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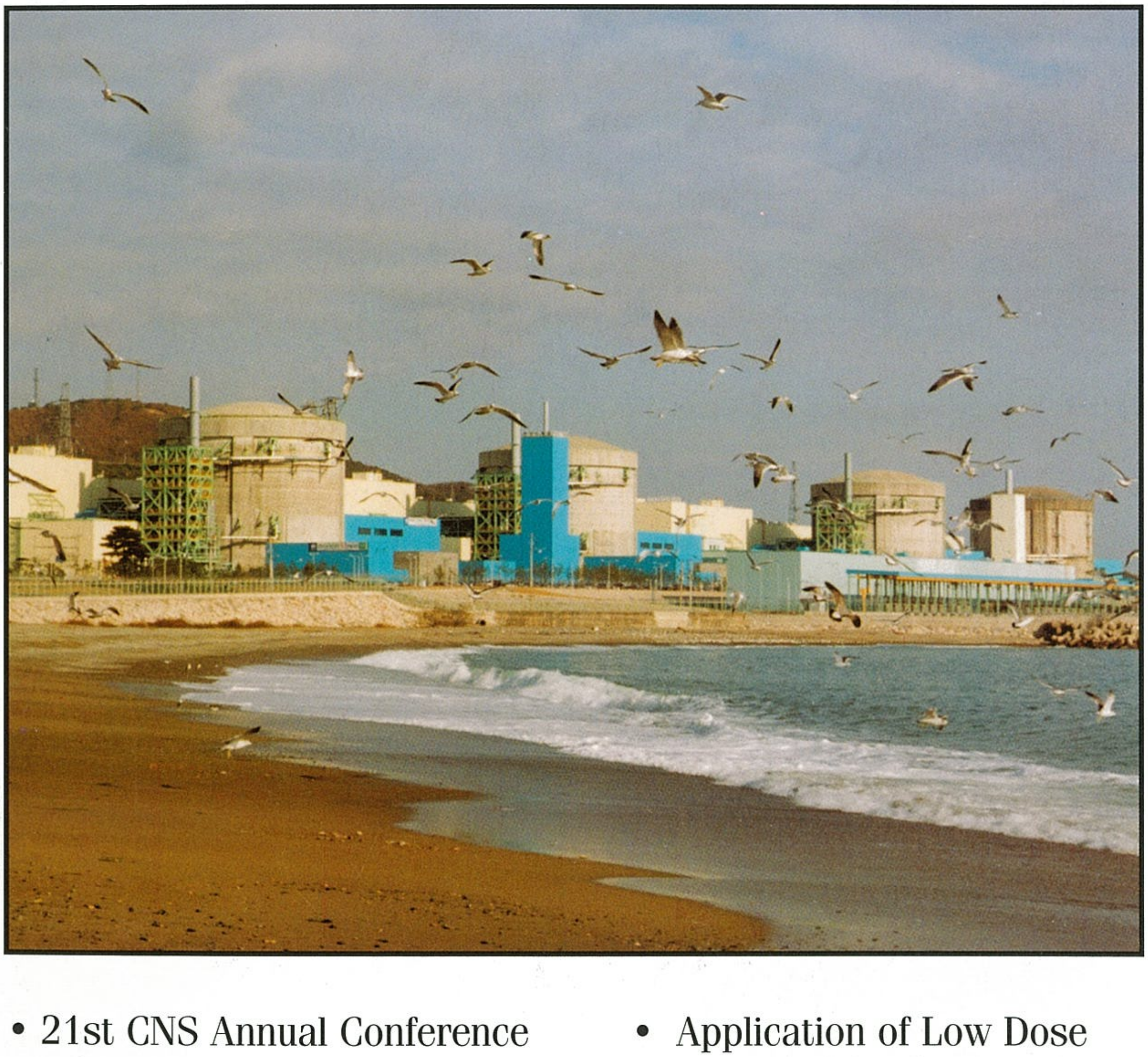

- 21st CNS Annual Conference
- Future of the Nuclear Industry in China
- Gentilly-2 Full Power Operation History and Future Challenges
- Application of Low Dose Radiation for Curing Cancer
- A Thermal Neutron Activation System for Detecting Land Mines

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Cover Illustration

The illustration on the cover is a recent photograph of the four CANDU reactors at the Wolsong site in Korea. The many organizations involved in the successful completion of Wolsong units 2, 3 and 4 were awarded the CNS Team Achievement Award.

CANADIAN NUCLEAR SOCIETY

bulletin

DE LA SOCIÉTÉ NUCLÉAIRE CANADIENNE

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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.
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A new player

As reflected in this issue, the major event over the past couple of months in the Canadian nuclear scene was the vary successful 21st Annual Conference of the Canadian Nuclear Society. We can echo here the words of the article on the Conference that the volunteer organizers did an amazing job despite formidable challenges.

However, the major news story in the nuclear field was the announcement of the agreement between Ontario Power Generation and Bruce Power (read British Energy) for the two Bruce stations. The deal is fascinating in many ways

First, British Energy appears to be willing to pay considerably more for the Bruce plants than they have, through their partnership with Peco, for the nuclear plants they have acquired in the USA. (Could that imply a judgement of CANDU or just the particular circumstances of the Bruce situation ?) And the Bruce deal is for a lease not ownership. Although it can be suspected that leasing has its own advantages by excluding certain liabilities.

Secondly, British Energy, through its subsidiary Bruce Power, has promised to keep all of the current staff (except those remaining with OPG). Given its record in the UK this is remarkable. Early this year the UK Nuclear Installations Inspectorate, the regulatory body, issued a report based on an "audit" it had conducted in 1999 of all of BE's operations. The NII raised strong questions about the amount of downsizing and ruled that it should stop until all of the questions raised by the audit were addressed. (It should be added that NII did state that, "staff at all levels were committed to safe operation".)

On the regulatory side the Canadian Nuclear Safety commission is also facing questions. Despite the Nuclear Safety and Control Act being only three years old it is silent on leasing. In the past the AECB always considered that the owner had primary responsibility. Nevertheless, as reported in this issue, Bruce Power has applied for licences.. There also remain a number of technical matters but, reportedly, BP (BE) is prepared to deal with them all. Given their concentrated focus, perhaps the people of BP (BE) will move faster than OPG has been able to achieve.

Further, they have stated that they will look hard at the feasibility of re-starting units 3 and 4 of Bruce A. (Everyone, apparently, has given up on units 1 and 2.)

There is no doubt that British Energy has been financially successful in the UK where their plants are operating in a competitive electricity market. The Ontario government's delay in moving into that regime may give Bruce Power some time to absorb the Bruce plants and get prepared from the future.

All in all this looks like a positive move for the Canadian nuclear power scene but many challenges lie ahead.

Fred Boyd

IN THIS ISSUE

Most of this issue, whether articles or papers, is drawn from the 21st CNS Annual Conference held in June 2000.

We begin with reports on the Conference, divided into three parts. The first article, **21st CNS Annual Conference,** provides a general picture and review of the plenary sessions. The second gives a brief (and, admittedly, inadequate) account of the **Technical Sessions.** And the third, in the form of a sidebar, offers a glimpse of the challenges faced, and overcome, by the organizing committee.

Following are four papers from the plenary sessions and one from the technical ones. (We will run further technical papers in the next issue.)

The first paper, **Future of the Nuclear Industry in China,** probably drew the most attention of any presentation. Dr. Li's remarks will, we suspect, be of interest to most readers. To complement that overseas view there are two papers dealing with our two domestic CANDU 600 units; **Gentilly 2 Full Power Operation - History and Future Challenges,** and, **Improving Performance at Point Lepreau.** The last plenary paper selected is a technically fascinating one on the innovative thinking going into possible future variants of CANDU, **Conceptual Designs for Very High Temperature CANDU Reactors.**

The one selection from the technical sessions reveals our bias. John Luxat's paper, **Safety Analysis Technology: Evolution, Revolution and the Drive to Establish Margins** is, despite the unwieldy title, an excellent review of how reactor safety analysis has been driven by extreme deterministic criteria in contrast to the early objective of risk-based goals.

Then there is a paper describing the **Development of a Thermal Neutron Activation System for Detection of Non-metallic Land Mines** which was the basis for one of the CNS Team Achievement Awards presented during the Conference. Finally a short paper by Jerry Cuttler, **Application of Low Dose of Radiation for Curing Cancer** is a further contribution to the on- going argument about the effects of low doses of ionizing radiation. (It should be noted that the CNS has not taken a stand on this issue and publication of this paper does NOT reflect endorsement or otherwise by the Society of the practice described.)

There is the customary short section on **General News** with a miscellany of items and a relatively long **CNS News** section with reports from the Annual General Meeting held during the Annual Conference. Also in that section is a report, **CNS recognizes achievers,** on the several awards presented by the Society at a special luncheon during the Annual Conference.

Finally, there are notes of some **Publications Available** that may be of interest, the updated **Calendar** and Jerry Whitlock's essay in **Endpoint.**

Your comments and contributions are always welcomed.

The 21st CNS Annual Conference

– "an excellent conference, organizationally, socially, technically"

An excellent conference, organizationally, socially, and technically, was the general opinion of the 270 attendees at the 21st Annual Conference of the Canadian Nuclear Society held in Toronto, June 11 to 14, 2000.

Unlike the annual nuclear conferences of the past 20 years which were run jointly by the Canadian Nuclear Association and the Canadian Nuclear Society this year's gathering of the Canadian nuclear community was organized totally by the CNS. *(See sidebar.)*

Following tradition the conference began with a reception on the Sunday evening, giving delegates a pleasant venue to renew acquaintances, conduct "networking", or just enjoy themselves. The actual conference, which ran over the following three days, was organized with three half-day plenary sessions and three half-days of four to five parallel technical sessions.

Leavening the formal sessions were two luncheons and a conference banquet (all included in the relatively modest registration fee). The first luncheon, on the Monday, featured **Gene Preston**, recently appointed executive vice-president and chief nuclear officer at Ontario Power Generation, as the guest speaker. The other luncheon was devoted to the presentation of CNS awards. *(See separate article.)* During the banquet a mock murder mystery challenged the sleuthing ability of the diners.

In his remarks, Gene Preston noted that nuclear provides about one half of OPG's generation. As mandated by the province two fossil plants were put up for sale, although that is now on hold, and offers were solicited for the Bruce nuclear complex. *(See "General News" for a report on the agreement for Bruce.)* Although performance has been improving OPG still has a way to catch up with comparable nuclear operators in the USA. To a question Preston commented that he was pleased to remain in Canada and added, to the audience's delight, that Canadian [nuclear] technology was better than that of the USA.

Embedded in the conference was the Annual General Meeting of the Canadian Nuclear Society, held late Monday afternoon. *(See a report on the AGM elsewhere in this issue.)*

Pierre Charlebois

David Torgerson

Allen Kilpatrick

The Canadian Nuclear Association took advantage of the gathering to hold its AGM on the Tuesday morning.

In opening the first plenary session, on the Monday morning, Conference chairman **Pierre Charlebois** noted that the Canadian program had started more than 50 years ago with the design and start-up of NRX. Referring to the conference theme *"A Better Nuclear Tomorrow"*, he commented on the progress to re-establishing world class performance of our nuclear plants.

In the session senior representatives of the industry provided updates of various sectors of the program. The first speaker, **Allen Kilpatrick**, president and CEO of Atomic Energy of Canada Limited, reviewed his company's recent activities. Fiscal year 1999-2000 was AECL's most successful year, he reported, although there were also disappointments. Revenue reached a record $550 million from domestic activities and overseas projects. The two CANDU 6 units being built at Qinshan, China were proceeding well, the Wolsong 4 unit in Korea entered commercial service and the first of two MAPLE isotope production reactors being built at the Chalk River Laboratories started up.

On the export front, Kilpatrick acknowledged that the market was very limited and competition fierce. Korea has not yet decided on its future program and China has stated it will not consider further units until the two units at Qinshan are completed. "Turkey remains an enigma", he stated. *(Subsequently, in mid July the president of Turkey announced the cancellation of the country's nuclear project.)* Romania is still seeking financing to complete the second unit at Cernavoda. He acknowledged AECL's disappointment that it had not been chosen to build Australia's new research reactor.

However, Kilpatrick noted, there is a growing market for services to the domestic nuclear power plants and he expected a positive decision by the government for a replacement of the NRU research reactor at CRL (the proposed Canadian Neutron Facility). He closed by noting the ongoing challenge to educate the public of the benefits of nuclear power and acknowledged the efforts of the CNS in this area. "We must get the message out", he concluded.

Jim Harvie

Bob Strickert, vice-president, Ontario Power Generation, speaking on "Pickering A Restart", first reviewed the NAOP review of 1997 which led to the lay up of Pickering A and Bruce A stations. He then outlined the program to restart the four units at Pickering A station. The required environmental assessment report was submitted to the Atomic Energy Control Board (now the Canadian Nuclear Safety Commission) in April. Work is proceeding on an enhanced shutdown system, a key regulatory requirement, and other improvements are underway.

Dave Torgerson, vice-president, AECL, gave one of his upbeat talks on "Next Generation CANDU Technology" in which he noted the many different approaches being examined to lower the cost and increase the efficiency of CANDU units. The basic concept of CANDU permits considerable design flexibility, ne noted. *(His paper "Reducing the Cost of CANDU", in Vol. 20, No. 4 issue of the* CNS Bulletin, *contains the essence of Torgerson's presentation.)*

Romney Duffey, chief scientist at AECL, provided an overview of the potential role of nuclear power in the global warming challenge in a presentation entitled "Going Up or Going Down? The History and Future of CO2 and Nuclear Power". The use of nuclear power, along with renewables, is essential, he stated, to reduce the emissions of greenhouse gases identified as a major factor in global warming. To stabilize CO2 concentrations at about current levels will require that non-carbon energy sources contribute 30 to 40 per cent of overall energy needs compared to approximately 10 per cent now.

"Improving Performance at Point Lepreau" was the title of the paper presented by **Rod White,** vice-president, New Brunswick Power. He provided an overview of the program of the past few years aimed at re-establishing the excellent operating record of the station in its early years. A major emphasis has been on the human factor since more than 50 per cent of unplanned events were determined to have a human failure component. The earlier Performance Improvement Program has now been replaced by a business planning process which encompasses risk assessment to ensure that station resources are aligned with the high level goals. A dedicated transition team was been created in early 1999 to focus on and monitor human performance, organizational effectiveness and station processes. *(The full paper by White et al is reprinted in this issue of the* CNS Bulletin.)

Peter Brown, of Natural Resources Canada, spoke on "Recent Developments re Disposal of High and Low Level Radioactive Wastes".The federal government is still studying the mechanism to oversee the management of nuclear fuel waste. He reported that Port Hope and surrounding communities are discussing with the government a plan for the local disposal of the historic low level waste in the area. On mine tailings he commented that the federal government had accepted responsibility for abandoned mines. Agreements with some provinces were in place and others being pursued.

Opening the second plenary session on the Tuesday afternoon, **Andy Schwabe,** vice-president OPG, gave an update on OPG's Integrated Improvement Program. The IIP was developed to improve safety, production, and cost performance. Of the 66 original projects 30 have been completed. Among achievements to date, all OPG nuclear sites have obtained ISO 14001 environmental certification. Pickering B reactor buildings have been returned to "clean area" zoning. The corrective maintenance backlog at all stations has been reduced. Schwabe concluded by noting that project planning is complete and project implementation is gaining momentum. Performance improvement is measurable, he said, and will be used to drive results.

In a paper entitled "Comparative Cost of Electricity Generation - Update 2000", **Sylvana Guindon,** of Natural Resource Canada, provided an update of the paper she and Brian Moore presented at PBNC 98 in the spring of 1998. *(That paper was printed in Vol 19, No 2 of the* CNS Bulletin.) She noted that, although the levelized unit energy cost of electricity from nuclear plants over thirty years can be shown to be comparable to that from fossil plants, the much higher capital cost of nuclear will inhibit investment in today's competitive market.

Outgoing CNS president Krish Krishnan presents a gift to Gene Preston, chief nuclear officer at Ontario Power Generation after his luncheon talk at the 21st CNS Annual Conference in Toronto, June 2000.

With his usual acerbic style, **Jim Harvie**, director general, Canadian Nuclear Safety Commission, spoke on "Regulatory Aspects of the Return of Pickering A to Service". A remaining licence condition, he noted, is the installation of an enhanced shutdown system to increase the reliability and effectiveness of the shutdown function. He reported that the CNSC and OPG have reached agreement on the many other improvements required. Harvie reminded the audience that the basic reason for shutting down Pickering A (and Bruce A) was to free up resources to improve the remaining plants. He warned that, if the appropriate improvements in the operating reactors have not been made the Commission may conclude that Pickering A should remain shutdown, even if it has achieved a level that would permit restart.

Sylvana Guindon

With the aid of a series of excellent photographs of the McArthur and Key Lake mines and the Port Hope conversion facility, **Robert Steane**, vice-president of CAMECO, presented an overview of the mining and processing of uranium. "Reactor fuel is not found in bundles", he quipped.

In a very thorough paper on, "Gentilly 2 Full-Power Operation: History and Future Challenges" **René Pageau**, nuclear safety manager at Hydro Quebec's Gentilly 2 station, reviewed the operation of G-2 with particular emphasis on the problem of safety margins associated with the ageing of the primary heat transport system. Without corrective action the plant power will probably have to be down-rated by 2002. *(Pageau's full paper is reprinted in this issue of the* CNS Bulletin.).

David Shier, of the Power Workers Union, spoke on "The Workers' Perspective of Safety Related Aspects of Nuclear Power Plants". He noted that his talk was based on a recent submission to a Senate Committee reviewing nuclear safety. The PWU, which represents workers at OPG's nuclear plants, feels that the essential safety infrastructure is in place and works well.

Betty Rozendall, of AECL, closed the second plenary session with a paper on "Climate Change and Emission Reduction Opportunities". She reviewed the climate change issue from the UN Framework convention of 1992, through the Kyoto protocol of 1997, the proposals for emission trading and the creation of Canada's Climate Change Secretariat in 1998. There is a significant potential role for nuclear power to meet the emission targets for greenhouse gases set out in the Kyoto protocol, she reported.

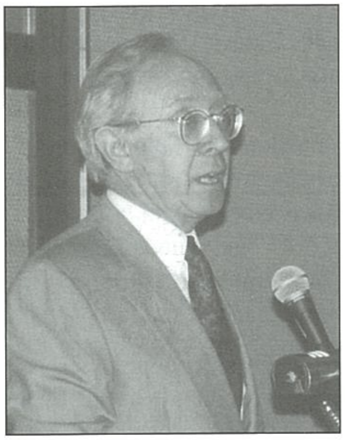
Panelists for plenary session 3 at the CNS Annual Conference in Toronto, June 14, 2000, await their turn.
Left to right: Paul Fahrenbach, Grant Malkoske, Yulan Li, and session chairman Bill Clarke.

The opening paper of the third plenary session was a widely anticipated one by Dr. Li, Yulan, of the China National Nuclear Corporation on "The future of the Nuclear Industry in China". Dr. Li outlined the current and expected nuclear power program but noted that there are major projects to bring natural gas from the western part of the country to the industrial area along the eastern coast. *(Dr. Li's full paper is reprinted in this issue of the* CNS Bulletin.)

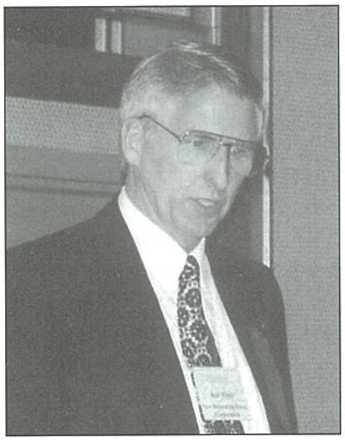
Grant Malkoske, vice-president, MDS Nordion, presented the only plenary paper not related to nuclear power, entitled, "Innovation for Health". He began with a human story of a Canadian Olympic athlete who contracted thyroid cancer which was successfully treated with the radioisotope I-131 produced in NRU and processed by MDS Nordion. Malkoske noted that the first of the two MAPLE dedicated isotope production reactors being built for MDS Nordion at the Chalk River laboratories had achieved criticality on February 19. MAPLE 2 will start up soon and should be in service by the end of the year, he said. MAPLE 1 and the new Processing Facility are expected to go to go into commercial service by early fall. He went on to describe MDS Nordion as: a software developer; a radiopharmaceutical manufacturer; and a supplier of health care solutions worldwide. Cobalt 60 , produced in OPG's reactors, is used in irradiation facilities for sterilization around the world. MDS Nordion, together with biotechnology companies is developing a process to attach radioisotopes to monoclonal antibodies. The first product in this class is named Bexxar and will be used to treat non-Hodgkin's lymphoma. *(For an overview of MDS Nordion see Vol. 19, No. 1 issue of the* CNS Bulletin.)

Paul Fehrenbach, of AECL, gave an overview and update on the proposed Canadian Neutron Facility, a 40 MW (th) MAPLE type reactor intended to replace the ageing NRU research reactor at the Chalk River Laboratories. CNF is designed with two major objectives: to provide for advanced material research using neutron beams; and, to provide an essential testing facility to support existing and future CANDUs.

Representing Ian McGregor, **Don Strange**, of the Climate Change Secretariat, gave the presentation on "Canada's Approach to Meeting its Kyoto Commitment". He reviewed the commitments by Canada and other developed nations at the COP 4 meeting in Kyoto in December 1997 to reduce their emissions of green house gases associated with global warming. To meet its commitment of a 6 per cent reduction from 1990 levels by 2010 will actually require a reduction of 26 per



Romney Duffey



Rod White

cent from the levels predicted for a "business as usual" approach. Electricity production is responsible for about 1/6 of Canada's GHG emissions. He outlined the national structures for dealing with the climate change issue, involving steering and coordinating committees and a large number of :issue tables" with broad membership where various sectors of the economy were studied in detail. The federal government has allocated more than $600 million over five years for initiatives related to climate change.

The possible evolution of CANDU was presented by **Stephen Bushby**, of AECL, in a paper co- authored with G. R. Dimmick and R. B. Duffey on, "Conceptual Designs for Very High Temperature CANDU Reactors". With wide ranging innovative thinking reflective of the early years of the nuclear power program, he described three conceptual designs in the CANDU-X program using supercritical water as the coolant. Each would have significantly higher thermodynamic efficiency over current CANDU designs. *(Their full paper is reprinted in this issue of the* CNS Bulletin.)

The plenary sessions closed with a presentation by **Pat Tighe**, president of COG, entitled "COG Information Exchange - the New Initiatives". He reviewed the initial creation of the CANDU Owners group in 1984 as a cooperative arrangement of Canadian CANDU owners and AECL. Overseas CANDU owners subsequently became involved. In 1999 COG was re-structured as an independent, not-for-profit, Canadian corporation and moved (from OPG) to new offices on University Avenue in Toronto. The new COG, he said, is going to a more proactive approach, anticipating issues rather than just being reactive to problems. A "New Initiative Program" has been adopted, emphasizing a spirit of cooperation. This summer the organization will launch a new Web site "COG ONLINE" to replace the current one "COGNET".

A report on the technical sessions is presented elsewhere in this issue of the *CNS Bulletin.*

CNS Annual Conference
- *behind the scene*

The 21st Annual Conference of the Canadian Nuclear Society was remarkable in many ways.

This was the first time the Society organized such a comprehensive conference, it was all done in little over six months, and was accomplished by volunteers.

For the past twenty years the CNS had partnered with the Canadian Nuclear Association in holding the annual gathering of Canada's nuclear community, except in 1998 when the CNA forewent its annual conference to support the Pacific Basin Nuclear Conference held in Banff.. The CNS did hold its own annual conference that year but restricted it to a forum for technical papers.

In late fall 1999 the CNA, as part of its decision to move to Ottawa and change its focus, cancelled its annual conference for the year 2000 (with which the CNS was committed). After some agonizing debate the CNS Council decided to run a full conference in June 2000, just over six months away. (The joint CNA / CNS conferences were scheduled at least two years in advance with detailed planning beginning immediately after the previous year's meeting.)

A small team of volunteers came forward, mostly from CNS Council members. Ben Rouben, a former CNS president, and Ian Wilson, jointly took on the executive chairmanship, Jad Popovic and Aniket Pant agreed to be program co-chairs, Ken Smith, then vice-president, took charge of finances and sponsorship, and CNS treasurer Andrew Lee became conference secretary.

Subsequently, Brian Thompson of the CNA signed on to do publicity, AECL's Isabel Franklin stepped in to handle hotel arrangements, and, Pierre Charlebois, vice-president at OPG agreed to become conference chairman..

The team quickly made plans and decisions. A time, June 11 to 14, and a location, the Delta Chelsea Hotel in downtown Toronto, were chosen. Calls for papers went out and industry leaders were solicited to give presentations in the plenary sessions. Unlike the previous years it was decided that there would be no overlap of the plenary sessions with the technical ones.

At the same time the CNS was facing other challenges. For the past two decades the CNS shared office space and services with the CNA. When the CNA decided to move to Ottawa the CNS Council chose not to follow. That meant finding new quarters in the Toronto area. A couple of frustrating months passed before the possibility arose of sub-letting space in COG's new offices. In addition, the CNA move led Sylvie Caron, who had looked after most of CNS administration, to decide to return to Montreal. After considering alternatives, the CNS Council engaged Denise Rouben as administrator. (Sylvie Caron returned to help with the registration for the Annual Conference.)

Despite all of these challenges, the results, as reported elsewhere, was an excellent conference that drew accolades from most of the 270 attendees. And, surprisingly, many of the same people have volunteered to help with next year's conference !

The 21st CNS Annual Conference
- *Technical Sessions*

One half of the time of the 21st CNS Annual Conference, held in Toronto, June 11- 14, 2000, was devoted to 13 parallel sessions in which 75 papers were presented. The Monday afternoon, Tuesday morning and Wednesday afternoon saw four or five concurrent sessions in which there were typically six papers. The titles for the sessions were:

- Physics I And II
- Environmental Assessment
- Thermalhydraulics I and II
- Safety and Licensing I and II
- Environmental Risk Assessment
- Reactor and Components
- Environmental Models and Monitoring
- Control Room
- Fuel and Fuel cycles
- Software and SciCodes

The provisional program which was printed in the last issue of the *CNS Bulletin (Vol. 21, No. 1)* was modified slightly due to last minute travel difficulties and other problems. A CD with most of the technical papers (and many of the plenary ones) is available from the CNS office.

To give some flavour of the scope of the presentations following are summaries of a few of the sessions as prepared by the respective chairpersons.

SAFETY and LICENSING II

by Bruce Willemsen
(Session Chairs: M.-A. Petrilli, B. Willemsen)

Changing standards in Canada and throughout the world have resulted in challenges for those directly and indirectly involved with nuclear energy. Speakers in this session shared their successes in the areas of IAEA Safeguards, new Packaging and Transport Regulations, safety upgrades to the NRU research reactor, decay power calculations, risk analysis techniques, and environmental qualification programs. The solutions to meeting ever increasing expectations requires innovation and expertise that was demonstrated by all of the speakers in this session. It was encouraging to see that our industry employs those who are capable of meeting the demands during these changing times.

PHYSICS I

by A. Baudouin (Hydro-Québec) and M. Gold (Ontario Power Generation), Session Co-Chairs

The session consisted of five papers.

Two of the papers dealt with improvements to the current approach to solving the static or dynamic core neutronic equations. The first, delivered by Jinchao Mao of Ecole Polytechnique, presented the results of replacing the finite-difference method with the more rigorous and accurate Analytical Nodal Method; the second, delivered by Benoit Dionne of Ecole Polytechnique, presented the results of a coupling of the reactor physics core calculation suite with the subchannel thermalhydraulics code ASSERT-PV.

The third paper, by Paul Sermer of Ontario Power Generation, gave an overview of an extremal statistics model, which is applied to the problem of ensuring that an operational parameter that is difficult to measure exactly is being kept below a prescribed licence limit. The model determines the required operational margin to the limit based on surveillance of the available measured data, and has been applied to define licence-limit compliance procedures for both the maximum channel power and the minimum axial gap.

The fourth paper, by Farzad Ardeshiri of AECL, presented the results of a validation of the reactivity coefficients of moderator and coolant temperature changes, based on re-analysis of Phase B temperature variation tests conducted at Darlington Unit 2 during its commissioning.

The fifth paper, by Simon Day of McMaster University, presented the results of physics analysis of local flux peaking in the McMaster Nuclear Reactor, using the WIMS-AECL/3DDT code package.

CONTROL ROOM

by Debbie Gillard (Ontario Power Generation), Co-Chair of session with E. Davey (Crew Systems Solutions)

"As I ponder the Control Room session and the day's presentations, three points strike me:

First, Dr. Jerry Cuttler's statement: "Work to change what is, to what should be."

Second, the definition of Operational Focus: " Leadership, behaviours and results of the whole organization that make safe and reliable operation the core activity of the Business" as presented by Lee Lane.

Third, not discussed, the Gestalt philosophy, "The whole is greater than the sum of its parts".

In the nuclear-power operating industry, the last concept applies to the Organization and to the plants we design and operate. Nowhere is this more evident than in the Nuclear Control Room. This complexity was reflected in the presentations in the session, which covered a broad range of topics applicable to the control room:

- Operator Error and Emotions, by B. Patterson of Human Factors Practical et al.
- Plant Status Control with an Operational Focus, by L. Lane of Ontario Power Generation
- The Importance of Function Analysis in the Nuclear Industry, by U. Sengupta and S. Chen-Wing of AECL
- Practical Control Centre Retrofit for Refurbishment, by M. Feher of AECL
- Criteria for Operator Review of Workplace Changes, by E. Davey of Crew Systems Solutions

I would like to challenge the attendees of the Control Room session to:

- Work to change what is, to what should be.
- In so doing, maintain an operational focus, and recognize and embrace the Gestalt philosophy bringing around the table the diverse expertise we have across the Canadian Nuclear Industry to meet the challenges our industry faces, not just to survive but to flourish.

SOFTWARE AND SCICODES

by P.D. Thompson
[Session Chairs H. Liot (Zircatec) and P.D. Thompson (New Brunswick power)]

Although the session on Software and Scientific Codes was one of the last sessions of the conference, it was very well attended and led to a lot of interesting discussion. All 5 speakers gave extremely interesting presentations. The session was chaired by Henry Liot of Zircatec Precision Instruments and Paul Thompson of New Brunswick Power.

The first speaker was Dr. Rudi Abel, formerly of AECL and now with R&M Abel Consultants Inc. Dr. Abel was the chairman of the subcommittee that created CSA Standard N286.7. Rudi gave a most interesting history of the development of the Standard and discussed the underlying principles that are contained within it.

The second speaker was Robin Prime from Brunswick Nuclear Inc. Robin presented a paper on the development and application of an electronic form which aids a computer program developer in ensuring compliance with N286.7. Given the current emphasis on demonstrating compliance with the standard, this form has great potential.

The third paper of the session was presented by M. Klukas of CRL and discussed the experimental work and the results of the validation of the computer code ADDAM (Atmospheric Dispersion and Dose Analysis Method) for the complex terrain at the Wolsong site. This work demonstrated that the method in ADDAM is unlikely to under predict the dose at an exclusion boundary as short as 500 m and for CANDU sites of moderate topographical complexity.

The last paper in the session was presented by D. Goland of AECL. David presented a very interesting and graphic presentation of the use of 3 D CAD on the Qinshan CANDU Project. In particular, David described AECL's work in applying computer aided engineering tools to the Qinshan project for use in Civil, Mechanical and EI&C design applications. It was interesting to see how the use of these tools has improved quality and reduced costs.

The future of the Nuclear Industry in China

by Li, Yulan (China National Nuclear Corporation)

Ed. Note: *Following is the slightly edited text of Dr. Li, Yulan's presentation at the 21st annual conference of the Canadian Nuclear Society on June 13, 2000, in Toronto.*

1. Updates And Progress Of Nuclear Power In China

Currently, three pressurized water reactor (PWR) units are in safe and sound operation with remarkable business revenue. The nuclear installed capacity of 2.1 GWe is 0.7% of the national total. China's installed electricity generating capacity has reached a record 300 GWe by the end of April 2000.

In 1999 China's three operational PWR delivered 15.2 billion kWh of electricity to the national grid, around 1.2% of the country's total power output.

Total electricity generation for the year was 1.23 trillion kWh, an increase of 6.2% over 1998.Of this total, 211.2 billion kWh was generated by hydropower and 1.003 trillion kWh by conventional thermal (including coal-fired) power station.

Two CANDU units and six PWR units, with a total installed capacity of 6.6 GWe, are under construction now. They will be put into operation during the tenth Five-year Plan period (2001 - 2005). By that time, the nuclear power will still account for less than 2% of the national total.

Regarding the next step of China's nuclear power program, many coastal provinces are actively applying to build new nuclear power plants. But up to date, the tenth Five-year Plan hasn't been worked out, so a complete list of proposed nuclear power projects in the plan is still not ready.

