing on technical papers she offered guidance on structure of papers and described the typical process of organizations in reviewing and selecting papers for publication or presentation. She cautioned potential authors to check the copyright policy of the organization involved since some are quite restrictive.

Next was **Lori Harding** of ARECVA NP Canada Limited who outlined sources of "Nuclear Facts" which should be noted if communicating with the public. On the often misunderstood question of radiation dose from nuclear plants she noted that eating a banana a day for a month gave the same radiation dose as spending a year living beside a nuclear power plant. In a series of slides she provided an excellent set of quick facts related to nuclear energy.

Turning to the human dimension **Lorraine Wiseman** of Newman Hattersley Ltd. spoke on "Leadership Skills". A leader must be several things, she stated, a visionary, a communicator, a strategist, a facilitator, and a contributor, and then went on to expand on each attribute. It is necessary to be aware of and understand different cultural and social viewpoints, she stated. Describing the nuclear industry as: slow to change, consistent, methodical, cautious and focussed on quality, she noted that it is now facing possible rapid growth. In closing she stated that a leader is a servant.

Closing out the session was **Dr. Kim Wamsley,** a clinical psychologist now working at Bruce Power. Although her topic was listed as of "Violence in the Workplace" she spoke primarily about conditions or actions that might lead to violence. These included:

- sustaining disgruntled employees
- sustaining non-diligent managers
- ignoring communication
- ignoring conflict resolution
- ignoring emotions

When situations get to a shouting match they can be dangerous, she said, as high stress leads to hearing loss and inhibits cognitive thinking.

The last hour of the morning period was devoted to reports from the several WiN branches. There are now branches at: AECL Mississauga; AECL Chalk River; Bruce Power; Darlington; Pickering; Point Lepreau, and one being formed at Gentilly 2. The total membership now exceeds 400.

At lunch, **Christiane Bergevin** of SNC Capital, the recently formed financial arm of SNC Lavalin, provided a different perspective on the Canadian nuclear power program. Her central message was that private capital is now ready to invest in nuclear power in Canada. She stated, however, that a necessary condition is a predictable regulatory system, which does not exist at this time.

After lunch a panel offered views on "What Women Opinion Leaders Really Think About Nuclear". This was moderated by **Joanne Thomas-Yaccato,** a consultant specializing in this topic. Members of the panel were: Christina Wanks, an internet consultant; Sarah Powell, a lawyer with Davies, Ward, Phillips and Vinberg; Christina Blizzard, a journalist with Sun Media; Dr. Lynn Buchanan, chief scientist at MDS Nordion; and Donna MacFarlane, V.P. communications and marketing, University of Ontario Institute of Technology.

Closing out the day, **Mitch Joel,** president of Twist Image, led an interesting discussion on "How blogs, podcasts and wikis change how we communicate".

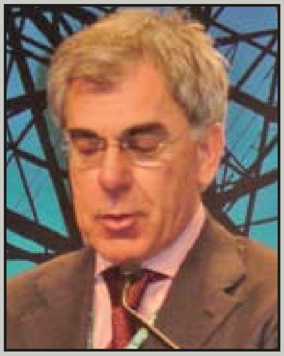
Then, most delegates proceeded to the nearby Westin Hotel to join in the opening receptionof the Canadian Nuclear Association 2007 Seminar.

Morning panel. Left to right: Lori Harding, Lorraine Wiseman, Kim Walmsley, Jad Popovic

Record Attendance at CNA Seminar


Gary Lunn


Duncan Hawthorne


Pierre Coulombe


Steve West

Reflecting the perceived "renaissance" of the nuclear industry in Canada, the annual Nuclear Industry Seminar of the Canadian Nuclear Association, held in Ottawa, March 1, 2007, drew a record attendance of over 500. Among the delegates were 60 engineering students, sponsored by Wardrop and Ian Martin. The accompanying exhibits occupied all of the lobby space on the convention floor of the Westin Hotel in Ottawa.

Preceding the actual seminar there was an elegant reception on the evening of February 28. Early in the evening, the Minster of Natural Resources Canada, **Gary Lunn**, briefly addressed the gathering with encouraging words including reference to the possible use of nuclear in the Alberta tar sands.

At a "pre-seminar breakfast", hosted by General Electric Canada, **Robert Dixon**, of the International Energy Agency, spoke about "Energy Technologies Perspectives". The world is hungry for energy, he began, and presented 2004 figures for the source of that energy: oil 35%; coal 25%; natural gas 21%; hydro and renewables 12 %; nuclear 6%. There is a real problem with CO_2 emissions, he noted with particular reference to China. "No single technology can do it all", he said.

In 2006 the IEA issued a report on Energy Technology Perspectives, in response to request from the G-8 summit held at Gleneagles in July 2005. They developed three scenarios: baseline; accelerated technology; technology plus (implying a dramatic change). Fifteen regimes were modelled. Only the "technology plus" scenario promised a significant reduction of greenhouse gas emissions. Even so, coal is still predicted to dominate electrical production in 2050. China puts 400 to 500 MW of coal generated electrical into production every week, he noted.

Duncan Hawthorne, CEO Bruce Power and chairman of the CNA, formally opened the seminar. He commented on the demographics, evident in the room, that in 10 years most would be gone. Repeating a statement he has frequently made that successful refurbishment of Bruce units 1 and 2 is essential, he reported that actual work on the replacement of the steam generators had begun the previous day.

The first speaker was **Pierre Coulombe,** president of the National Research Council. Much of his presentation dealt with the Chalk River Laboratory beginning with its creation by NRC in 1944. He referred to ZEEP, the first reactor outside the USA, NRX, NRU, and the work of Bertram Brockhouse who won a Nobel Prize for his developments in neutron spectroscopy. NRC still operates the Canadian Neutron Beam Centre, based at the NRU reactor. Although noting that NRU is now 50 years old he had no answer about a replacement.

Steve West, president of MDS Nordion, gave an overview of the wide range of products and services his company offers based on radioisotopes produced at the NRU reactor and the Cobalt 60 produced in various CANDU plants. MDS Nordion supplies more than 50 % of the world's medical isotopes to over 60 countries, he stated. He spoke of a new technology, commercially called "Therasphere", in which small radioactive beads are injected into a cancerous liver.

After a break, **Linda Keen,** president of the Canadian Nuclear Safety Commission spoke on *"Challenges of Regulating an Expanding Nuclear Industry in Canada"*. She began by stating that there were "several misconceptions" about the CNSC's proposed standards for nuclear power plants, then turned to speak about the broad mandate of the agency, involving radiation protection, mining, radioisotopes, as well as nuclear power plants. The CNSC's "client" is the Canadian people, she emphasized. Although CNSC received incremental funding in 2006 it needs a long-term increase to enable the expansion necessary to meet growing demands. She commented that two documents were being issued that day: *"Supplemental Information on the Design Review for New Build"* and *"Licensing Process for New Uranium Mines and Mills"*. Returning to the point of "misconceptions" she stated it is false to claim that the regulatory framework will "make or break" the Canadian industry. To a question she stated that senior CNSC staff are having discussions with industry executives about licensing requirements.

At the luncheon, hosted by AREVA, **Mark Mills,** chairman of ICx Technologies, gave an interesting talk on *"The Seven Realities of Our Energy Future: From Oil Sands to Internet Server Farms"*. He noted that the US economy had moved from 50% oil and 40% electricity a few decades ago to 60% electricity and 40% oil today. Energy efficiency actually leads to increased demand, he noted, because it implies a lower cost. To a question he stated that there is no impediment to meeting environmental objectives, it is just a problem of money. He closed by commenting that "the laws of physics will trump political laws but the latter will win in the short-term".

The afternoon session began with a two-person panel of **Duncan Hawthorne,** Bruce Power, and **David Torgerson** form Atomic Energy of Canada Limited, on the topic *"Nuclear Power: Preparing for the Future"*. Hawthorne recited global energy factors: increased demand; security of supply; ageing infrastructure; environmental concerns; desire for renewables. There is a need for new nuclear designs, he commented. Because of the high cost, there is a need for government support to build Generation III plants.

