CANADIAN NUCLEAR SOCIETY

Bulletin

DE LA SOCIÉTÉ NUCLÉAIRE CANADIENNE

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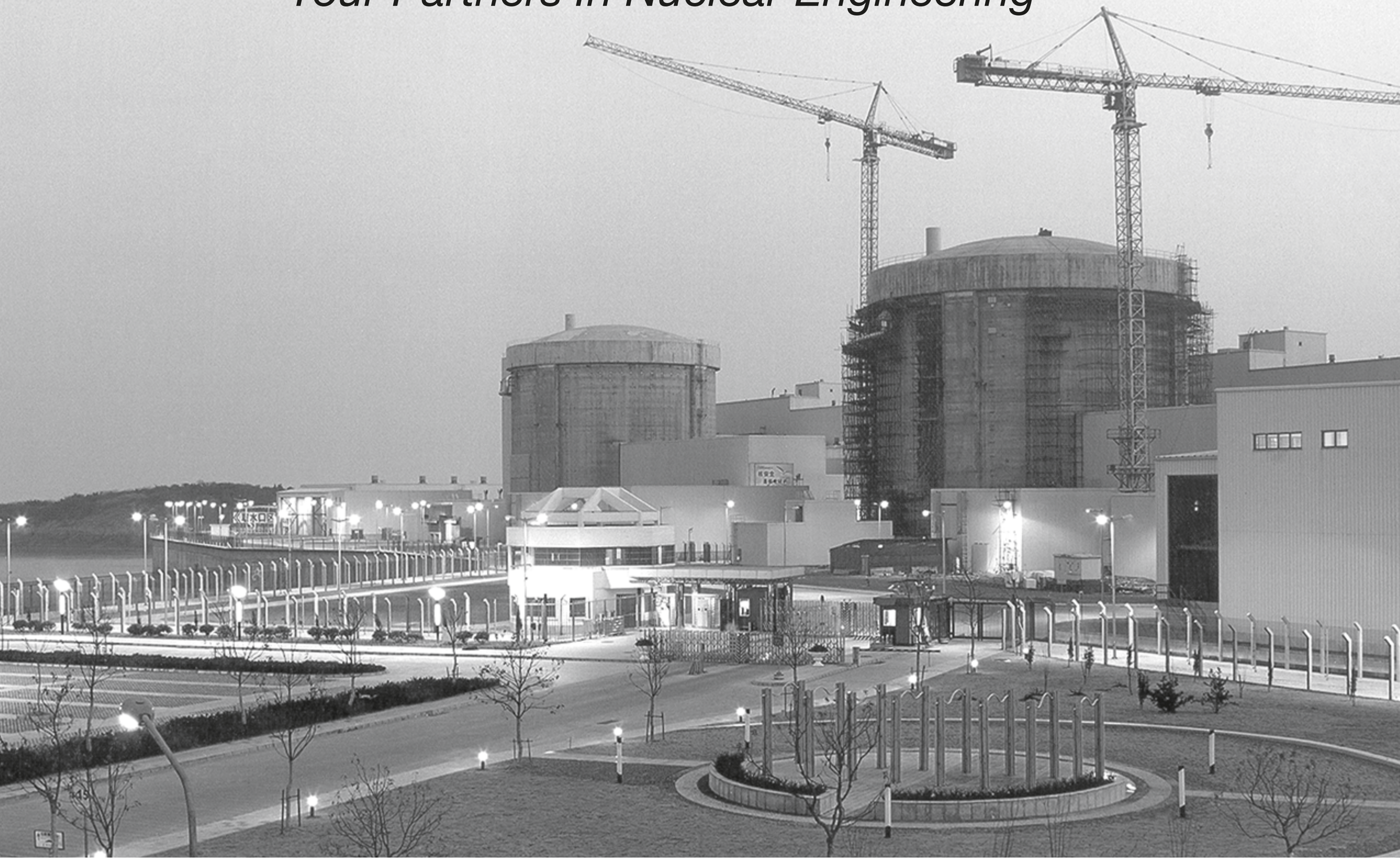
• 15th Pacific Basin Conference • DUPIC Fuel Status
• Future of Isotope Supply • UOIT Nuclear Program
• Bruce A Refurbishment • PHYSOR 2006



An "interesting" year

This being the last issue of the Bulletin for 2006 it is an opportunity to look back over what has been a very eventful year for the Canadian nuclear program.