2. Opportunity – China Needs To Develop Nuclear Power Commensurately

Electricity Demand

The country's power industry has seen rapid growth in the past two decades. Statistics showed that the country's installed capacity reached 100 GWe in 1987, 200 GWe in 1995 and 300 GWe at present. The rapid development of the power industry has eased power supply shortages significantly and backed up the country's economic growth. However, the per capita electricity consumption in China is only about 40% of the world average. Obviously, there is much room for expansion of the electricity demand in China, the world's most populous country. With China's rapidly growing economy and the continuing improvement in the quality of people's life, the electricity demand will increase in the next century.

Opportunity to Develop Nuclear Power

It is well known that China's energy consumption is heavily reliant on coal, which is still the principal source of energy even though several natural gas fields are being exploited. The heavy reliance on coal and the huge coal movements from west to east and from north to south has resulted in significant impacts on the environment. The prob-

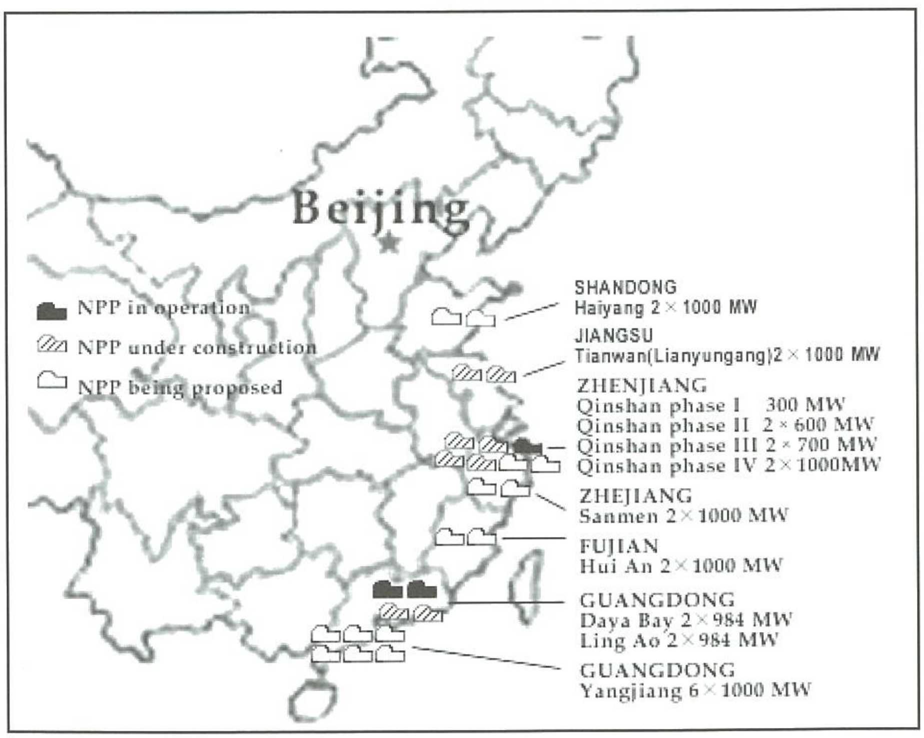


Figure 1: Location of nuclear power plants in China

lems concerning environmental and ecological protection have been put on the agenda. One of the key issues is to adjust energy structure, especially to reduce the use of fossil fuels. More and more people have recognized that nuclear power is a reasonable option as a substituted energy. In addition, the State Power Corp is striving to gradually integrate the country's 12 regional grids to form a united one, which will be helpful for transmitting electricity nationwide. The integrated grid is suitable for nuclear power plants as a basic load power station. China needs to develop nuclear power commensurately.

3. Challenges – Nuclear Power Meets Competition from Power Market

The first two decades of the 21st century will be a critical period with challenges in the world nuclear power history, because most existing nuclear power plants are to be decommissioned. However, regeneration of nuclear power is upcoming. Further nuclear power development faces two issues: (1) nuclear safety and final disposal of high-level radwastes; (2) economic competition with conventional power generation technologies like clean coal, combined cycle and LNG.

Besides the common issues above, the country's nuclear power meets competition from the power market. The proposed west-to-east gas pipeline project and west-to-east electricity transmission strategy will provide the eastern regions with large energy/power supply which might occupy a part of the power market supplied by nuclear power. It is quite clear that nuclear power in China has to meet higher and higher safety goal and much improved economy.

In addition, we have to pay attention to the decrease in "electricity elasticity"(around 0.5) in the country during the past years, specially in the eastern regions. It means that the growth in power demand has subsided since the mid 1990s due to the adjustment in the industrial structure (specially, high-tech contribution) and the introduction of power saving technologies.

4. Requirements For China's Future Nuclear Power

Regarding nuclear power plants, whether in operation or under construction, in China, it is quite clear that over-diversification of nuclear steam supply system technologies is not good for safety and economics. After passing criticism on it, the relative departments of the government and nuclear power sector are focussing on standardization and localization. It is evident that standardization and localization will become preconditions to the further development of nuclear power in China. Although PWRs are the dominant reactor for the time being this does not exclude other technology that is distinctively advanced in safety and economy in the future.

Besides, the following requirements must be met.

Much More Safety

A severe core damage probability should be 10-5 per reactor-year or lower, and post-accident

radioactive release probability should be decreased to less than 10-6 per reactor-year.

Improved Economy

The construction cost of nuclear power plants should be decreased to the extent that nuclear power is economically competitive with other advanced power technologies, like clean coal, natural gas combined cycle and LNG.

Higher Uranium Efficiency

Higher energy output and much small amount of radioactive wastes per unit of uranium are needed for nuclear power. Uranium efficiency as high as possible is quite important for China's nuclear power program due to our small per capita energy resource.

5. Expected Nuclear Program

Technological Target

China's nuclear power program started late. Even the TMI core melt accident in 1979 and Chernobyl disaster in 1986 did not affect China's determination and confidence in our nuclear program. After learning the worldwide lessons from the past and our own experiences from three operating units and eight units under construction, China's nuclear sector and the relative departments of the government emphasize proven technologies for proposed nuclear power projects in the tenth Five-year Plan. The emphasis must be placed on advanced technologies for the middle term development of the country's nuclear power program.

Expected Installed Capacity

When the eight units being built are completed, the country's nuclear power installed capacity will reach 8.7 GWe by 2005.

According to expert estimates, the expected installed nuclear capacity might be 20 GWe by 2010, around 40 GWe by 2020,. However, the actual scale of installed capacity will depend on carrying out the policy to develop nuclear power as substituted energy and on the uranium resource..

Besides the sites for the being built units in Qinshan. Lingao and Tianwan, in which there is a certain room to expend new units, several reserve sites have been selected for future nuclear power plants.

R&D of Passive Safety Technology

While the very first Qinshan nuclear power plant was being built, we also initiated R&D on the next generation advanced PWR technology to face challenge of new century. Taking into consideration China's reality, we have engaged in the devel-

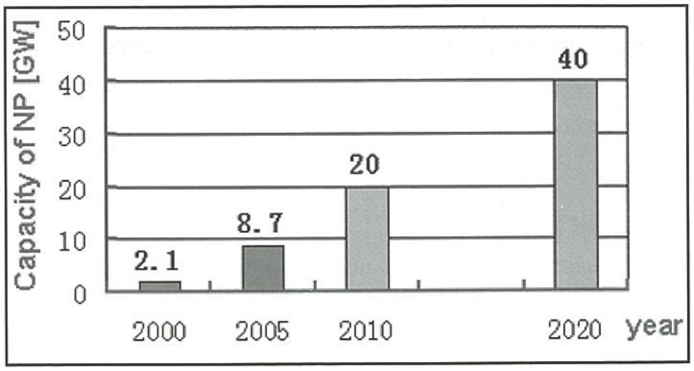


Figure 2: Actual and predicted nuclear power capacity in China.

opment of key AC-600 technology and upgrading its capacity to 1000 MW (AC-1000). With the efforts of two Five-year Plan periods, the step-wise outcome has been achieved. The AC developments concentrate on advanced reactor and advanced core, passive plus active safety system, simplified systems and reduced number of components, digital I&C, modular construction, etc.

High-Tech Program

The state high-tech (863) program proposed by four famous scientists involves two reactor projects: (1) a high temperature gas-cooled reactor (HTGR), and (2) a fast breeding reactor (FBR). A HTGR of 10 MW(th) has been built at Tsinghua University and is now being commissioned. The FBR, of 65 MW(th) and 25 MW(e) is to be built at the China Institute of Atomic Energy (CIAE). CIAE has recently received a construction licence for the FBR and first concrete will be poured very soon. The main purpose of the 863 high-tech program is to follow the track of advanced technologies worldwide. The HTGR and FBR will play significant roles. The future program will depend on the scale of thermal reactors and the policy for reprocessing spent fuel.

Transition from Fission To Fusion

Nuclear fusion promises to become the ultimate source of energy on the earth: safe, non-polluting, and with the oceans themselves supplying limitless fuel. Fusion research started in China in the 1950s. Two academic institutions engage in fusion research. The achievements of fusion R&D have been obtained on the devices such as HL1, HL2 and TH7. Certainly, there is a long long way to go to actually use fusion energy.

Generally speaking, many people follow with interest the transition from fission to fusion in the nuclear energy cycles. Besides FBR to be built as mentioned above, the accelerator drive system (ADS) has been recently launched in CIAE, which is a state fundamental research item.

Nuclear Fuel Cycle

For more than 30 years ago China has devoted efforts to establish a complete nuclear fuel cycle system. This paper will mention fuel production, storage and reprocessing of spent fuel, treatment and disposal of radwastes.

6. Fuel Production

China launched its nuclear power program in the middle of the 1980s, dominated by PWR.

A nuclear fuel element production line was built in Yibin Fuel Factory, which provides the first domestic unit in Qinshan with PWR fuel assemblies of 11 tons a year. Successively, the other production line was established in the same factory, which supplies 26 tons a year of PWR fuel assemblies to the Daya Bay units.

Two CANDU units are under construction now. After the first core load, the consequent fuel bundles for Qinshan CANDU units will be supplied by Baotou Fuel Factory. The CANDU fuel bundle production line project was launched last April.

It is quite clear that new fuel element production lines should be established for the other nuclear power plants under construction now.

7. Status And Prospects of Spent Fuel Storage And Reprocessing

Closed Fuel Cycle Strategy

When China started to develop nuclear power, a closed fuel cycle strategy was also formulated and declared at an IAEA conference in 1987. The spent fuel activities involve: at-reactor storage; away-from-reactor storage; and reprocessing. A state regulation on civil spent fuel treatment was drafted by CNNC a few yeas ago. The draft regulation is being reviewed prior to issue by the government. It is needed to work out a long term program for the back-end of the nuclear fuel cycle.

Spent Fuel Arisings

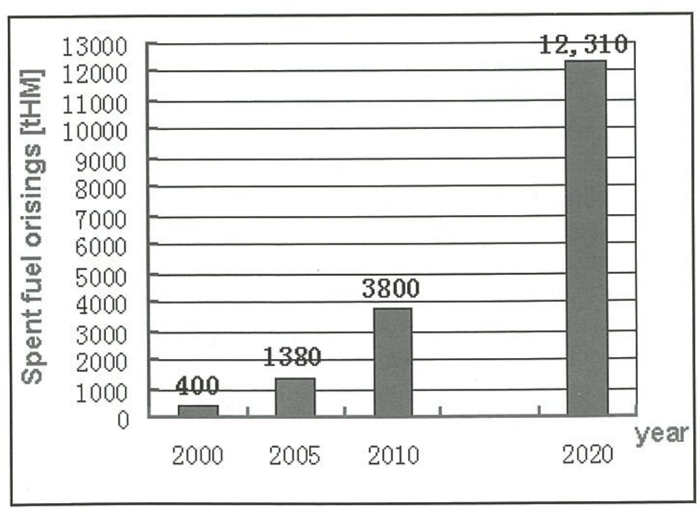


Figure 3: Actual and predicted quantities of spent fuel in China.

Currently, 60 tHM [heavy metal] of spent fuel is discharged annually from the three operating PWR units. The amount of discharged spent fuel will not increase until 2003. Up to now, the cumulative arisings are around 350 tHM.

The six PWR units and two CANDU units, which are under construction, will operate one after another in the tenth Five-year Plan. The annual PWR spent fuel arisings will quickly increase to 168 tHM per year. Meanwhile, the two CANDU reactors will discharge 176 tHM of spent fuel annually.

Based on expected installed capacity of 20 GWe by 2010 and 40 GWe by 2020, the annual spent fuel arisings will amount to 600 tHM in 2010 and 1000 tHM in 2020, the cumulative arisings to about 3,800 tHM and 12,300 tHM, respectively. For the long term nuclear power program we have to think about the tremendous figures of spent fuel arisings.

Anticipated Storage Capacity

Spent fuel discharged from reactors has to be stored in pools at the reactors for at least for 5 years to reduce its radioactivity significantly and to simplify transport and reprocessing process. Generally, the at-reactor storage period could be extended to 10 years. However, the reactor pool of Qinshan phase I (300 MW PWR unit) has a capacity of 15 year's fuel discharge. Obviously, nuclear power plant owners will have to consider the away-from-reactor storage of spent fuel.

To store spent fuel temporarily, a Centralized Wet Storage Facility (CWSF), located in LanZhou Nuclear Fuel Complex (LNFC), was launched in 1994. The first stage of that project will reach a capacity of 550 tHM in 2001 and could be extended with an additional capacity of 500 tHM. By that time, it could receive and accommodate all the spent fuel from the Daya Bay plant over its 20 years' joint venture period. The capacity of CWSF might be modularly expended further over the long term.

Reprocessing Of Spent Fuel

R&D on reprocessing of PWR spent fuel has being carried out in the laboratories of several institutes since the middle of 1970s. A multi-purpose reprocessing pilot plant (RPP) project is under way, with cold commissioning expected in 2002.

With the large amount of accumulated spent fuel, a large-scale commercial reprocessing plant, based on the experience from the pilot plant, very probably with a capacity of 800 tHM/a, could be set up around 2020 to match with the corresponding nuclear power capacity. Further, MOX fuel should be included in China's nuclear industry.

8. Management Of Radwastes And Tentative Plan For HLLW

The regionalized concentrative storage strategy of low and intermediate level waste (LLW/ILW) was made by CNNC many years ago. Phase one of the Northwest Repository Project for solid LLW/ILW was finished in 1998 and will receive conditioned wastes very soon. This repository, composed of a set of shallow land burial areas with capacity of 20,000 m^3, is located in LNFC site.. In the future, it can be easily expanded to 60,000 m^3, even 200,000 m^3.

A vitrification process for high level liquid waste (HLLW) has been defined, using a liquid-fed ceramic melter. An active plant is expected to be in operation within the first decade of the new century. Vitrified wastes in canisters would be placed in interim storage for at least 30 years prior to ultimate disposal in a deep geological formation. A specific R&D programme of ultimate disposal of HLLW has been carried out for more than 10 years. Commissioning of a HLW repository is planned around 2040 at a site to be screened by 2030.

Conclusion

In the 21st century, China's nuclear power will be growing in a commensurate manner with new generation technology. The actual scale of installed capacity for the mid and long term depends, to a great extent, on carrying out the policy of developing nuclear power as a substituted energy and on our uranium resource. Self-reliant development combined with introduction of advanced technology will be the way.

China has implemented the closed nuclear fuel cycle strategy. However, this needs to be formalized in law and regulations. Based on the large amount of spent fuel arisings, the facilities for storage, reprocessing and ultimate disposal should be gradually established to match the nuclear power program. It can be expected that the business in this field will be a mainstay in China's nuclear industry.

Gentilly-2 Full Power Operation: History and Future Challenges

by René Pageau and Guy Hotte[1]

Ed. Note: *The following paper was one of the most technical ones presented in the plenary sessions at the 2000 CNS Annual Conference held in Toronto, June 11-14, 2000.*

Abstract

The Gentilly-2 nuclear generating station performance has been affected, in the recent past, by the reduced safety margins resulting from heat transport aging mechanisms. Margins provided at the design of the CANDU-6 stations, to cater for the in-service aging degradation that was expected to occur, have eroded to a point where remedial actions needed to be taken in order to continue operation at full power. Steam generator fouling was originally considered by plant designers as the single most important aging mechanism affecting safety margins in CANDU PHW reactors. Changes were expected for other heat transport components such as that resulting from pipe roughness degradation and pressure tube diametral creep; however these were not deemed to be unduly detrimental to safety margins and were not explicitly considered in the safety margins determined at the design of the stations. Monitoring of Gentilly-2 plant operating data has indicated that these aging mechanisms significantly affect the heat transport system hydraulic characteristic. As a consequence, effective Regional OverPower (ROP) setpoints have been reduced in order to mitigate the impact of these aging mechanisms on safety margins. Also a number of actions have been taken to restore safety margins and maximize operating reactor power; these actions include replacement of the steam generator bolted divider plates by the welded design, reduction of secondary heat transport steam pressure, refinement in channel selection rules for refueling and steam generator primary side cleaning using Siemens-SIVABLAST. In spite of the success of these actions, safety margins are expected to be further eroded by the recently identified aging mechanism such that operation at full power may no longer be possible in the near future. This paper summarizes the evolution of Gentilly-2 data since first commissioning of Gentilly-2 and presents the relative contribution of the various aging mechanisms which impact on the safe operating envelope. Challenges to the future full power operation of the Gentilly-2 nuclear generating station are identified and avenues are identified for possible corrective actions which could be taken to restore full power operation or to minimize production losses.

Introduction

Steam generator fouling was originally considered by plant designers as the single most important aging mechanism affecting safety margins in CANDU PHW reactors. Accordingly, reactor shutdown system trip setpoints were determined with sufficient margins to ensure trip effectiveness to end-of-life conditions, defined in terms of a limiting reactor inlet header temperature or reactor outlet header quality which could be expected for plants with fully fouled steam generators. Changes were expected for other heat transport components such as pipe roughness degradation, pressure breakdown orifice erosion and pressure tube diametral creep; however these were not deemed to be unduly detrimental to safety margins and were not explicitly considered in the design safety analyses. As a consequence, allowances provided at the design of the CANDU-6 stations were deemed to be sufficient so that the shutdown systems could prevent onset of intermittent dryout (OID), in slow loss of regulation events, therefore meeting the design requirements for these systems [1] with a significant margin during the entire operating life of the stations.

Monitoring of Gentilly-2 plant operating data and of heat transport flows inferred from heat balances, pump head-flow characteristics and from theoretical calculations show that other aging mechanisms significantly affect the heat transport system (HTS) hydraulic characteristic [2]. Also recent experimental measurements [3] have indicated that, for given inlet coolant conditions and channel flow, the channel power at OID critical heat flux (CHF) was considerably lower for the crept pressure tube geometry than for the uncrept geometry, with power decreasing further as the amount of creep increased. As a result, HTS aging mechanisms combined with pressure tube diametral creep contributed to erode allowances provided at the design to a point where remedial actions needed to be taken in order to ensure that operation at full power remains within the safe operating enve-

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lope originally defined by the designer.

The first part of this paper summarizes the evolution of the HTS parameters since first commissioning of Gentilly-2 and discusses the relative contribution of the various aging mechanisms on margin reductions, that can be inferred from this data. A second part summarizes the impact of the aging mechanisms on safety margins and presents the result of actions taken at Gentilly-2 to ensure that operation remains within the safe operating envelope originally defined by the designer and to restore margins for full power operation. Current estimates of the possible impact of the combined effect of the identified HTS aging mechanism on maximum achievable operating power are given. Finally, possible actions that are being considered to maintain full power operation or to minimize production losses are summarized.

Evolution of Gentilly-2 Heat Transport System Hydraulic Characteristic

In CANDU reactors, the primary heat transport system is controlled at constant reactor outlet header pressure and the secondary heat transport is controlled at constant steam pressure. Evolution of the primary heat transport system characteristics is therefore indicated by variations in the reactor inlet coolant subcooling and the reactor core pass and channel flows. Primary and secondary heat transport systems are instrumented with a number temperature, pressure, differential pressure and flow measurements used by the Digital Computer Control and by the Reactor Shutdown systems computers. Core pass flows are not directly measured in CANDU-6 reactors, but flow variations can be inferred from reactor inlet and channel outlet temperature measurements, from reactor inlet to outlet differential pressure measurements and from pump head measurements, although these inferences add some uncertainty to the value. Instrumentation used to monitor this data is illustrated on the heat transport schematic diagram shown in Figure 1.

The station computers were not originally designed to collect and log all of the available instrument signals. In 1994, Gentilly-2 installed a system which continuously collects and logs all the process and shutdown system instrument signals. Since then, complete sets of data are available to identify trends in the different HTS parameters; in particular, we have compiled comprehensive sets of single phase HTS operating data taken during deratings (to single phase flow conditions - at around 80% of full power) for flow verification, made to confirm no channel blockage. These are done on a monthly basis since initial commissioning.

Prior to 1994, a limited number of instrument measurements could be retrieved from the plant control computers on demand for various specific needs. Among these, a large number of data were collected and logged during the initial commissioning tests; all of these measurements are for single phase coolant conditions. Since first commissioning in 1983, reactor inlet header temperatures, reactor outlet header pressures and reactor header to header differential pressure drops have been recorded a few times a week for the shutdown systems Regional OverPower Trip (ROPT) calibration; most of these data can not be easily used to track the evolution of the heat transport system characteristic, because, after 1988, the coolant boiling conditions were different. However, all of the 380 channel outlet temperatures and reactor inlet header temperatures have been logged on a monthly basis, along with neutron detector measurements, at reduced reactor power for channel single phase monthly flow verifications. This constitutes a comprehensive set of data since the station initial commissioning, allowing to trend the heat transport system flow evolution, as determined from heat balances computed for each of the primary heat transport loop (each reactor core and steam generator passes). Pump suction to reactor inlet header differential pressure measurements are also available for some of the monthly power reductions prior to 1994 and for all monthly power reductions after that date. This data constitutes a second consistent set of data since the station first commissioning, permitting to trend the heat transport system flow evolution, as determined from the pump head-flow characteristics. This data set provides an independent verification of the flows inferred from heat balance calculations. The methodology and accuracy of the heat balance and pump head-flow characteristics HTS flow calculations are documented in [2]. The accuracy is inside 2,6% .

Reactor Inlet Header Temperature

Figure 2 illustrates the evolution of reactor inlet header temperature taken at full power, except for some of more recent measurements where power had to be reduced to

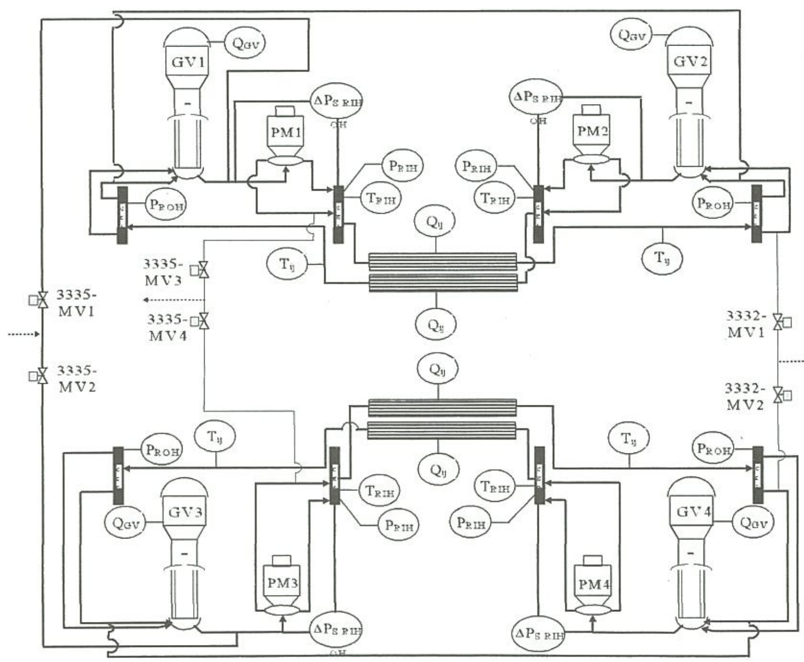

Figure 1: Heat Transport Instrumentation used to Monitor Coolant Flow and Subcooling

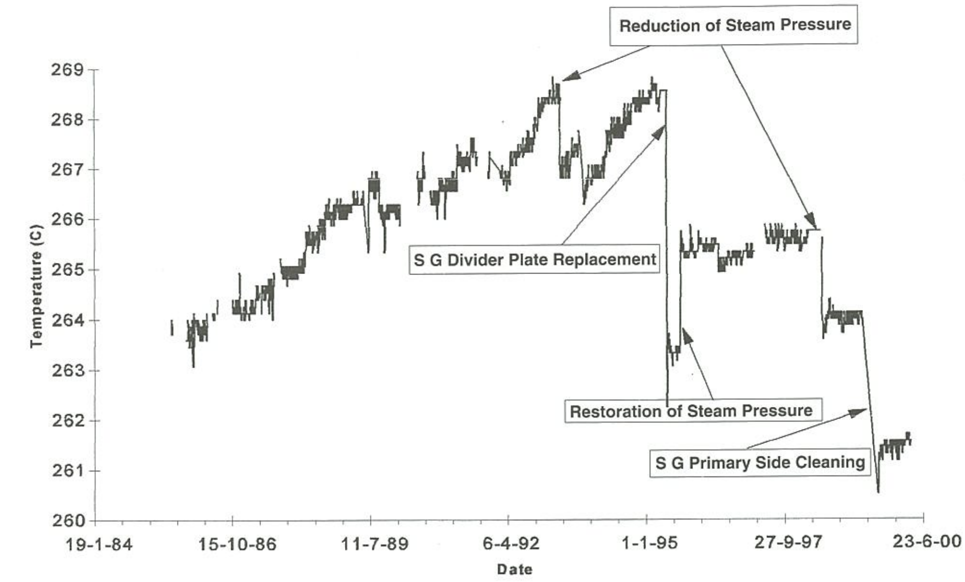

Figure 2: Maximum Reactor Inlet Header Temperature

between 95 % and 98 % full power due to reduced safety margins. This figure shows that steam generator performance degradation is indeed an important aging mechanism in CANDU reactors.

Gentilly-2 has experienced a continuous increase, from 262°C to 268°C, of the reactor inlet header temperature at full power. This is a direct result of steam generator performance degradation. In 1993, after 2750 Effective Full Power Days (EFPD), the maximum inlet header temperature had reached a level where action had to be taken to ensure that continued increases would not result in reactor operation outside the safe operating envelope analyzed limit of 270°C. At that time, action was taken to reduce the secondary side heat transport system steam pressure in order to obtain reduced primary side inlet header temperatures.

Inspection of the steam generator during annual outages indicated that the divider plates ensuring the separation between the steam generator primary side inlet and outlet plenums were leaking. This leaking, caused by erosion, was slowly increasing with time and steam generator pressure had to be reduced further in 1995, before the divider plates could be changed from a bolted to a welded design. This design change was very successful and the reactor inlet temperature dropped to around 263°C for the reduced steam pressure and to around 265°C when the steam pressure was restored to it's nominal design value. This replacement indicated that divider plate leakage was an important factor contributing to steam generator performance degradation; this flow by-pass was not considered in the original design [4].

Since the divider plate replacement, reactor inlet header temperatures have remained nearly constant, with a slow increase of around 0.5"C/1000 EFPD attributed to steam generator fouling. Steam pressure has recently been decreased again when it was realized that inlet header temperatures had to be limited to approximately 265°C at or near full power to ensure SDS2 high pressure trip effectiveness for loss of single even numbered pump events. SDS-2 original design did not consider single PHT trip as a limiting design condition.

Primary Heat Transport System Flow

Figure 3 illustrates the evolution of the single phase primary heat transport system coolant flow. This figure shows that there is more to heat transport system aging than steam generator performance degradation

Figure 3 shows the evolution of the total primary coolant flow obtained from pump head characteristic and from reactor and steam generator heat balances; the ±2.6% uncertainty in steam generator heat balance flow [2] and the

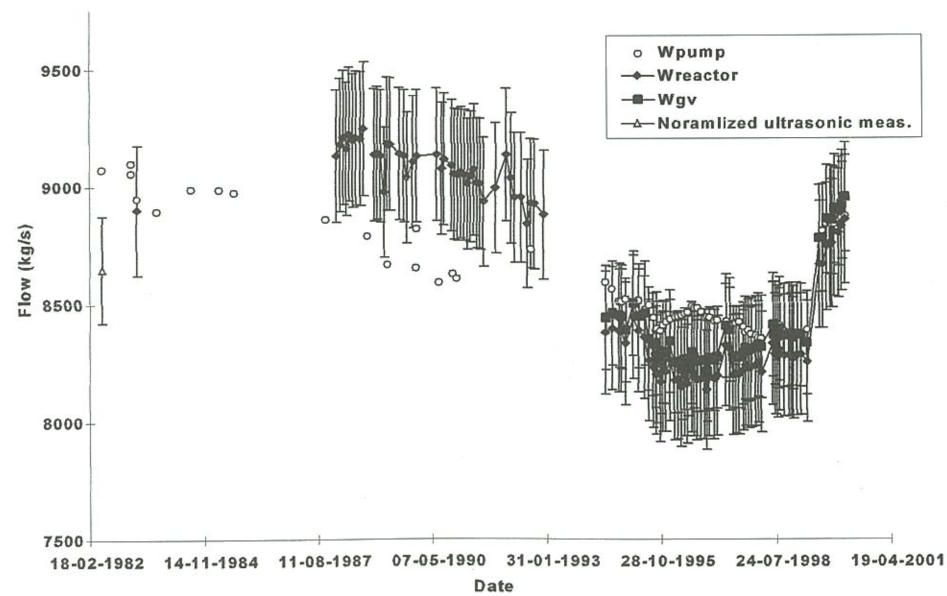

Figure 3: Evolution of Total Single Phase Core Flow Based on Pump Head and Heat Balance Calculations

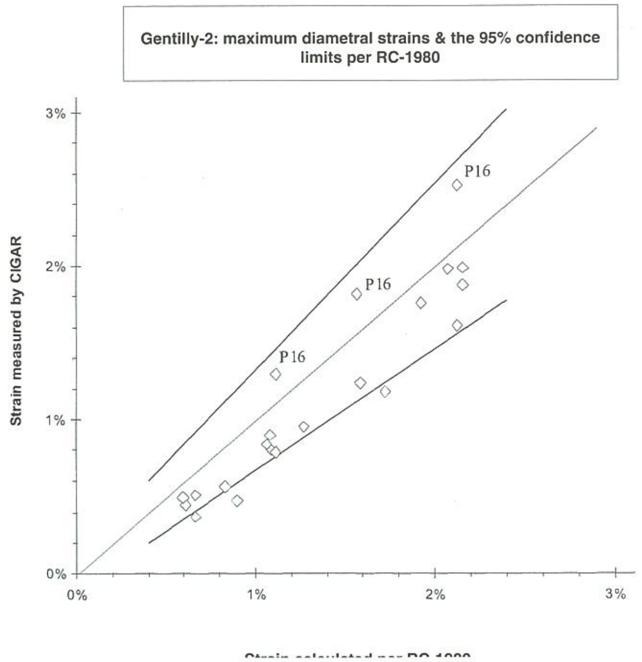

Figure 4: Maximum Measured Diametral Strains for the Gentilly-2 Pressure Tubes as a Function of the Maximum Diametral Strains Calculated per Equation RC-1980. (Compared to the 95% confidence limits based on all the data through 1997 from CANDU 6 reactors)

±3.1% uncertainty in reactor heat balance flow [2] are shown by error bars. Error bars are not included for the pump head flows as their uncertainty has not yet been formally established. Also shown in figure 3 is the sum of the ultrasonic measurement of channel flows taken during the 1982 commissioning at 40°C, 0% FP and extrapolated to 262°C; the uncertainty of the ultrasonic measurements, estimated at ±2.6% at 40°C, is also illustrated for that point in figure 3. As shown, all measurements agree within the measurements uncertainties, with the sum of ultrasonic measurements underestimating by around 3% the flows established at first commissioning based on reactor heat balance and pump head characteristic.

Figure 3 shows that Gentilly-2 has experienced a significant decrease in primary heat transport flows, since first commissioning. Although the data is sparse prior to 1987-88, the flow decrease seems to have started from the 1987-88 period. The data shows that the flow reduction has subsided since 1995. Although there may be no correlation, the period of flow reduction coincides with a period of operation with average reactor outlet qualities greater than around 2%.

The reactor designer, AECL, has linked the flow reduction to magnetite transport in heat transport system which increases the heat transport system piping roughness [5]. Replacement of the steam generator bolted divider plates by the welded design in 1995 resulted in an additional 2% to 3% decrease in flow due to increase resistance in the Steam Generator tubes (no more flow by-pass), after which the core pass flows remained approximately constant indicating that the effect of magnetite transport may have subsided. Steam generator primary side cleaning using Siemens-SIVABLAST restored around 5% of the core pass flow.