Linda Keen

Wayne Henuset

Torgerson looked further into the future to talk about Generation IV designs. The Generation IV International Forum (GIF) was initiated by the USA but now has 10 countries participating. Six conceptual designs have been chosen for further study: sodium cooled fast reactor; lead alloy cooled; molten salt cooled; gas cooled fast reactor; very high temperature thermal reactor; super critical water cooled thermal or fast reactor. Canada is involved with the last two concepts.

A four-person panel tackled the subject of *"Training, Retraining and Motivating the Next Generation of Nuclear Workers"*. The participants were: **Beth Medhurst,** AECL; **Jack Bigham,** Bruce Power; **Don MacKinnon,** Power Worker's Union; **Bill Robinson,** Ontario Power Generation.

Beth Medhurst noted that through recent hiring the age distribution at AECL is now "bimodal" with a group under 35 and another over 50. AECL has a retirement management program, which includes phased retirement; reduction in workload; post-retirement opportunities.

Don MacKinnon noted that 38% of nuclear workers are over 50 years of age. A poll of a group of 18 – 29 year-old revealed that 85% had never considered a career in nuclear.

Jack Bingham noted that Bruce Power had hired over 1,000 since 2001, causing their average age to drop from 48 to 45. Nevertheless 30% are eligible to retire within five years.

Bill Robinson commented that for the Pickering 1 refurbishment they faced a limit of skilled trades. Knowledge transfer remains a critical issue.

The last speaker of the day brought a different perspective, that of an entrepreneur. **Wayne Henuset** is a founding partner of the Energy Alberta Corporation, a company set up to build nuclear plants to supply the energy needs of the Alberta tar sands. The demand for natural gas, to extract the bitumen from the sand, is excessive and illogical, he commented, comparing its use to burning gold to make coal.. His company has an agreement with AECL to build a two-unit plant for operation in 2016. To a question he stated that he expected to have a site chosen within a few months.

With that, **Murray Elston,** president of the Canadian Nuclear Association closed the seminar and invited delegates to join in the closing reception.

There was a long list of sponsors: AECL; AREVA; Wardrop; Ontario Power Generation; GE Canada; Kinectrics; Cameco; Bruce Power; Newman Hattersley Ltd.; E.S.Fox; Hydro Québec; Power Workers Union; Ian Martin; L3 Communications; Nu-Tech Precision Metals; Babcock& Wilcox Canada; Energy Solutions; McMaster University; SNL Energy; Moeller; AECON; Lisle Metrix Ltd.; Versatile Measuring Instruments Inc.; Canadian Nuclear Society.

CNA president Murray Elston stated that all presentations would be placed on the CNA website: www.cna.ca

Scenes from CNA Nuclear Industry Seminar 2007

GENERAL news

*(**Ed. Note:** All of the items in this section are taken from official releases, without comment.)*

EA project description for Bruce "new build" accepted

On January 26, 2007, the Canadian Nuclear Safety Commission informed Bruce Power that it had accepted the "Project Description" for an environmental assessment (EA) for the "Bruce Power New Build Project".

Unlike most environmental assessments that are specific to a particular proposed project the document identifies six different reactor technologies, which Bruce Power states is "to keep our options open".

The document specifically identifies five "Generation III" designs:

- ACR 1000 (1085 MW) (Atomic Energy of Canada Limited)
- AP 1000 (PWR) (1100 MW) (Westinghouse - Toshiba)
- EPR (PWR) (1600 MW) (Areva / Framatome, France)
- ESBWR (BWR) (1560 MW) (General Electric)
- SWR –1000 (BWR) (1254 MW) (Areva)

but states that, "Bruce Power is also considering the Enhanced CANDU 6", noting that, although it has a smaller capacity (740 MW) it has many of the features of Generation III designs.

The most demanding (environmental) characteristics from all of the possible designs will be used for the actual environmental assessment.

Two proposed sites on the Bruce property are identified, each for a twin station. One is just south of the Bruce A station, the other immediately north of Bruce B. Both of these locations offer relatively short connections to the grid.

The tentative timetable shows Bruce Power identifying their preferred design in 2008 with new build site preparation beginning in 2009 for completion of the first unit by 2014.

The detailed scope of the EA still needs to be approved.

AECL to train Argentinians on retubing

On February 22, 2007, Atomic Energy of Canada Limited (AECL) signed a Memorandum of Understanding (MOU) with Nucleoeléctrica Argentina S.A. (NASA) to provide specialized training to assist NASA engineers in acquiring the necessary planning and implementation skills to retube Central Nuclear Embalse, Argentina's CANDU 6 power station, sister station to New Brunswick Power's, Point Lepreau Generating station.

The signing between representatives of AECL and Nucleoeléctrica S.A., an Argentinian government-owned company operating nuclear stations, was witnessed by the Honourable Shawn Graham, Premier of New Brunswick and the Secretary of Energy for Argentina, the Honourable Daniel Cameron at a ceremony held in Saint John, New Brunswick.

Training will be carried out by AECL at its facilities in Saint John, New Brunswick and at the Point Lepreau Generating Station, using the Point Lepreau refurbishment project as hands-on training for approximately 10 NASA employees. The program will run between 2007 and 2009.

Argentina's nuclear power program is centred on heavy water reactors, including the very successful Embalse, an AECL CANDU 6 power reactor that was connected to the grid in 1983.

In May 2006, AECL announced an Agreement for Nuclear Energy Cooperation with Argentina that specifies a number of nuclear-related projects on which AECL, NASA and CNEA are collaborating. These include the refurbishment of Embalse, a feasibility study for the next CANDU station to go into service around 2015 and assistance to Nucleoeléctrica Argentina S.A. to help complete a reactor originally supplied by Germany. The agreement will also create commercial opportunities for Argentina to supply services and heavy water to international CANDU markets.

Bruce Power selects US recruiter

Bruce Power has selected Korn/Ferry International (NYSE: KFY), a premier global provider of talent management solutions, as the advisor for its executive recruitment, middle-management recruitment and leadership development initiatives.

As part of the five-year agreement, Korn/Ferry will support Bruce Power's efforts to develop its existing senior-level talent pool, as well as supplement it by identifying and attracting top executives from outside the company. The Korn/Ferry team, based across Canada and the U.S., will build an external talent pipeline for Bruce Power on a local, national and international basis, and will also work with dedicated Bruce Power staff to strengthen the company's ongoing professional development programs.

Since its creation in 2001, Bruce Power has hired more than 1,000 new employees and developed detailed training and workforce strategies to help manage an ageing workforce of approximately 3,700 employees. Bruce Power will see 30 per cent of its current workforce eligible to retire within the next five years.

Korn/Ferry Interbnational, with more than 70 offices in 40 countries, is a premier global provider of talent management solutions. Based in Los Angeles, the firm delivers an array of solutions that help clients to identify, deploy, develop, retain and reward their talent. For more information on the Korn/Ferry International family of companies, visit www.kornferry.com.

Background
D2O produced at Bruce for 25 years

Heavy water, another name for deuterium oxide, is found as a natural substance in most bodies of water. In Lake Huron, concentrations are usually about one drop of heavy water for every 7,000 drops of ordinary water.

Heavy water was extracted at the Bruce Heavy Water Plant for use in CANDU reactors in Ontario and abroad from 1972 until its final demise in 1997. The last of its tower sections were torn down in 2005.

Maintained in the nuclear stations as more of a component than a consumable, only make-up amounts are required after a reactor's initial fill. The liquid is continually bled from reactor systems for cleaning and purification to reduce radioactivity and to ensure good chemical balance, which inhibits corrosion.

Third-generation CANDU reactors currently under design by AECL (ACR) will use light water as a coolant rather than heavy water. Heavy water will still be used as the moderator. (The Bruce Power reactors currently on site are considered second-generation reactors while the AECL-owned Douglas Point reactor, retired in 1984, is considered first-generation.)

With thanks to Rob Liddle of Bruce Power

CNSC Appoints New Vice-President

The Canadian Nuclear Safety Commission (CNSC) has created a new senior executive position to head the recently created Regulatory Affairs Branch and appointed Patricia McDowell as Vice-President of Regulatory Affairs Branch.