With "renaissance" in the air the Annual Seminar of the Canadian Nuclear Association back in February drew a record crowd only to be struck the first blow from the nuclear regulator when Linda Keen announced that the Canadian Nuclear Safety Commission was moving to "international standards". That was followed up the next day with a CNSC public meeting at which senior CNSC staff restated the position Keen had announced but provided little detail.

Despite those announcements, Bruce Power completed the environmental assessment for the refurbishment of the Bruce A station and it was accepted by the CNSC. Thereafter the "Bruce A Restart" program for units 1 and 2 moved into high gear (as described in our short report in this issue).

Later in the summer Bruce Power announced that it was requesting, in essence, site approval for possible "new build" (new nuclear units on the Bruce site) and in September Ontario Power followed with a similar application to the CNSC for possible new units on the Darlington site.

For the Environmental Assessment, the first step in the regulatory process, it is understood that, in both cases, instead of a specific project, which is the normal requirement, parameters for a "composite" nuclear plant will be developed so that any current nuclear power plant technology could be employed.

Meanwhile the folks at New Brunswick Power Nuclear are finalizing plans for the refurbishment of Point Lepreau, which is now scheduled for 2008. Although Hydro Quebec has not yet made any decision on the future of Gentilly 2 it is proceeding with new dry fuel storage.

Then, at the end of October, CNSC's Linda Keen took the unusual step of directly informing senior executives of the nuclear industry of her determination to apply "international standards". Again, there have been few details but the interpretation of many knowledgeable of IAEA and other international standards is that current CANDU 6 reactors would not pass a strict application of those rules, which reflect LWR characteristics.

Worse is the suggestion that CNSC might apply these standards to the refurbishments under way. In our view that would be unconscionable. The refurbishments at Bruce A and Point Lepreau have been in the planning stage for years, huge sums have been spent, and at Bruce there is a small army ready to carry out the actual work on Bruce A units 1 and 2. All of this was done under the understanding that rules of the game would not change.

So, the year ends with great potential but ominous signs from our regulator. Let us hope that some rational solution is found.

Fred Boyd

In This Issue

This issue draws heavily on an international conference in which Canadians were very active, the **15th Pacific Basin Nuclear Conference** held in Australia in October 2006, and begins with a report on that conference.

Then follow six papers presented at that conference, five of them by Canadian authors, one from Korea on a subject related to their use of both CANDU and PWR reactors, **The Current Status of DUPIC Fuel Technology Development.**

The next paper deals with a "generic" safety question that has been around almost as long as your editor, **Molten Fuel Moderator Interaction Program at Chalk River Laboratories,** which is an illustration of how difficult (and costly) it can be to answer apparently simple questions.

Following is a paper with really two parts, one on the use of radioisotopes in medicine, the other on the status of the MAPLE reactors and isotope processing facility at the Chalk River Laboratories, under the title, **Ensuring Reliable Medical Isotope Supply.**

Into the realm of the controversy about the "linear, no threshold" (LNT) concept for radiation effect there is paper by an expert in the field, Ron Mitchell of AECL-CRL, **Cancer and Low Dose Responses *In Vivo:* Implications for Radiation Protection.**

Switching focus Dan Meneley and co-authors describe the role of CANTEACH in their paper **Preserving Technical Knowledge – When Technology's Lifetime Exceeds the Human Life Span.**

Last in this group from PBNC is a related paper on **Nuclear Undergraduate Programs at UOIT,** accompanied by a short note on **UOIT Nuclear, a Students Perspective.**

There are short reports on the **PHYSOR 2006** reactor physics conference in Vancouver in September 2006, the **Douglas Point Commemoration** held at the end of September, and the status of the **Bruce A Refurbishment.**

The balance of the issue contains our usual eclectic selection of items in **General News,** some information on activities of the Society in **CNS News,** and the ever-interesting perspective of Jeremy Whitlock in **Endpoint.**

We hope you find some interesting items for your year-end reading and welcome your comments.

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~ Cover Photo ~

The cover photograph is a very new aerial view of the Bruce site looking north with Bruce B station in the foreground. The large Mammoet crane can be seen behind the Bruce A station in the distance and the new Support Centre building at the right.