The increase in pipe roughness associated to magnetite transport is in fact much greater than that suggested by the flow reductions. Indeed, pressure tube diametral creep increases the flow area in the channel as the heat transport system ages. Figure 4 illustrates the range of maximum pressure tube diametral deformation obtained from CIGAR measurements taken at G2 and compares them to those predicted by the RC-1980 prediction model, which is based on all available CANDU 6 CIGAR measurements [6]. Figure 5 show the diametral strains obtained for the maximum creep rate predicted by the RC-1980 model. Diametral strains of Gentilly-2 pressure tubes were in the range of around 2% to 3%, in 1998, for high power channels. Experimental measurements taken at Stern Laboratories [3], on a full scale simulated bundle string for creep profiles typical of that seen in Gentilly-2, show that channel flows should be 10% to 15% higher, at constant fuel string pressure drop, in a channel with 2% to 3% maximum diametral creep than that in a channel with no creep. Although, the reactor is not operated at constant fuel string pressure drop, such a large decrease in channel hydraulic resistance should result in higher core pass flows with aging, assuming creep is the only mechanism affecting the heat transport hydraulic characteristic.

Impact and Mitigation of Heat Transport Aging Mechanisms Gentilly-2

Channel flow reduction and temperature increases reduce the minimum margin to OID CHF. Full scale experiments [3] show that, at constant fuel string pressure drop, diametral expansion of the pressure tube due to creep does not affect the margin to dryout, because the flow increases as a result

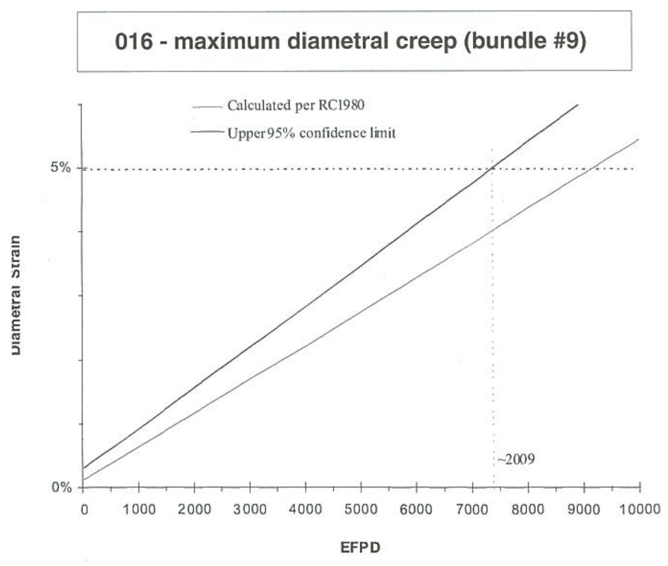

Figure 5: Maximum Strain (i.e. the channel with the highest predicted strain rate – Channel 016) Calculated per Equation RC-1980. (The upper 95% confidence limit is established on the basis of the data through 1997 from all the CANDU 6 reactors).

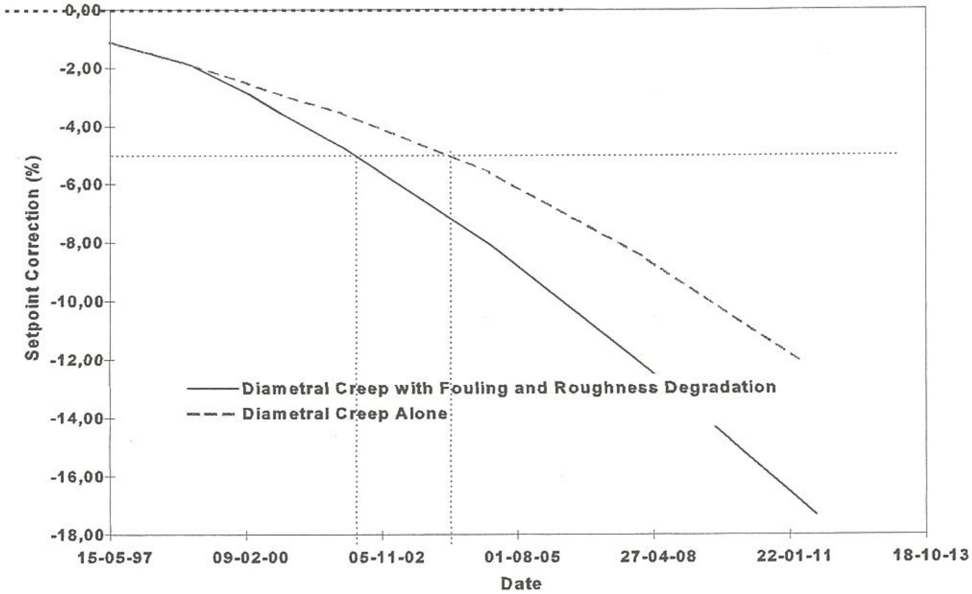

*Figure 6: ROPT Setpoint Correction for PT Diametral Creep and HTS Aging. **

of the pressure tube creep. However if we consider more realistic reactor condition, for given coolant inlet conditions and channel flow, full scale experiments show that the OID CHF is significantly lower for the crept geometry than for the uncrept geometry.

Based on recent AECL analyses and recommendations [5,7], Gentilly-2 has seen a reduction in effective ROP setpoints from 121% in early 1985 to 112% at the end of 1998, as a consequence of heat transport system aging. The replacement of the steam generator bolted divider plates by the welded design in 1995 and the reduction of secondary heat transport steam pressure in 1998 have restored the reactor inlet header temperatures to the level seen in 1985 and therefore the 8% setpoint reduction (9%/121%) is entirely due to the reduction in margin to dryout resulting from the combined effects of flow reductions associated with pipe roughness degradation due to magnetite transport and of pressure tube diametral creep. With the minimum operating margin to ROP trip setpoints at around 6% for an average CPPF of 1,07, even with careful channel selection and improved operating procedures, the setpoint reduction had reached a level where operation at full power was compromised and frequent reactor deratings were required.

In 1999, cleaning of the primary side of the steam generator was attempted using Siemens-SIVABLAST. The cleaning was quite successful as this decreased reactor inlet temperatures by around 3°C and increased reactor flows by around 5%. As a result, 3% operating margin was immediately recovered from the ROPT calibration because of the decrease of the RIH temperatures. However, increase in margin to dryout associated with flow increases is not yet included in the ROPT calibration procedure. This gain in operating margin has to be approved by AECB (CNSC).

Future Challenges to Full Power Operation

The increased flow obtained from the cleaning of the primary side of the steam generators provides around 5% increase in margin to OID CHF. However, in order to determine the net impact on station performance, this margin needs to be discounted for the margin erosion due to the combined effects of continuing pressure tube diametral creep and pipe roughness degradation and due to the increased uncertainties associated with prediction of pressure tube diametral creep rates.

Pressure Tube Deformation by Diametral Creep

Figure 6{3} illustrates our estimate of the impact of pressure tube diametral creep on the ROP trip setpoint, based on the most recent NUCIRC calculations, performed by AECL for 37-element fuel strings. Specifically, Figure 6 shows the decrease in ROPT margins determined for the current ROP setpoint limiting case set, for the maximum pressure tube deformation and channel axial deformation profile, as predicted based on the average of all available CIGAR diameter measurements taken in CANDU-6 reactors. Setpoint corrections are given for the effect of pressure tube creep alone and for the combined effects of pressure tube creep and HTS aging. As shown by the 95% confidence limits, illustrated in Figures 4 and 5, established on the basis of the CIGAR data through 1997 from all the CANDU-6 reactors, there is a significant variation in the channel creep rates. The ROPT margin reductions include the effect of a ±16% uncertainty in channel creep rate to account for this variance in creep rates. The decreases are given relative to the 1997 ROP setpoint update for G2. The 1997 ROP setpoints included the effect of pressure tube diametral deformation, based on CIGAR measurements taken at G2, as determined by an interim model developed at AECL taking into consideration the limited number of experimental measurements available at that time [3,5]. The decrease from the 1997 ROP setpoint includes an initial correction, which result form the new models predicting a slightly greater impact of diametral creep than the interim model, followed by a gradual decrease in setpoint. The curve showing the effect of pressure tube diametral creep alone is determined assuming no further fouling of the steam generator and core flow increases as a result of diametral creep, such that reactor inlet header temperatures and reactor header-to-

* The dates shown in Figure 6 are based on an 82% availability factor at expected reduced operating power limits

header pressure drop remain constant. As shown, in those ideal conditions, the 5% margin for flow increases obtained from the steam generator cleaning would be entirely eroded by pressure tube diametral creep alone around 2004 and this assuming acceptance by the regulator of our submission for increased setpoints for steam generator cleaning.

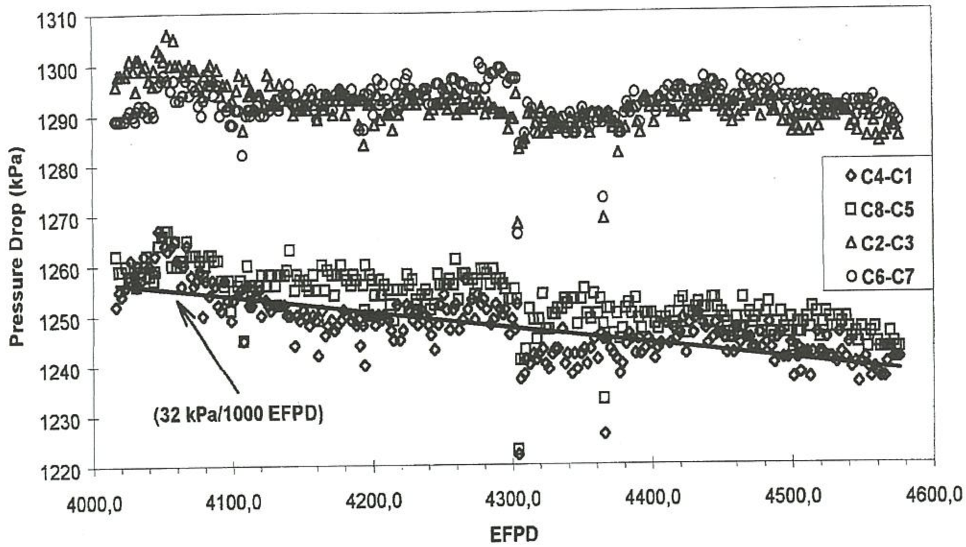

Figure 7: Typical Recent Evolution of Header-to-Header Pressure Drop.

Fouling and Roughness Degradation

Fouling of the steam generators and pipe roughness degradation is expected to continue from magnetite formation and deposition. The combined effect of steam generator fouling and roughness degradation will be to increase inlet header temperature and to limit flow increases expected from pressure tube diametral creep, resulting in a decrease in reactor header-to-header differential pressure. Both of these effects have indeed been observed in recent G2 operating data, as shown in Figures 7 and 8. The combined effects expected from fouling and roughness degradation is illustrated in the second curve given in Figure 6. This additional setpoint reduction corresponds to expected increases in reactor inlet header temperature at a rate of 0.5°C/1000 EFPD and decreases in header-to-header pressure drop of 30 kPa/1000 EFPD (based on past experience). A shown, the 5% margin for flow increase obtained from the steam generator cleaning, if accepted by the regulator, would be entirely eroded by the combined effects of fouling, roughness degradation and pressure tube diametral creep no later than 2002.

Further Mitigation of HTS Aging Mechanism

The setpoint reductions shown in Figure 6 illustrate the future challenges to full power operation of the Gentilly-2 nuclear generating station. Meeting these challenges is important both for operation until current end-of-life of the station and for possible plant life extension; indeed, after a plant refurbishment, HTS aging effects will eventually result in power limitations which will affect the return on investments. Solutions will need to provide significant increases in margin to OID critical heat fluxes to ensure full power operation in the current regulatory context, as shown in Figure 6. Remaining available corrective actions, even when combined, may not provide enough additional margin to permit full power operation until the expected end-of-life of Gentilly-2. In addition, most remaining options are complex and expensive to implement and the actual gains expected from their implementation are, in some cases, uncertain. Possible corrective actions include the following in order of increasing level of complexity:

- optimization of the channel power distribution to maximize ROP setpoints,
- comprehensive CIGAR measurements to reduce the uncertainty in diametral creep rates variations,
- four-bundle shift refueling,
- use of CANFLEX bundles expected to provide higher CHF,
- alignment of the fuel bundle string using bundles with modified endplates,
- chemical cleaning of the primary heat transport system.

ROP Trip Confidence and Effectiveness

Current power limitations due to aging mechanisms are the result of reduced margin to ROP trip setpoints. ROP setpoints are determined in order to prevent OID CHF in the event of a postulated slow loss of regulation accident. Both in-reactor and out-of-reactor tests [3,8] have shown that there is a significant margin between OID CHF and the actual regulatory design requirement for CANDU reactor shutdown systems, which is to prevent "failure of the primary heat transport system due to over pressure, excessive fuel temperatures or fuel break-up" [1]. Accordingly shutdown system trips are shown to be effective after limited periods of post-dryout operation (PDO), as long as sheath temperatures remain under temperature limits at which fuel sheath integrity has been demonstrated in the experiments. This has been recognized by the AECB in the C-144 regulatory guide [9]. ROPT setpoints are particular since they are designed to ensure shutdown system trip for slow loss of regulation accident scenarios, in which time duration in PDO can be long and for which a large number of neutron flux shapes need to be covered. ROPT setpoints are therefore determined in a best-estimate probabilistic assessment ensuring that reactor trip will prevent OID dryout with a 98% confidence level for slow loss of reactor regulation events. The ROP system was designed to

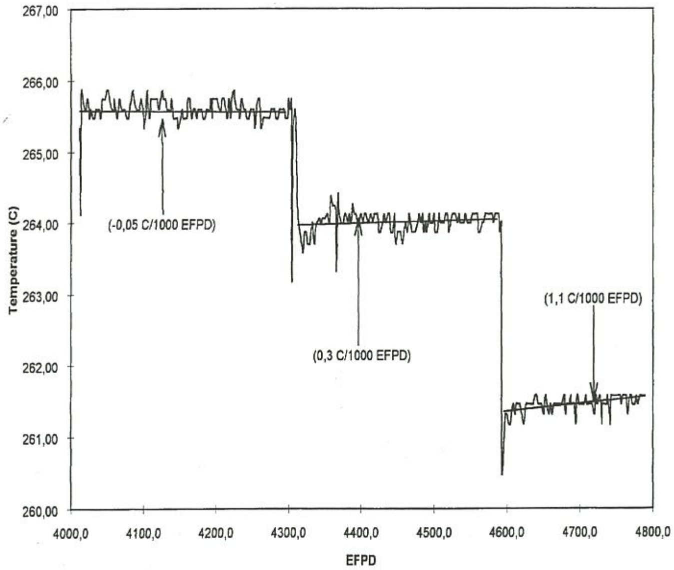

Figure 8: Typical Recent Evolution of Reactor Inlet Header Temperature

be highly reliable, with a significant safety margin at reactor trip.

With the current levels of operating margins to ROP trip setpoints, any reduction in margins to OID CHF will result in a corresponding limitation in reactor power, even though this power limit may not be justified on the basis of the shutdown system requirements set by the regulator. Indeed, there would still be a significant margin to OID CHF, at the original design ROP trip setpoints, for a significant number of the possible flux shapes that could result of a loss of regulation. In most postulated LOR scenarios, dryout would be of limited duration, for the most limiting flux shapes, with a significant margin to fuel overheating that could result in failure of the primary heat transport system. Experiments on full scale bundle test assemblies, such as the tests recently completed at Stern Laboratories [3], show that, for LOR flow conditions, the channel power has to be increased by more than 15% above that which results in OID dryout to get the sheath temperatures to around 600°C. The tests further show that, at these sheath temperatures and fuel element powers, the heat transfer from fuel to coolant is high enough to ensure a significant margin to fuel center line melting. Time in dryout could only be unacceptable for very improbable slow loss of regulation accidents; in these events there would be a number of indications of the LOR occurrence in the control room so that operator action could be credited to limit the period in post dryout to an acceptable duration.

It is not unreasonable to suggest that changes to the ROPT design could permit operation of the reactors at full power, even when the aging mechanisms not included in the original design are considered. This will surely be complicated and controversial, as this may require hardware changes for new instrumentation, such as an increased number of neutron flux detectors, and trip control logic, such as automatic setpoint reductions. Although, these changes may not be easily introduced in operating reactors, the challenge of producing an ROPT system, which could provide operating margin such that full power operation would be achieved during the entire expected life of the stations, should not be disregarded, if we intend to operate and extend the life of CANDU-6 reactors.

Conclusions

Monitoring of Gentilly-2 heat transport system data has indicated that the following aging mechanism have occurred in the station since first commissioning:

- reactor inlet header temperatures increased due to steam generator performance degradation caused by fouling in the steam generator and steam generator divider plate bypass flow;
- diametral expansion of pressure tubes resulted in an increase in maximum pressure tube diameter; in 1998, the range of this expansion was around 2% to 3% for high power channels;
- magnetite deposition has led to an increase in the hydraulic resistance of the heat transport piping, which has led to a decrease in core pass flows.

A number of actions have been taken to mitigate the impact of these aging mechanisms on safety margins and to maximize allowable operating reactor power. These include:

- reduction of effective ROP setpoints from 121% to 112%,
- replacement of the four steam generator bolted divider plate by the welded design,
- reduction of the secondary heat transport steam pressure,
- careful channel selection in order to minimize channel power peaking factor,
- cleaning of the primary side of the steam generators using SIVABLAST.

The observed evolution of the Gentilly-2 heat transport system hydraulic characteristic has indicated the importance of systematic monitoring of heat transport system data in order to ensure that safety margins remain acceptable. To this end, we are integrating a number of activities at G2 to monitor the heat transport aging and to take appropriate actions to ensure that the plant is maintained in the safe operating envelope.

In spite of the success of these actions, ROPT margins are expected to be further eroded by aging mechanism such that, in the near future, operation at full power may no longer be possible. Corrective actions need to provide significant increases in margin to OID critical heat fluxes to ensure full power operation up to the end of station life, if there is no change to the current regulatory context. Most remaining options are complex to implement and the actual gains expected from their implementation are still to be confirmed. These include the following :

- optimization of the channel power distribution to maximize ROP setpoints,
- CIGAR measurement to reduce the impact of variations in diametral creep rates,

- four-bundle shift refueling
- use of CANFLEX bundles expected to provide higher CHF,
- alignment of the fuel bundle string using bundles with modified endplates,
- chemical cleaning of the primary heat transport system.

Hydro-Québec will implement some of those measures in the near future, more specifically the optimization of the channel power distribution and CIGAR measurements. The other alternatives are still under evaluation. Of course, change in the Regulatory requirements are not expected unless there is a joint effort to resolve this issue by all the concerned parties.

ROPT setpoints are designed to ensure shutdown system trip for slow loss of regulation accident scenarios in which time duration in PDO may be long and for which a large number of neutron flux shapes need to be covered. ROPT setpoints were therefore determined in a probabilistic assessment ensuring that reactor trip will prevent OID CHF with a 98% confidence for slow loss of reactor regulation events. It has been recognized that shutdown system trips remain effective after limited periods of post-dryout operation (PDO) as long as sheath temperatures remain under temperature limits at which fuel sheath integrity has been demonstrated in the experiments [9]. It is important to note that prevention of OID dryout for all shutdown system process trip setpoints would require limiting channel and bundle powers to a level where full power operation would also not be possible, even with the additional margins that could result from a change to CANFLEX fuel. Possible changes to the ROPT system design, which could provide greater operating margin, should not be overlooked as a possible solution to ensure full power operation during the entire life of the stations.

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Improving Performance at Point Lepreau

by R. M. White, W. S. Pilkington, R. Crawford, K. Miller, B.M. Ewing, J. J. McCarthy, and P. D. Thompson

Ed. Note: The following paper was presented in the opening plenary session of the 21st CNS Annual Conference, held in Toronto, June 11-14, 2000.

ABSTRACT

Point Lepreau had an excellent operating record between the time it began operation in late 1982 up to the 1995 SLAR outage. However a series of events over the following two-year period led to a number of forced outages of significant duration, and called into question a number of underlying processes and the overall effectiveness of the organization. This resulted in the need for an intensive review of all aspects of station operation and an ensuing program to improve processes and performance.

This paper provides an update on the various activities that have taken place at Point Lepreau over the past few years in order to return the station to excellence. This covers not only the changes to the technical and managerial processes, but also on the processes that were used to deal with transition and change with station staff.

With the completion of the Performance Improvement Program (PIP) this year, the station has introduced a business planning process, which will ensure that resources are applied to the appropriate areas in the future. Although it is difficult to turn performance around over night, there are encouraging signs that performance is improving and the future for the station is optimistic.

2. INTRODUCTION

As part of the corporate mission of debt reduction which began in the early 1990's, station resources failed to match the increasing demand. In essence there was a corporate failure to understand the mission required for lifetime management of a nuclear station. The result was that the additional effort required to deal with emerging technical and ageing issues exceeded the capability of available resources to do quality work within allocated times.

In addition, the early success of Point Lepreau did not challenge the programs and policies. Furthermore, many of the basic oversight programs such as Self-Assessment, Peer Reviews, and use of relevant leading Performance Indicators were lacking. Consequently there was a false sense of security. This only became evident when plant mid-life challenges emerged.

In 1996, Point Lepreau had its first ever peer review by WANO (World Association of Nuclear Operators). Based on the results of this review and the issues raised by station management and the Atomic Energy Control Board, it was clear that there were a number of underlying problems at the station and that corrective action was required on an urgent basis.

As outlined in our paper presented at the 1998 CNS Conference (Reference 1), a number of immediate actions were undertaken. One of first was the establishment of the position of Vice President - Nuclear so that there was a direct line of reporting from the station to the President. Secondly, there was a significant increase in the resources allocated to the station. Thirdly, there were corrective action plans put in place to address the known deficiencies. Finally, a Performance Improvement Program was introduced to identify more fundamental improvements that were required and to prioritize these and put the necessary plans into action.

3. Performance Improvement Program

In developing our overall performance improvement program we initially identified in excess of 40 projects. These projects were identified based on the following:

- our own internal review
- areas for improvement from a full peer assessment by WANO
- Regulatory staff observations

The plan involved the establishment of a small performance improvement group to budget, plan, schedule, monitor, initiate corrective action as appropriate,

1 All of the authors are associated with the Pt. Lepreau NGS of New Brunswick Power.

and report progress. The actual work required to implement the various projects was the responsibility of the line organization. Each project had an assigned member of the line organization responsible to progress the project such that schedule milestones were achieved.

A steering committee comprising senior corporate staff members, the performance improvement group leader, and the station line managers (including the station manager) meet initially on a two week frequency to address any problems, establish new or reinforce existing priorities, ensure line organization's continued commitment to priority projects and to ensure continued corporate focus.

We initially attempted to address all projects, only being limited by the availability of qualified staff. We took this rigorous approach realizing that it was a commitment to the regulator.

The effort required to progress many fronts at once quickly became a concern. Equally, we were concerned that our program was not independently verified.

In June of 1997 we had WANO do an independent assessment to verify the adequacy and scope of our proposed improvement program. The assessment involved a review of recent unplanned events and a series of one-on-one and group interviews with staff from all station work groups. They concluded that our proposed improvement program would address our performance problems. However, they cautioned us that success would be unlikely unless we narrowed our focus to several key initiatives.

Concurrently, a second group of external advisors (a group of three senior executives commissioned by our president to provide independent advice on our approach and the likely expectations of a regulator) also recommended that success would be greatly enhanced if we limited our focus to less than five issues.

The feedback from both of the above groups prompted us to act immediately. From an earlier assessment of unplanned events, we determined that human performance was the most common unplanned event causal factor. Greater than 50% of the events examined had some element of human failure. This is consistent with findings documented in other published reports. This finding prompted our decision to focus our program on three human performance initiatives:

- Conduct of work
- Safety culture awareness
- Supervisory effectiveness & Performance Management

Other projects were continued in the background, but not at the expense of progressing projects supporting the focal issues.

Focusing on these issues involved developing documentation, promotional campaigns, and extensive staff training followed by evaluation to assure that the desired effect was achieved. In addition extensive effort was placed on updating staff on the need for change and for improved performance and on describing the various improvement initiatives.

By the summer of 1998, the project phase for the majority of the focal projects were complete. The strategy for the next year and a half was to maintain the emphasis on human performance, while at the same time broaden the focus to include the next most important areas requiring improvement. Following the development of selection criteria, 17 projects were identified. These were then categorized into four focal areas of which 10 projects were designated Category A (the highest priority), while the remaining 7 were assigned to group B. Regular progress reports were provided to AECB staff on quarterly basis, and to the AECB Board on a semi annual basis. A list of these projects is provided in Appendix I.

The performance improvement program was the most important and comprehensive program ever undertaken at Point Lepreau. Aspects that made the program a challenge included:

- a shift from the historic focus on technical issues to those associated with human performance, work processes and staff practices
- it was initiated in parallel with our attempt to hire additional staff to address a large backlog of work
- it was necessary to show positive results in a timely manner

An important element of the PIP program was the need for station buy-in, communication and feedback. Part of this was accomplished via a newsletter to station staff issued on a biweekly basis. The reestablishment of the Plant Advisory Committee, which had representation from both management and the shop floor, also provided an important two way communication function.

4. Establishment of a Transition team

In early 1999, Point Lepreau had its second WANO peer review. The results indicated improvement in some areas, however the overall rate of progress was deemed too slow. In the spring of 1999 a transition team was established to help the management team in its commitment to continuous improvement, and to effectively manage significant and necessary changes. This was a dedicated team focussed on improving:

- Human performance
- Organizational effectiveness
- Station processes

The role of the transition team in supporting the station management team is to:

- Bring consistent methods in improving processes and managing change
- Prevent parallel improvement initiatives from interfering with each other

- Ensure that the changes implemented do not compromise the safe operation of the station
- Work on significant changes that require a systematic approach to identifying and implementing improvements.

Approach used in a given project is as follows:

- Management team approves the project
- One or more members of the management team is the sponsor, responsible for championing the development, implementation and monitoring progress
- A Project team is established consisting of one or more transition team members as facilitators, support from consultant groups, and station staff representing impacted groups
- The current state is established
- The group determines how work can be done more effectively
- The process improvement is designed (along with the development of change management strategies)
- The change is piloted
- The change is implemented by the line organization
- The effectiveness of the change is measured
- Follow-up is provided if required

Two examples of process improvement projects completed to date involving the transition team are the revisions to the work plan and work permit processes. The work plan process was significantly streamlined while ensuring that the necessary safety and quality elements remained in place. In the case of work permits, a number of activities that previously required permits were eliminated and the requirement to surrender the permit at the end of a shift was eliminated.

Examples of improvement in organizational effectiveness were the creation of dedicated groups to address: outage planning, operational documentation, and station refurbishment. The position of facilities manager was also created to administer the areas of security, service maintenance and administration support. This allowed the other managers to concentrate on their core activities.

Another program that was supported by the transition team was Vision and Interpersonal skills (VIPS) training.

5. Vision and Interpersonal skills training

One of the critical aspects of station recovery is the importance of getting station staff to understand and accept the need for change, while at the same time ensure that they retain their dignity and self-respect. One of the ways in which this was done was to put all station staff through a 3-day training seminar. The objectives of the seminar were to:

- Create the proper environment for individual participation and learning
- Clearly and effectively establish the need for change
- Develop interpersonal skills through experiences and insights, as a foundation for leadership and teamwork
- Develop individual understanding of, alignment with, and commitment of the Point Lepreau vision
- Prepare staff for future actions with their own work groups and functional leaders
- Create greater alignment and momentum towards transformation at Point Lepreau
- Develop process of individual feedback in a positive and constructive manner.

An additional workshop on world class performance awareness is planned for all plant staff at the conclusion of VIPS training. This will communicate the link between having a successfully decision on station refurbishment with the need for demonstrated good performance against the WANO performance objectives and the areas for station improvement identified by WANO.

6. Vision

To ensure proper alignment of station staff an overall Vision statement was prepared. This was followed by the creation of Purpose and Mission statements and establishment of Core Values.

- Our Vision is: *Quality today for an assured future*
- Our Purpose is: *to enrich the lives of those we serve through the energy of our people and our technology*
- Our Mission is: *to within the next decade, together we will refurbish and operate Point Lepreau in a world-class way.*

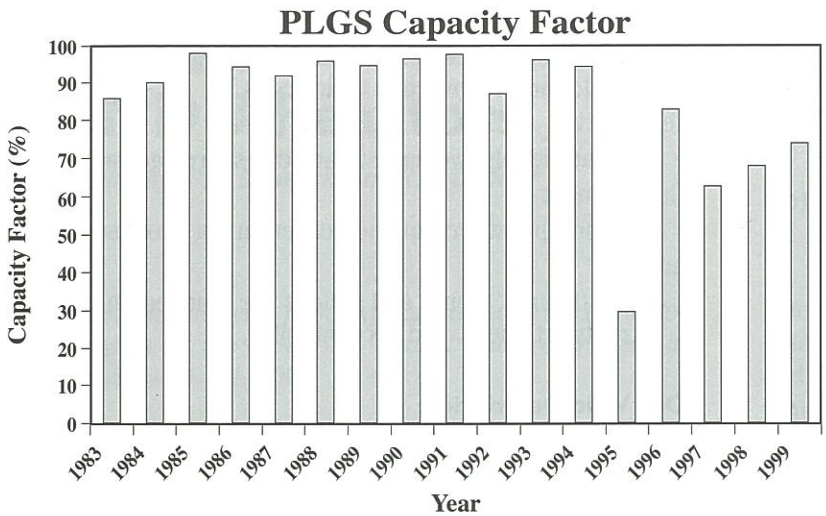
Our core values and vivid description are provided in Appendix II.

7. Management Commitments

One of the projects of the transition team was to clarify the roles, responsibilities and accountabilities within the station. Activities at the station were mapped into the Nuclear Energy Institute process model. As a logical extension to this, the management group accepted responsibility for achieving specific results in a specified time frame. For each commitment, a "charter was produced which specified the problem statement, scope, objectives (expected outcomes), benefits, as well as costs/risks and potential barriers. Approval of station charters that align with station goals is the method for introducing projects into the station business planning process.

8. Business planning

Beginning in the spring of 2000, Point Lepreau introduced a business planning process. This will allow us to better relate our business priorities to station resources, taking into account business risk assessment and allowing us to apply



resources where they are most valuable.

The business plan identified four goal areas:

- **Safety / quality**
  - Achieve and maintain a strong safety culture
  - Maintain a high standard of personal, operational and public safety
  - Control the impact on the natural environment
  - Maintain capability to respond to station contingencies
- **Generation**
  - Complete outages as planned
  - Operate and maintain the station to ensure a consistent and predictable capacity factor
  - Retain the station operating Licence
  - Operate and maintain the plant equipment to achieve a successful refurbishment decision
- **Organizational effectiveness**
  - Promote a culture which encourages behavior consistent with our core values
  - Evolve our organizational structure to support efficient and effective operation
  - Attract, develop and retain people with the competencies we need now and in the future
  - Establish clear roles and responsibilities for all staff
  - Maintain the confidence of the AECB, WANO, NB Power board of directors, and the communities we serve.
- **Cost / productivity / profitability**
  - Effectively plan, prioritize and manage our costs for OM&A, capital projects and outages
  - Maintain a consistent and predictable capacity factor
  - Evolve our business processes to support efficient and effective operation.

The first plan was introduced in April of 2000. It incorporated the Phase II manager commitments; the WANO identified areas for improvement (AFI's) and any carry-on PIP projects. The plan is being actively managed on a monthly basis. This will include assessment of work accomplished as well as financial management compared to required goals. Corrective actions are taken when necessary. The plan will be updated yearly and is integrally linked to the station budget process.

9. Summary

Since encountering difficulties in performance starting in the mid 1990's, NB Power has made a number of fundamental changes in how it conducts business at Point

Lepreau. These changes were initially introduced through the Performance Improvement program, and now are being administered through a business planning process which encompasses risk assessment and ensues that station resources are aligned with the high level goals. Improvements in areas of human performance, organizational effectiveness and station processes are aided by the use of a dedicated transition team. The need for change and continuous improvement has been communicated to all station staff and that they understand that they must take ownership of change. Care was taken so that this message was delivered in a manner such that the dignity and respect for the individual was respected.

The application of continuous improvement through programs such as use of leading performance indicators, corrective action program, self-assessment program and peer reviews are now part of the standard way of doing business.

While it takes time to implement significant change into an organization and to see results, station staff and management are confident that the goals will be achieved.