Patricia McDowell was previously Executive Director of Policy and Research at the Canada Mortgage and Housing Corporation. Prior to that, Ms. McDowell spent eight years at Natural Resources Canada as Director General, Corporate Policy and Portfolio Coordination Branch, where she was responsible for directing areas such as the development and implementation of policy initiatives, regulatory affairs, sustainable development, stakeholder relations, strategic communications and cooperative relations focussed on the Cabinet and legislative plans. She was also responsible for leading the overall corporate strategic planning and priority-setting process in collaboration with business sectors, partner departments and agencies, and federal central agencies.

This senior executive position in the new Regulatory Affairs Branch was created to provide strategic direction and implementation of the CNSC's regulatory policy, planning, and communications activities. With the continuing growth of the CNSC the need for more strategic leadership in all the three areas of this new Branch was identified.

Cameco continues restoration at Cigar Lake

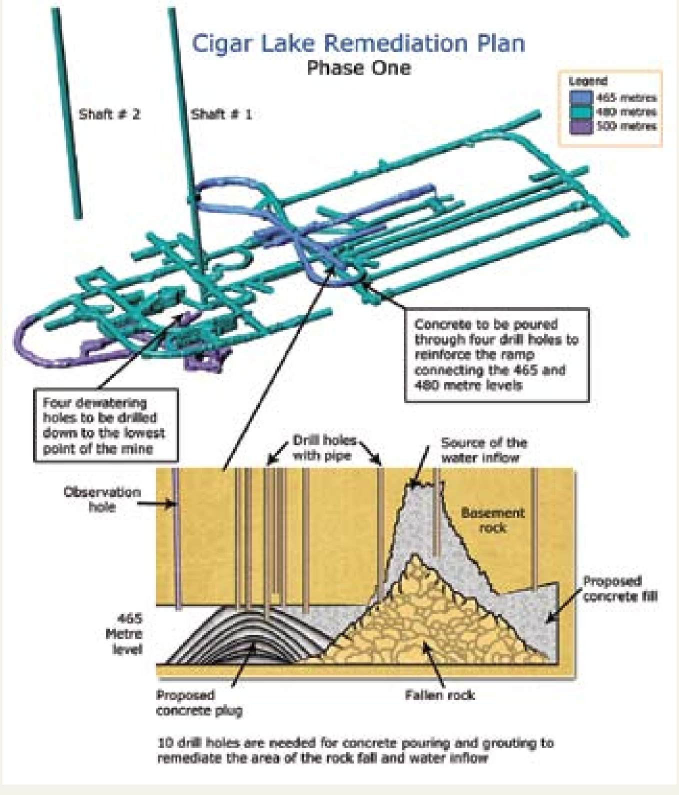
Cameco Corporation recently reported on its progress to restore the underground workings at Cigar Lake after a water inflow on October 23, 2006 flooded the underground development. *(See Vol. 27, No. 4, December 2006 issue.)*

The first phase of the remediation plan involved drilling holes down to the source of the inflow and to a nearby tunnel where reinforcement may be needed, pumping concrete through the drill holes, sealing off the inflow with grout and drilling dewatering holes. Subsequent phases include dewatering the mine, ground freezing in the area of the inflow, restoring underground areas and resumption of mine development.

Six of the 14 drill holes planned for reinforcing and sealing off the water inflow area are now complete.

Concrete will be poured in two locations – one near the rock fall to seal off the inflow area and another in a nearby tunnel to provide reinforcement. About 200 cubic metres of concrete has been poured in the reinforcement area. *(See figure)*. The concrete mixture is designed to harden under water and will be poured in successive layers.

Experience gained through drilling the initial holes is reduc-



ing the time required for subsequent holes. Cameco hopes to complete the work necessary to seal off the water inflow in the second quarter of 2007 despite the challenges related to drilling through the Athabasca sandstone.

Cameco had previously planned to provide preliminary capital cost estimates and timelines for the remediation in February 2007. However, the information will now be available in late March 2007 in order to incorporate the more detailed information compiled in the technical report.

"Cigar Lake is an extremely valuable deposit that is expected to play a significant role not only in Cameco's future but as part of the world's uranium supply," Rogers said. "Given its importance, we believe taking extra time to develop our remediation plans and estimate costs is prudent."

There are about 280 people working on site including drilling personnel working on the remediation program. Work on surface facilities including water treatment plant, mine ventilation fan foundations and an electrical substation continues.

The Cigar Lake project is a joint venture owned by Cameco Corporation (50%), AREVA Resources Canada Inc. (37%), Idemitsu Canada Resources Ltd. (8%) and TEPCO Resources Inc. (5%). The project is located in northern Saskatchewan.

CNSC recommends EA panel for deep geologic repository

Following a public hearing held on October 23, 2006, in Kincardine, Ontario, the Canadian Nuclear Safety Commission (CNSC) announced, December 21, 2006, its decision to recommend to the federal Minister of the Environment that Ontario Power Generation Inc.'s (OPG) proposed project to construct and operate a deep geologic repository within the Bruce Nuclear Site in Kincardine, Ontario, be referred to a review panel.

The Minister of the Environment must now decide on this recommendation. An environmental assessment (EA) is required pursuant to the *Canadian Environmental Assessment Act* (CEAA).

The CNSC also decided to approve the Scoping Document (EA Guidelines), modified to require the establishment of a baseline for monitoring environmental effects resulting from this project.

A number of factors led to the Commission's recommendation to the Minister of the Environment, including uncertainties as to the nature of the wastes to be managed and the proposed site, as well as the first of kind nature of a deep geologic repository project in Canada.

The Record of Proceedings, including Reasons for Decision, is available on the CNSC Web site at www.nuclearsafety.gc.ca.

During the public hearing, the Commission considered written submissions and oral presentations from CNSC staff, OPG and 57 intervenors.

Gentilly-2 Operating Licence Renewed

In late December 2006, the the Canadian Nuclear Safety Commission (CNSC) announced its decision to renew the Nuclear Power Reactor Operating Licence for Hydro-Québec's Gentilly-2 Nuclear Generating Station (NGS). The licence is valid until December 31, 2010.

The decision followed two days of public hearings, August 16, 2006, in Ottawa, Ontario and November 7, 2006, in Bécancour, Québec.

In making its decision, the Commission requested that CNSC staff present a status report to the Commission on the performance of the Gentilly-2 NGS. The report will be part of the *CNSC Staff Annual Report on the Canadian Nuclear Power Industry*. The status report will be presented at a public proceeding of the Commission.

During the public hearing, the Commission considered written submissions and oral presentations from Hydro-Québec, CNSC staff and 14 intervenors.

The Record of Proceedings, including Reasons for Decision is available by contacting the CNSC. An English version will be published at a later date. Transcripts of the hearing are available on the CNSC Web site at www.nuclearsafety.gc.ca, or by contacting the CNSC.

Cernavoda 2 fuel loading begun

Loading of fuel of the second CANDU unit at Cernavoda, Romania began in January. The schedule calls for the unit to achieve criticality in early April. First synchronization and connection to the grid is planned for May with the plant to be in service in June 2007.

A consortium of AECL and Ansaldo Energia of Italy, with owner Societatea Nationala Nuclearelectrica (SNN), is managing the completion of the construction of the Cernavoda Unit 2 power plant - the second in a series of CANDU 6™ power plants that began construction in the early 1980s.

Cernavoda Unit 1, which started commercial operation more than a decade ago, in December 1996, has been successfully operating with an average capacity factor of more than 87 per cent.

AECL and Ansaldo were contracted in 2003 to complete construction and commissioning of Unit 2, which was about 50 per cent complete and with much of the original large equipment already installed. Given the long period the plant was in a suspended state many unique problems had to be faced. All of the installed equipment had to be thoroughly inspected and much refurbished.

Some of the numerous highlights of 2006 were:

- turnover to commissioning of virtually all systems of the project
- successful delivery and loading of heavy water in the moderator system
- successful delivery and storage of nuclear fuel
- completion of the reactor building proof pressure and leak rate test
- successful on-site repairs to pressurizer and degasser condenser weld defects on nozzles incurred during manufacturing in the 1980s
- hot conditioning of the primary heat transport system, the Emergency Core Cooling dynamic test fire and standby diesel generator load testing was completed

MDS Nordion to train European oncologists on TheraSphere®

- Creates centres of excellence for innovative liver cancer therapy

In early February 2007, MDS Nordion annouced that it had established four Centres of Excellence in Europe for TheraSphere®, its innovative liver cancer treatment. The Centres, located in Spain, France, Germany, and Italy will serve to train and educate oncology professionals on the use of the innovative technique.