– Photograph courtesy of Bruce Power

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The Canadian Nuclear Society
480 University Avenue, Suite 200
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Telephone (416) 977-7620
Fax (416) 977-8131
e-mail: cns-snc@on.aibn.com

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

Editor / Rédacteur
Fred Boyd Tel./Fax (613) 592-2256
e-mail: fboyd@sympatico.ca

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15th Pacific Basin Nuclear Conference

Canada has strong presence at international meeting

Although the flurry of activity in the Canadian nuclear scene over the past few months kept some of Canadaís senior people at home, there was a strong contingent from Canada at the 15th Pacific Basin Nuclear Conference (PBNC 2006) held in Sydney, Australia, October 15-20, 2006.

In addition to Atomic Energy of Canada Limited (AECL) being a prime sponsor of the event, Canadians presented 24 papers and co-chaired several sessions.

A meeting of the Pacific Nuclear Council (PNC), the custodians of the PBNC series of meetings, was held on the Sunday preceding the conference.

Ian MacFarlane, Australian Minister of Industry, gives the opening address at the 15th Pacific Basin Nuclear Conference in Sydney, Australia, 16 October 2006.

The first Pacific Basin Nuclear Conference (PBNC) was held in 1976 in Hawaii. Since then they have been held about every two years, initially under the joint sponsorship of the American Nuclear Society (ANS) and the nuclear energy society selected by the ANS to host each conference. After the Pacific Nuclear Council (PNC) was formed in 1988, with membership of nuclear associations and societies from countries around the Pacific Rim, the authority for the PBNC meetings was transferred from the ANS to PNC. PBNC has been held in Canada twice, once in Vancouver in 1983, before the creation of PNC, and the very successful one at Banff in 1998.

About 300 delegates from 26 countries attended the four-day event, which began with the typical reception on the Sunday evening. The conference proper began with an opening ceremony on the Monday morning chaired by **Ian Smith,** head of the Australian Nuclear Science and Technology Organisation (ANSTO) and General Chairman of the conferrence. He referred back to 1994 when Australia had previously hosted a PBNC meeting. Times are different now, he said, noting that their new research reactor, OPAL, was in the final stages of commissioning.

Paul Fehrenbach, president of the Pacific Nuclear Council presents a plaque to Ian Smith, General chairman of the 15th Pacific Basin Nuclear Conference at the opening ceremonies in Sydney, Australia, 16 October 2006.

He then invited **Ian Macfarlane**, Australia's Minister of Industry, to officially open the conference. After doing so, Macfarlane spoke about Australia and global warming. It is time for a sensible debate about nuclear power, he said, and about expansion of Australia's uranium mining industry. A major study commissioned by the government on the prospects of nuclear power in Australia would be issued before the end of the year, he stated in closing. This represents a dramatic reversal of the policy the country has followed for at least three decades and is being pursued at least partially because of the concerns of climate change.

Smith introduced **John Harries,** president of the Australian Nuclear Association, the primary sponsor of the conference, and **Rolfe Hartley,** deputy president of Engineers Australia, the 80,000 strong national organisation of engineers which was a co-sponsor.

After a pause, the opening "invited" session was introduced by **Paul Fehrenbach,** a vice-president of Atomic Energy of Canada Limited and outgoing president of PNC. In his opening remarks, Fehrenbach said, "The PBNC series of conferences are all about sharing of information and best practices in order to promote and facilitate the peaceful uses of nuclear technology. They were started in 1976 in recognition that applications of nuclear technology were about to increase dramatically in the countries around the Pacific Rim. History shows this to have been an accurate perception. These meetings are still very relevant, and the theme of this conference, *'A pacific nuclear future: nuclear science and engineering for a sustainable society'*, is particularly appropriate."

"However", he continued, "it is not enough to rely only on the environmental advantages of nuclear power. We must also continue to demonstrate to the public, and to investors, that nuclear power is safe, that it is economic, and that spent fuel and other radioactive waste can be managed safely and effectively, without proliferation risk."

Then, he presented Ian Smith, the conference chair, a plaque created at the first PBNC and a gavel, "to maintain order".