Reference:

Paper presented at the 1998 CNS Conference in Toronto, Canada, "Improving Performance in a Competitive Environment", by R. M. White, J. J. McCarthy, W. S. Pilkington and P. D. Thompson.

APPENDIX I - List of PIP Projects

CATEGORY A

- Supervisory effectiveness
- Improvement to work control processes
- Reduce maintenance backlog
- Reduce backlog of corrective actions
- Improve progress on AECB Action Items
- Implement a Problem Identification and corrective action program
- Introduce a work management system for technical work
- Implement Plant life management program

- Develop a strategic plan
- Implement a self assessment program

CATEGORY B

- Produce interpretation document for OP&P
- Follow-up safety culture training and create human factors program
- Establish a configuration assurance program
- Progress improvement in operations documentation
- Improve the design change process
- Develop a succession plan
- Introduce a comprehensive training program for all work groups

APPENDIX II - Core Values & Vivid Description

Our core values are:

Safety First

We recognize and take seriously the unique safety requirements of the nuclear core. We are committed to employee and public safety.

Pursuit of Excellence

We strive to achieve world class standards through continuous improvement.

Openness

We readily consider the views of others, and willingly and sincerely express ours. We share knowledge and information for the benefit of all.

Respect for the individual

We value our people, trust them, support their development, and acknowledge their needs.

Teamwork

As individuals, we unite to achieve shared goals.

Commitment

We accept ownership and deliver on our promises.

Integrity

Our thought, words and actions are founded on honesty, trustworthiness, and accountability.

Our Vivid Description:

We are working with renewed vigor and a sense of accomplishment

We are each where we can best contribute and love it!

We each make a difference

We trust and are trusted

Our processes are as good as our people

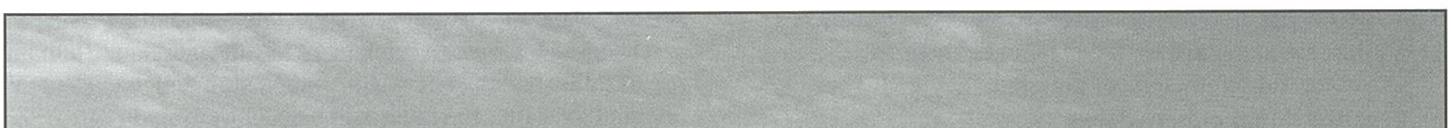
We and our families are proud to say we work at Lepreau

Kids think working at Point Lepreau is cool

People travel from around the world to learn from our success

Our customers feel we provide real value

Our community is confident in us



Conceptual Designs for Very High-Temperature CANDU Reactors

*by S.J. Bushby, G.R. Dimmick, and R.B. Duffey **

***Ed. Note:** The following paper was presented in the third plenary session of the 21st CNS Annual Conference held in Toronto, June 11- 14, 2000*

ABSTRACT

Although its environmental benefits are demonstrable, nuclear power must be economically competitive with other energy sources to ensure it retains, or increases, its share of the changing and emerging energy markets of the next decades. In recognition of this, AECL is studying advanced reactor concepts with the goal of significant reductions in capital cost through increased thermodynamic efficiency and plant simplification. The program, generically called CANDU-X, examines concepts for the future, but builds on the success of the current CANDU designs by keeping the same fundamental design characteristics: excellent neutron economy for maximum flexibility in fuel cycle; an efficient heavy-water moderator that provides a passive heat sink under upset conditions; and, horizontal fuel channels that enable on-line refueling for optimum fuel utilization and power profiles. Retaining the same design fundamentals takes maximum advantage of the existing experience base, and allows technological and design improvements developed for CANDU-X to be incorporated into more evolutionary CANDU plants in the short to medium term.

Three conceptual designs have been developed that use supercritical water (SCW) as a coolant. The increased coolant temperature results in the thermodynamic efficiency of each CANDU-X concept being significantly higher than conventional nuclear plants. The first concept, CANDU-X Mark 1, is a logical extension of the current CANDU design to higher operating temperatures. To take maximum advantage of the high heat capacity of water at the pseudo-critical temperature, water at nominally 25MPa enters the core at 310°C, and exits at ~410°C. The high specific heat also leads to high heat transfer coefficients between the fuel cladding and the coolant. As a result, Zr-alloys can be used as cladding, thereby retaining relatively high neutron economy.

The second concept, CANDU-X NC, is aimed at markets that require smaller simpler distributed power plants (~300 - 500MWe). The steam cycle and coolant conditions are proposed to be the same as CANDU-X Mark 1. The major difference between the reactors is that natural convection would be used to circulate the primary coolant around the heat transport system. This approach enhances cycle efficiency and safety, and is viable for reactors operating near the critical point of water because of the large increases in heat capacity and thermal expansion coefficient across the core.

The third concept, CANDUal-X, is a dual cycle concept, with core conditions similar to the Mark1 and NC. In this concept, coolant leaving the core is first expanded through a VHP turbine in a direct cycle. Employing a dual steam cycle avoids a high-pressure steam generator. The conditions of the core and the VHP expansion can be designed such that the exhaust from the turbine is used as the heat source for an indirect cycle; that is, the secondary side can be equivalent to that presently employed in conventional CANDU plants. An advantage of this concept over conventional direct cycle nuclear plants is that only one relatively small turbine is exposed to radioactive coolant, and it is located within containment.

In summary, the reactors described above represent concepts that evolve logically from the current CANDU designs to higher efficiency, with only modest extensions of current technology. This paper presents a technical overview of the different conceptual designs, as well as a brief discussion of the enabling technologies that are common to each, which is the focus of current R&D.

INTRODUCTION

It is expected that in the future, the energy and electricity markets will change rather dramatically from their present state. Environmental concerns regarding the emission of green-house gases (GHGs) are growing and this, plus the prospect of dwindling fossil fuel reserves, and privatization and deregulation of much of the electricity sector will strongly affect the decisions that governments, utilities and investors will make when considering energy options.

From an environmental perspective, it is generally accepted (Bertel, 1999, Fetter, 1999) that increasing the amount of electricity generated by nuclear plants is a viable option toward meeting the CO2-reduction targets set in Kyoto in 1997 at the third Conference of the Parties (CoP-3) for the UN Framework Convention on Climate Change. Although its environmental benefits are demonstrable, nuclear energy must be economic to ensure its place in the emerging energy markets of the next century. New nuclear plants will only be built if the initial capital costs, and risks associated with plant

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operation and performance are shown to compete favourably with competing regional energy sources. In most areas of North America, this competition is fossil-fired combined cycle gas turbines (CCGT).

AECL has a program in place, generically called CANDU-X, that examines new, innovative, reactor concepts that can be built and operated at significantly reduced capital and unit energy costs. In addition, the reactors should also possess enhanced safety features, and a flexible, proliferation-resistant fuel cycle.

The most significant cost reductions for the CANDU-X concepts are expected through an increase in thermodynamic efficiency by raising the coolant temperature, and any simplification in plant design that may result. Although numerous high-temperature coolants were examined early in the CANDU-X project, water at supercritical pressure and temperatures has been adopted as the coolant of choice. The concept of utilizing supercritical water (SCW) in a power plant is not a new one; fossil-fired plants cooled by SCW have been in operation for over 30 years. Supercritical-water-cooled reactors were first studied seriously in the late 1950's and early 1960's (Keyfitz, 1964, Marchaterre and Petrick, 1960). With the drive toward increased economic competitiveness, this interest has been renewed in a number of countries in the 1990's (Silin et al., 1993, Dimmick et al, 1998, Bushby et al, 1999, 2000, Oka and Koshizuka, 1993). In each case, these reactors are believed to be very competitive economically because of the higher thermal efficiency and the possibility of plant simplification. As an example of the latter, steam separators and dryers are not required in a direct cycle because SCW is a high-density gas, which does not encounter the two-phase region. Independent of steam cycle, the absence of a second phase alleviates concerns of fuel dryout, thereby enabling an increase in channel power. This, in combination with the enhanced thermodynamic efficiency, yield reductions in fuel, specific capital and O&M costs.

The use of SCW also enhances safety because of the possibility of using natural circulation for the primary coolant (Dimmick et al, 1998), taking advantage of the gas expansion coefficient and large density change with temperature around the critical point. At an average in-core temperature of around 400°C (i.e., just above the pseudo-critical temperature of 370°C), the high specific heat leads to a greatly reduced mass flow, and thus pressure drop. The large density change between the core inlet and exit results in sufficient driving head, with a moderate elevation difference to permit natural circulation.

Three design variants of a supercritical cooled CANDU are described and are shown in Figure 1. The first is the logical extension of the current CANDU design to higher pressure and temperature. The second utilizes natural circulation for the primary coolant, and the third is a variant of the first but utilizes the innovative idea of a very high pressure (VHP) turbine in the primary circuit inside of containment. Although only conceptual at present, the possibility of stretching the third variant to the limit currently set by steam turbine materials is also considered. These various design concepts are compared to the CANDU-6 in Table 1.

CANDU-X Mk I

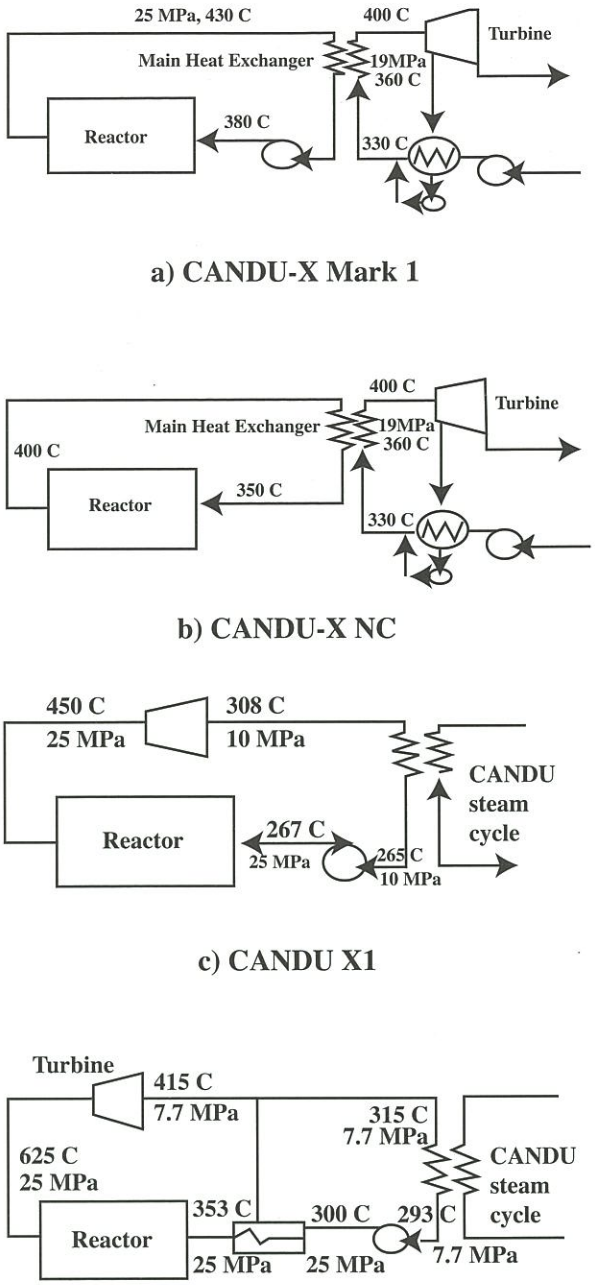
The CANDU-X Mk 1 is a logical extension of the present CANDU design. An indirect cycle is employed, but the temperature of the primary coolant at 25 MPa is increased to 380°C at the inlet and 430°C at the outlet, yielding an increase in thermodynamic efficiency of roughly 20% over conventional water-cooled reactors. The core would consist of 380 channels, each running at an average power of 6 MW(t), or 2280MW(t) for the entire reactor. At an assumed overall cycle efficiency of 41%, the electrical output is 910MW. The conditions for the CANDU-X Mark 1 were chosen to take maximum advantage of the marked increase in enthalpy, and thus heat capacity, that occurs at ~385°C (the pseudo-critical temperature). The high heat capacity leads to a three-fold increase in core enthalpy change, and a corresponding three-fold reduction in channel flow (compared with current CANDU values) for the same channel power and temperature rise. Channel pressure drop is similarly reduced. The relatively high coolant density at the pumps (~0.6g/mL), in addition to the reduced mass flow and pressure drop, results in a six fold reduction in the primary pumping power for the Mark 1 compared to current CANDU values (Dimmick et al, 1998).

The core design will be horizontal and employ interlaced flow in adjacent channels, similar to the approach used in conventional CANDU plants. Thus, even though there is a large density gradient along each channel, the average core density will be the same on each side

Table 1: CANDU-X Design Numbers

	CANDU 6	CANDU-X Mark 1	CANDU-X NC	CANDUAL-X1	CANDUAL-X2
Thermal Power (MW)	2064	2280	930	2340	2536
Gross Electric Power (MW)	725	910	370	950	1143
Eff. (%)*	35	41	40	40.6	45
Press. (MPa)	10	25	25	25	25
Inlet Temp (°C)	266	380	350	312	353
Outlet Temp(°C)	310	430	400	450	625
Inlet Density (g/mL)	0.780	0.451	0.624	0.720	0.615
Outlet Density (g/mL)	0.690	0.122	0.167	0.109	0.068
Core Flow (kg/s)	7700	2530	976	1504	1321
Number of Channels	380	380	232	~300	~300
Ave. Channel Power (MW)	5.4	6	4	7.8	8.5

NOTE: *estimated



a) CANDU-X Mark 1

b) CANDU-X NC

c) CANDU X1

d) CANDUal - X2

Figure 1: CANDU-X Designs.

of the reactor because each face contains an equal number of channel inlets (where the coolant density is highest) and outlets (where the coolant density is lowest). This will significantly simplify the physics and control aspects of the reactor compared to a unidirectional vertical core design (Dobashi et. al., 1998).

The high specific heat at the pseudo-critical point leads to high heat transfer coefficients between fuel cladding and coolant (Yamagata et. al. 1972, Koshizuka et. al. 1994). As a result, cladding temperatures are predicted to be only 60-70°C above the coolant temperature which is within the range of Zr-alloys. In in-reactor tests, uranium dioxide clad with various zirconium alloys has been operated successfully in superheated steam coolant at sheath temperatures of up to 500°C. After six months of irradiation, the zirconium oxide thickness was 12 mm. This would indicate a metal loss of 5 to 10% of the wall thickness over two years. In addition, out-reactor experiments have revealed that some Zr-alloys exhibit acceptable corrosion resistance at the proposed burnups of the different fuel types, if the temperature of the cladding is kept below roughly 475°C. Acceptable corrosion rates are achieved at higher temperatures when the surface of the cladding is treated with a thin corrosion-resistant layer.

Options for the thermodynamic cycle of Mark 1 are illustrated in Figure 2. The first option under consideration is a very high pressure (VHP) turbine with the exhaust directed toward a conventional LWR turbine set that operates under typical LWR conditions. In the dry region, efficiencies lie between 94 and 96%, but drop off to 82% near the exit from the HP turbine where the steam quality is reduced to 0.85.

Expansion into the wet region for both the high pressure and low pressure turbines results in a reduced cycle efficiency, which for Mark 1, is estimated to be ~6%. Most of these losses could be recovered by employing multiple (2 or 3) stages of reheat, thereby avoiding expansion into the two-phase region. A cycle employing three stages of reheat (i.e. a single high pressure reheat and two lower-pressure (PWR type) reheats) avoids the wetness in the HP expansion, and reduces the wetness in the LP expansion. A similar result could be obtained with two high-pressure reheats, whereas wetness could be avoided completely with two high pressure and one lower pressure reheats; however, it needs to be determined whether the proposed reheating could be done efficiently, without excessive heat degradation. A more efficient option would be to perform the high-pressure reheat using heat directly from the primary system. The flow from each outlet header would divide to supply a steam generator and a reheater in parallel.

CANDU-X NC

To meet the needs of markets that require smaller, distributed power plants, the output of the CANDU-XNC reactor is approximately 350 MW(e). The reactor is smaller since this output can be accommodated by a reduced number of channels running at a lower average channel power (232 channels at ~ 4 MW vs 380 at 6 MW for the Mark 1). The smaller core will have a reduced amount of heavy water in the moderator, and fewer loops and steam generators (2 compared to 4 in current CANDU designs). These differences lead directly to reduced construction and capital costs.

The principal difference between the Mark 1 and the CANDU-X NC is that natural convection is employed for 100% of the heat removal from the core under normal operating conditions. This represents an improvement in passive safety compared to forced convection; most notably, accident scenarios involving loss of Class IV power are no longer a con-

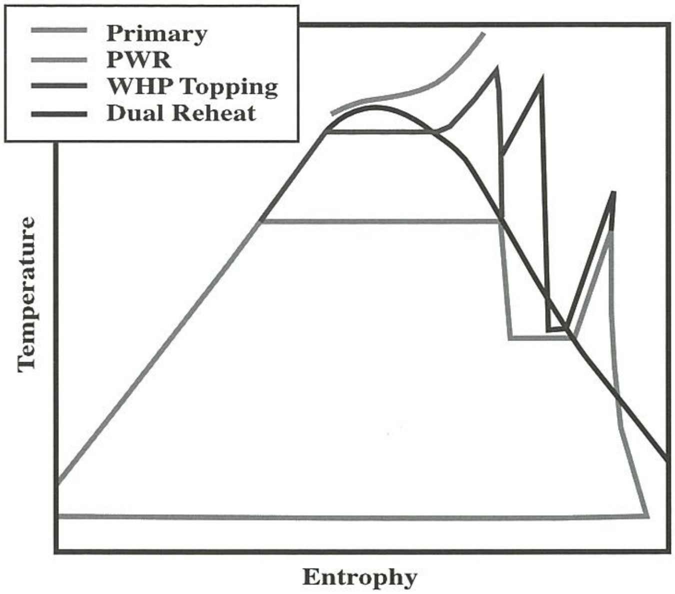


Figure 2: Possible Cycle options for CANDU-X Mark 1.

cern. Cycle efficiency is improved since a percentage of the reactor power is not required to drive the heat transport pumps during operation (Figure 1b).

To investigate the feasibility of natural convection, a simple steady-state, natural-circulation program was written. This program included the full physical variations of the thermo-physical properties of supercritical water. The initial and boundary conditions to the core, the operating pressure and temperature, along with the circuit resistance coefficients and the elevation difference between the core and the heat exchanger were specified. With an initially assumed flow, the program, using a supercritical water property routine, iterated around the loop on flow to calculate the steady-state density and enthalpies at each node in the circuit. To understand the parametric trends, many thousands of these calculations were done for different input conditions and the output data were plotted against each other to display the trends. The effect of the large density and enthalpy changes around the critical temperature can be seen in this Figure where the inlet temperature is a parameter. Below about 370°C the outlet temperature/channel power surface is relatively flat (except for high loss coefficient combined with high power), whereas as soon as the inlet temperature exceeds 380°C the outlet temperature rises very sharply regardless of the channel power and loss factors. If the fluid enters the core below the critical temperature, it is at relatively high density and low enthalpy, and exits above the critical temperature at low density and high enthalpy. The large density difference gives a large natural-convection driving force, and the large enthalpy change allows a high channel power with relatively low flow and, hence, pressure drop.

This illustrates that to utilize the maximum design flexibility of elevation and loss coefficients within a maximum outlet temperature limit with a high-powered channel, it is necessary to keep the inlet temperature below the critical temperature and the outlet above the critical temperature. If the inlet temperature is allowed to rise above the critical temperature, the much-reduced density and enthalpy changes result in a very much higher outlet temperature. Although this would lead to higher thermodynamic efficiency, it also would require low neutron cross-section materials capable of operating in the 600°C range, beyond the capability zirconium alloys without a corrosion-resistant coating.

For the CANDU-X NC concept, it is proposed for coolant to enter the core at 350°C and exit at 400°C, thereby allowing cycle options similar to those for Mark 1 shown in Figure 2. These temperatures were also chosen because they provide ideal conditions for natural circulation. The coolant enters the core below the critical temperature at a relatively high density and low enthalpy; whereas, it exits the core above the critical temperature, at low density and high enthalpy. From calculations performed to-date, natural convection of the primary flow in a CANDU-X NC will be possible with a heat exchanger that is 10-20m above the core, and if pressure losses around the primary circuit are minimized.

To address the thermalhydraulic issues with the CANDU-X reactor, experimental and analytical programs are underway. A large pumped loop using supercritical CO2 is being commissioned to study heat transfer and pressure drop, and for fluid-to-fluid modelling studies of supercritical fluids. This loop will subsequently be converted to natural circulation to study instabilities, both in single and multiple parallel channels. In addition, a small natural-convection supercritical water loop is operational as a materials test facility. This loop operates between 360°C and 450°C, i.e. across the critical temperature, in a stable manner. Current plans are to extend the loop to multi-channel and to add an active chemistry control system.

CANDUal-X

The CANDUal-X concepts utilize a dual steam cycle to take maximum advantage of proven systems used in conventional water-cooled reactors. As shown in Table 1, conceptual designs for two CANDUal-X reactors operating at different temperatures have been developed. In both cases, the coolant leaving the core drives a VHP turbine in a direct cycle. For CANDUal-X1, expansion of the coolant through the VHP turbine produces steam at temperature of 306°C, which is fed directly into the primary side of a CANDU 6 steam generator. This approach avoids the expense and uncertainty associated with a steam generator operating at a shell-side pressure of 18 or 19 MPa (c.f. Mark 1). Also, because the primary side of the steam generator is now condensing, a smaller steam generator is required to transfer the same amount of heat. The dual-cycle concept also makes use of proven turbine technology that is presently being used in SCW-cooled fossil-fired plants (Smith, 1999). The addition of the VHP turbine onto a conventional CANDU indirect cycle in this manner adds 310 MW(e) to a standard CANDU 6 station output, to yield a net efficiency of 40.6%.

For CANDUal-X2, the intent is to achieve the highest possible efficiency by operating the core at the maximum temperature achievable with existing steam turbine technology. At an outlet temperature of 625°C, CANDUal-X2 would produce 1143 MW(e) of electricity at 45 % efficiency. In this case, exhaust from the VHP turbine (yielding 500 MW(e)) is first fed into a high-pressure regenerator prior to the steam generator. The regenerator reduces the steam temperature from 415°C to ~315°C, making it suitable for the standard CANDU indirect cycle. The core temperature is beyond the operating envelope for Zr-alloys; thus, cladding made from a Ni-based alloy or stainless steel could be used, although a high temperature ceramic with a low neutron cross section would be preferable on the basis of neutron economy.

It is possible to locate the VHP turbine in the containment because of its relatively small size compared to low pressure turbines. The conditions of the core and the VHP expansion have been chosen such that the exhaust from the turbine can be used as the heat source for an indirect cycle, equivalent to that employed in conventional CANDU plants. Moreover, the radioactive coolant remains wholly within containment, unlike a conventional BWR. There is a potential safety implication of having a turbine within containment and also a potential problem of deposition of activated corrosion products on the turbine and these are being evaluated.

DESIGN FEATURES COMMON TO ALL CONCEPTS

Core Design and Primary Coolant

Significant cost reductions will be achieved with CANDU X by reducing the inventory of heavy water. If natural uranium is the fuel of choice for a future customer, the primary coolant should be heavy water to achieve sufficient fuel utilization. However, since the density of SCW is much lower than water at ~ 300°C and 10MPa, there is a considerable reduction in D2O inventory compared to current CANDU designs. An added benefit of the lower density coolant is the reduction in the coolant void reactivity (CVR). Depending on the design of the CANDU X core, reductions in CVR of three to five times present values can be achieved.

If slightly enriched uranium is used as fuel, the primary coolant can be light water which results in a significant reduction in heavy water inventory as well as a simplification in the heavy water recovery systems. With light water coolant the lattice pitch of the channels needs to be reduced to between 20 and 21 cm to get a near zero coolant void reactivity which results in additional heavy water savings because of the reduced size of the calandria. Initial indications are that this lattice pitch is achievable especially with bi-directional flow and single ended refuelling as described below.

Fuel Channel Design

For a conventional design to be used in SCW conditions, the thickness of the pressure tube would have to be approximately doubled because the operating pressure is much higher, and because the ultimate tensile strength of Zr-alloys decreases sharply above 400°C. Such a large increase in tube thickness is contrary to the design premise of neutron economy, and will almost certainly necessitate fuel enrichment, or depletion of the 91Zr isotope from Zr-containing components in the core to achieve acceptable fuel burnup. The absolute rates of corrosion and deuterium would also be greater at SCW temperatures, but it needs to be determined whether this would affect the projected lifetime of a much thicker pressure tube.

To preserve neutron economy, especially at high coolant temperatures, a change in fuel-channel design is needed. The CANTHERM insulated fuel channel, shown in Figure 3, is currently under development at AECL. It has no calandria tube, and the pressure tube, in contact with the cool heavy-water moderator, is insulated from the high-temperature coolant. Thermally insulating the pressure tube removes the need for an annulus gap, and consequently, the calandria tube. In the CANTHERM design, the pressure tube will be in direct contact with the moderator, and, therefore, operate cold. At moderator temperatures, corrosion and deuterium ingress into the pressure tube should be greatly reduced. Moreover, the strength, and likely the creep resistance, of commercially available Zr-alloys will be such that the thickness of the pressure tube can be roughly equal to the present CANDU design; i.e., a significant neutron penalty is not expected. In addition to the supercritical application, such a fuel channel could be employed to increase coolant temperatures and pressures in a conventional CANDU PHTS.

Fuel and Refueling

With conventional CANDU plants, on-line refueling is used to achieve optimum power profiles and fuel utilization. The best profile from the fuel cooling aspect has the peak power skewed toward the core inlet and can be accomplished by positioning new bundles at the channel inlet and the highest burnup bundles at the outlet. Fuel defects associated with

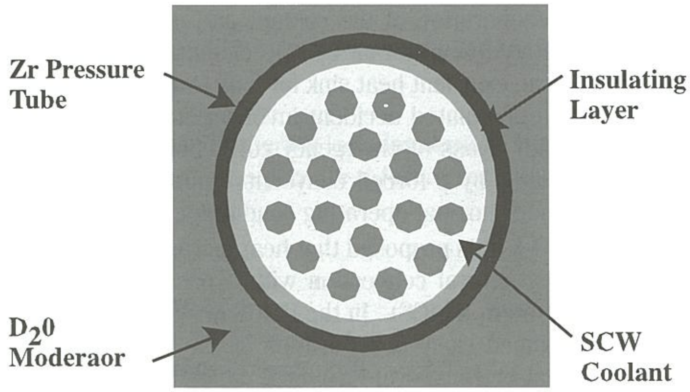


Figure 3: Schematic of CANTHERM fuel channel design. The pressure tube is insulated from the hot coolant, removing the need for a calandria tube and an annulus gap.

power ramping will be reduced because generally a bundle is subjected to a declining power history over its lifetime. To prevent a large flux asymmetry across the core bidirectional flow would be used so that adjacent channels have the channel inlet at opposite sides of the core. Two fueling machines are employed in present CANDU designs: one to load new fuel bundles, and the second, on the opposite end of the channel, to receive spent bundles. For CANDU-X, single-ended refueling from the inlet side of the channel will be adopted, since elastomeric seals within the fueling machine (F/M) perform better at the lower inlet temperature. Two F/Ms will still be required, but they will access different channels on opposite sides of the core because of the interlaced flow. Because access by the F/M to the outlet end of the channel is not required, the diameter of the outlet end fitting can be reduced, allowing smaller lattice pitches to be achieved. This design was originally proposed for the CANDU-3 design reactor (Anon.) although with the fueling machine accessing the outlet of the channel rather than the inlet.

Single-ended refueling from the inlet side of the channel requires that all bundles are extracted against the coolant flow. After the spent bundles are removed, the channel is refueled with the coolant flow, using the remaining extracted bundles first, followed by the new ones. Extraction of the fuel from the inlet requires the individual bundles to be tied together, probably using a central tie rod. This is standard procedure for experimental fuel string irradiations in the NRU reactor and was also used in the Gentilly-1 boiling light water reactor. An alternative option would be to design a bundle with a coupling on the end plates to connect adjacent bundles. This development would simplify the design of the fueling machine because a long receiving chamber and tie rod may not be required; individual bundles could be separated from the rest of the fuel string as they exit the core. For both systems the bundles would be aligned to reduce the pressure drop across the core. This is especially useful for CANDU-X NC, where the reduced pressure drop will facilitate natural circulation of the flow.

Passive Moderator cooling.

The separation of the coolant and moderator is an attractive safety feature of all CANDU designs. The moderator provides an excellent heat sink for long term cooling of the core under a postulated accident involving a loss of coolant combined with a loss of emergency core cooling. Presently, heat is removed by a forced convection loop, which is also employed under normal operating conditions.

For CANDU-X, it is proposed that heat be removed from the moderator by natural convection with a passive moderator circulation system (PMCS). In the PMCS design, the moderator is maintained close to saturation at the calandria pressure, and heat is transported from the calandria to an elevated passive heat exchanger in a natural-circulation loop (Khartabil et al. 1995). Under normal operating conditions, heat has to be continuously removed from the moderator. This is done in existing plants by using a forced convection loop. An attractive feature of the PMCS is that flashing occurs close to the calandria exit. This proximity provides a large driving force, because of the large density difference between the cold-leg subcooled liquid and the hot-leg two-phase mixture. This design feature makes it possible to remove moderator heat under both normal and accident conditions using natural-convection flow. Moreover, having the moderator temperature close to saturation provides the option of utilizing the moderator heat for feedwater heating, which improves plant efficiency.

The main feature of this design is that vapour is generated by flashing. Simulations using the CATHENA code (Hanna, 1998) have shown that a flashing-driven natural-circulation loop can be used to remove moderator heat under normal operating conditions without any flow instabilities. Under some conditions, limit-cycle oscillations were observed experimentally. With a few exceptions, the experimental results were successfully described by the CATHENA code (Dimmick et al., 1999). Experiments with two-phase flow in large diameter vertical pipes (Shoukri et al., 2000) have shown that slug flow does not occur eliminating one of the design concerns with this concept.

CONCLUSIONS

A CANDU reactor cooled by supercritical water has significant potential to be competitive in future energy markets through increased thermal efficiency and plant simplification. Three reactor concepts cooled by SCW have been developed that span the entire power range for future competitive markets. The three concepts all use the same flexible horizontally-oriented core design, and can be matched to both direct and indirect steam cycles. Thus the concepts build on the successful heavy-water moderated, pressure tube reactors that represent the existing CANDU designs. This approach takes maximum advantage of the existing experience base, and enables technological and design improvements developed for the CANDU-X program to be spun off and incorporated into evolutionary CANDU plants in the short to medium term, as part of AECL's continuing program to develop and improve the CANDU design. Enabling technologies that are generic to each of the reactor concepts will remain the focus of the CANDU-X program. These include development of a CANTHERM fuel channel, SCW thermalhydraulics, chemistry, materials compatibility, and safety.

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Last Notice

21st CNS Nuclear Simulation Symposium

Sheraton Ottawa Hotel, Ottawa, Ontario

September 24 - 26, 2000

The 21st Nuclear Simulation Symposium organized by the Canadian Nuclear Society will be held September 24 to 26, 2000 at the Sheraton Ottawa Hotel in Ottawa, Ontario.

The scope of the Symposium covers all aspects of nuclear modelling and simulation, and generally includes sessions in thermalhydraulics, reactor physics, and safety analysis. The main objective of the Symposium is to provide a forum for discussion and exchange of views amongst scientists and engineers working in the nuclear industry.

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Safety Analysis Technology:

Evolution, Revolution and the Drive to Re-Establish Margins

by John C Luxat

Ed. Note: John Luxat, who is Manager, Nuclear Safety Technology, at Ontario Power Generation, presented this extensive and critical review of reactor safety analysis in Canada at the 21st CNS Annual Conference held in Toronto in June 2000.

INTRODUCTION

Over the past twenty-five years safety analysis has been undertaken on an on-going basis at Ontario Hydro (now Ontario Power Generation), in part to support the licensing of new stations and in part to address safety related issues that have periodically arisen. The analysis methodologies employed have been based almost entirely upon deterministic methods, similar in general nature to methods used in the rest of the Canadian industry and, indeed, the rest of the international nuclear industry. Associated with the deterministic methods is the need to make specific assumptions regarding physical models and parameters. These assumptions have been characterized by conservatism in their selection.

Significant conservatisms have typically been built into the physical models and analysis assumptions in order to accommodate either uncertainty in supporting knowledge or deficiencies in ability to model physical processes. These conservatisms, considered appropriate at the time, have been used to offset limitations in analysis technology and, as such, they have reflected the state of technology development.