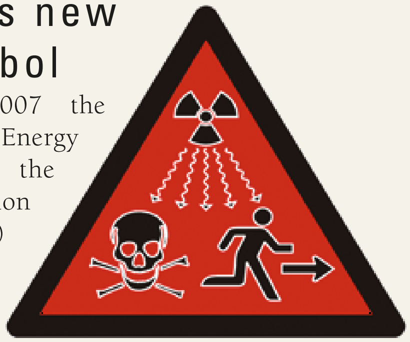
TheraSphere® is a low toxicity, liver cancer therapy, which consists of millions of micro-glass beads containing radioactive yttrium-90. The product is injected by physicians into the main artery of the patient's liver through a catheter which allows the treatment to be delivered directly to the tumor via blood vessels. Unlike chemotherapy, it has few side effects. Patients rarely experience nausea and vomiting usually associated with high-dose, systemic chemotherapies.

TheraSphere® is used in Europe primarily for the treatment of hepatocellular carcinoma (HCC), the most common form of primary liver cancer; or secondary liver cancer that has migrated to the liver from another location.

HCC is the fourth most common cancer in the world. Chronic hepatitis B and C and cirrhosis are known risk factors that increase the risk of HCC. Rates of HCC are higher in Europe than in North America. In North America the incident rate of liver cancer is about 2.1 per 100,000 people. In northern Europe the rate is approximately 5 per 100,000 population, while in southern Europe the rate ranges from 5-20 cases per 100,000 population.

In September 2006, MDS Nordion announced it had received approval from the U.S. Food and Drug Administration (FDA) to begin clinical trials on patients with secondary liver cancer. FDA has also approved TheraSphere® for the treatment of patients with hepatocellular carcinoma (HCC), who have partial or branch portal vein thrombosis (PVT) and who have been identified as suitable candidates by their physicians.

IAEA launches new radiation symbol



On 15 February 2007 the International Atomic Energy Agency (IAEA) and the International Organization for Standardization (ISO) introduced a new ionizing radiation warning to supplement the traditional international symbol for radiation, the three cornered trefoil. The new symbol is being launched to help reduce needless deaths and serious injuries from accidental exposure to large radioactive sources. It will serve as a supplementary warning to the trefoil, which has no intuitive meaning and little recognition beyond those educated in its significance. The new symbol is aimed at alerting anyone, anywhere to the potential dangers of being close to a large source of ionizing radiation. The result of a five-year project conducted in 11 countries around the world, the symbol was tested with different population groups - mixed ages, varying educational backgrounds, male and female - to ensure that its message of "danger- stay away" was crystal clear and understood by all. The symbol is intended for IAEA Category 1, 2 and 3 sources defined as dangerous sources capable of death or serious injury, including food irradiators, teletherapy machines for cancer treatment and industrial radiography units. The symbol is to be placed on the device housing the source, as a warning not to dismantle the device or to get any closer. It will not be visible under normal use, only if someone attempts to disassemble the device. The symbol will not be located on building access doors, transportation packages or containers.

Pierre Charlebois

Appointments at Ontario Power Generation

Last fall **Pierre Charlebois,** Executive Vice-President at Ontario Power Generation was appointed Chief Operating Officer, making him responsible for all of OPG's generation facilities.

In early February 2007, Charlebois made two senior level appointments. One was for **Tom Mitchell** as Chief Nuclear Officer, a role Charlebois had in the past.

Mitchell had been senior Vice-President, Pickering B and earlier Vice-President, Nuclear Operations. Mitchell has over 29 years nuclear experience. Prior to joining OPG in 2002 he was Vice-President at the Institute of Nuclear Power Operations (INPO) in Atlanta, Georgia. Previously he spent several years at the Peach Bottom Atomic Power Station where he progressed through Manager of Operations support; Director of Site Engineering and Site Vice President.

The other appointment was **Gregory Smith** to be Senior Vice-President, Nuclear Generation Development and Services Division. Smith had been Senior Vice President, Darlington Nuclear Station.

Prior to joining OPG in 2002 Smith was Vice President, Nuclear Operations at Energy Northwest. Earlier he held senior positions with Entergy and Core Laboratories.

Extension of Waste Facility at Point Lepreau completed early

Atomic Energy of Canada Limited (AECL) has completed the construction of the Point Lepreau *Solid Radioactive Waste Management Facility (SRWMF)* a year ahead of schedule.

The SRWMF extension, completed at the end of November, will store waste created during refurbishment and the extended operation of the Point Lepreau Generating Station.

NB Power awarded AECL fixed price/firm schedule contracts in July 2005. As general contractor, AECL is managing and executing all of the fieldwork and is responsible for three aspects of the overall project:

- construction of the SRWMF
- retubing – removal and replacement of all 380 fuel channels and associated feeder tubes, and,
- refurbishment – removal andupgrading of ageing components and outdated technology.

Record output from Bruce Power in 2006

Bruce Power set new company records for electricity production in 2006, capping a year in which Bruce B was ranked Canada's best performing multi-unit nuclear station.

Led by Unit 6, which ran steadily for every day of 2006, Bruce Power's six operating units generated 36.47 terawatt-hours (TWh) of electricity compared to 32.9 TWh in 2005, an increase of nearly 11 per cent. Since assuming operations of its site in 2001, Bruce Power has now increased its electrical output by 12.37 TWh.

With Unit 8 returning to service in November following its scheduled inspection, the remaining five units recorded capacity factors of 96 per cent or better during the fourth quarter of 2006, topped by Unit 6 at 100 per cent. Units 4, 5 and 7 each had capacity factors of 99 per cent for the quarter, placing them among the industry's top performing units.

An increase in nuclear production and the moderate temperatures Ontario enjoyed last year helped contribute to significantly lower electricity prices than in 2005. In 2006, the province's average spot price was $46 per megawatt hour compared to $68 the year before. As a result, Bruce Power's electricity revenues of $1.86 billion in 2006 were down slightly from $1.91 billion in 2005.

Meanwhile, 2006 saw the project to restart Bruce A Units 1 and 2 begin in earnest, with more than 1,200 additional workers converging on site by year's end to help return 1,500 MW of electricity by 2009. To the end of December, approximately $1 billion had been invested in the $2.75 billion project, which remains on budget and on time.

Zircatec to do EA for enriched fuel line

Zircatec Precision Industries in Port Hope, Ontario, has been required to conduct an environmental assessment (EA) on its proposal to add a new fuel manufcturing line using slightly enriched uranium (SEU). The uranium will contain about 2 percent U235. This is for the "low void reactivity fuel" (LVRF) for the Bruce reactors. A test is currently underway at Bruce B.

The slightly enriched fuel will be brought in from the USA. Cameco (Zircatec's owner) had considered blending the SEU at its conversion facility, also in Port Hope, but decided against the project when faced with a considerable public outcry.

The fuel to be manufactured will have the SEU in the outer elements and blended dysprosium and natural uranium in the centre elements.

Zircatec has made small quantities of fuel with enriched uranium over the years as special orders.

At an open house hosted by the Canadian Nuclear Safety Commission, held February 12, a number of members of the public expressed concern about health and environmental effects of the new production line.

(Port Hope has been the scene of continuous public outcry gainst the activities of Cameco and Zircatec. See the article "A Very Public Debate" in Vol. 27, No. 3, September 2006 issue.)

CNS news

CNS writes to federal ministers

***Ed. Note:** In December 2006 the CNS Council authorized the CNS president to write to the key federal ministers involved with energy policy (Gary Lunn, Minister of Natural Resources; Jim Flaherty, Minister of Finance; John Baird, then President of the Treasury Board) on the role of nuclear energy.*

Following is the text of that letter. It was appended by four pages of expanded notes on each of the identified subjects. the full document can be read on the CNS website: www.cns-snc.ca.