The first speaker, **John Ritch**, head of the World Nuclear Association, began his wide-ranging talk with a reference to the Australian debate. Climate change is a pending calamity, he stated, with no borders. The growing concentration of "greehouse gases" could have apolectic consequences, he continued. We have a world of extremes, he noted, with 20% of the population using 80% of the resources. Nuclear power is not growing quickly enough, he conteneded, and suggested elevating investment in nuclear power to national or even international priority to achieve a 20 fold increase. Although security is important he commented that the Non-Proliferation Treaty should not impede nuclear programs.

He was followed by **Yang Changli,** of the China National Nuclear Corporation. China intends to build two to three 1,000 MW nuclear units per year over the next 15 years, he stated, and noted they had completed design of CNP 1000, an advanced PWR. China is also building a 65 MW prototype fast reactor as well as being a partner in the ITER fusion program.

Next, **Shunsuke Kondo**, chairman of the Atomic Energy Commission of Japan, outlined Japan's overall nuclear policy, noting an emphasis on life extension. Second generation LWRs are planned along with a Fast Breeder reactor. A reprocessing plant is under construction in Rokkasho, northern Japan.

In a change from national programs, **Peter Lyons,** a commissioner on the United States Nuclear Regulatory Commission, spoke about the USNRC program for reactor certification and licensing. Effective regulation is necessary and entails both technical and public input. USNRC is proceeding with implementing its goal of "risk-informed" regulation. They also have a problem with the ageing of their staff, with more than half being over 47 years old. USNRC supports a significant research and development program, he noted, to support their regulatory efforts.

The final speaker in this opening session was **Lee Joon-Jae**, president of the Korea Hydro and Nuclear Power Company. Through a number of slides of nuclear plants under construction, he illustrated the continuing program in Korea. On the operation side, he noted that KHNPC nuclear plants had capacity factors well above the world average, which he attributed to good management, thorough training and attention to maintenance.

The plenary session continued in the first part of the afternoon with two more national perspectives, from Argentina and Russia and a different international view by a representative of the International Atomic Energy Agency focussing on the IAEA's role in assisting developing countries. **Jerry Hopwood,** of AECL, presented a paper slated to be given by Ken Petrunik entitled, *Requirements for Nuclear New Build in the Pacific Basin: Beyond the Technology,* which looked at the economic, social and other factors associated with a large nuclear project.

A view of the Atomic Energy of Canada Limited booth at the exhibition associated with the 15th PBNC conference in Sydney, Australia, October 2006.

Clarence Hardy, incoming president of the Pacific Basin Council presents a plaque to Paul Fehrenbach, at the closing ceremonies of the 15th PBNC, in recognition of his contributions to PNC during his two and a half year tenure as president.

During the balance of the afternoon there were three parallel technical sessions. That evening the Russian delegation held a special session, enticing delegates with an offer of refreshments. Unfortunately there were technical difficulties with the A/V equipment and the speakers spoke primarily in Russian with an interpreter. One speaker noted that there is a need to develop fast breeder reactors because uranium resources are limited. He added that fast reactors are not competitive at this time but predicted they will be eventually. Afterwards, the Russians kept their word with a reception at which the vodka flowed freely.

Tuesday morning began with another plenary session with two further overviews of national programs, in Russia and the USA, and a paper, *Economics of Nuclear Energy in a Sustainable Development Perspective,* by a speaker form the Nuclear Energy Agency of the OECD.

After "morning tea" the plenary session continued with five varied presentations. Ian Smith, head of the Australian Nuclear Science and Technology Organisation, spoke about their new OPAL research reactor, which was in the final stages of commissioning. [OPAL reached its design power of 20 MWth on November 3]. As well as being a neutron source for research OPAL will be a major producer of medical isotopes. A speaker from Taiwan described their nuclear regulatory system and a delegate from Mexico stated that recent "comprehensive" studies showed that nuclear could be competitive with natural gas in that country. A speaker from Bechtel Corporation in the USA talked about the imminent expansion of nuclear power in that country while one from Westinghouse gave primarily a sales pitch.

The afternoon had two sets of five parallel technical sessions, before and after the "afternoon tea", a pattern that continued over the following two days, with the exception of short plenary sessions each morning.

Tuesday evening saw the official conference dinner at which awards were presented to the sponsors. Among the entertainment were three young women violinists, dressed in provocative clothes, but playing expertly.