There has been an evolution over the past two decades in the state of knowledge of safety related phenomena and physical processes and in the corresponding modeling capability. In this same period revolutionary changes in computing power have occurred. The central mainframe computer that at one time appeared to be evolving toward parallel processing supercomputers was supplanted by networked work-stations and personal computers, yielding greater power and functionality at the analyst's desk than was conceivable only years ago. However, analysis methodology has evolved relatively slowly in the corresponding period since it has been knowledge-bound rather than computing-bound. Point estimates of consequences of accidents have varied primarily in terms of the nature of assumptions applied in analysis. These changes have been denoted by qualifying phrases that primarily reflect the limitations of the methodologies – for example, the changes in analysis methods from "limit-consequence" to "best effort' to "limit of operating envelope".

A deleterious consequence of using deterministic analysis methodology and associated conservative assumptions is that events that are at the boundary of both the design basis as well as the risk spectrum - and sometimes beyond the design basis - have taken on their own reality. In fact, many people often perceive these analysis assumptions as representing a "more probable reality". This, in turn, has led to the perception of small safety margins in the design and has resulted in analysis that is not robust to perturbations in either the knowledge base or analysis assumptions. Neither of these two outcomes is conducive to supporting rationale decision making.

Efforts are underway at Ontario Power Generation to develop new safety analysis methodology that will support better definition of the Safe Operating Envelope (SOE) and, in so doing, will demonstrate that significant safety margins do exist. The safety analysis methodology development at OPG is more revolutionary than evolutionary in nature. It has an underlying probabilistic basis, currently referred to as "Best Estimate plus Uncertainty Analysis", but is intended to be more than just a particular implementation of such techniques. The urgent driver for this development effort is the need to re-establish safety margins in order that safe, reliable and less complex operation of nuclear units can be supported through analysis.

Given the changes that are occurring in the electricity market in Ontario and the impact this will have on the nuclear option, there is a need to focus on maintaining competitiveness in all activities – and safety analysis is not exempt. The features of the OPG methodology that are designed to specifically address these challenges, as well as the demographics of an aging safety analysis community, will be described in more detail in this paper. However, in order to understand the path to this new technology it is necessary to understand the historical context of safety analysis in OPG.

A historical perspective of the evolution of safety analysis technology at OPG is presented below. The key elements of the new safety analysis methodology are then described together with its relationship to other components of Canadian nuclear safety technology. This development is placed in context with similar work being conducted in the international Light Water Reactor (LWR) community.

HISTORICAL OVERVIEW

The evolution of safety analysis methodology has been neither smooth nor continuous. In reality the evolution has been discontinuous and can be related to specific events and issues that, at the time, imposed an immediacy and urgency on the objectives of the analysis. By and large, this evolution has been dominated by needs associated with Loss of Coolant Accidents (LOCA) – primarily the large break LOCA event and, within the context of the Siting Guide requirements (Ref. 1), LOCA events with ECIS impairments. Another characteristic of this evolution is that each of the changes in analysis methodology has subsequently been distorted by the conservatism applied to analysis assumptions to the extent that they have overwhelmed and, ultimately, negated any advances in physical modeling.

Five distinct safety analysis development phases can be identified together with the events and issuers that defined the needs of the period. These phases are:

- The ECIS Effectiveness Issue
- Limit Consequence Methodology
- Best Effort Methodology
- Limit of Operating Envelope (LOE) Methodology
- Best Estimate plus Uncertainty Analysis Methodology (the current phase)

The genesis of these phases and their inter-relationships is discussed below.

The ECIS Effectiveness Issue

The origins of this issue goes back to the initial licensing of Bruce NGS A in the early 1970's. The issue revolved around concerns that had been identified during design analysis regarding the effectiveness of the low pressure Emergency Coolant Injection System (ECIS), based upon gravity feed injection, to prevent significant fuel failures. This resulted in Ontario Hydro receiving a "show-cause" letter from the AECB in 1976 requesting reconfirmation by analysis of the effectiveness of the emergency core cooling systems for operating stations - at that time Pickering A was Ontario Hydro's only operating station.

The analysis tools of the period were relatively rudimentary and the regulator lacked confidence in the ability to demonstrate through analysis the effectiveness of this special safety system to perform its intended function. The state-of-the-art thermal hydraulic modeling of this era, represented by the homogenous equilibrium model (HEM) implemented in the SOPHT code (Ref. 2), was still being developed and reactor point kinetics was still the primary means to represent reactor kinetics.

The issues in contention related to the ability to deliver cold water into a hot steam-filled system (hot wall delay effects), the ability to rewet and cool the fuel, and the general limitations and uncertainties associated with the analysis tools of that period. Enhancement of physical models to address these issues was hampered by a lack of supporting experimental data against which to validate the models. Consequently, effort was placed on performing experiments in facilities relevant to CANDU designs. The early facilities involved included the Cold Water Injection Test (CWIT) facility built in 1974 at Westinghouse Canada's laboratory in Hamilton (now Stern Laboratories) and the scaled RD-12 thermalhydraulic loop built in 1976 at AECL's Whiteshell Laboratories in Manitoba. The CWIT facility, in particular, was used to generate experimental data to address channel refill and fuel rewetting behaviour for conditions involving cold water injection into a hot steam-filled fuel channel.

However, the accumulation of experimental data was of no significant benefit in resolving the issues because it was difficult to demonstrate the applicability and scaling of the data to reactor-specific conditions. The fact that the system thermalhydraulic codes could only represent homogenous two-phase mixtures (i.e. liquid and vapor phases well mixed and possessing equal velocities) limited their usefulness as a means to extrapolate the experimental results to reactor geometries and conditions. It was in the late 1970's that thought was given to developing a two-fluid code which later resulted in the development of the TUF code (Ref. 3) approximately five years later. This mirrored efforts underway in the United States that ultimately resulted in the LWR two-fluid codes RELAP (Ref.. 4) and TRAC (Ref. 5).

The effectiveness of ECIS remained an unresolved issue following licensing of the Bruce NGS A station. However, it took on a different direction in the early 1980's as a result of the development of "limit consequence" analysis methodology, discussed below.

Limit Consequence Methodology and its Impact

Limit consequence analysis methodology was developed over a short period of time starting in 1980 and ending in 1981 with the so-called "Green" and "Blue" book reports for Bruce A and Pickering A, respectively (Ref. 6, 7). The genesis of this methodology was a request from the AECB for a reanalysis of the consequences of a large break LOCA event in Pickering A and Bruce A.

A few years prior it had been established that for certain postulated LOCA events it was possible for channels in one core pass to experience sustained very low flow conditions. These conditions were referred to as "stagnation break" conditions because the analysis of that time exhibited what appeared to be stagnated channel flows for a specific break magnitude and location - a Reactor Inlet Header (RIH) break. More importantly, for these "stagnation break" conditions it was possible for pressure tubes to heat-up while still at pressure such that gross deformation due to thermal creep strain could occur – the so-called pressure tube "ballooning" phenomenon. This phenomenon, together with possible fuel bundle deformation at high temperatures, put into question the integrity of fuel channels. In turn, this raised questions regarding the effectiveness of ECIS since one of the fundamental nuclear safety tenets applied in demonstrating effectiveness was assurance of a coolable core geometry – which ultimately became synonymous with assuring no fuel channels failures.

Recognizing the inability to address the contentious issues with the HEM-based system thermalhydraulics code, SOPHT, and the difficulty to directly utilize available experimental data, Ontario Hydro adopted a bounding analysis methodology termed "limit-consequence" (Ref. 8). Explicit in this methodology was an attempt to circumvent the uncertainties in crediting ECIS coolant injection to re-establish adequate fuel and fuel channel cooling. Instead analysis assumptions were applied which deliberately bounded the possible consequences by imposing conditions that maximized the exothermic Zircaloy-steam oxidation reaction. Through parametric analysis it was established that arbitrary flows of the order of 25 to 100 g/s of steam, assumed to be superheated at the channel inlet, flowing through affected fuel channels maximized the consequence. The underlying premise of the limit-consequence methodology was that if the clearly extreme bounding assumptions could be demonstrated to yield acceptable consequences, then the need to address more realistic but less limiting conditions would not be required.

As a result of the assumed sustained low steam flow, widespread pressure tube deformation, either by early pressure tube ballooning in the broken pass, or delayed pressure tube sagging in the unbroken pass, was calculated. However, core coolability was assured by heat rejection to the moderator from deformed channels. Thus the concept of the moderator as the ultimate heat sink was established. The focus of analysis and supporting experimental programs now shifted to issues pertaining to fuel behaviour at high temperature (Ref. 9, 10) and fuel channel integrity (Ref. 11, 12, 13, 14). Experimental programs were established to quantify moderator subcooling required to assure

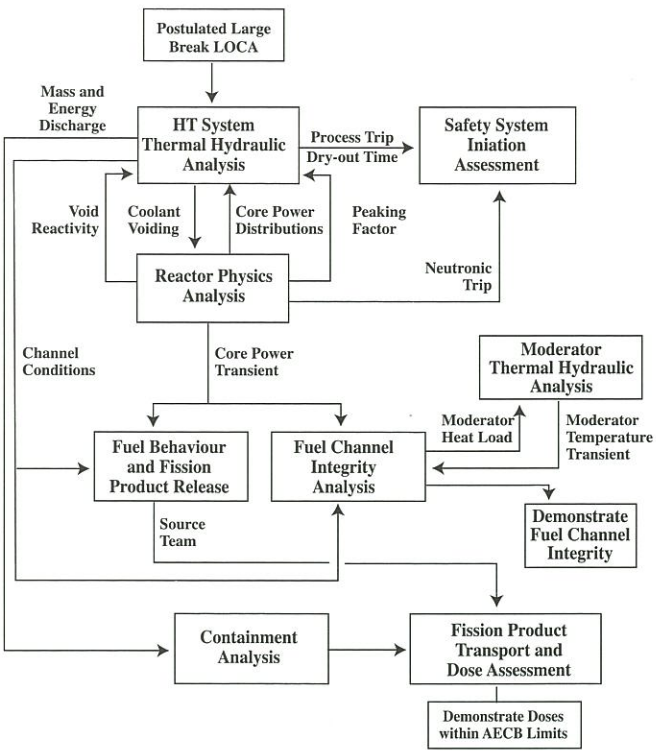

Figure 1: Basic Modules Used on LOCA Anaylsis

fuel channel integrity (Ref. 15) and to study the role of contact conductance in controlling heat transfer rates between deformed pressure tubes and calandria (Ref. 16, 17).

However, defining the required moderator subcooling was necessary but not sufficient. The subcooling available during the LOCA event had also to be calculated in order to demonstrate assurance of fuel channel integrity. This led to the development of the MODTURC computer code (Ref. 18) that was designed to predict flow and temperature distributions in the moderator. Jointly developed by Ontario Hydro and Advanced Scientific Computing Limited of Waterloo, Ontario (now part of AEA Technologies) the development of this code progressed to the state-of-the-art computational fluid dynamics (CFD) code MODTURC_CLAS (Ref. 19), which is now the Industry Standard Toolset (IST) (Ref. 20, 21) code for three-dimensional moderator thermalhydraulic calculations.

The development of limit-consequence methodology also coincided with the establishment of three-dimensional neutron kinetics as an integral part of safety analysis. This was facilitated by the deployment of the spatial modal kinetics code, SMOKIN (Ref. 22, 23), in the first limit consequence analyses. Originally developed as a tool for analysis of spatial control problems in design studies for Ontario Hydro's 1250 MW conceptual reactor design, SMOKIN was developed further for use in accident analyses and subsequently has served as the standard space-time kinetics calculation tool in Ontario Hydro for the past two decades.

Limit-consequence methodology became an established analysis approach for bounding the consequences of LOCA and was employed in the safety report analyses submitted for licensing of the Pickering NGS B, Bruce NGS B in the early 1980's and Darlington in the late 1980's (Figure 1). However, the methodology did not accommodate a clear distinction between a LOCA event with ECIS available and a LOCA event with impaired ECIS. By the very definition of the bounding steam flow assumptions, and the limited credit for blowdown cooling, the consequences of these events essentially appeared to be one and the same. More importantly, the arbitrariness of the assumptions and their disconnection from specific failure event scenarios led to the perception of LOCA and LOCA/LOECI having consequences that are more closely related to severe fuel damage events in other jurisdictions (i.e. they appeared de facto to be severe accidents). The phenomenology associated with limit-consequence methodology was that of a severe accident – widespread gross deformation of fuel channels, severely overheated fuel resulting in bundle "slumping", and large amounts of hydrogen gas being produced from the Zircaloy-steam reaction.

With time and continuing application of the methodology it came to take on its own "reality". What in other jurisdictions was beyond design basis severe accident behaviour became part of the design basis envelope in Canada and exerted a significant influence on a number of generic safety issues including ECIS effectiveness and hydrogen behaviour in containment.

Best Effort Methodology

During the licensing of Bruce B the issue of ECIS effectiveness resurfaced and initial attempts were made to resolve the issue within the limit-consequence framework. These initial studies, referred to as "Best Effort ECIS Effectiveness, Phases I and II" were focussed on demonstrating that the reliance on moderator as a heat sink was of limited duration. The approach adopted was to use experimental data, primarily from hot feeder refill tests performed in the CWIT facility at Stern Laboratories, together with lumped parameter approximation models of feeder hot wall delay behaviour. However, it was soon recognized that this approach did not directly address the issue of ECIS performance effectiveness and the regulator remained dissatisfied with what they considered to be the speculative nature of limit consequence methodology.

The Best Effort Phase III study was initiated in 1986 with the specific objective of providing, on a best effort basis, an estimate of the consequences of a LOCA with ECIS available. Darlington was selected as the target station. The approach adopted was to apply the recently developed two-fluid code, TUF, as a "best estimate" code to quantify the governing behaviour during the early stages of blowdown cooling and subsequent injection of cold ECIS water into the heat transport system. It was felt that the accumulated experimental data from the CWIT facility, from the RD-14 loop facility at AECL Whiteshell Laboratories, and more recently from the modified multiple parallel channel RD-14M facility provided a strong supporting basis for modeling the governing phenomena. Furthermore, there was a strong belief that the consequences of the postulated LOCA events were significantly less severe than those associated with limit-consequence methodology.

The first pilot application for a Darlington unit was completed in 1993 and a report was submitted to the regulator. The results of the analysis did indeed demonstrate a number of significant differences from limit-consequence methodology. These differences included:

- Blowdown cooling was effective in the short term in limiting the magnitude of fuel heatup during and immediately after the power pulse,
- Stagnation break behaviour was primarily a figment of simulating one flow pass in the core with one equivalent single channel – for the same header boundary conditions close to zero net flow in a core pass could be achieved by the sum of relatively high transient bi-directional flows in different groups of channels in a core pass. Furthermore, it was virtually impossible, given the differences in elevations and powers of the channels in a core pass, to have all channels in the pass behave in exactly the same manner.
- Low flow conditions could not be sustained for any length of time during blowdown because, ultimately, as the heat transport pump head degraded due to void developing at the pump suction the balance between the pump head and the break was broken.
- The ECIS was effective in re-establishing good fuel and fuel channel cooling and the timing of initiation of injection flow into the heat transport system was not very critical – injection just needed to occur during the blowdown period.

The application of this Best Effort analysis of blowdown cooling during LOCA became the standard approach used in updating the safety report analysis for the Bruce A&B and Pickering A&B stations as part of Ontario Hydro's generic safety report update program. However, before the results could be consolidated the "discovery" of fuel string relocation reactivity occurred and led to increasing conservative assumptions within the "limit of operating envelope" approach.

Limit of Operating Envelope (LOE) Methodology

The recognition of the reactivity effect associated with coherent and rapid relocation of all fuel bundle strings in the channels of the affected pass of a core during a LOCA has had a profound impact on safety analysis in Ontario Power Generation. For reactor designs such as at Bruce and Darlington where fuelling is against the flow (i.e. new fuel bundles are introduced at the outlet end of fuel channels) the reactivity addition is positive and occurs shortly after the break is initiated. The rapid positive reactivity insertion that occurs before shutdown is initiated augments the positive coolant void reactivity and exacerbates the magnitude of the power pulse – hence, this issue is often referred to as the "power pulse" problem. Additionally, the magnitude of reactivity insertion is dependent upon the pre-existing gap between the upstream end of the fuel string and the inlet shield plug – the gap being larger for older reactors due to uncompensated axial creep of the pressure tubes.

The reactors most affected by this reactivity effect were those at Bruce A&B and Ontario Hydro voluntarily derated all the units to 60% FP until compensating measures could be established to offset the effect of the additional positive reactivity insertion. Design change measures included reversing the direction of fuelling in the Bruce A reactors and introduction of long fuel bundles in Bruce B and Darlington reactors as a means of fuel string/shield plug gap management. A significant safety analysis effort was initiated both to support the design modifications and to establish restrictions on the operating envelope that would allow the power level of the reactors to be increased. Operating limits on allowable flux tilts were reduced significantly, as were limits on moderator and coolant isotopic purity and limits on moderator poison concentration. The latter restrictions were aimed at compensating for the fuel string relocation reactivity by reducing the magnitude of the coolant void reactivity feedback.

However, a new challenge to fuel channel integrity was introduced with restrictions on the gap between the fuel string and the inlet shield plug. Relative thermal expansion of the overheated fuel string and pressure tube could result in a reduction of the gap and the possibility of constrained expansion if the fuel string expanded sufficiently to contact the shield plug. This resulted in an additional safety evaluation criterion; avoidance of constrained relative fuel string axial expansion, being introduced into the analysis.

The new safety concern and compensatory measures placed a focus on multiple operating parameter variations. Accommodation of these factors in the on-going re-analysis that was being performed resulted in a rapid change into methodology that provided bounding point estimates of consequences – now generally referred to as "limit of operating envelope" (LOE)

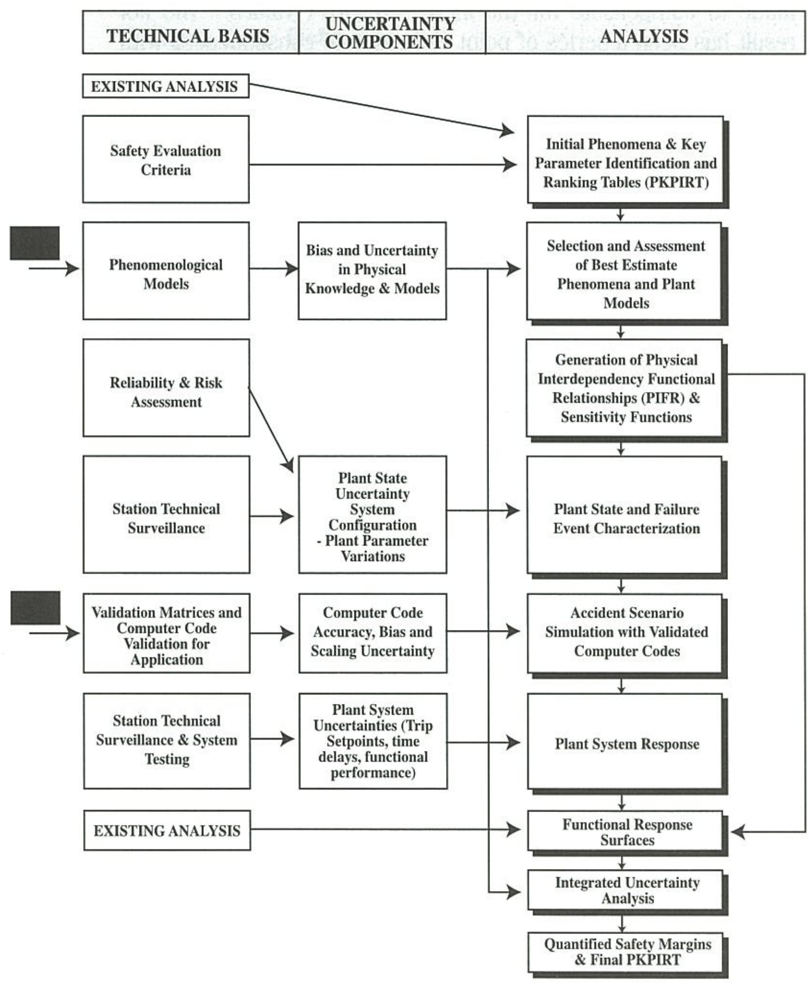

Figure 2: Elements of OPG's Best Estimate + Uncertainty Methodology

methodology. While LOE concepts had been employed in the past the perception of the criticality of operating parameter assumptions had not been as great until the "power pulse" issue arose.

After a series of LOCA re-analyses, narrowly focussed on power pulse and constrained expansion issues, the power levels of the Bruce reactors were gradually increased. In 1996 approval to return to 94% FP, the desired Ontario Hydro power level, was obtained – only to be negated by discovery of an error in one of the safety analysis codes. The Bruce B reactors have been limited to 90% FP since that time.

No sooner had the Bruce reactors been returned to 90% FP, than a new challenge, generic to all CANDU reactors, developed. As a consequence of experimental measurements of simulated mid-burnup fuel in AECL's ZED-2 research reactor at Chalk River Laboratories it appeared that the allowance for under-prediction of void reactivity by the POWDWRPUFS-V lattice cell code was significantly lower than previously thought. Furthermore, it appeared that there was uncertainty in the WIMS-AECL lattice cell code, the code to which the industry is migrating.

As a result of reporting this preliminary research finding, Ontario Power Generation undertook a series of large break LOCA re-analyses for Bruce B with increasing values of the void reactivity error allowance (VREA) while experiments continued at Chalk River to better define an appropriate value for VREA. At each re-analysis a further tightening of operating limit assumptions were made to compensate for the increased VREA values. The net result has been a series of point estimates of consequences with assumptions that force the results, by very definition, to the edge of the acceptable region of the safe operating envelope – in the process leaving the perception of small safety margins.

Best Estimate plus Uncertainty Analysis Methodology

Results of LOE analysis notwithstanding, it are generally accepted that safety margins are, in reality, larger than current analysis indicates. However, the challenge is to demonstrate in an acceptable manner that these margins exist and quantify their magnitude. This situation is not unique to Ontario Power Generation, or the other Canadian utilities. Similar issues have faced the LWR designs. The US NRC provided an alternative to the 10 CFR 50 Appendix K prescriptive rules by allowing best estimate methods to be employed, but in so doing also required that there be a systematic quantification and accounting of uncertainties associated with the analysis. This resulted in development of a framework methodology termed CSAU (Code Scaling, Applicability, and Uncertainty) (Ref. 24) and an application to a Westinghouse PWR design limiting large LOCA.

However, concerns remain regarding the practicability of the CSAU methodology for large scale accident analysis in an operating utility. For this reason Ontario Power Generation embarked on development of new safety analysis methodology aimed at incorporating the essential features of Best Estimate plus Uncertainty Analysis but modifying the elements to address analysis needs in the anticipated competitive future environment. The primary driver is the need to re-establish the safety margins that are believed to exist.

ONTARIO POWER GENERATION METHODOLOGY DEVELOPMENT

Development of a methodology to perform best estimate and uncertainty nuclear safety analysis has been underway at Ontario Power Generation Inc. for the past two years. The objectives of the analysis are multi-fold and include:

- Providing a basis for systematic quantification of safety margins within a best estimate framework with integrated accounting of uncertainties,
- Supporting the definition of Safe Operating Envelope (SOE) limits,
- Supporting operating compliance strategies associated with the SOE,
- Providing a formal basis for conducting safety analysis in an incremental fashion through direct incorporation of past analysis results, and
- Providing an ongoing learning and training component to support maintenance of safety analysis skill and competency.

A key driver for the methodology development project, and one of the major challenges faced, is the need to demonstrate safety margins on an ongoing basis in a cost-effective manner. This challenge is of importance given the inevitable aging of both operating plants and the nuclear safety analysis community and the transition to competition in the electricity marketplace.

This paper presents the methodology framework, identifies the elements that are key to ensuring viability within an operating nuclear utility, and presents results of prototype application for two accident categories in different Ontario Power Generation stations. The prototype applications considered are large break LOCA in a Bruce generating unit and a Loss of Flow accident in a Darlington generating unit.

Basis and Purpose of the Methodology

The underlying basis of the analysis methodology is that best estimate models of physical processes, best estimate or operating centre plant states, and most probable system configurations and failure events provide the most realistic representation of plant behaviour and consequences during accidents. Deviations from these best estimate conditions can and will occur, which will result in uncertainty in the outcome of the best estimate analysis. In order to quantify this uncertainty, it is necessary to identify and characterize the components contributing to uncertainty, and evaluate their impact on safety consequences. The primary purpose of the methodology is to define the ranges of governing parameters, within which safety objectives can be met to a prescribed level of confidence, through the use of an integrated probabilistic approach.

Furthermore, it is recognized that the safety analysis process has an underlying element of refinement whereby new information or revised models and uncertainty allowances are applied to evaluate their impact on calculated consequences. In the past, this has been accomplished by undertaking significant re-analysis, with no formal method for incorporating prior knowledge and experience. Therefore, another objective of the methodology is to provide a systematic, formal framework for incrementally incorporating new information and knowledge with prior information and knowledge, derived from existing analyses. This is a key feature designed to insure that safety analysis can be maintained current without requiring an ongoing extensive re-analysis effort.

ELEMENTS OF THE ANALYSIS METHODOLOGY

The elements of the safety analysis methodology are shown in Figure 2 and described below.

Technical Basis Definition

This element establishes the technical basis for a particular analysis. The main purpose of the technical basis is to systematically collect and document pertinent technical information that describes the underlying knowledge base. The safety concerns related to the accident scenarios under consideration (e.g. large LOCA, small LOCA, Loss of Flow, etc.) provides the specific focus for this element.

The technical basis includes the physical process behaviour exhibited during the progression of the accident; the physical phenomena that occur; and the modelling and physical representation of the plant. As such the technical basis serves as a repository reflecting current state-of-knowledge and, therefore, serves a role in knowledge transfer and training to new staff.

In particular, the following aspects are addressed in the technical basis:

Safety Evaluation Criteria

The criteria that are utilized to characterize the safety concerns and making judgements on the acceptability of the consequences of analyzed accident scenarios are collected and recorded, together with the underlying rationale supporting their use. These include, for example, criteria that are used to assess the effectiveness of reactor shutdown, such as trip parameter effectiveness criteria, the adequacy of fuel cooling, the assurance of fuel channel integrity, the effectiveness of heat sinks, the integrity of containment functions, and the acceptability of dose consequences. This information is included in the Technical Basis Document, the content of which is specified in an Ontario Power Generation Methodology Development Guideline.

Physical Phenomena

The physical phenomena, which influence the behaviour of the reactor system during an accident scenario, are collected and recorded. For each physical phenomenon, the following aspects need to be documented:

- A technical background summarizing the manner in which the phenomenon influences system behaviour during the accident scenario.
- A summary of the state of knowledge and uncertainties in quantifying the phenomenon. This includes, for example, physical models and empirical correlations that are used to simulate system behaviour, as well as their applicability with reference to supporting R&D results.
- A brief assessment of the potential impact of uncertainties in the phenomenon on expected behaviour during the accident.
- A list of related phenomena (i.e. other phenomena that are influenced by, or which influence the phenomenon being described).
- A list of references to papers, reports and other documents that describe or quantify the phenomenon.

This information is included in the Technical Basis Document as per specifications in an Ontario Power Generation Methodology Development Guideline (Guideline for Preparation of Technical Basis Documents).

Validation Matrices

CANDU validation matrices have been developed for all the major disciplines involved in accident analysis (Ref. 25). They identify and rank key physical phenomena for the accident scenario under consideration and identify the experimental database that is available for validating the relevant phenomena modelled by computer codes. The validation matrices are employed in developing the validation plans for specific computer codes and also provide systematic collations of historical R&D information.

Plant State Characterization

The technical data and information that is necessary to characterize and quantify the plant operating state and equipment and system configurations are collected and recorded. Typically, this information is derived from technical surveillance and system testing at site, and from design documentation.

Existing Analyses

Information from previous analyses, including identification of computer code versions, physical models used, assumptions and input data, and result files and documentation are assembled and referenced.

Analysis Basis Definition

This element establishes the basis for a particular analysis to be performed by systematically collecting and recording pertinent technical information relating to the computer codes to be used, their applicability to the analysis, assumption to be applied, and the reference data sets that represent the plant and physical models. In particular, the following aspects are addressed in the analysis basis:

Computer Codes and Physical Models

The versions of the computer codes to be used, together with references to the associated models that represent the underlying physical phenomena, are collected and recorded.

Computer Code Applicability

The applicability of computer codes for the safety analysis application needs to be established through relevant computer code validation. Based on the relevant validation matrices, computer code validation exercises are performed. The applicability of the computer code to the analysis is established with reference to the validation that has been performed.

Best Estimate Basis

The assumptions and supporting data that define best estimate conditions are collected and recorded. This may include assumptions relating to best estimate physical models and best estimate or "operating centre" Plant State. This information includes such items as safety evaluation criteria, physical and geometric modelling and plant characterization data.

Accident Scenario Characterization

The possible failure events and combinations of plant states that are to be considered in the analysis are identified. This establishes the analysis structure and scope. Through consideration of event combination frequencies and potential consequences, an appropriate set of safety evaluation criteria are selected which reflect approximately equal risk. Deterministic criteria (e.g. number of shutoff rods available, backup trip credited, etc.) can be applied via the assignment of appropriate probabilities such that they can be used in the integrated uncertainty analysis.

Additionally, the manner in which existing analysis results collected in the Technical Basis are to be employed, either to generate or validate Physical Interdependency Functional Relationships (see below) is specified.

Phenomena and Key Parameter Identification and Ranking

The phenomena and parameters that are of importance in postulated accidents are systematically reviewed and assessed. The outcomes of this systematic review are the Phenomena and Key Parameter Identification and Ranking Tables (PKPIRTs). The content and method of preparation of PKPIRTs is specified in an Ontario Power Generation Methodology Development Guideline (Guideline for the Preparation of Phenomena and Key Parameter Identification and Ranking Tables).

The parameters in a PKPIRT include the operational values of process variables, such as pressures, flows, temperatures and levels; reactor core state parameters, such as bulk and regional powers, flux tilts, and bundle and channel powers; parameters that relate to reactor safety systems, reactor and process control systems; parameters that characterize the physical geometry of equipment and components; and values of parameters used to model systems, components and physical processes in the computer analysis codes.

In the initial PKPIRT parameters are ranked according to their impact on relevant accident consequences, as quantified by the safety evaluation criteria. This focuses attention on a smaller set of key parameters that are important in an accident event. The final PKPIRT reflects the outcome of the analysis and summarizes the relative importance of the key parameters to the various safety concerns.

Physical Interdependency Functional Relationships

Functional relationships that describe the underlying physical interdependencies between parameters are developed. These relationships, which are used as a basis for quantification of the sensitivity of plant behaviour and specific safety consequences to the identified key parameters, are called Physical Interdependency Functional Relationships (PIFRs). This is a novel feature of the Ontario Power Generation methodology and is based upon the considerable body of work in the areas of Dynamic Systems Theory, Automatic Control Theory and System Identification.

Three levels of ascending detail are specified as acceptable means to generate PIFR, ranging from non-linear polynomial function fitting commonly used in response surface generation techniques to non-linear coupled differential equation representation of dynamic sensitivity based upon the variational methods of modern control theory.

These functions provide the basis for generating Functional Response Surfaces (i.e. the variation in a dependent parameter to combinations of variations of independent key parameters) and, in turn, provide the means for quantifying the integrated uncertainty in the quantitative safety criteria. They also provide the means for evaluating the sensitivity functions that are necessary for quantification in the PKPIRT process.

The requirements related to PIFRs, and their application to generate Functional Response Surfaces, are specified in an Ontario Power Generation Methodology Development Guideline (Guideline for the Preparation of Physical Interdependency Functional Relationships and Functional Response Surfaces).

Quantification of Uncertainty Components

All sources of uncertainty that influence the key parameters in an analysis, and hence contribute to the uncertainty in quantifying a safety concern, are systematically identified, classified, and quantified.

Identification and classification is the process of determining the nature of the uncertainty, that is, whether it is a systematic bias or whether it represents a random variation around a best estimate value. Quantification is the process of determining the values for a statistical model that describes the expected variability of parameters.

The sources of uncertainty to be quantified include:

- uncertainties related to the state of knowledge of physical processes and phenomena (typically from interpreting R&D results),
- uncertainties related to plant state, including plant process parameter variation,
- uncertainties related to plant system functional performance variation (e.g. setpoints, instrumentation delays, system response versus time), and uncertainties related to modeling physical behaviour (e.g. computer code uncertainty)

The process to be used in specifying best estimate parameter values and parameter uncertainty is contained in an Ontario Power Generation Methodology Development Guideline (Guideline for Specification of Best Estimate and Uncertainty Values for Plant and Modeling Parameters)

Integrated Uncertainty Analysis

The probability of acceptable safety consequences, as defined by the safety evaluation criteria, is quantified. The integrated uncertainty analysis uses the PIFR-based Functional Response Surfaces to generate outcomes that determine the conditional probability that a safety evaluation criterion will be exceeded as the underlying key parameters vary according to their defined statistical model of variability.