Dear Ministers:

Re: The Future of Nuclear Energy in Canada

The Canadian Nuclear Society (CNS) understands that the Government of Canada soon will make policy decisions about investment in the future of nuclear energy, and we wish to contribute our insight to this topic. The CNS is a not-for-profit professional society of over 1000 members -- including scientists, engineers, and technical staff dedicated to research in nuclear science and technology, to application of nuclear techniques in medicine, to extraction of nuclear fuels, and to the design and construction of nuclear reactors for electricity production.

The following key points summarize our thoughts on this important subject. Further detail is provided in the attached notes, which follow the same subject headings.

1. Electricity Demand

Conservation and efficiency measures will achieve some savings in the demand for electricity, but this will be offset by the effects of population growth and by added electricity requirements for new technologies. Thus there will be a continued growth in demand for electricity.

2. Electricity Supply

New sources of energy supply will be required -- to replace existing capacity as it is retired and to meet the growing demand. This will require a mix of energy types, one of which will have to be nuclear power.

3. Sustainable Technologies

Nuclear generation is the only base-load technology which is widely available and meets sustainability requirements. Canada has large uranium resources, and the Government of Canada has recently received recommendations from the Nuclear Waste Management Organization (NWMO). If adopted, these recommendations will serve to resolve the long-standing public concerns about what to do with radioactive waste.

4. Nuclear Capability in Canada

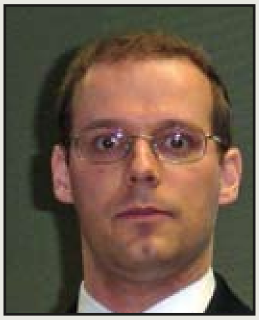
Canada has an indigenous nuclear capability developed through a long history of technical initiatives and successes. Regardless of what reactor technology might, in future, be adopted, we need to maintain this capability in order to respond to the immediate, zero-emissions electricity requirements of Canadian provinces and those of the developing world. Thus, re-investment and maintenance of funding in the facilities and operations of the Chalk River Laboratories is essential.

I will be pleased to respond to any questions you may have on this important issue.

Sincerely yours,

Daniel A. Meneley, President

2006 World Nuclear University Summer Institute - A Unique Opportunity by Dominic Rivard[1]



For six weeks during July and August 2006, 12 young Canadian nuclear industry professionals had a lifetime experience by attending the 2006 World Nuclear University Summer Institute in Sweden and France. This paper will describe that unique event.

The World Nuclear University (WNU) is a partnership focused towards international cooperation for the transfer of knowledge in nuclear engineering for peaceful use. The WNU, created in 2003, has four founding partners: the

1 Hydro Quebec, Centrale Nucleaire Gentilly,
email: rivard.dominic@hydro.qc.ca

Canadian delegation at 2006 WNU Summer Institute. Front row: Carla De Waele (AECL), Wenjie Zhu (AECL), Lisa Mcisaac (Cameco), Yung Chung Hoang (Nuclear Safety Solutions Ltd). Second row: Raymond Yeung (AECL), Brent Douglas Berg (Cameco), Madiba Saidy (AECL), Lovell Gilbert (Bruce Power). Back row: Dominic Rivard (Hydro-Quebec Gentilly 2 NPP), Robert F. Deabreu (AECL), Nathaniel B. Flaman (Cameco), Nicholas Torenvliet (Bruce Power).

International Atomic Energy Agency (IAEA), the World Association of Nuclear Operators (WANO), the World Nuclear Association (WNA) and the OECD Nuclear Energy Agency (NEA).

One of the initiatives of the WNU is its Summer Institute. Held once a year since 2005, the WNU Summer Institute is a unique educational opportunity aimed to develop a global leadership in the field of nuclear sciences and technologies. In 2006, a total of 89 fellows from 34 countries attended the 2006 WNU Summer Institute. Interestingly, Canada was the country with the most delegates at this event, a total of 12 fellows (shown in the photo).

For five weeks, the participants attended lectures on various topics related to energy policies, environment, radiological protection, economical and safety considerations of nuclear energy, future developments of nuclear technologies and non-proliferation of nuclear weapons. The invited speakers were worldwide recognized experts in their respective fields, including managers of corporations related to nuclear technologies as well as representatives of the International Atomic Energy Agency.

Group working sessions were held every day (lectures review, case studies and a final project) to synthesize the notions learned. In order to support the groups, one mentor was associated to each team. The eight , mentors were senior professionals having an extensive experience in nuclear energy, which they shared with the fellows. Each group completed a final project related to a nuclear issue.

A week-long trip in France allowed the visit of several nuclear-related facilities. This included the AREVA Chalon/St-Marcel Plant (PHTS component manufacturing), the MELOX Plant (MOX fuel manufacturing), the Centraco Plant (treatment and conditioning of low level radioactive waste), the EURODIF Plant (uranium enrichment by gaseous diffusion process), the AREVA La Hague Plant (spent fuel reprocessing) and Tore Supra at Cadarache (supraconductor Tokamak). These tours covered several aspects of the nuclear fuel cycle, while giving an interesting perspective of the French nuclear industry. In addition , the group visited the Simpevarp nuclear waste management site in Sweden. This site includes the Äspö Hard Rock Laboratory where underground experiments are being conducted to test the technologies involved in a final repository for spent nuclear fuel.

All the WNU Summer Institute Fellows agreed that this was an extraordinary experience to get a broad overview of the nuclear industry and of the whole nuclear fuel cycle. As well as the relevant lectures, the networking between participants was exceptional. This led to several exchanges on the status of the nuclear industry in various countries as well as establishing useful contacts for the future years.

In 2007, the WNU Summer Institute will be held at Daejeon, Korea and in 2008, this event is very likely to be in Canada! This would be an exceptional opportunity to showcase the Canadian nuclear industry to future leaders coming from the all around the world.

For more information on the World Nuclear University and its programs, please see http://www.world-nuclear-university.org

Branch News

CHALK RIVER – Blair Bromley

Following are the major activities over the past two months.

- On December 8, 2006, Jan Veizer, Professor of Geology, University of Ottawa, gave a seminar on “Climate, Water and Carbon Cycles: Terrestrial Records Across a Hierarchy of Time Scales”. This seminar was well attended with over 50 people.
- Dr. Jintong Li gave a seminar on January 25 on China’s Nuclear Power Program. The seminar was well attended, with more than 40 people.
- Ticket sales are underway for our next seminar, which will be a special dinner meeting on Wednesday, March 7, 2007. Our guest speaker will be CNS President Dan Meneley.
- The PEO/CNS-CRB organizing committee has held a couple of 1-hour meetings on to discuss and organize the planned symposium on discussing the feasibility of a new NPP in Renfrew County. We have been following up on leads for recruiting speakers who can give presentations to cover the various topics of the symposium. We have speakers to cover most of the topical areas now. Hopefully we will have a complete slate by early March. We have finalized a date and place for the symposium (Saturday, May 12, 2007 at the New Miramichi Lodge in Pembroke).
- We have recruited some new auxiliary members of the Chalk River Branch executive. Tracy Gagne (AECL) is our local liai-

son with WiN. Penny Neal (AECL) is our local liaison with NA-YGN. In addition, we have also recruited a new Member-at-Large, Nihan Onder (AECL).

- With the leadership of CNS-CRB Membership Chair, Ragnar Dworschak, the branch has been pushing to recruit new members for the CNS. We have been able to recruit close to 10 new members, and we're going to continue to make membership recruitment a high priority.
- Chalk River Branch members Chris Canniff, Morgan Brown, and Bernie Surette have been working on a banner design for the Chalk River Branch. We should have this design ready within the next two months, and it will be quite useful for various public events.
- The Chalk River Branch is providing financial support for the Renfrew County Science Fair for 2007. This year two prizes are being established for the two science fair projects that best illustrate directly (or indirectly) an application of nuclear science and technology.

The Chalk River Branch is currently planning the following activities:

- Establish a Nuclear Science and Technology prize for the Renfrew County Science Fair.
- Establish a scholastic award for graduating high school students in Renfrew County.
- Set up a poster contest for grade school students (Grades 7/8) – due date in late April.