The results of the integrated uncertainty analysis provide the basis for quantifying safety margins to a specified level of statistical confidence. The ranges in parameter space for which safety consequences are acceptable, at the specified level of confidence, define a portion of the Safe Operating Envelope.

The process to be used in performing integrated uncertainty analysis is contained in an Ontario Power Generation Methodology Development Guideline (Guideline for Integrated Uncertainty Analysis)

APPLICATION OF THE METHODOLOGY

Application of the nuclear safety analysis methodology to date has been as follows.

Darlington Loss of Flow

A licensing quality submission of best estimate plus uncertainty analysis of a single heat transport pump trip in a Darlington unit was submitted in April 2000. This analysis was in support of a new ROH-to-ROH differential pressure trip designed to provide backup coverage for loss of flow events and allow the units to return to full power operation.

This analysis successfully demonstrated the effectiveness of both primary and backup trips to meet safety design criteria at high confidence levels (95%/95%) with significantly larger margins relative to LOE analysis.

Bruce B Large LOCA

A prototyping best estimate plus uncertainty analysis was submitted to the regulator as part of a commitment to develop the new safety analysis methodology. The results of this prototyping analysis were positive in that they demonstrated significant larger margins relative to LOE analysis to fuel centreline melting, fuel sheath melting and constrained fuel string axial expansion. Additionally, the preliminary results also indicated a low probability of pressure tube ballooning during the large LOCA, which is significantly different from limit consequence and LOE results.

An important feature of the Bruce B application was that no new analysis was performed specifically to support the application of the new methodology. Existing analysis dating back to the Safety Report update in 1994 was solely employed. This demonstrated the feasibility of implementing an incremental analysis approach as opposed to one involving large-scale reanalysis.

CONCLUSIONS

The evolution of safety analysis technology over the last two decades at Ontario Power Generation has been presented. The major issues that have shaped this evolution were described. The impact of adopting the limit consequence approach in the early 1980's has been major and has tended to distort the perception of consequences of LOCA accidents toward the more improbable severe accident domain at the expense of the more realistic design basis events.

The current effort to develop a new safety analysis methodology based upon a Best Estimate plus Uncertainty Analysis framework is aimed at re-establishing safety margins that are believed to exist and are expected to be large than those associated with deterministic limit of operating envelope analysis.

Based upon experience with applying this methodology it appears that the re-establishment of demonstrated margins is achievable. However, significant work remains to gain acceptance of the methodology and, based upon the historical evidence, avoid having the methodology drift once more into the domain of bounding conservatism.

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Using Thermal Neutron Activation To Detect Non-metallic Land Mines

by T.Cousins, T.A.Jones, J.R.Brisson[1], J.E.McFee[2], T.J.Jamieson, E.J.Waller, F.J.LeMay[3], H.Ing, E.T.H.Clifford and E.B.Selkirk[4]

Ed. Note: *The above team was awarded the CNS John Hewitt Team Achievement Award for their work on developing the detector described in this paper. The paper below is a slightly updated version of one published in the Journal of Radioanalytical and Nuclear Chemistry in 1998 under the title"The Development of a thermal Neutron Activation (TNA) System as a Confirmatory Non-metallic Land Mine Detector" .*

Introduction:

Estimates put the number of buried land mines at 110 million covering 64 countries, with a growth of about 2 million per year.[1]. These mines represent a threat to military forces and civilians worldwide.

The Canadian Department of National Defence (DND) has a clear need to detect and locate these buried landmines when carrying out its peacekeeping activities. This problem has been addressed by the DND Improved Landmine Detection Project (ILDP) which has designed, constructed and is testing a multisensor system.

The confirmatory element of the ILDP system involves positive detection of mines using Thermal Neutron Activation (TNA) and subsequent detection of nitrogen gamma rays. This paper describes the design and development of the system (both from electronic and radiation shielding aspects) and the results of laboratory and field trials. The TNA system is shown capable of confirming the existence of the vast majority of anti-tank (AT) mines and many anti-personnel (AP) mines in time periods ranging from a few seconds to a few minutes.

Background:

1) ILDP System

A comprehensive report by Defence Research Establishment Suffield (DRES) [2] concluded that no one detector could satisfy the needs of land mine (especially non-metallic land mine) detection. Rather a suite of four detection systems mounted on a single vehicle was proposed. See Fig (1).

The three detection systems on the front of the vehicle

- Electromagnetic Induction Metal Detector (EMI)

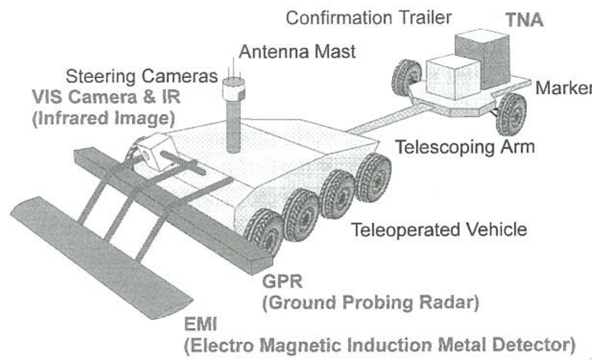

Fig. 1) Conceptual drawing of DND ILDP system showing the three primary detection systems and the TNA confirmatory detection system.

- Ground Probing Radar (GPR), and,
- Forward Looking Infrared Imager(IR)

work in concert as the primary system to detect a possible mine site. Each detector has advantages and drawbacks, but the combination of the three should serve to significantly reduce false alarms. Once a prospective mine site has been determined, it is physically marked and the confirmatory detector - TNA - is positioned above the mark. By examination of the activated gamma-ray spectrum, the TNA will either confirm or deny the existence of a mine at that particular location by counting for a preset amount of time.

The accuracy of the primary system in locating potential mine sites was estimated as ±30 cm. This served to determine source strength, detector type, shielding, mass and size for the TNA system.

2) TNA for Non-metallic Landmine Detection

All landmines contain explosives which in turn contain Nitrogen. Thus for the ILDP TNA system it was decided that, in the strictest sense, a nitrogen detector rather than an explosive (or landmine) detector would be built.

Upon thermal neutron capture Nitrogen emits a

1 Defence Research Establishment Ottawa
2 Defence Research Establishment Suffield
3 Science Applications International Corporation (SAIC Canada)
4 Bubble Technology Industries

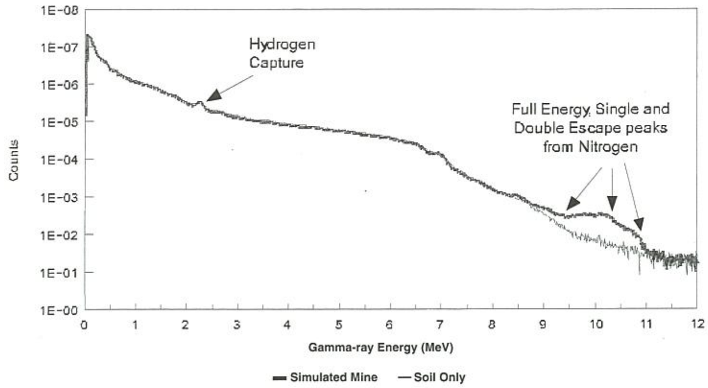

Fig. 2) Simulation experiment at DREO using weak ^{252}Cf source and one 2" x 2" NaI(Cl) detector with a 1 kg N "mine", for an 8 hour run.

number of prompt gamma rays. For landmine detection, the most attractive of these is the highest energy transition at 10.835 MeV which occurs with 15.00 % probability [3]. The main reason for choosing this transition is that at this high energy there will be virtually no competing reactions - save the weak 10.611 MeV transition from neutron capture in ^{30}Si (Silicon is a common constituent in most soils). The judicious choice of this transition also allowed for the use of poor-resolution (NaI(Tl)) detectors as opposed to high-resolution cryogenically-cooled detectors (intrinsic Ge).

In order to clarify the above, Fig (2) shows the results of early DREO experiments using a weak ^{252}Cf source (1 x 10^6 n/s) and a 2" x 2" NaI(Tl) detector. In order to simulate the mine, a container of fertilizer, with Nitrogen mass of about 1 kg, was used. Positive detection of Nitrogen reduces to the detection of a statistically significant number of counts above background in the energy region of interest - roughly 9 to 11 MeV. The excessive count time for this experiment (about 8 hours) clearly indicated the need for a stronger ^{252}Cf source and/or more efficient detectors in the final ILDP TNA system.

ILDP TNA System:

1) Basic System Parameters

Based upon the anticipated primary system detection accuracy, preliminary experiments and an analytical study, it was decided that the ILDP system would consist of the components as listed in Table 1.

Table 1
ILDP TNA System Components

Neutron Source Type	252 Cf
Neutron Source Intensity	1 x 108 n/s
Gamma-ray Detector Type	3" x 3" Nal (TI)
Number of Detectors	4 @ every 90°
Source-Detector Distance	30 cm

2) Shielding

Choice of shielding materials was based upon two considerations - shielding of the NaI(Tl) detectors from direct neutron and gamma-ray radiation from the ^{252}Cf source and biological shielding for personnel in the area. The computer code MCNP4A [4] was used to ascertain the effects of various combinations of materials. Fig (3) shows the final configuration.

This configuration lowered the count rate at the detectors to about 200,000 cps - which was a baseline for the electronics design described below.

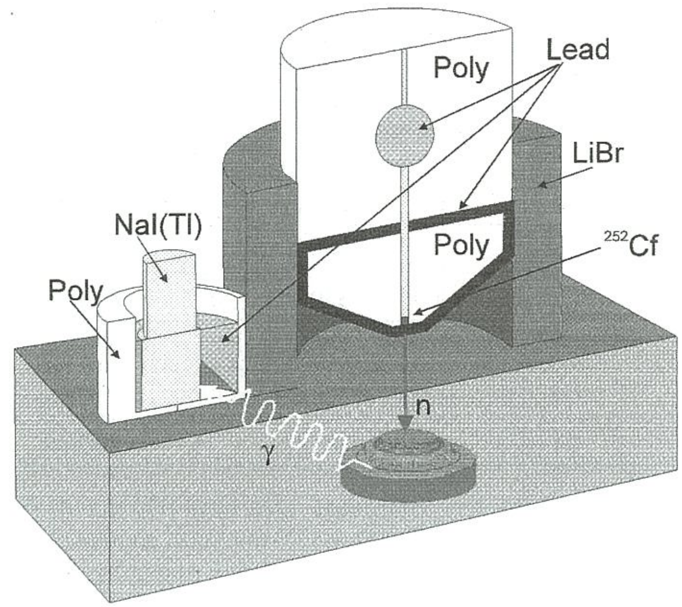

Fig. 3) Cut-away diagram of ILDP TNA head showing shielding materials.

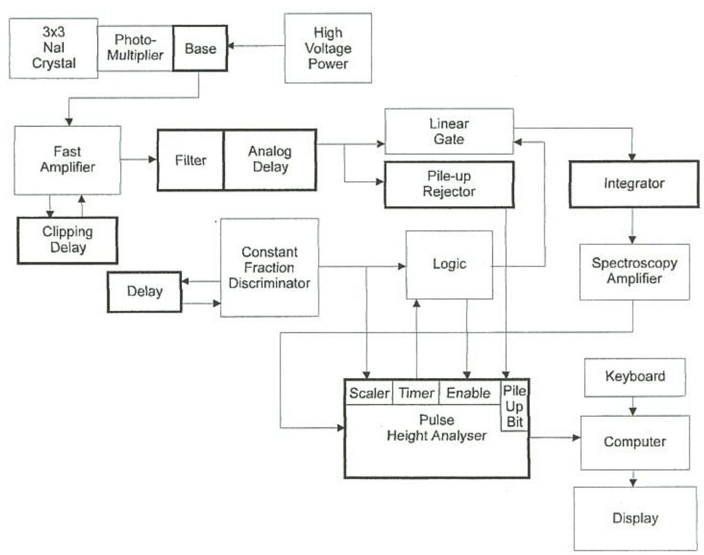

Fig. 4) Block diagram of electronics for ILDP TNA system. The electronics were designed to handle the very high count rates encountered near the source.

Table 2
Results of DRES Mine Detection Trials

Mine	Nitrogen Mass	Burial Depth (to top of mine)	Count Time for Positive Detection (93%) (s)
M15	3.6 kg	surface	5
M15	3.6 kg	3"	19
TMA3	1.2 kg	surface	6
TMA3	1.2 kg	3"	11
TMA3	1.2 kg	6"	37
M21	1 kg	3"	31
TMA5A	870 g	4"	48
C4	680 g	surface	8
C4	680 g	3"	20
C4	340 g	surface	14
C4	170 g	surface	45
C4	85 g	surface	254
C4	40 g	surface	>1000

The measured dose equivalent rates were 550 mSv/h (55 mRem/h) neutron and 26 mSv/h (2.6 mRem/h) gamma at the surface of the TNA head, and 18 mSv/h (1.8 mRem/h) neutron and 8 mSv/h (0.8 mRem/h) gamma at 1 m from the surface.

3) Detectors and Electronics

Fig (4) gives a block diagram of the detector and electronics system used for the ILDP TNA system. The sophisticated electronics were necessary since the observed count rates at the detector, even with the shielding described above, was roughly 200,000 cps. The main contributor to these counts are gamma-rays from the ^{252}Cf source, however neutron capture gamma rays from a variety of sources, including the NaI(Tl) crystal itself, contribute.

The NaI(Tl) crystal and photomultiplier tube are commercially-available models, but were pre-qualified based upon their abilities to handle both the rates and high energies expected. The base was built specifically for this project.

The first part of the electronics serves to lower the counting rate to 5,000 cps. This is accomplished by means of a fast linear gate controlled by a constant fraction discriminator (CFD) whose threshold was set to approximately 5 MeV. The linear gate is open for 160 ns for each accepted pulse. However it was observed that pileup was a problem when the gate was open, necessitating the use of pile-up rejection circuitry.

The pile-up rejector, specially constructed for this work, employed a gated-integrator technique [5] which rejected pulses based upon shape distortion compared to "normal". Both pre- and post-pile-up events could be detected. Using this technique, distortion in pulses as closely spaced as 15 ns could be detected, and the pile-up pulse would be rejected.

4) Data Acquisition and Analysis

a) Energy Calibration

As a prelude to data analysis accurate energy calibration was essential. This was accomplished by allowing the system to acquire a "background" spectrum - i.e. a spectrum with the TNA head sitting over an area known not to contain a mine. Three peaks generated by neutron activation in Aluminum within the head were prominent enough to be used for calibration - the full energy peak from the 6.103 MeV transition and the double and single escape peaks from the 7.726 MeV transition at 6.704 MeV and 7.215 MeV, respectively. A linear extrapolation of this fit into the energy region of interest was then performed. Fig (5) gives the result of experiments at DREO, showing both the effects of the pileup rejection circuitry and the energy calibration peaks.

b) Statistical Analysis of Data

Following acquisition of the background spectrum, the TNA head could then be moved to a marked location (suspected land mine site) and another spectrum acquired. Using the standard Gaussian detection limit approach [6] to low-level counting, the false alarm and mine detection probabilities were based upon the number of excess counts in the energy

Table 3
Radial Variation in System Sensitivity (M15 Mine Surface Buried)

Radial Distance of Mine to Source (cm)	Count Time for Positive Detection (93%) (s)
0	5
10 (between detectors)	4
20 (between detectors)	9
30 (under detector)	8
30 (between dectors)	80
40	>1000

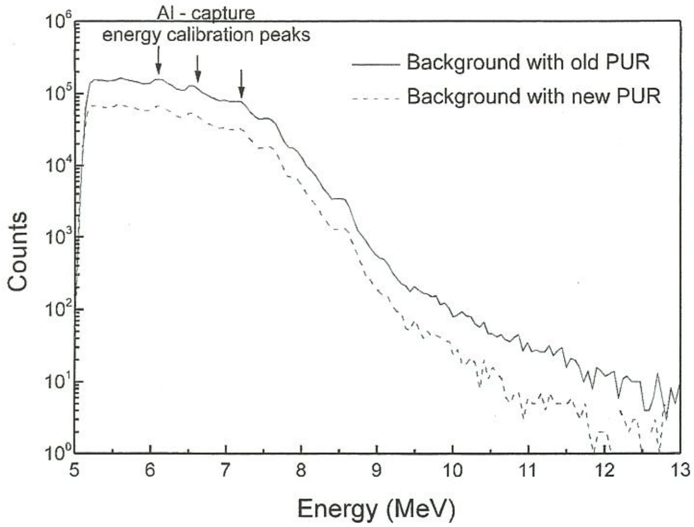

Fig. 5) Effects of pileup rejectors on measured energy spectrum. Note the large effects in the energy region of interest, roughly 9 - 11 MeV.

region of interest. Under certain circumstances of large background fluctuations or abnormal structure in the background spectrum (such as excessive silicon in the soil, for example) the detection limit statistical approach can generate false positive indications of a mine. To improve upon the detection probability, a combined Gauss-Bayes statistical approach was employed.[7]

Field Trials

Field trials of the ILDP TNA system were held at specially prepared mine fields at Defence Research Establishment Suffield (DRES) in Jan 1997. Weather conditions during these trials were adverse, but realistic - temperatures between - 200C and - 300C, with winds up to 50 km/h and snow cover of over 30 cm. Fig (6) shows the system in the field.

During the trials, four mines (M15, TMA3, M21 and TMA5A) representing different masses of nitrogen, were buried at different depths and interrogated. Additionally, different masses of C4 plastic explosive (34 % N by mass) were surface-buried and interrogated. Figs (7) and (8) show spectral results for

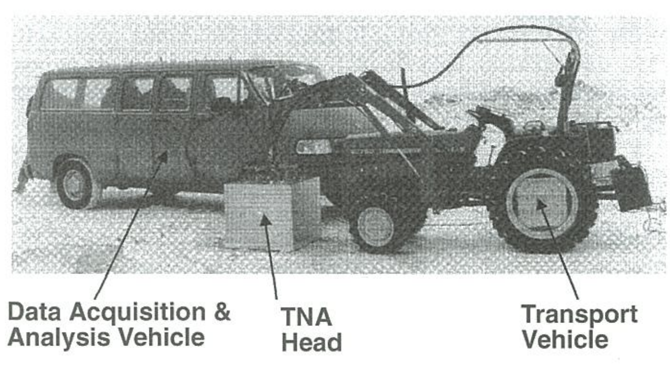

Fig. 6) Field trials of ILDP TNA system at DRES.

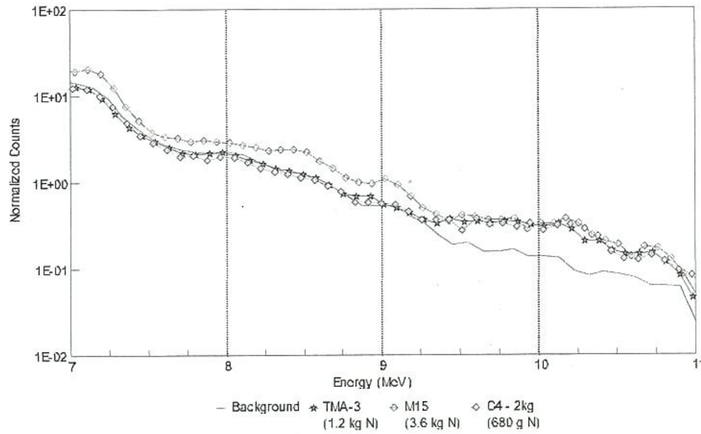

Fig. 7) Acquired energy spectra at DRES for "large" mines. All runs are 10 minutes. Note the structure in the M15 spectrum, due to the metallic shell.

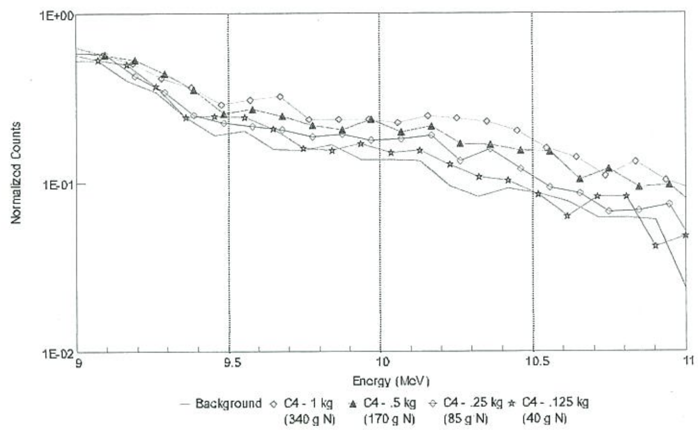

Fig. 8) Acquired energy spectra at DRES for "small" mines. All runs are 10 minutes. All save the .125 kg (C4) (40 g N) could be positively detected in less than 5 minutes.

these while the table below summarizes the experimentally determined count time for 93% detection probability. This count time was arrived at by an iterative solution to the statistical analysis techniques described above, based upon the experimentally measured background and net counting rates.

Two further sets of trials were conducted in the USA in 1998 which confirmed the effectiveness of the system.

Several features should be noted.

Firstly, for the case of the largest AT mine (M15) there is considerable structure below 9 MeV. This is likely due to neutron capture in other elements in the M15 mine - and the large peak at about 7.1 MeV may be the first escape from the prominent iron capture transition. This is supported by the fact that the M15 is encased in steel, while C4 and the other non-metallic mines are not.

Secondly there is an indication of structure in the background around 10.1 MeV, which could be the first escape from the Si-capture peak mentioned earlier (the soil at DRES is quite sandy, and thus high in Si-content). Silicon activation will eventually determine the final lower detection limit of the system.

Thirdly, from the table and the figures, the lower detection limit of the system is slightly under 100 g of N (for reasonable count times of less than 5 minutes). This means that the system is capable of detecting almost all AT mines (at depths down to 6") and many larger AP mines - which would be surface buried.

Finally one should note that there is virtually no difference in the positive detection counting times for some of the mines examined here, despite their large differences in mass of N (500 g to 3.6 kg). This is due to a convolution of the thermal neutron flux profile (which drops rapidly with depth) and the distribution of Nitrogen within the mines (for the physically larger M15, there is far more Nitrogen at greater depths than for C4, for example).

Experiments were also conducted to determine the radial field of view of the system. The results of these appear in table (3).

The field of view is quite constant out to about 25 cm, begins to drop rapidly thereafter, and at 40 cm detection is not possible (this is physically outside of the TNA head). This illustrates the importance of accurately locating the mine with the primary systems.

Discussion and Conclusions:

The ILDP TNA system has proven itself capable of confirmatory detection of land mines having N masses of greater than about 100 g in a few minutes, over a radial area of about 1200 cm2. This will enable almost all AT and large AP mines to be positively detected. Smaller surface buried AP mines (containing less than 100 g N) will be eliminated by such techniques as flailing. The system has clearly shown the ability to perform in adverse weather conditions.

Prior to the field trials in the USA several changes / modifications to the system were made, including

i) Replacement of the electronics modules with a miniaturized box.

ii) Automation of energy calibration, data acquisition and data analysis techniques as well as integrating TNA results into the full ILDP system.

Still being considered is the replacement of the radioisotopic source with a Cockroft-Walton neutron generator. A neutron generator has the advantage of only being radioactive when on - possibly lowering shielding requirements, and (potentially) having a lower background in the region of interest. However, an accelerator would be more complex and costly than the radioisotopic source.

The ILDP system is now undergoing formal DND "critical design review". When that is completed four systems will be ordered with delivery expected in mid 2001.

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Application of Low Doses of Radiation for Curing Cancer

by Jerry Cuttler, Myron Pollycove[1], James S. Welsh[2]

Ed. Note: *Jerry Cuttler joined the criticism of the liner, no-threshold hypothesis for biological effect of radiation several years ago and subsequently became intrigued with the work, largely in Japan, on the beneficial uses of low doses of radiation. Following is the basic text of a presentation he made in July 2000 to a group of health professionals in Toronto. Formerly with Atomic Energy of Canada Limited, Jerry now has his own company, Cuttler and Associates Inc.*

Abstract

Successful clinical trials of low dose irradiation therapy for curing cancer were carried out in the USA in the 1970s and, more recently, in Japan and France. A cure of colon cancer and a case study of the successful control of a cancer of the blood following this low-dose therapy are reported. The prompt, beneficial response of the patient's blood data to the radiation exposures supports the notion of radiation hormesis in humans. Widespread application of low dose therapy would help many cancer patients and could help to correct misconceptions and resolve the controversy about the biological effects of low doses of ionizing radiation.

Introduction

Beneficial health effects following low doses of ionizing radiation have been observed for more than a century, but such applications fell into disrepute in the early 1930s following incorrect association of such treatments with homeopathy and well publicized cases of large overdoses.[1] Fear of radiation was augmented by the use of A-bombs in World War II.. Fear of low-dose radiation was promoted when the linear no-threshold model of radiation carcinogenesis (LNT) was adopted by regulators to protect people from avoidable exposures to radiation.

The LNT model was challenged by scientists, from the beginning. A comprehensive review of contradictory data was produced by T.D. Luckey in his 1980 and 1991 books on *radiation* hormesis, a particular agent of hormesis – the stimulative effect of a *subinhibitory dose* of a stressing agent: physical, chemical or biological. His 1982 paper in the Health Physics Journal led Japanese investigators to request an assessment by the US EPRI and to an international symposium in 1985.

This event stimulated the start of a large research program in Japan to study this phenomenon.[2] In addition, organizations were formed, such as: Biological Effects of Low Level Exposures (BELLE) to chemicals and radiation, the International Committee on High Natural Background Radiation and Radon Areas (ICHNBRRA), and the International Centre for Low Dose Radiation Research (ICLDRR) at the University of Ottawa.

Japanese scientists published many scientific studies, which lent support to radiation hormesis. The controversy over the beneficial health effects following low doses has become intense as many of them realized that public fear of radiation is impairing application of nuclear technology.[3] Some believe this fear would diminish significantly if the net effect of low doses of radiation could be convincingly shown to be beneficial.

The overall assessment of the origins, history and scientific foundations of radiation hormesis by Calabrese and Baldwin[1] gave additional confidence in the existence of this phenomenon. Pollycove has provided a biological explanation of how low doses stimulate the body's natural defenses to prevent and cure cancers (and other diseases) and how high doses impair these defenses.[4]

The people with the greatest stake in the resolution of the controversy over low-dose radiation are the patients who suffer from cancer and other life-threatening diseases, such as diabetes.[2].

Cancer therapy with low doses of radiation

Administration of low-dose total-body irradiation (TBI) therapy to patients with non-Hodgkins lymphoma, receiving standard chemotherapy and localized high dose radiation of tumors, was reported from Harvard University by Chaffey et al[5] and Choi et al[6], from Tohoku University, Japan by Sakamoto et al[7] and from Institut Bergonie RCC by Richaud et al.[8]

The Harvard 1976 and 1979 studies reported that low-dose TBI increased the four-year survival to 70% and 74% of those treated, which is greater than that of the controls, 40% and 52% of those treated, respectively, who received early COP and subsequent CHOP chemotherapy and local high-dose radiation. Similar TBI, or equally effective upper half-body irradiation (HBI), therapy at Tohoku University increased four-year survival to 84% of those treated, which is greater than the survival of the controls, 65% of those treated, who received CHOP and local high-dose radiation therapy. All Japanese patients receiving TBI or HBI survived five additional years, while the survival of the controls at nine years was 50% of those treated. Sakamoto stated that 12-year survival of these 20 patients continues to be 84%.[9] The Bergonie Institut reported that low-dose TBI was very well tolerated, gave a high response rate (83%) and extended recurrence-free survival. Safwat provided a new, positive assessment of this therapy.[10]

Japanese medical scientists have been studying the effects of low doses of radiation on living organisms for more than 20 years.[2] Sakamoto carried out research on mice from the late 1970s.[7] Over the past ten years, he has treated ~150 cancer patients using repeated TBI or HBI treatments of 10 to 15 cGy (rad) – 30 cGy per week for five weeks – a total dose of 150 cGy, and has achieved beneficial results including long-term cures with no symptomatic side effects.

It would appear that many cancer patients[3†] could benefit greatly from this therapy, at little (if any) risk.

Total body irradiation for Kiyohiko Sakamoto MD

Dr. Sakamoto, at age 66, is himself a survivor of advanced colon

1 Dr. Myron Pollycove is an adviser with the U.S. Nuclear Regulatory Commission, Rockville, MD.

2 Dr. James Welsh is on the staff of the Johns Hopkins Medical Insititue, Baltimore, MD.

3 † In the USA, more than a quarter of human mortality is due to cancers of all types.

cancer. Following surgery to remove tumors in three places, he was in very poor health. After applying his TBI protocol to himself in July 1997 and repeating it in February 1998 as a booster, he recovered to excellent condition.[9]

Total body irradiation for Edward J. Bauser[11]

US Navy Captain (retired) E.J. Bauser, age 81, has Waldenstrom's Macroglobulinemia – a rare cancer of the blood – another incurable lymphoma. With the present median survival rate of five years, there are between 6000 and 12,000 people with this disease in the United States at any one time; the incidence rate is approximately 1000 per year.

Mr. Bauser explained that the problem is the overproduction of a normal protein, IgM, in his bone marrow where both the lymphoma and new blood cells grow. Not only does this impair (starve) production of new white cells, red cells and platelets; the very high concentration of this protein makes his blood very thick, putting a strain on his heart. It also leads to strokes and other problems. The symptoms normally associated with this disease are weakness, fatigue, drowsiness, fever and other symptoms.

The disease was first diagnosed in 1992, during analysis of a sample of his bone marrow. Regular blood tests followed for several years as plasma viscosity and IgM concentration continued to increase to the point where his marrow was fully packed with lymphoma cells. The IgM concentration in the blood reached ~4000 mg/dL, well above the normal range of 50 to 330.

In January 1998, Bauser was placed on oral chemotherapy for six months. During this treatment, he experienced nervousness and extreme sleeplessness, but the IgM and plasma viscosity decreased to about one-half of the highest readings. This treatment had to be stopped because complete loss of the marrow blood cell system can result from over-medication.

The symptoms of the disease began to return after the termination of the chemotherapy. Bauser's colleague from the Rickover nuclear submarine propulsion program, Dr. Ted Rockwell, informed Bauser about a low-dose, total-body irradiation (TBI) therapy which had been developed in Japan. It appeared to have no adverse side effects. Bauser contacted Dr. Myron Pollycove, who was familiar with this medical protocol, and eventually more than a dozen medical and radiation oncologists at various medical institutions in the US. He asked whether they would agree to perform this irradiation procedure on him, but was unable to arrange for the procedure at any of these institutions. Bauser was also told that his bone marrow blood cell system would be completely destroyed by such a treatment.

Dr. Pollycove referred Capt. Bauser to Dr. James S. Welsh at the Johns Hopkins Medical Center in Baltimore. Dr. Welsh reviewed all of the Harvard and Japanese data on the procedure and concluded it had sufficient merit and a low enough risk to justify its use.

Dr. Welsh began the TBI therapy at Johns Hopkins on September 10, 1999 and completed it on October 11. The doses were 15 cGy, twice a week, for five weeks – ten exposures totaling 150 cGy. Bauser experienced no discomfort whatsoever from this procedure. His IgM readings improved from ~4000 to ~1600 protein mg/dL, which is similar to the improvement achieved with chemotherapy a year before. His spleen, which had enlarged as a symptom of the illness, decreased 30% to normal size following the TBI therapy. The viscosity of his plasma decreased: 3 to 1.7.

Due to marrow sensitivity, the TBI therapy depressed the platelets and white blood cells somewhat, but they returned to normal within 1-2 months. The red blood cell count decreased by only 17% and recovered.

Some months after TBI therapy, the IgM reading began to increase again, reaching 3200 mg/dL in April 2000. Bauser was examined and found to be in healthy shape, "for a person of any age." Dr. Welsh then administered a booster series of the same low-dose irradiations, from April 21 until May 23, but limited them only to the spleen. (Sakamoto's research on mice[7] suggested that low-dose irradiations, localized to the spleen, would produce a beneficial effect like that of TBI, with insignificant marrow suppression.) The IgM concentration stopped increasing, and the June 20 blood sample showed a decrease to 2470 mg/dL, with no decrease of blood platelets or white blood cells.

Bauser praises his association with the Johns Hopkins Medical Centre – "a fine, highly professional organization. I have never been treated with such consideration; they care!" He is quite optimistic about the prospects for success and is keen to cooperate in the development of knowledge on this radiation procedure. He hopes it will allow him and others to avoid the sickening side effects and complications of chemotherapy.

Conclusions

The prompt, favourable responses of the IgM concentration and plasma viscosity to these applications of low-dose therapy supports the notion of radiation hormesis in humans.

The ease of application, short duration and lack of any significant, adverse side effects suggest this therapy is advantageous for treating cancer, by stimulating the body's natural defenses. Yet many oncologists seem to be very reluctant to employ low-dose irradiation therapy.