GOLDEN HORSESHOE – Dave Novog

The Golden Horseshoe Branch held lunch hour seminars in January and February for CNS members and other interested students. Kevin Routledge, President of AMEC-NCL and Bruce 1 & 2 refurbishment project director gave a talk on January 12th regarding nuclear industry opportunities and challenges in general, and Bruce 1 & 2 specifically. The talk focused on the interesting peoplepower, technological, engineering and supply issues going on at Bruce 1 & 2, as well as discussing the broader issues of nuclear power in Ontario.

Charles Gordon, Director of Client Interface and Quality Manager at Nuclear Safety Solutions, gave an encore of his talk previously presented at a CNS Toronto branch in 2006 and to the Young Generation of Nuclear. His talk on February 12 provided details and information on the Chernobyl accident, and the repercussions in terms of media attention, public perception and measured biological effects. Included was excellent footage of the aftermath. For students who might not have been alive at the time of the accident, this was an excellent multi-media presentation of the event. The talk was well attended and stimulated much discussion by both students and CNS members. I would highly recommend other branches consider inviting Charles to repeat his talk.

NEW BRUNSWICK – Mark McIntyre

On February 1, 2007, Syed Zaidi delivered an illustrated lecture at the Saint John Regional Library entitled: "The Impact of the Point Lepreau Refurbishment". The lecture prompted a lengthy discussion amongst attendees about the future of nuclear energy in New Brunswick. The factors that will influence the need for a second reactor were also discussed. Thanks to Syed for his well researched lecture.

CNS New Brunswick is also anxiously awaiting the publication of Roger Steed's (CNS NB Branch member) new book. CNS NB will be purchasing copies for distribution to local schools and libraries.

OTTAWA – Jim Harvie

The second meeting of the Branch this season had a different format, it was held over lunch instead of in the evening, on November 24th, with David Mosey addressing "The Role of Institutional Failure in Reactor Accidents". The meeting attracted a fairly good audience and, as usual, resulted in a spirited discussion.

A branch meeting was held on February 8th, 2007, at which Mike Taylor spoke on "The Regulatory Style of the CNSC". Mike's background as both a senior member of CNSC staff, and subsequently a member of the Commission, made this a very interesting talk which addressed aspects of the regulatory role that had not been fully appreciated by the audience. The talk was reasonably well attended. On March 1st, 2007, CNS President, Dan Meneley, will talk on "A Stroll Down the Risk Acceptance Curve".

Two members of the Branch assisted at the display organized by Bryan White at a Professional Development Day for science teachers of the Ottawa-Carleton District School Board on February 9th.

QUEBEC – Michel Rheaume

On the January 29, 2007 in collaboration with École Polytechnique de Montréal during the week dedicated to Physics, the CNS Quebec Branch organized a conference on Climate Change. The speakers for this occasion was M Daniel Caya, the coordinator for climatic changes simulations from Ouranos Consortium.

The Ouranos Consortium, whose creation was announced on May 16, 2002, pools the expertise and disciplines of numerous researchers in order to advance the understanding of the issues and the associated requirements for adaptation resulting from climate change on the scale of the North American continent.

Ouranos is international in its scope, with a team including more than one hundred scientists and specialists. The partnerships founded by Ouranos add contributions from over 150 academic and institutional researchers.

The creation of Ouranos stems from the initiative and participation of the Government of Québec, Hydro-Québec, the Meteorological Service of Canada, and Valorisation- Recherche Québec.

More than eight Government of Québec ministries and agencies are involved, along with three universities: the Université du Québec à Montréal, McGill University, Université Laval, and a research institute, the Institut national de la recherche scientifique.

The value of long-term commitments in the form of pooled human, financial, technical, and computer resources is about $12 million annually, nearly 40% of which are cash contributions from Ouranos' partners.

Many students, professors and CNS Members were present at this very interesting conference that was mainly organized by: M. Gilles Sabourin P. Eng., from EACL-Montreal.

Additional information and pictures are on the CNS Web (Quebec Branch Section)

SHERIDAN PARK – Adriaan Buijs

The Sheridan Park Branch had a seminar on January 24th by the CNS President, Dan Meneley with the title: Stroll down the Licence Acceptance Curve Used by the CNSC.

At the same gathering we also had the annual branch meeting.

UOIT – Nafisah Khan

A new CNS-UOIT Branch website was launched on January 12, 2007. This website is comprised of information about us, our executive, our events, a photo gallery and various Branch related information.

On February 8, 2007 we hosted the second Seminar of the 2006-07 academic year with CNS President, Dr. Daniel Meneley. He addressed the topic of "Nuclear Energy in the Future World" with an outlook of the prospects of the nuclear field. Approximately 60 people attended, comprising UOIT faculty members, university students and about 18 personnel from the nuclear industry. Nuclear industry personnel came from companies such as Ontario Power Generation, Nuclear Safety Solutions, Cameco Corporation, ANRIC Enterprises Inc., Thermodyne Engineering Limited, and Henry Controls Inc. as well as retirees.

News of CNS Members and Colleagues
Nouvelles des membres de la SNC et collègues

Congratulations/Félicitations

Congratulations to CNS member Laurence Leung and his colleagues from the Thermalhydraulics Branch at Chalk River Laboratories: Dé Groeneveld (Researcher Emeritus), Aleks Vasic and Jun Yang. With international co-authors, they won the "Best Paper" award at the NURETH-11 (Nuclear Reactor Thermal Hydraulics) conference held in Avignon, France, 2005 October 2-6. Their paper was entitled "The 2005 CHF Look-up Table"; it won Best Paper in a program of more than 400 papers. The paper was praised for its "exceptional quality and archival value". It is to be noted that the CHF look-up table methodology, which predicts the critical heat flux (CHF), was pioneered at Chalk River and has now found use in many reactor-safety codes throughout the world. The international co-authors were Prof. J. Shan from Xi'an Jaiotong University, China, Prof. S.C. Cheng and Prof. A. Tanase from the University of Ottawa, and Prof A. Durmayaz from Istanbul Technical University, Turkey. The award, in the form of a plaque, was presented at the Winter Meeting of the American Nuclear Society, held in Albuquerque, New Mexico, November 2006. Dé Groeneveld received the award in person. Congratulations! Félicitations!

Some Recent Retirements of CNS Members/ Quelques retraites récentes de membres de la SNC

- **Ken Dormuth** (Director of Environment and Radiological Sciences, & Director of Environmental Assessment) from AECL, 2007 January / de l'EACL, janvier 2007
- **Paul Fehrenbach** (Vice-President & Special Advisor) from AECL, 2007 January / de l'EACL, janvier 2007
- **Fernando Iglesias** (Technical Advisor, Fuel & Fuel Channels) from Bruce Power, 2007 January / de Bruce Power, janvier 2007
- **Ben Rouben** (Senior Reactor-Physics Consultant) from AECL, 2007 February / de l'EACL, février 2007

Please send newsworthy items about CNS members, to be considered for inclusion in the next Bulletin, to Ben Rouben, roubenb@alum.mit.edu. Thank you.

Veuillez envoyer des nouvelles des membres de la SNC, qui pourraient être considérées pour inclusion dans le prochain Bulletin, à Ben Rouben, roubenb@alum.mit.edu. Merci.

Ed. Note : See additional notes on Paul Fehrenbach and Ben Rouben in this issue.

Two former CNS presidents retire

As noted in the article on "News of CNS Members and Colleagues" Paul Fehrenbach and Ben Rouben have recently retired. Both were former presidents of the Canadian Nuclear Society

Paul Fehrenbach retired from his position as Vice-President and Special Adviser at Atomic Energy of Canada Limited on January 31, 2007 after 35 years with the company.. He was previously Vice-President, Nuclear Laboratories from 2003 to 2005. Previously he was Chief Operating Officer for the Nuclear Laboratories, Site Head of Chalk River Laboratories and General Manager CANDU Technology Development. Earlier he was involved in fuel development and reactor safety research.

Paul is a charter member of the CNS, joining in 1980. Over the next decade and a half he was very active in the Society, becoming president in 1993 – 1994. He was appointed a Fellow of the Society in 1997. In 2004 he agreed to be nominated as president of the Pacific Nuclear Council, an international association of nuclear organizations around the Pacific Rim and served as PNC president from 2004 to 2006.

Ben Rouben retired as Senior Reactor Physics Consultant at Atomic Energy of Canada Limited on February 16, 2007 after 37 years with the company. He was previously Manager of the Reactor Core Physics Branch, at AECL Mississauga, from 1994 to 2006. Earlier he worked on 3_D reactor modelling, fuel management, safety analyses and other related problems.

Ben has been active in the CNS since joining in 1982, becoming president in 1997-1998, the year when the Society became legally separated from its founding parent, the Canadian Nuclear Association. He has remained very much involved in the Society and now serves as the (voluteer) Executive Administrator.

He is also active with the American Nuclear Society where he is the current chair of the ANS Reactor Physics Division. In that capacity he chaired the large and successful PHYSOR 2006 conference heldin Vanacouver in September 2006

New members / Nouveaux membres

We would like to welcome the following new members, who have joined the CNS in the last few months.

Nous aimerions accueillir chaudement les nouveaux membres suivants, qui ont fait adhésion à la SNC ces derniers mois.

Aruna Adhya, Newman Hattersley Limited
Leyland Allison, UOIT
Satyen Baindur, Ottawa Policy Research Associates, Inc.
Matthew Billy, UOIT
Gen A. Bird, AECL
Ken C. Brown, AECL-BNPD
Anupama Bulkau, UOIT
Jeffrey Burridge, Atlantic Nuclear Services Ltd.
Guangli Chen
Tian Jin Cheng, University of Waterloo
Michael K. Cheung, AREVA NP Canada Ltd.
Ken Chuong, Bruce Power
Elaine Cowling, Zircatec Precision Industries
Ronald Culligan, NB Power Nuclear
Byrne Currie
Franz Dambo, Studvik Nuclear Services
Emmanuel T. dela Cruz, McMaster University
Alexander Demenschonok
Fernand Desbiens, Bruce Power
Melisa Durak-Buljubasic, Canadian Nuclear Association
Wissam Eldib, Atlantis Systems International
Andrew Feicht, University of New Brunswick - CNE
Bernard Fitzpatrick, University of Toronto
John P.S. Froats, CANDU Owners' Group Inc.
Gordon Galvin, Industrial Audit
Rick Gauthier, NB Power Nuclear
Victor Gomez-Carballo, Atlantis Systems International Inc.
Richard Goodman, Merlin General Corporation
Jawad Haroon, UOIT
Budhaditya Hazra, University of Waterloo
Ian Hill, AECL
Daniel M. Hobbs, UOIT
Laurence Hoye, University of Lethbridge
Jingliang Hu, AECL
Bronwin Hyland, AECL
Balraj Singh Jassar, UOIT
Mikko Ilmari Jyrkama, University of Waterloo
Sanjay Kalra, Bruce Power
Janice Keating, NB Power Nuclear
Ghulam Khawaja, Atomic Energy of Canada Limited
Michael Krause, Newman Hattersley Limited
Natalie Kupiec, AECL
Gary Lewis, Contractor to Syncrude Canada Ltd.
Stephen Livingstone, AECL
Henry Lo, Nuclear Safety Solutions Ltd.
Rakesh Maharaj, Kinectrics Inc.
Taylor Mali, AECL
Dan Mao, University of Waterloo
David C. McColl, Energy Alberta Corp
Thomas Mitchell, Ontario Power Generation
Romson Monichan, UOIT
Damien Moule, UOIT
Vinay P. Mulgundmath, University of Ottawa
Syed Mohammad Munir, AMEC-NCL
Robert Olive, University of New Brunswick
Venkat Parthasarathy, SNC-Lavalin Nuclear Inc.
Guru Prakash, University of Waterloo
Jim Prince, Ontario Power Generation
Enam Rabbani, GE Energy - Nuclear Products
Arif M. Rai, Atomic Energy of Canada Ltd.
David Reinholz, UOIT
Richard Scrannage, UOIT
Kenneth Sedman, Bruce Power
Fred T. Shortts, American Warming & Ventilating
Matthew Simon, UOIT
Neil M. Smith, Merlin General Corp.
Piti Srisukvatananan, University of New Brunswick
Paul Stevens, Ontario Power Generation
Ralph Stube, Ontario Power Generation
Albert Yabiao, Sun AECL
Frank Yi Tian, CPUS
Sanela Turkanovic, Canadian Nuclear Association
Joseph P. van Langen, Ontario Power Generation
Bryan C. Villamère, UOIT
Angela Weaver, Student
Roger Webb, Savannah River National Laboratory
Eric D. Wilson, AECL
Jungsook Wren, University of Western Ontario
Lingzhi Xia, University of Western Ontario
Marek Zigin, AECL
Steven Zucchet, Borealist Infrastructure Management Inc.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In June 2007, join us in Saint John, NB as we embrace the future, and all aspects of renewal and growth in Canada's vital nuclear technology sector.
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• Technical visit: Point Lepreau G.S. (numbers limited)
• North American Young Generation in Nuclear Professional Workshop
• Reception, breaks, exhibits, and other networking opportunities
• Guest program: breakfast, tours, shopping, etc.
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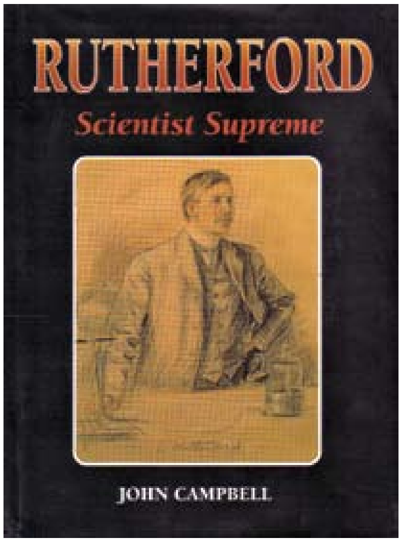

Rutherford: Scientist Supreme

by John Campbell. AAS Publications, 1999; ISBN 0 473 05700 X

Reviewed by J.E. Arsenault

This book complements a string of good biographies of Earnest Rutherford by adding much new material, especially of the early years in New Zealand and a longer perspective on Rutherford's place in science. It comes as no surprise, as the author is a professor of physics at the University of Canterbury at Christchurch, New Zealand, and has researched Rutherford for over 25 years. The New Zealand connection pervades the entire book, Rutherford having been born there in 1871 at Nelson, South Island.

In summary, the book consists of 21 chapters comprising 516 pages, contains a forward by Sir Mark Oliphant, and is lavishly illustrated with artifacts related to Rutherford, including maps, photos, family trees, letters, school songs, sketches of experimental apparatus, mementos, postal stamps, and awards.

Perhaps of most interest to Canadian readers are Chapters 9, 10, 11 and 12, beginning with the discovery of radioactivity and ending with a Nobel Prize. After early education in New Zealand and winning an Exhibition of 1851 Scholarship in 1895, Rutherford attended Cambridge University, Cavendish Laboratory, and studied under J.J. Thomson (discoverer of the electron). In 1898 he joined McGill University as MacDonald Professor of Physics. MacDonald was the benefactor, who had made his fortune in tobacco but nevertheless abhorred the smoking habit. McGill was reputed to have one of the best-equipped laboratories in the Western Hemisphere.

During his nine years at McGill, Rutherford wrote 69 papers and two books, essentially all related to radioactivity, that together transformed largely anecdotal observations into a science via accurate repeatable measurement, and laid the foundation for the many related discoveries that followed. At McGill, Rutherford characterized the three types of rays associated with the known radioactive elements, elucidated the theory of transmutation of the elements, established an accurate theory of radioactive decay and the concept of half life, defined the products of radioactive decay chains, measured the heat output of radioactive substances, and made estimates of the age of the universe based on radioactive decay. He accomplished all this with simple but ingenious theories and instruments, many of which he built himself and which can be seen today in the Rutherford Museum at McGill.