Widespread use of this therapy for cancer and study of its applications for treating other diseases would help resolve the controversy over the beneficial effects of low doses of ionizing radiation and lead to greater public acceptance of all nuclear technologies.

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GENERAL news

Bruce Power Applies for Licence

Mike Taylor, deputy director general, Reactor Regulation, at the Canadian Nuclear Safety Commission (CNSC) has informed the CNS Bulletin that Bruce Power submitted its formal application for Operating Licences for the Bruce A and B nuclear power stations on August 2, 2000. He commented that it was a comprehensive submission which appeared to address all of the questions the Commission had identified.

In the interim, the CNSC was scheduled to consider a renewal of OPG's Operating Licence for Bruce A at its August 16 hearing.

On July 11, 2000, Ontario Power Generation Inc. (OPG) and British Energy plc jointly announced that an agreement had been signed between Bruce Power Partnership (Bruce Power) and OPG which on completion will result in Bruce Power entering into a lease up to 2018, with an option to extend for up to another 25 years. Bruce Power is owned by British Energy Canada Ltd. which, in turn, is a wholly owned subsidiary of British Energy plc.

The agreement provides for an opportunity for the two main unions on site, the Power Workers' Union and the Society of Energy Professionals to each subscribe to 5% of the equity.

The transaction involves the following proposed payments by Bruce Power to OPG:

a) $625 million, representing the initial lease payment of $540 million and the acquisition of stocks and other assets valued at $85 million, both subject to various adjustments. A first payment of $400 million will be made on closing subject to normal closing adjustments. The remaining $225 million will be paid in two installments of $112.5 million each.
b) Annual rent payments thereafter, partly varying with market conditions and plant output. These payments are estimated to be about $150 M in calendar year 2002.

Financial close is expected to take place by summer 2001 subject, inter alia, to Bruce Power obtaining the appropriate licences, permits and consents including licences from the CNSC and the Ontario Energy Board.

Bruce Power will offer employment to all employees at the Bruce site, other than those being retained by OPG. Employees remaining with OPG include those that provide waste management and centralized nuclear operations support services. Bruce Power will accept the current collective bargaining agreements and will safeguard existing pensions and other benefits. It also proposes to enter into discussions with the unions to develop new working arrangements for the new company.

OPG had invited bids for the Bruce stations as part of its move to respond to conditions of its operating licence from the Ontario Energy Board to reduce its share of generating capacity in Ontario to no more than 35 per cent of that available to the province 10 years after the market opens. British Energy was selected following an extensive worldwide competitive process over the last two years. There were, reportedly, several bidders. British Energy has significant operating experience and a proven safety track record with a range of nuclear reactor types. It is the largest electricity generator in the United Kingdom where it owns and operates 15 reactors. Through its joint venture, AmerGen, it is involved with a further two in the USA.

Bruce Power will sell the output of the Bruce stations into the new Ontario electricity market. Bruce Power reports that it has already signed off-take contracts with third parties in respect of a significant proportion of its anticipated output for periods of between three and five years and intends to enter into further off-take contracts in due course.

Each of the two power stations on the Bruce site have four reactors. Those of Bruce A, with an aggregate capacity of 3 GW (approx), were commissioned between 1977 and 1979 and are currently out of service having been laid up at different times since 1995. The Bruce B reactors were commissioned between 1984 and 1987. They also have an aggregate capacity of 3 GW (approx) and are all operational, achieving an average capability factor of 79% over the last five years. Bruce Power officials state that they believe that there is scope for restarting two of the reactors on Bruce A and will shortly undertake an engineering and regulatory review program to confirm the technical and commercial feasibility of doing so.

Robin Jeffrey, the Chairman and CEO of British Energy Canada Ltd. was quoted as saying, "We are delighted to have the opportunity to invest in Ontario's deregulating electricity market. British Energy plc has a high regard for CANDU technology and for the skills of the staff at Bruce. Through working with the staff and unions, we believe that, Bruce Power can achieve world class safety and commercial performance."

More food irradiation approvals in USA - none in Canada

On July 21, 2000 the U.S. Food and Drug Administration (FDA) published in the Federal Register its final approval for the use of irradiation to reduce Salmonella in fresh shell eggs. This ruling comes as a result of a petition filed in 1997 by Dr. Edward Josephson at the Food Science and Nutrition Research Centre, University of Rhode Island with MDS Nordion as a co-petitioner.

Consumer acceptance in the USA of irradiated foods is growing. In the past three years, more than one million pounds of Hawaiian fruit has been irradiated using an MDS Nordion-built gamma irradiator just outside Chicago, Illinois. After the FDA approval of the irradiation of red meat earlier this year, several grocers and meat markets in Florida have been selling beef that has been irradiated by Food Technology Service Inc., employing MDS Nordion's gamma technology. The company has been irradiating chicken for food distributors and local supermarkets since 1992.

The U.S. Department of Agriculture issued final regulations for the irradiation of red meat on February 22, 2000, allowing irradiation of raw ground beef, steaks and pork chops to prevent food-borne illness by destroying harmful pathogens such as E.coli O157:H7.

Irradiation is a safe and effective way to eliminate food pathogens and can also be described as ion pasteurization because it is comparable to the process of pasteurizing milk. Food irradiation has the support of numerous health organizations, such as the World Health Organization, the American Dietetic Association, and the American Medical Association.

The US Center for Disease Control attributes 9,000 deaths every year to food-borne disease Children, the elderly, and people being treated for serious illness are most at risk. Last year Canada experienced the largest and most serious food-borne disease outbreak in Canadian history. More than 800 cases were reported across the country.. Over 80% of these involved children and many were hospitalized.

Health Canada has yet to act on a 1998 petition by the Canadian Cattlemen's Association to allow irradiation of red meat. A petition to permit irradiated poultry has languished for 6 years. Craig Hunter of MDS Nordion has commented, "As one of the world's largest providers of irradiation technology, it is ironic that the Canadian government will not embrace a safe and effective Canadian solution to help prevent such outbreaks here in this country,"

US authorities have now approve irradiation of: pork, poultry, red meat, vegetables fruit, spices, herbs. Canada has approved irradiation of potatoes and onions (for sprout inhibition) wheat, spices and herbs. Among petitions still pending in Canada are: chicken, May 1993; fruit, Oct. 1994; red meat, March 1998.

CNSC decisions

Over the period since the last issue of the CNS Bulletin, the Canadian Nuclear Safety Commission has made a number of licensing decisions, including the following:

- The operating licence for the irradiation facility of Shield Source Inc. at Peterborough, Ontario was renewed for three years, with a requirement for a report in one year.
- Canadian Light Source Inc. in Saskatoon, Saskatchewan, was granted a Construction Licence for its large accelerator. See Vol. 20, No. 2 issue of CNS Bulletin.)
- Renewed the Operating Licences for three years for the SLOWPOKE reactors at: University of Alberta, Saskatchewan Research Council, Royal Military college, Dalhousie University, Ecole Polytechnique, and the University of Toronto (even though the last has been shut down for over a year).
- Granted approval for the start-up for MAPLE 2, the second isotope production reactor being built at AECL's Chalk River Laboratories, for MDS Nordion, although there were many questions raised about problems in the commissioning of MAPLE 1

Swedish shutdown leads to more CO2

According to the European Nuclear Society the shutdown of the Barsebäck 600 MW nuclear power plant last fall by the Swedish government (as part of its nuclear phase-out policy) has resulted in a significant increase in emissions of CO2 and other greenhouse gases, in another country. To replace the lost generation Sweden has been importing electricity from Denmark which produces it using 100,000 tonnes of Russian and Polish coal monthly.

India's 12th NPP enters service

India's twelfth nuclear power plant, Rajasthan 3, a 220 MWe nuclear plant with a pressurized heavy water reactor, started commercial service in July. The operating plants consist of two of BWR design near Madras, of 170 MWe each; the rest are PHWRs

Like most of India's nuclear power plants, Rajasthan 3 is descendant from the 200 MWe Douglas Point design, the first full scale CANDU unit. Douglas Point was built at what is now the Bruce site and operated from 1966 to 1984. The first unit at Rajasthan was a direct copy of Douglas Point and was built with Canadian assistance. It began operation in 1973 and is now operating at 150 MWe. All nuclear cooperation with India was discontinued after that country denoted a nuclear explosive in 1974 which used plutonium produced in the Canadian supplied CIRUS research reactor.

Rajasthan 3 has advanced control and monitoring systems developed by the state Nuclear Power Corporation, two shutdown systems and double containment. Its seismic design has also been upgraded.

Over the years India has modified and improved the design of their PHWR plants while keeping them at the 200 MWe size. Two further plants similar to Rajasthan 3, Rajasthan 4 and Kaiga 1, are nearing completion. India has developed a 500 MWe version of the design and two units are under construction, Tarapur 3 and 4.

AECB becomes CNSC

On the morning of May 31, 2000 in Ottawa, there occurred a brief formal session that saw the five members of the Atomic Energy Control Board dissolve the AECB and reconstitute themselves as the first commissioners of the Canadian Nuclear Safety Commission.

This was the culmination of a process that began several years ago and resulted in the passing of the Nuclear Safety and Control Act in March 1997. That Act when in force, would replace the Atomic Energy Control Act of 1946. Before it could be put into force all of the associated regulations had to be in place, This required revising and updating of the regulations that had been issued under the AEC Act as well as writing new ones. After three years of work and consultation the new set of regulations were approved by the Board at its March 23, 2000 meeting. (See Vol. 21, No. 1 issue of the CNS Bulletin.) Following formal acceptance of the new regulations by the government everything was in place for the declaration that the NS&C Act was in force. The new regulations came into effect at the same time as the transformation of the AECB into the CNSC.

Among the new or significantly modified regulations are ones applying:

- lower dose limits
- more clearly defined powers for inspectors
- increased penalties
- power to demand financial guarantees for decommissioning and waste management

One of the more visible changes is the more formal nature of the Commission's meetings. They now include a "hearing" session in which licensing issues are considered, as well as a general meeting period primarily for information. A new CNSC publication INFO 0715 Canadian Nuclear Safety Commission - Public Hearings on Licensing Matters" describes the process. In general there will be two hearings for licensing issues, one to receive the application and reports from the CNSC staff and the second primarily to receive input from intervenors.

The CNSC has a new Web site: < www.nuclearsafety.gc.ca >

Obituary

(The following note was inadvertently left out of the previous issue of the CNS Bulletin.)

Dr. John Robson, one of the pioneers of the Canadian nuclear program, died in Peterborough, April 29, 2000.

Born in London, England, in 1920, he studied at Cambridge University. On obtaining a bachelor's degree in 1942 he was recruited for the wartime radar program. After the war he returned to Cambridge to obtain a masters degree in physics in 1945. Later that year he came to Canada as part of a British team to work at the Chalk River Nuclear Laboratories then under construction. When others of the team returned to the UK he decided to remain in Canada

While at Chalk River he occasionally lectured at the University of Ottawa and, in 1960, he accepted the post of chair of the physics department there. While at the University of Ottawa he wrote a doctoral thesis based on his research on the decay of neutrons and received a D.Sc. From Cambridge in 1963. In 1968 he moved to become head of the physics department at McGill University in Montreal where he remained until his retirement in 1985.

CNS news

Annual General Meeting

Outgoing CNS president Krish Krishnan (L) passes the traditional gavel to 2000-2001 president Ken Smith at the Annual General Meeting, June 12, 2000, in Toronto.

The Annual General Meeting of the Canadian Nuclear Society was held Monday afternoon, June 12, 2000, in the Delta Chelsea Hotel, Toronto, in the wings of the 21st CNS Annual Conference. This was the third AGM of the society as an incorporated organization. There were 59 registered members in attendance.

The meeting followed the standard pattern. Minutes of last year's AGM, held in Montreal during the CNA/CNS conference, were approved and, with no business, arising was followed by reports from the outgoing president, Krish Krishnan and treasurer, Andrew Lee. *(Krishnan's report is printed below. The financial reports are presented elsewhere in this issue of the* CNS Bulletin.).

The chairs of the various committees presented brief oral comments to augment their written reports which were tabled with copies available for the participants. Bill Clarke, new president of the Canadian Nuclear Association spoke on the move of their offices to Ottawa and their focus on government policy, regulation and public acceptance. He commented that a memorandum of understanding was being developed to formalize the relationship between the CNA and the CNS.

Paul Thompson introduced a motion to modify the By Laws of the Society to increase the maximum number of elected Council members from 18 to 22. After seconding by A. Hadfield the meeting unanimously approve the change.

Then, as past-president and chairman of the nominating committee, Paul Thompson formally presented the slate of candidates for Council that had been distributed with the notice of meeting. There being no further nominations from the floor he moved that those on the slate be declared elected by acclamation. Frank Stern seconded the motion and the meeting quickly voted in favour.

Following tradition, outgoing president, Krish Krishnan, passed the inscribed gavel to incoming president, Ken Smith and turned the chairmanship of the meeting over to him. He called on Paul Thompson who presented a plaque to Krishnan in recognition of his services to the Society. Paul noted that, in a sense, Krish had served a year and a half because he (Paul) had been so limited in his activities following his severe car accident in December 1998. *(See Vol. 19, No. 4, CNS Bulletin.)*

In his brief address as incoming president Ken Smith spoke of the key elements he considered necessary for the CNS to move forward. (See Incoming President's Message.)

Before closing the meeting, Ken Smith noted that Sylvie Caron, who, in her twelve years with the CNA was the primary administration person for the CNS, had left the CNA to return to Montreal. With a round of applause, attendees recorded their unanimous appreciation of Sylvie' service to the CNS over those twelve years .

The meeting was adjourned at 6:45 p.m.

(Note: The draft minutes of the Annual General Meeting, with attachments, will be posted on the Society's web site < www.cns-snc.ca >)

Paul Thompson (R) presents a plaque to outgoing CNS president Krish Krishnan for his services to the Society, at the Annual General Meeting, June 12, 2000.

President's Report to AGM, June 12, 2000

Welcome to our third Annual General Meeting. I will describe briefly the highlights of the Society's activities in the past year, and the major tasks that lie ahead. Detailed reports from the Committee and Division chairs will follow later in the meeting.

We had a busy year as usual. In fact, it began with a major challenge. Early in the year, the Canadian Nuclear Association (CNA) announced their intention to relocate their offices to Ottawa. As you know, we had been sharing offices with the CNA for over 20 years. We carefully reviewed various options to continue providing you with office services effectively and economically. Thanks to the CANDU Owners Group (COG) our office space problem was solved, at least in the short term. COG has donated the use of a portion of their offices, until we can find a permanent solution. We also contracted with DPR Consulting to provide office administration services. These two measures have allowed us to continue our business with minimal disruption.

- Financially, we closed the 1999 year with a small surplus, thanks to better than expected revenues from conferences and courses. These are important activities and achieve the Society's objective of promoting the exchange of information related to the peaceful uses of nuclear science and technology. Of the five CNS Technical Divisions three (Nuclear Science and Engineering, Fuel Technologies, Environment and Waste Management) organized successful events during the year. The Design & Materials, and Nuclear Operations Divisions have planned conferences later this year.
- The various CNS branches have been active, some more than the others, in reaching out to the membership. The Sheridan Park Branch has been at the forefront again in organizing seminars, followed by Chalk River, New Brunswick and Toronto. I would like to appeal to all the Branch chairs to organize a few seminars or other events of interest to the membership every year. Branches form the backbone of the Society and represent the first-level link with the membership and the public.
- The Universities Committee under the leadership Bill Garland made a presentation to the AECL R&D Advisory Panel on the current concerns about the situation in nuclear education. It organized the Annual Student Conference, and has also started the CANTEACH project. The latter has the objective of producing technical educational material on CANDU reactors.
- The Intersociety Affairs Committee headed by Parviz Gulshani has formed collaborative ties with a number of technical societies in Canada. The committee is currently discussing a collaboration arrangement with the Engineering Institute of Canada. Early in the year, the Committee submitted a proposal on an interactive CANDU reactor exhibit to the Ontario Science Centre on behalf of the CNS, AECL and OPG.
- The Education and Communications Committee's Science of Nuclear Energy and Radiation Course has received recognition by the New Brunswick Department of Education, thanks to efforts by Clair Ripley and Mark McIntyre. The Department is offering the course as a summer institute in July.
- I am sure you have noticed that our Bulletin content has increased in recent issues. The articles are interesting and there are more of them to read. I want to thank Fred Boyd for doing an outstanding job as Bulletin editor. This is a service that we members should all be pleased to receive. I for one eagerly look forward to receiving my copy of every issue of the Bulletin
- The CNA has appointed Bill Clarke as its new President and CEO. I would like to assure Bill Clarke that the CNS values its long-standing relationship with the CNA. The work of both organizations is important in maintaining a strong and vibrant nuclear scene in Canada. Despite their relocation to Ottawa, our hope is that we will continue to work in close cooperation with one another. We wish Murray Stewart, the former CAN President and CEO, all the best in his endeavors, which I'm sure will include nuclear.
- The present young generation (YG) must carry the mantle of nuclear in the future. I am encouraged to see several YG representatives in Canada becoming actively involved in promoting nuclear. However we need to bring more of them into the picture. The CNS should give them all the support they need.
- ITER Canada has selected Clarington as the site for its bid to host the ITER facility. Should Canada win the bid, the opportunities for nuclear science and engineering in Canada will be tremendous. The CNS is a supporting member of ITER Canada, and therefore we must do our best in helping bring the facility to Canada.
- Public acceptance of nuclear science and technology is going to be paramount in the future. No matter how good, safe, or competitive we think a nuclear science and technology product is, the general public must accept it as good, safe and competitive. The CNS must continue to work to educate the general public on the benefits of nuclear.
- Strengthening the membership base continues to be a challenge. We are still short of my personal target of 1000 members. Ben Rouben has worked hard to sign up new members and to remind past members to renew. Membership fees are an important revenue source, necessary for the conduct of the Society's business. So please send in your annual fees on time and encourage others to join the CNS. Remember the CNS is not just Council. It is all of you.

It was an honour and a privilege serving you as your President this past year. I thank you for the opportunity. Your new President-elect Ken Smith is an able and energetic individual with many years' experience in the nuclear industry. Please extend him the support you gave me in leading us through the challenges that face us.

Sincerely,
V.S. (Krish) Krishnan
President

CANADIAN NUCLEAR SOCIETY

FINANCIAL STATEMENTS

December 31, 1999

Ed. Note: *Although the Canadian Nuclear Society operates functionally, and the term of officers runs, from one Annual General Meeting (typically in June) to the next, the fiscal year is the calendar year. The following financial statement, for calendar year 1999, was tabled at the Annual General Meeting of the Society held in Toronto, June 12, 2000.*

As CNS treasurer Andrew Lee noted, a significant predicted deficit became a modest excess of revenue over expenses because of higher than expected income from conferences and courses. He thanked all of the organizers for their efforts.

Auditor's Report

To the Members of the Canadian Nuclear Society

I have audited the balance sheet of the Canadian Nuclear Society as at December 31, 1999 and the statements of revenue and expenses, changes in net assets and cash flows for the year then ended. These financial statements are the responsibility of the Society's Council. My responsibility is to express an opinion on these financial statements based on my audit.

I conducted my audit in accordance with generally accepted auditing standards. Those standards require that I plan and perform an audit to obtain reasonable assurance whether the financial statements are free of material misstatement. An audit includes examining, on a test basis, evidence supporting the amounts and disclosures in the financial statements. An audit also includes assessing the accounting principles used and significant estimates made by management, as well as evaluating the overall financial statement presentation.

In my opinion, these financial statements present fairly, in all material respects, the financial position of the Society as at December 31, 1999 and the results of its operations, changes in its net assets and its cash flows for the year then ended in accordance with generally accepted accounting principles.

The financial statements as at December 31, 1998 and for the year then ended were audited by other chartered accountants who expressed an opinion without reservation on those statements in their report dated March 4, 1999.

David W. Rogers, Chartered Accountant
Markham, Ontario
March 1, 2000

CANADIAN NUCLEAR SOCIETY
STATEMENT OF REVENUE AND EXPENSES
Year Ended December 31, 1999

		1999		1998
REVENUE				
Membership fees	$	36,299	$	37,475
Publications		6,390		8,228
Advertising		3,849		2,800
Memorial Trust Fund interest		77		—
Education Fund interest		2,594		2,395
Sponsorships		1,500		—
Investment income		13,766		15,777
		64,475		66,675
Projects - excess (deficiency) of revenue over expenses				
Annual Conference		17,892		21,506
Prior conferences/courses		580		3,753
1998 Lattice Physics Course		—		6,755
1998 Steam Generator and Heat Exchanger		(363)		25,669
1998 Pacific Basin Nuclear		433		96,482
1999 Candu Fuel (Note 6)		30,000		—
1999 Reactor Safety Course - March (Note 6)		12,517		—
1999 Reactor Safety Course - November (Note 6)		15,870		—
1999 Climate Change (Note 6)		26,066		—
1999 Candu Quality Assurance Course (Note 6)		3,913		—
		106,908		154,165
		171,383		220,804
EXPENSES				
Net expenditures by branches		8,523		16,513
Committees		12,326		22,569
Office overhead		85,225		76,481
Office operations		9,358		10,869
Canadian Nuclear Society Bulletin		33,848		36,869
Other items		18,448		26,123
		167,728		189,424
Excess of revenue over operating expenses		3,655		31,416
Expenditures from Special Projects Fund (Note 7)		—		14,501
Excess of revenue over expenses	$	3,655	$	16,915

BALANCE SHEET

December 31, 1999		1999		1998
ASSETS				
CURRENT				
Cash				
Bank accounts	$	292,970	$	230,542
Memorial Trust Fund		1,392		1,615
Nuclear Operations Division		1,793		1,793
Branch bank accounts		7,552		9,614
Accounts receivable		—		49,197
Sales taxes recoverable		2,177		3,187
Prepaid expenses		4,985		4,940
		310,842		300,888

INVESTMENTS (Note 3)		65,835		65,071
EDUCATION FUND (Note 4)		49,987		50,393
EQUIPMENT (Note 5)		1,351		1,931
	$	428,015	$	418.283

LIABILITIES

CURRENT

Accounts payable and accrued liabilities	$	23,239	$	22,848
Membership fees received in advance		24,372		18,884
Due to Canadian Nuclear Association		14,458		14,260
Portion of Education Fund due to CNA (Note 4)		28,000		28,000

NET ASSETS

Invested in capital assets	1,351	1,931
Internally restricted		
Memorial Trust Fund (Note 8)	1,392	1,615
Special Projects Fund (Note 7)	18,117	18,117
Education Fund (Note 4)	21,987	22,393
Unrestricted	295,099	290,235
	337,946	334,291

CANADIAN NUCLEAR SOCIETY
STATEMENT OF CHANGES IN NET ASSETS

Year Ended December 31, 1999

	Invested In Capital Assets	Special Projects Fund	Education Fund	Memorial Trust Fund	Unrestricted	1999 Total	1998 Total
Beginning of year	$1,931	$ 18,117	$ 22,393	$1,615	$ 290,235	$334,291	$311,591
Transfer of accumulated interest from CNA	—	—	—	—	—	—	5,785
Excess of revenue over expenses (expenses over revenue)	—	—	(406)	(223)	4,284	3,655	16,915
Amortization	(580)	—	—	—	580	—	—
End of year	$1,351	$18,117	$21.987	$1,392	$295,099	$337,946	$334,291

CANADIAN NUCLEAR SOCIETY
STATEMENT OF CASH FLOWS

Year Ended December 31, 1999

		1999		1998
Increase (decrease) in cash				
OPERATING ACTIVITIES				
Excess of revenue over expenses	$	3,655	$	16,915
Amortization		580		635
Net fund activity		629		(1,223)
		4,864		16,327
Changes in non-cash operating working capital				
Accounts receivable		49,197		(33,422)
Accrued interest		—		500
Sales taxes recoverable		1,010		(6,713)
Prepaid expenses		(18)		(4,940)
Conference advances		—		24,803
Accounts payable and accrued liabilities		391		(43,543)
Membership fees received in advance		5,488		5,058
Due to Canadian Nuclear Association		198		18,975
		61,130		(22,955)
INVESTING ACTIVITIES				
Additions to equipment		—		(900)
Net increase in investments		(764)		(11,644)
		(764)		(12,544)
Increase (decrease) in cash		60,366		(35,499)
Cash, beginning of year		241,949		277,448
Cash, end of year	$	302,315	$	241,949
Cash is comprised of				
Bank accounts	$	292,970	$	230,542
Nuclear Operation Division		1,793		1,793
Branch bank accounts		7,552		9,614
	$	302,315	$	241,949

NOTES TO FINANCIAL STATEMENTS

Year Ended December 31, 1999

1. NATURE OF OPERATIONS

The Canadian Nuclear Society ("CNS" or "the Society") was formed in November 1979 and wasfederally incorporated in June 1998. The CNS is a not-for-profit, voluntary organization comprised of individuals with an interest in nuclear science and technology. The CNS operates from a central office and through a number of branches in various cities. The financial activities of the branches are included in these financial statements.

The objectives of the CNS are:

- to act as a forum for the exchange of information relating to nuclear science and technology;
- to foster the development and beneficial utilization of nuclear science and technology
- for peaceful uses;
- to encourage education in, and knowledge about, nuclear science and technology; and
- to enhance the professional and technical capabilities of those involved in nuclear science and technology in the Canadian context.

2. SUMMARY OF SIGNIFICANT ACCOUNTING POLICIES

Revenue Recognition

Membership fees are included in revenue in the year to which they relate. Conference revenue is recorded in the year the event occurs. Interest is recorded on the accrual basis. Mutual fund capital gains and dividends reinvested in additional units are recorded as revenue in the year they are declared and reinvested.

Use of estimates

In preparing financial statements, management is required to make estimates and assumptions that affect the reported amounts of assets and liabilities, the disclosure of contingent assets and liabilities at the date of the financial statements and reported amounts of revenue and expenses during the year. Actual results could differ from these estimates.

Investments

Investments are carried at cost.

Equipment

Computer equipment is recorded at cost and amortized over its estimated useful life on a 30% declining balance basis.

3. INVESTMENTS

		1999		1998
Guaranteed investment certificate				
6.05% interest due December, 2002	$	25,000	$	—
Mutual funds		40,835		39,571
Provincial bond		—		25,500
		$ 65,835		$ 65,071

The approximate market value of the investments at December 31,1999 was $77,000.

4. EDUCATION FUND

From 1988 to 1991, annual contributions amounting to $3,000 from CNS and $7,000 from the Canadian Nuclear Association (the "CNA') were made to the Education Fund. In 1995 CNS made an additional contribution of $5,000. The interest on these funds is available for educational purposes to the local branches of CNS while the principal which is invested in a provincial bond, remains the property of the CNA and CNS Principle responsibility for the day-to-day management of the fund rests with the CNS.

		1999		1998
Principal contributions				
Canadian Nuclear Association	$	28,000	$	28,000
Canadian Nuclear Society		17,000		17,000
		45,000		45,000
Accumulated net interest available to local CNS branches		49,987		50,393
	$	49,987	$	50,393
Balance, beginning of year	$	50,393	$	50,785
Interest earned		2,594		2,614
Allocations to branches		(3,000)		(3,006)
Balance, end of year	$	49,987	$	50,393

5. EQUIPMENT

	Cost	Accumulated Amortization	Net 1999	Net 1998
Computer equipment	$ 2.860	$ 1,509	$ 1,351	$ 1931

6. GROSS REVENUE AND EXPENSES FOR CONFERENCES AND COURSES

	CANDU Fuel	Reactor Safety - March	Reactor Safety - November	Climate Change	CANDU Quality Assurance	Total
Gross revenue	$ 71,425	$ 21,845	$ 26,235	$ 59,965	$ 5,480	$ 184,950
Expenses	41,425	9,328	10,365	33,899	1,567	96,584
Net revenue	$ 30,000	$ 12,5.17	$ 15,870	$ 26,066	$ 3.913	$ 88,366

7. SPECIAL PROJECTS FUND

In 1997 the Council internally designated $50,000 from its unrestricted surplus for a Special Projects Fund which is to be used for non-budgeted and unforeseen projects. In 1998 the Council approved an additional transfer of $7,000 from its unrestricted surplus.

		1999		1998
Fund balance, beginning of year	$	18,117	$	25,618
Transfer from unrestricted surplus		—		7,000
Expenditures		—		(14,501)
Fund balance, end of year	$	18,117	$	18,117

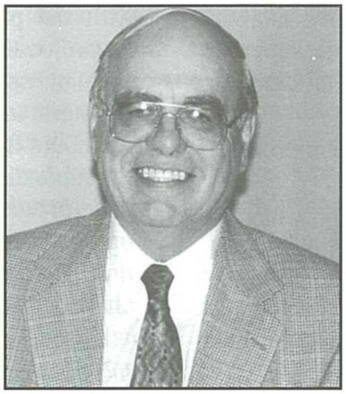
8. ERIC CARRUTHERS MEMORIAL TRUST FUND

In 1998 the Sheridan Park Branch of CNS created a Trust in memory of a past member. In 1999 interest income was received and an award was made at the Senior Science Fair.

9. FUTURE EVENT

In March 2000, the CNS entered into agreements for administrative and accounting support. Furthermore, the CNS is negotiating an agreement for office space. The budgeted costs for office space and services in 2000 is $80,000.

Meet the new president



Ken Smith

Taking the reins at the Annual General Meeting of the Canadian Nuclear Society in Toronto on June 12, 2000, as President for 2000 / 2001, Ken Smith identified himself as the society's first "retiree" president. More accurately, that should have been "semi-retiree" as Ken still actively runs his own business, UNECO, which, among other things, publishes a monthly newsletter for the nuclear and uranium industry, entitled "UNECAN News".

Ken comes originally from the west of the country, Victoria, and attended University of British Columbia, obtaining a degree in mechanical engineering in 1956. Winning an Athlone Fellowship he spent the following two years at the Imperial college of Science and Technology in London. England, gaining a diploma in nuclear engineering.

On returning to Canada in 1958 he joined Atomic Energy of Canada Limited at the Chalk River Nuclear :Laboratories (as they were known in those days). There he was initially involved in economic analysis and concept studies of various reactor designs being considered. Subsequently he led a group on the development and testing of a pressure tube with internal ceramic powder insulation for use with high temperature coolants. When work on that concept was terminated he oversaw the conceptual design and manufacturing development of fuel channels for Gentilly 1, a boiling light water cooled CANDU design.

In 1965 he moved, with the Gentilly 1 team, to what was then the Power Projects division of AECL at Sheridan park in Mississauga, still working on the G-1 fuel channels. Four years later, in 1969, he became senior project engineer for AECL's design and procurement work on the Pickering A station. (He says that one of his fond memories is being in the control room of Pickering unit 1 when it started up in February 1971 and he now holds "secret" wish to be invited back when the first unit of Pickering A re-starts.)

In 1972 he moved to the team negotiating AECL's work on Gentilly-2 and, then, the following year was appointed senior project engineer for AECL's involvement in the Bruce A station. Moving away from direct engineering and project work he spent a year over 1974 - 75 as assistant to the vice-president of AECL Power Projects (then the senior person at Sheridan Park). Over the following decade (1975 - 1985) he held a series of management positions in: administration and engineering services; reactor and fuel handling engineering; project services.

Then, in 1986, he left AECL to join the then Department of Energy, Mines and Resources in Ottawa, as adviser, uranium and nuclear energy, subsequently director, uranium exports. In that role he was involved in the development and application of Canada's uranium export policy, resolution of trade issues and broad advice on the nuclear fuel cycle.

Taking early retirement in 1991, but not wishing to "retire" he established his business UNECO, began his monthly newsletter and started becoming very active in the Canadian Nuclear Society. He has been on the CNS Council since 1992 and on the executive for the past five years, as treasurer, second vice-president and first vice-president.

Ken and his wife Pat live in Mississauga. He has four children and three step children, all adults, and five grandchildren. Occasionally he gets to play some golf.

News of Members

Jerry Cuttler, president of the Canadian Nuclear Society in 1995 - 96 has decided to leave Atomic Energy of Canada Limited after 26 years. Not prepared to "retire" he has formed a company and is pursuing actively what has been his avocation over the past few years.

Jerry has joined with the opponents of the linear, no-threshold, hypothesis (LNT) for the biological effects of radiation which he and others feel has been distorted and is partially responsible for the negative feelings of the public to things nuclear. He has gone further and, after considerable study, is strongly supporting the concept of radiation hormesis, that low doses of radiation can be beneficial. (Elsewhere in this issue is a copy of a paper he prepared on the subject with two prominent co-authors from the USA, which he presented recently to a group of health professionals. Jerry's new e-mail address is: < jerrycuttler@home.com >

New members

We welcome the following new members who have joined the Canadian Nuclear Society since the last issue of the CNS Bulletin.