It is no exaggeration to believe that Rutherford's work at McGill led directly to his 1908 Nobel Prize for Chemistry "...for his investigations into the disintegration of the elements, and the chemistry of radioactive substances". With the award came fame and fortune. Rutherford had moved to Manchester in 1907, where important discoveries followed, including investigations leading to the organization of the periodic table in terms of atomic number, the theory of the atom consisting mostly of empty space with a nucleus surrounded by electrons, many improvements in measurement technique, and the transformation of elements by natural means. When J.J. Thomson retired in 1919, Rutherford moved back to Cambridge University and took over the Cavendish Laboratory. Here he remained for the rest of his life and witnessed the discovery of the neutron, the splitting of the atom via artificial means, and the theoretical prediction of the positron. Before he died in 1937, perhaps unnecessarily, he had become Sir Earnest Rutherford of Nelson and was many times nominated for a second Nobel Prize.

While at Cambridge, Rutherford trained a generation of nuclear scientists including many on Exhibition of 1851 Scholarships from the Commonwealth, similar to himself. Indeed, several notable Canadians trained under Rutherford and made significant contributions to progress in nuclear technology in Canada, including George C. Laurence and B. Weldon Sargent who in 1941/2 nearly succeeded in constructing the world's first self-sustaining nuclear reactor (E. Fermi succeeded in late1942). Canada's fledgling nuclear pursuits took a large step forward when John Cockcroft began directing the National Research Council's Montreal Laboratories from 1944, followed by W. Bennett Lewis in 1946 who led the way to the CANDU reactor family so familiar today. Both of these gentlemen trained under Rutherford at the Cavendish.

If the book has any faults, it is the lack of a Bibliography, although a visit to the author's web site (www.rutherford.org.nz) mitigates this issue considerably and is a highly recommended follow-up. It should be noted that the author is planning to produce a documentary on Rutherford for release in 2008 on DVD, to coincide with the 100th anniversary of the Nobel Prize award–the section on Rutherford and Canada should prove interesting.

An Unbearable Greenness Of Being

by Jeremy Whitlock

"That was 2007: the year that Climate Change became a religion."

I'm sitting in a darkened cell. A secure room somewhere, I don't know where. I was led here behind a blindfold.

The man across from me is old and weary: I can tell this just listening to his voice.

"It was in 2007 that 'climate change deniers' became the label for those who dared to question the climate change theory."

The man leans forward in the dark.

"Anthropogenic climate change, that is. As everyone agreed soon enough, climate does indeed change…"

He chuckles hoarsely, then leans back and tightens a sweater around his neck. It's cold in this room. It's cold everywhere.

"In 2007 the environment became Canadians' number one concern. The government, the opposition, politicians of every stripe started heavy petting with the environmentalists. Not the real environmentalists, of course; they were busy solving real problems.

"The Greens... the intellectually bankrupt, politically rich. They thrived like fungus."

Again he leans forward. There is no anger in his voice, only sorrow.

"They shut down the science. By 2007 the journals were already censoring the 'deniers'. Papers rejected, funding declined, projects cancelled. They shut it all down."

"An Inconvenient Truth", I mutter, aware of the irony.

He nods slowly. My eyes can now make out clouds of condensation when he breathes.

"Very few questioned the self-contradiction of the 'Scientific Consensus': truth determined by political compromise. In fact it was embraced. Expediency, mediocrity, misunderstanding: all veiled behind the shibboleth of the 'Precautionary Principle'.

"While real pollution abatement languished, billionaires offered prizes for innovative ways to suck carbon dioxide out of the atmosphere. Imagine that: an indispensable agricultural nutrient.

"It was like a clarion call to the Green army, waiting years to crawl out from under every rock. Their leaders prostituted themselves on every talk show and university campus. The most exalted entered towns like messiahs, riding mules of ignorance and treading on the palm fronds of real science.

"It wasn't long before climate change 'deniers' were rounded up. Nobody appeared to notice that these were largely the atmospheric scientists, the paleoclimatologists, the astrophysicists: those that lived and breathed planetary dynamics their whole careers. The ones that knew of climate change over the millennia: of ice ages and warm periods. The ones that paid due respect to solar cycles and cosmic interaction.

"And even as the cosmic connection was then being pinned down, heretics giving it any credence were stoned in the street. It was said that Satan manufactured the correlation between solar magnetic activity and mean temperature."

I shift uneasily. He becomes more animated.

"It snowballed, and all of science was soon quenched. Anything politically incorrect at first, but soon free thought itself was frowned upon. We began to stagnate intellectually as a species.

"The Climate Change Inquisition gathered steam under the United Nations, rolling through several countries. No government stood in its way. No punishment was too severe for the skeptics."

He leans back, breathing uneasily as if recalling unsettling memories. Finally I see him shrug.

"After a couple of decades, as you probably know, evidence for planetary cooling became embarrassingly obvious. Five years of crop failure in central Europe, glacial advance, closure of the Northwest Passage and the ceding back to Canada of all now-useless Arctic waters."

He pulls the sweater even closer.

"The Second Little Ice Age had, quite clearly, begun. And with it, the Second Dark Age."

He muffles a dry cough as I stand and pace the dark room.

I knew the rest of the story. The Disillusionment. The backlash towards not just environmentalists, but all manifestations of leadership, vision, control. Science was long cast out, and now the New Ideology was known to be a farce. Nothing remained. Tribal structures filled the void. Institutions were smashed. Real scientists, subsisting for years in safe houses writing Java script for pop websites, were now reduced to a hunter-gatherer desperation like the rest.

I thank him but he's now curled up in the fetal position somewhere in the shadows. I leave and enter the cold. All signs are that it's going to get a lot colder.

2007

Mar. 14 - 16
PHYTRA-1
1st International Conference on Physics and Technology of Reactors and Applications
Marrakech, Morocco
email: erradi@hotmail.com

May 14 - 16
2007 International Conference on Advances in Nuclear Power Plants (ICAPP '07)
Nice, France
email: philippe.pradel@ces.fr

June 3 - 6
28th Annual CNS Conference & 31st CNS/CNA Student Conference
Saint John, New Brunswick
website: www.cns-snc.ca

June 24 - 28
ANS Annual Meeting
Boston, Mass
website: www.ans.org

Aug. 12 - 17
SMiRT 19
19th Conference on Structural Mechanics in Reactor Technology
Toronto, Ontario
website: www.engr.ncsu.edu/smirt-19

Aug. 19 - 23
13th International Conference on Environmental Degradation of Materials in Nuclear Power Systems
Whistler, BC
website: www.cns-snc.ca

Sept. 16 - 19
ANS Topical Meeting on: Decommissioning, Decontamination & Reutilization
Chattanooga, TN
website: www.ans.org/meetings

Sept. 30 - Oct. 4
NURETH-12: 12th International Meeting on Nuclear Reactor Thermalhydraulics
Pittsburgh, PA
website: www.ans.org/meetings

Nov. 11 - 15
ANS / ENS International Conference
Wasington, D.C.
website: www.ans.org/meetings

CNS Membership Renewal Reminder

If you have not yet renewed your CNS membership for 2007, but would like to retain your membership in good standing, please take a moment to do it now. Please return the individual membership renewal form which you received in November, or fill out and return the renewal form, which is available on the CNS website at www.cns-snc.ca. Or you may simply communicate with the CNS office by e-mail at cns-snc@on.aibn.com or by phone at 416-977-7620.

Non-renewed memberships will be definitely cancelled in mid March.

Thank you.

Ben Rouben
Chair, Membership Committee

Rappel de renouvellement d'adhésion à la SNC

Si vous n'avez pas encore renouvelé votre adhésion à la SNC pour 2007, mais aimeriez garder les bénéfices de votre adhésion, veuillez prendre un petit moment pour le faire tout de suite. Veuillez renvoyer le formulaire individuel que vous avez reçu en novembre, ou bien remplir le formulaire de renouvellement, qui est disponible sur le site internet de la SNC, à www.cns-snc.ca. Ou bien vous pouvez simplement communiquer avec le bureau de la SNC, par courriel au cns-snc@on.aibn.com ou par téléphone au 416-977-7620.

Les adhésions non renouvelées seront définitivement annulées à la mi-mars.

Merci bien.

Ben Rouben
président du comité d'adhésion

2006-2007 CNS Council • Conseil de la SNC

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