Narinder Bains	Naomi Lau
Roland Boucher	Peter J. MacGillivray
John Stuart Brining	David W Marinacci
William L. Clarke	Brent Edward McLellan
Pratap (P.K.) Doshi	Minh Nguyen
Katsumi Fushiki	Ross Reid
Michael David Gabbani	Jovica R. Riznic
Julian Ginniver	David A. Scott
Marv Gold	Masud Shams
Bastiaan Groenenboom	Manick Sivaperumal
Fred M. Hoppe	Peter K. Smith
Serge Julien	Jacek Urbanowicz

Incoming President's Message

I am privileged to be able to serve our Society as your President for the coming year. I hope that, with your support, I can be as successful as my predecessors were in handling the challenges of this position.

Let me take just a few minutes to talk about some of the challenges that face all of us.

The first challenge is that this is an organization which is largely dependent of the volunteer effort of its members, and in many cases the voluntary support of their employer for some of their time and minor expenses. Without such voluntary support, the Society could not operate successfully.

However, there may be times when we might be expecting too much from our members. We all have other work to do, and families that demand our time and attention. This is one of the reasons that we have voted to expand the number of members on Council. I am keenly aware of the fact that during the past year, and in previous years, much of the organizational work has been done by a relatively small number of people. In particular, too much reliance has been placed on the volunteer efforts of the five man Executive. In the coming year, I hope that we will be able to distribute this workload more evenly, and fully utilize the contributions that can be made by the expanded Council. The benefits of an expanded Council will be lost if we are unable to achieve a better distribution of the workload.

The second challenge has two components: to expand our membership base, and to develop more active Branch programs in those Branches that have been relatively inactive over the past few years. These two go hand in hand, because without an active Branch program, it is difficult to attract new members. Because of the geographical shape of our country, our CNS Branches are separated by large distances, and it's very difficult for Branches to obtain assistance from other Branches, or from our central office in Toronto. We have not met this challenge very well over the past few years, and it will continue to be a major challenge for everyone. I have no simple solutions, but as mentioned previously, I am hoping that our expanded Council can contribute to finding some solutions.

The third challenge is to maintain a full conference and course program. I would ask all members for their assistance in organizing conferences, courses, seminars, or any other forum that you can think of to promote nuclear science and technology. Taking part in a conference organizing committee can be both rewarding and enjoyable. I might add that these events are a major source of revenue for the CNS, and without a full program of conferences and courses, our ability to do the other things that we want to do would be severely limited.

If we are successful in meeting the first three challenges, then we will be able to do a better job of dealing with our fourth challenge - more and better outward communication with the public, the media, and the government. In this regard, we have had some selective successes in the recent past by sponsoring or co-sponsoring training courses for teachers, and the media. But we need to do more. Some members have suggested that we should be more pro-active in responding to incorrect or biased media reports. There is general agreement with this objective, but limited agreement on how to go about it. We have no employees to develop quick responses, and finding the volunteer effort to meet this challenge is, in itself, a challenge.

Before I close, let me add a personal comment. My principle paid activity these days is the production of a monthly, subscriber funded, newsletter for the uranium and nuclear industry in Canada. My principle unpaid activity for the next year will be as the first retiree President of the CNS. I look forward to working with all of you in this capacity. We have some continuing challenges to deal with, and I am hoping that we can all pull together to tackle these issues.

K.L. (Ken) Smith

BRANCH ACTIVITIES

(Although summer is typically a slow time for Society activities, several Branches have held meetings or other events. The following reports are from the Branch chairs, as indicated.)

BRUCE (Eric Williams):

The Bruce Branch held a meeting on Tuesday, 13 June 2000, at the Bruce Nuclear Information Centre with guest speaker David Burke. His topic was "A Personal View Of UK Nuclear Plant Privatization", a very relevant topic for the Bruce Nuclear. Twenty-four attendees were present. A social hour preceded the presentation. Mr. Burke's presentation was based on his personal experience at the Dungeness Station in the United Kingdom, and the statistics and outcome related to their privatization. Mr. Burke's presentation and enthusiasm conveyed optimism for those at the Bruce as they proceed through the privatization process.

The Bruce Branch also wishes to congratulate Ms. Stephanie Hunn on her recent marriage. Stephanie has been a long serving member of the Bruce Branch. Following her marriage she has relocated to a job in Toronto. We will miss her.

CHALK RIVER (Michael Stephens):

The Chalk River Branch of the CNS sponsored the Deep River Science Academy summer evening lectures, each Thursday, starting July 13, through to August 3. The lectures were held in the newly air-conditioned Childs Auditorium, at

Mackenzie High School in Deep River and were open to the general public with no charge for admission. Refreshments were available.

The first speaker (July 13) was Dr. John Root, of the National Research Council. Dr. Root's topic was "Advanced Materials Research with Neutron Beams". His presentation included key examples of neutron scattering projects in physical and engineering sciences, as practiced by university users of the Neutron Program for Materials Research at Chalk River. The proposed Canadian Neutron Facility, which will be the centre for neutron scattering in Canada in the twenty-first century, was also outlined.

Phyllis Heeney, a member of the AECL "Pickering A" Restart environmental qualification group at the Chalk River Laboratories was the second speaker on July 20. The design and construction of the Pickering A nuclear generating station units predates the development of formal environmental qualification methods. The four "A" units entered service in the period 1971 to 1973. They were shut down in 1998 and require major rehabilitation to return them to service. Environmental Qualification (EQ) of the safety-related systems is one of the prerequisites to their future restart. EQ is a process designed to ensure that every essential piece of equipment can function for the lifetime of the reactor and the duration of a hypothetical accident.

On July 27, the third speaker in the series was AECL Vice-President, Dr. David Torgerson. Dr. Torgerson's spoke on "Knowledge: The New Measure of Wealth". In his presentation, he explored how the rapid expansion of knowledge arising from research and development is affecting individuals, corporations (including AECL), and nations.

Dr. Rod Miller of BTI (Bubble Technology, Chalk River) gave the final lecture in the series on August 3. Dr. Miller's topic was "BTI and Landmine Detection". He gave an overview of BTI, describing its historical origins and business evolution leading to its involvement with the Improved Landmine Detection Program in 1995. Dr. Miller described the Thermal Neutron Activation sensor developed by BTI for the Advanced Development Model (ADM) and discussed some of the challenges involved in moving from the ADM to final field models.

DARLINGTON (Jacques Plourde):

Jacques Plourde has taken over as Interim Chair and plans to try to revive the Darlington Branch. An open house is planned for September and a Branch meeting in October. .

MANITOBA (Morgan Brown):

Morgan writes: no activity in the Manitoba Branch except for enhancements to the CNS Manitoba web pages, notably the addition of more "nuclear pioneers". For the page on Harry Thode, I contacted McMaster University and was given permission to copy some articles from the alumni journal and the newspaper. The contact at McMaster was very helpful, and was delighted that I put the page together - she said she'd now get the McMaster webmaster to make a link to the "Harry Thode" page. I think this is a very positive way to get others to take notice of the CNS, if

only because we provide useful information. Perhaps we (I'm not volunteering right now) should put together some basic nuclear engineering pages, with technical info (equations, constants, parameters, etc.) that is of a quality (i.e.well checked) necessary for teaching purposes. Such a page could be used to advertise books like that of Daniel Rozon (perhaps he could write some of the pages, snipped from his book). In addition to my previous brief report, some CNS Manitoba web pages have again been updated (Latest from my Canadian nuclear history page: Did you realize that Martin Marietta set up a radioisotope generator-powered automatic weather station in the Canadian arctic in the late 1950's?)

On Friday July 14, I gave a 2-hr lecture/lab demonstration/interactive event to the Whiteshell Campus of the Deep River Science Academy, on nuclear energy. Lots of fun, and I heard through the grapevine that it was well-liked by the students. I presented it on behalf of the CNS (which donates to the DRSA on both local and national levels), putting up our banner.

I will also give the last three CNS-Manitoba copies of "Bluebells and Nuclear Energy" to the three DRSA students working on nuclear-related projects (gas mixing in containment and aerosol behaviour in containment). I will write in them to indicate they are from the CNS. A bit of changing hats for me - I'm also chair of the Whiteshell Campus of the DRSA. If CNS members would like to see what they've been supporting at the DRSA, our web site is at < www.granite.mb.ca/~drsa >, and is linked from the Manitoba CNS page.

NEW BRUNSWICK (Mark McIntyre):

On July 25, 2000, the NB Branch held a "Point Lepreau Refurbishment" information session for all CNS Branch members and PLGS staff. The guest speakers were Stu Groom of NB Power and David Scott of AECL. Stu Groom outlined the possible projects to be listed under the "Refurbishment" plan. PLGS is planning to replace the Pressure Tubes, Calandria Tubes, and the feeders below the "freezer cans". Other potential work is an upgrade to the Turbine / Generator Set and upgrades to special safety systems.

The plan is broken into three phases. Currently, NB Power is in Phase 1- a phase where preliminary engineering, system condition assessment, licensing issues and economic feasibility are analyzed. Phase 2 (Detailed Planning) and Phase 3 (Implementation) will only take place if a positive outcome from Phase 1 is achieved.

The second part of the lecture had Dave Scott from AECL explaining how a full core retubing using "Fast Channel Replacement" techniques could be performed at PLGS. The presentation gave details about what lessons have been learned from previous fuel channel replacement (FCR) work. Another theme was how technology, specifically computer modeling, has helped to put forward solutions to improve FCR work.

At the conclusion of the noon time session, CNS Branch, Chairman Mark McIntyre presented an Inukshuk sculpture and read a letter from the CNS National Executive to Paul Thompson, in recognition of his years of service to the CNS.

OTTAWA (Bob Dixon):

The Ottawa branch does not have a summer program. Planning for the coming season is underway..

SHERIDAN PARK (Parviz Gulshani)

CNS SP Branch has had one seminar on July 11, 2000 at 12:00 noon. Mr. Terrance P. Stopps, Manager, Ontario Climate Change Branch, Ontario Ministry of the Environment spoke on the topic of "Ontario Air Issues and Climate Change"

TORONTO (Adam McLean)

The Toronto Branch held two seminars which were co-sponsored by the Ontario Power Generation's Probabilistic Risk Assessment Department (PRAD) and took place at OPG's head office. Both have been extremely well presented and also had overflow attendance!

On June 1 William Webb, from OPG, presented a talk entitled "Bruce B Risk Assessment Results and Applications". This gave insight into OPG's risk assessment scope and process as well as future implications on an international scale.

On June 29 Keith Dinnie, also of OPG, spoke on the "Environmental Cost of Nuclear Power". The audience enjoyed a revealing description of how the energy industry is purposing to add environmental costs to the cost of energy production. Recommendations of assessment guidelines contributing to consistent treatment of environmental impact consistent across alternative generating options were presented.

On July 26, Dr. Joseph Yeremian, President of Thermodyne Engineering, spoke on the topic of "Simulation of Ageing in Nuclear Reactor Systems".

NA-YGN on the move

Mark McIntyre speaks on the North American Young Generation in Nuclear during the 21st CNS Annual Conference.

What, you ask, is NA-YGN? It stands for North American Young Generation in Nuclear, an organization aimed at the under 35 professional in the nuclear field in North America.

Mark McIntyre, who is with NB Power, is the most active resident Canadian in the group. (Paul Wilson who has been spear-heading the movement is a Canadian but resident currently in the USA.)

Mark made a special presentation at lunch time on the second day of the recent CNS Annual Conference in Toronto. Although his audience was not large those who attended were impressed with his enthusiasm and the message of NA-YGN.

Mark was among the YGN people from several European countries as well as Canada and the USA the world who participated so effectively during the COP 5 meeting on climate change in Bonn, Germany last fall. (See Vol. 20, No. 4 issue of the CNS Bulletin.) He also attended the first International Youth Nuclear Congress, held in Bratislava, Slovakia, April 9-14, 2000 where over 300 young professionals from 32 countries joined in sessions focussing on how to communicate the benefits of nuclear science and technology.

He emphasized that for the new organization to be effective it will need the full support, financial as well as moral, of nuclear organizations.

The CNS 1999-2000 executive preside at the Annual General Meeting, June 12, 2000. Left to right Andrew Lee, Ian Wilson, Krish Krishnan, Ken Smith, Paul Thompson.

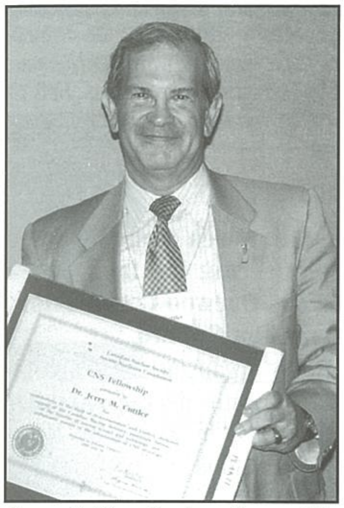
Sylvie Caron displays the gift given to her for her 12 years of service to the Society at the CNS Annual General Meeting June 12, 2000.

CNS recognizes achievers

- Society presents awards to teams and individuals at Annual Conference

At the special Awards Luncheon held on Wednesday, June 14, 2000, during the 21st CNS Annual Conference the Canadian Nuclear Society presented five sets of awards. "Sets" because two of the awards were for sizable teams that had been involved in difficult, if quite different, projects.

Beginning with the individual awards, **Jerry Cuttler**, president of the Canadian Nuclear Society in 1995 - 96 and a long-time supporter of the Society as well as being a strong advocate for nuclear science and technology, was named a **Fellow** of the Canadian Nuclear Society, with the right to use the initials FCNS after his name. The criteria for admission to this special category of membership include "major and sustained contribution to the science and/or professions that relate to the advancement of nuclear technology in Canada". The citation for Jerry Cuttler read:



Jerry Cuttler displays the certificate naming him as a Fellow of the Canadian Nuclear Society, presented at the CNS 21st Annual Conference, June 2000.

> *For contributions to the field of Instrumentation and Control, dedicated support of the Canadian Nuclear Industry, passionate defence of the benefits of nuclear science and technology, and enthusiastic pursuit of the advancement of CNS objectives.*

Murray Stewart, former president of the Canadian Nuclear Association was presented with the **CNS Education and Communication Award** for his enthusiastic and effective communication with governments, public and media over the period of his position at the CNA. This award is to recognize individuals for "significant achievements in improving the understanding of nuclear science and technologies among educators, students and the public. The citation on his certificate reads:

CNS president Krish Krishnan presents the certificate of the CNS Education and Communication Award to Murray Stewart at the CNS Annual Conference in Toronto, June 2000.

> *for outstanding performance in communicating the climate-change benefits of nuclear energy to industry, governments, and international audiences.*

The **CNS Innovative Achievement Award** is intended for the recognition of "significant innovative achievement, implementation of new concepts, or outstanding contribution in the nuclear field in Canada" This year the award was presented to **Ralph Hart** formerly of Atomic Energy of Canada Limited for his many contributions to the design of CANDU over the years. His citation reads:

> *for the generation and integration of innovative concepts into the evolution of CANDU reactor designs.*

CNS president Krish Krishnan, (L) presents the certificate of the CNS Innovative Achievement Award to Ralph Hart at the 21st Annual Conference in Toronto, June 2000.

Representatives of the team that won the CNS Team Achievement Award for their development of a detection system for non-metallic land mines pose with CNS president Krish Krishnan (L). L to R: Tom Cousins, Jim McFee, Ed Waller, Harry Ing.

Two groups were presented with the **CNS's John S. Hewitt Team Achievement Award.** This award was created in memory of John Hewitt, a founder and early president of the Society who died in 1994. The award aims at recognizing

Ted Clifford and Barclay Selkirk were part of the Bubble Technologies Inc. group on the team awarded the CNS Team Achievement Award for developing a detetion system for non-metallic land mines.

the recipients for "outstanding team achievements in the introduction or implementation of new concepts or the attainment of difficult goals in the nuclear field in Canada".

The first group was a team from four organizations in Canada who developed a technique using neutron activation for the detection of non-metallic land mines. The team consists of: **T. Cousins**, **T.A. Jones**, and **J.R. Brisson** of the Defence Research Establishment Ottawa; **J.E. McFee**, of the Defence Research Establishment Suffield, **T.J. Jamieson**, **E.J. Waller**, and **F.J. Lemay**, of SAIC Canada; and, **H. Ing**, **E.T.H.Clifford** and **E.B. Selkirk**, of Bubble Technology Industries.

Trevor Jones

Their citation reads:

> *for the creative conceptualization and innovative application of a thermal-neutron- activation-based system for detecting non-metallic land mines, allowing the effective detection and removal of these deadly devices.*

(Ed. Note: A paper describing this system is presented in this issue of the CNS Bulletin.)

The other Team Achievement Award went to a much larger group for a much larger project, the design and construction of the Wolsong units 2, 3, and 4, in Korea. The team was identified by the several organizations involved: **Atomic Energy of Canada Limited, Canatom NPM Inc., Korea Heavy Industries & Construction Co. Ltd. Korea Electric Power Corporation, Korea Power Engineering Co. Inc., Korea Atomic Energy Research Institute, Daewoo Corporation, Hyundai Engineering & Construction Co. Ltd.**

With CNS president looking on, representatives of three of the organizations presented with the CNS Team Achievement Award for the successful completion of Wolsong 2, 3 & 4 show their certificates. Left to right: Joe Howeison, AECL; Donsoo Suh, of Hanjung (Korea Heavy Industries); Philippe Brodeur, Canatom.

Representatives of the first three organizations were on hand to receive the Award at the Toronto meeting. Another presentation was made at a gathering in Korea by Hong Huynh, former president of the CNS, who is currently posted in Beijing, China.

The citation on all of the certificates reads:

> *for outstanding teamwork in completing the Wolsong 2, 3, & 4 Project on schedule.*

The CNS Honours and Awards Committee is chaired by Hugues Bonin, who read out the citation and, with outgoing president Krish Krishnan, presented the certificates.

In early July, during a KNS-KAIF-CNA symposium in Korea, AECL's Hong Huynh (a former president of the CNS) presented certificates for the CNS Team Achievement Award to representatives of all of the organizations named for the successful completion of Wolsong units 2, 3 and 4.

CRPA has a new Web site

The Canadian Radiation Protection Association has a new, much easier to remember and use Web site. Previously their site was a subsidiary one through the University of British Columbia. Their new site is: < www.crpa-acrp.ca >

Over the past several months the Nuclear Energy Agency (NEA) of the Organisation for Economic Co-operation and Development (OECD, which is based in Paris, has issued a number of reports and documents that may be of interest to readers, and some of them are free.

Nuclear Education and Training: Cause for concern?

This 38 page document is a summary of a study which included a survey of nuclear education and training in some 200 organizations in 16 countries. The authors identified a number of concerns:

- decreasing number of nuclear education programs
- decreasing number of students taking nuclear subjects
- ageing faculty
- ageing research facilities
- many nuclear graduates not working in the nuclear industry

Their number one recommendation is "We must act now."
Available without charge from:

OECD Nuclear Energy Agency
Issy-les-Moulineaux, France
e-mail: nea@nea.fr

Annual Report 1999

The 28th Annual Report of the OECD Nuclear Energy Agency provides not only a review of NEA activities but some views of programs in members countries.
Also available without charge.

Nuclear Power Plant Operating Experiences

This 44 page report shows how the analysis of more than 300 nuclear incidents over the period of 1996 - 1999 provided many lessons which have led to improvement in safety and operation.
Also available without charge

Uranium 1999: Resources, Production and Demand

This is the most recent updating of the "Red Book" which is jointly prepared by the NEA and the International Atomic Energy Agency. It provides statistics based on official information from 49 countries as of the beginning of 1999. In 1998 world annual demand related to nuclear power were estimated at 59,600 tonnes of natural uranium equivalent. World production that year was about 35,000 tonnes.
Cost: FF 510 or $77.00 US Can be ordered on-line: www.oecd.org/publications

Economic evaluation of bids for nuclear power plants - 1999 Edition

IAEA Technical Reports Series No 396

This report is an update of Technical Reports Series No. 269, Economic Evaluation of Bids for Nuclear Power Plants; A Guidebook (1986). It contains state of the art information, advice and recommendations on the different principles, methods and guidelines which should be used and applied when conducting an economic evaluation of nuclear power plant bids.

STI/DOC/010/396 (224 pp., 21 figures; 2000) ISBN 92-0-100400-1 Price: 710 Austrian schillings (EUR51.60)

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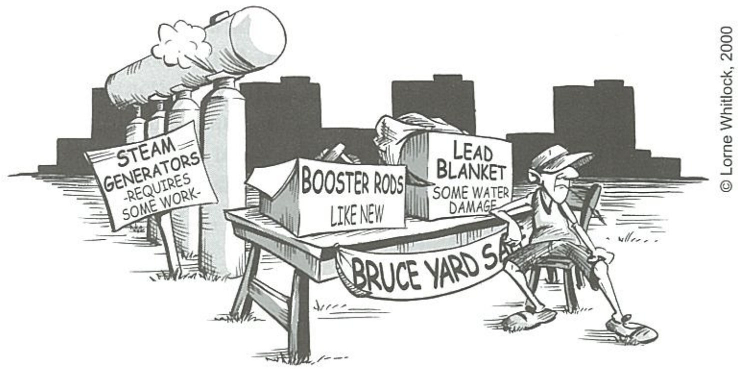
The Times They Are A-Changin'

by Jeremy Whitlock



The nuclear landscape is shifting in Canada. In days of yore, when Research and Development meant two different things, nobody was sure of the future but most suspected it was going to be bright. Rarely was a new CANDU unit not under construction somewhere in the country. Three or four maple leaves routinely adorned the "Top Ten" lists, plastered with pride on every office and corridor wall in the industry.

That's not to say that anti-nukes had it tough either, for it was also the Golden Era of Public Inquiries. The afterglow of the Sixties faded just in time for many to dust themselves off, hang an "Intervenor" sign around their necks, and line up at the trough. Intervenor status also delivered public credibility on a platter, just a hair above an appearance on CBC's "The Nature of Things".

Nuclear power, it seemed, was Science's gift to humanity. The quintessential windfall from government research, it created gobs of clean electricity at cost, buoyed by a public infrastructure that no private enterprise could support. It was large, remote, complex, eerie, and in many ways seemed to befit its crown-corporation mantle.

Yet even in those heady days, as we now know, trouble was brewing. Our reactors were run like colonial outposts, with as much regard from above as France and Britain accorded their own North American colonies three centuries ago. Then, as now, decay was inevitable. In recent years we hung our heads as eight reactors closed simultaneously for repairs. We winced helplessly as strutting Americans ran our largest nuclear utility. We took down the "Top Ten" lists and replaced them with Dilbert cartoons.

And in our darkest hour, as so often happens, a storm blew in from a different quarter that changed everything. Deregulation of the electricity market was sweeping the continent.

For a while Ontario's fleet of 20 publicly-owned reactors were bulwarks against the tide. Open competition could never infiltrate Canada's industrial heartland while Ontario Hydro was enthroned, and Ontario Hydro could never be broken without fragmenting its nuclear bloc at the same time. Eventually, and inevitably, the hammer came down with a vengeance on Ontario Hydro, and rumours circulated shortly afterwards that the Bruce reactors were for sale.

Bruce for sale?

One might as well suggest the Queen join a rap band. Surely power for the people would forever flow from the people's reactors? What attraction could nuclear power, love-child of physics and philanthropy, possibly have for the private sector?

As it turns out, quite a lot. This summer an 18-year lease agreement was announced with British Energy, purveyors of fine pollution-free electricity in the U.K. The eight Bruce reactors (some good, some bad, some ugly) are to become the cornerstone of major North American expansion, nuclear and non-nuclear, for the upstart company.

Despite initial bewilderment (can electricity be flogged any cheaper than at-cost?), it has to be recognized that the auctioning off of Canada's once proud flagship nuclear plant was really only a matter of time. Commercialization is a mark of nuclear power's coming of age, and more importantly nuclear power's coming into the Age of Decentralization.

Much deionized water has passed under the man-bridge. The men and women who first wrested nuclear technology off the pages of textbooks and onto the country's electrical grid have passed out of the industry, and those who knew them are retiring. Soon nuclear engineers will be hired who weren't born when Pickering Unit 2 blew its G16 pressure tube on August 1, 1983.

In many areas of nuclear R&D the torch will have to be passed across a yawning chasm – the legacy of years of attrition in the workforce. Exacerbating the age gap is this country's collapsing infrastructure for nuclear education: Fewer and fewer capable hands are coming forth to receive the torch, and the industry, sadly, appears to be doing little about this mushrooming problem.

"Youth, future, nuclear" was the theme embraced by hundreds of bushy-tailed nuclear newcomers, gathering from 32 countries in Bratislava this past Spring. A noteworthy outcome of the first annual "International Youth Nuclear Congress" was a well-publicized gaffe symbolizing the gulf between Old and New. Russian Minatom boss Yevgeny Adamov largely mortified his "dear young colleagues" when he exhorted them to proudly work on nuclear weapons if so asked. The Congress subsequently rejected this notion.

If Canada's nuclear industry has matured, so has its regulator. The Atomic Energy Control Board, an entity that started life supplying the budget for Chalk River Nuclear Laboratories, has gained strength and sovereignty over the years. To commemorate a recent legislative refurbishment that equalizes its bite with its bark, the AECB gets to change its name: long live the Canadian Nuclear Safety Commission. Never again to have its acronym confused in the public mind with AECL, the CNSC stands with autonomous pride next to the CNS, the CNA, and hopefully soon the CNF. It's all very clear now, thanks.

There is cause for concern as Canada tumbles headlong into this brave new world of nuclear realism. True, we are blessed with one of the world's premiere machines, but entrepreneurs care little about lifetime cost and even less about technical elegance. Capital investment, five-year horizons, public judgement – this is where the enterprise stands or falls, and this is why pollution-belching gas turbines will remain popular despite escalating fuel prices. Canada has a strategy for meeting this challenge with the atom, but we're a bit tardy off the mark.

We also have trouble removing our head from the sand, in a world where Energy Probe is mainstream and the national broadcaster shamelessly flaunts its anti-nuclear bias. Scoffing at the lies and deceptions will lose us the day. It is time for the industry to put public affairs and education on an equal business footing with our product.

Perhaps our friends at British Energy will show us the way.

2000

Aug. 30 - Sept. 1
25th Annual Symposium on the Uranium Institute
London, UK
Visit website: www.uisympoium.com

Sept. 24 - 26
21st CNS Nuclear Simulation Symposium
Ottawa, Ontario
contact: Ms. Anca McGee
AECL-SP
Tel. 905-823-9060 ext. 6540
e-mail: mcgeea@aecl.ca

Sept. 24 - 28
Spectrum 2000 International Conference on Nuclear and Hazardous Waste Management
Chattanooga, Tennessee
contact: Spectrum 2000 secretariat
Tel: 865-974-5048
e-mail: spectrum2000@engr.utk.edu

Sept. 25 - 28
ICENES 2000: 10th International Conference on Emerging Nuclear Energy Systems
Petten, The Netherlands
contact: Dr. Harm Gruppelaar
Petten, The Netherlands
e-mail: gruppelaar@ecn.nl
website: www.ecn.nl

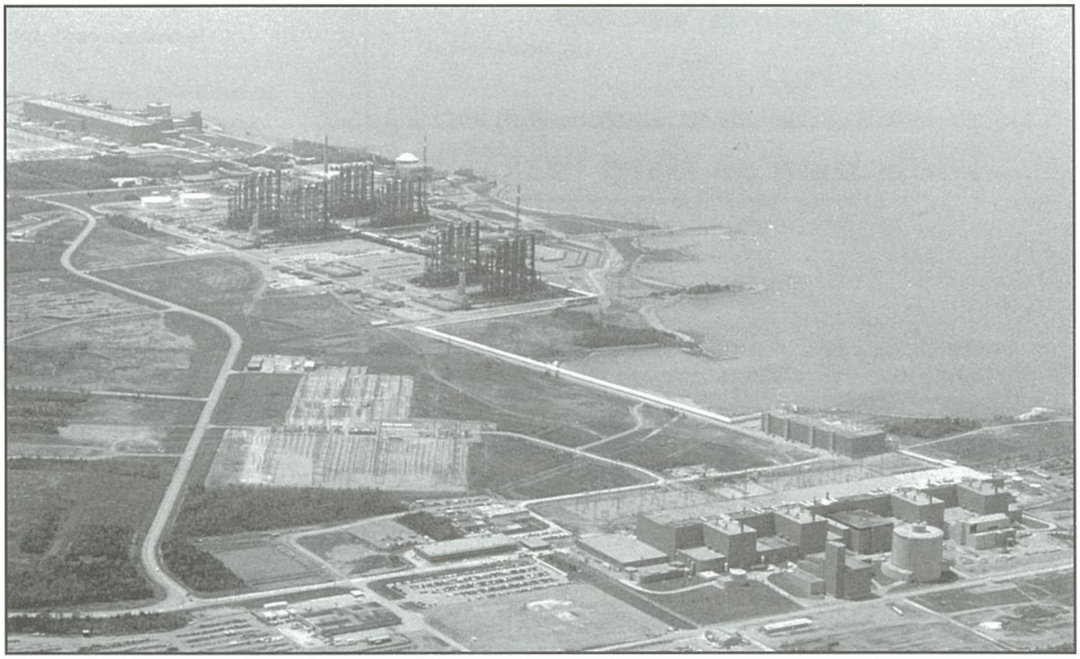
Oct. 1 - 5
Safewaste 2000
Montpellier Corum, France
e-mail: arnous.sfen@wanadoo.fr

Oct. 9 - 11
Plutonium 2000 – an international conference on the future of plutomium
Brussels, Belgium
contact: Werner Couwenbergh
Belgian Nuclear Society, Brussels
tel: +32-2-774-05-38
fax: +32-2-774-05-02
e-mail: Pu2000@belgonucleairc.be

Oct. 24 - 26
ATALANTE 2000
Scientific research on the back-end of the fuel cycle
Avignon, France
e-mail: ATALANTE2000@cea.fr

Oct. 29 - Nov. 2
12th Pacific Basin Nuclear Conference
Seoul, Korea
contact: Mr. Kyo-Sun Lee
KAIF
Seoul, Korea
Fax: +82-2-785-3975
e-mail: kaif@borna.dacoin.cc.kr

Oct. 29 - Nov. 1
Symposium on Hard Facing Alloys in Water Reactor Environments
Quebec, Quebec
contact: Dr. E.V. Murphy
AECL-SP
tel: 905-823-9040
e-mail: murphyv@aecl.ca



An aerial view of the Bruce site from 1992, with Bruce "A" in the right foreground and Bruce "B" in the upper left. In between are the towers of the Bruce heavy water plant and the decommissioned Douglas Point plant.

Oct. 30 - 31 — **7th Int. Conf. on Decommissioning of Nuclear Facilities**
London, UK
Visit website: www.ibcglobal.com/ea1136
e-mail: cust.serv@informa.com

Nov. 5 - 10 — **Heat Transfer Enhancement in Multiphase Flow at 2000 ASME International Congress & Exposition (IMECE 2000)**
Orlando, Florida
contact: Jovica Riznic
AECB Ottawa
Tel: 613-943-0132
e-mail: riznic.j@atomcon.gc.ca

Nov. 12 - 17 — **ANS/ENS 2000 International Meeting**
Washington, D.C.
contact: ANS Office
La Grange Park, Illinois
Tel: 708-579-8257
Fax: 708-579-8234

Nov. 13 - 17 — **ANS International Topical Meeting – Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies**
Washington, DC
contact: Richard Wood
Oak Ridge National Laboratory
Tel: 865-574-5578
e-mail: woodrt@ornl.gov

Nov. 19 - 21 — **CNS 5th International Conference on CANDU Maintenance**
Toronto, Ontario
contact: Martin Reid
OPG Pickering
Tel: 905-839-1151 Ext. 3645
e-mail:
martin.reid@ontariopowergeneration.com

Dec. 11 - 13 — **Americas Nuclear Energy Symposium**
Miami, Florida
Visit Website: www.nes2000.org

Dec. 14 - 19 — **Radioisotope Production and Applications in the New Century at 2000 International Chemical Congress**
Honolulu, Hawaii
contact: Dennis Phillips
Los Alamos National Laboratory
Tel: 505-667-5425
Fax: 505-665-3403

2001

April 8 - 12 — **ICONE-9 9th Int. Conf. on Nuclear Engineering**
Nice, France
Visit website: www.sfen.fr/icone9

June ? — **22nd CNS Annual Conference**
Toronto, Ontario
Contact: Denise Rouben
CNS office
Tel: 416-977-7620
e-mail: cns-snc@on.aibn.com

June 17 - 21 — **ANS Annual Meeting**
Milwaukee, Wis
Visit website: www.ans.org

Symposium on Hard Facing Alloys in Water Reactor Environments

Québec City, Québec

October 29 - November 1, 2000

This specialized symposium is co-sponsored by the Canadian Nuclear Society and the Société Française de l'Énergie Nucléaire.

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