At the Wednesday plenary session **John Loy,** head of the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), described their regulatory process, followed by **Peter Burns,** also of ARPANSA, a member of the International

Commission Radiological Protection (ICRP), who spoke about draft ICRP recommendations. A delegate from Indonesia said plans are proceeding for a nuclear power plant in that country.

On Wednesday evening many delegates participated in an optional dinner cruise on Sydney Harbour.

The Thursday morning plenary session saw four presentations on varied subjects. A Japanese delegate spoke about the ITER [fusion] project and a representative of Malaysia reviewed his country's experience with technology transfer. **Charles McCombie** of ARIUS, Switzerland, emphasized the continuing challenge of radioactive waste management in the context of an expected nuclear renaissance while a representative of the Australian Department of Innovation described the science underway at the Australian Synchrotron.

At the closing ceremony late Thursday afternoon, John Harries, president of the Australian Nuclear Association, the primary organizer, served as chairman. Paul Fehrenbach, as the outgoing PNC president, congratulated the ANA and their partner, Engineers Australia, for an excellent conference. Then he presented the traditional gavel to Clarence Hardy as the incoming PNC president. Hardy, in turn, commented on the "extraordinary contribution" Fehrenbach had made to PNC over his 2-1/2 years as president, including expanding the influence of PNC and representing PNC at the IAEA.

After the official close of PBNC 2006 **Dr. Kazuaki Matsui**, of Japan spoke briefly about the 16th PBNC to be held in Aomori, Japan, in October 2008, and then showed a video of the city, which is 2-1/2 hours north of Tokyo by bullet train. The latest Japanese reprocessing plant is nearby.

There was another optional social event on Thursday evening, a visit to the spectacular Sydney Opera House to see a presentation of Pirates of Penzance.

On the Friday many delegates took advantage of the offer to tour the laboratories of ANSTO, which are located about 50 km outside of Sydney.

A separate Workshop on Radiation Oncology was held on the Thursday in conjunction with PBNC 2006. This was primarily for Australian oncologists.

Clarence Hardy was the executive chairman of the conference, supported by a 15 person national organising committee, an international steering committee and an international technical committee, chaired by Neil McDonald of Australia.

There were 189 technical papers presented and 37 as posters.

An exhibition ran throughout the conference and was the venue for the morning and afternoon "teas" and the lunches. Exhibitors were: AECL; ANSTO; ARPANSA; Australian Department of Education, Science and Training; Australia Nuclear Association; Bechtel Power; Curtis Wright Flow Control; Doosan Heavy Industries & Construction Co. Ltd. (Korea); International Nuclear Services (UK); Korea Hydro & Nuclear Power co. Ltd.; Korea Nuclear Fuel co. Ltd.; Mitsubishi Heavy Industries Ltd.; Tenex (Russia); Thermo Electron Corp. (USA); Westinghouse Electric Company.

As noted above the next PBNC will be held in Aomori, northern Japan in October 2008.

Canadian papers presented at PBNC 2006

*(*signifies those reprinted in this issue of the CNS Bulletin)*

Requirements for Nuclear New Build in the Pacific Basin: Beyond the Technology, Ken Petrunik, AECL, (presentation only)

Enhanced CANDU 6 Reactor Status, S. Azeez, AECL

Harmonization of Nuclear codes and Standards – PNC report
S.S. Dua, AECL

Canada – Committed to a Nuclear Future
M. Caplan, MZ Consulting Inc.

Uranium 2005: Resources, Production and Demand
R. Vance, NRCan

Uranium Production, Exploration and Mine Development in Canada, R. Vance, NRCan

***Nuclear Undergraduate Programs at the University of Ontario Institute of Technology**, G. Bereznai, UOIT

***Ensuring Reliable Medical Isotope Supply**
K. R. Hedges, AECL; G. Malkoske, MDS Nordion

ACR-1000: Technical summary and Development Status
J. Hopwood, AECL

***Preserving Technical Knowledge – When Technology Lifetime Exceeds the Human Life Span**, D. Meneley, CNS

The Future Generations of CANDU:Advantages and Development with Passive Safety, R.B. Duffey, AECL

Health Effects of Low Level Radiation: When Will We Acknowledge the Reality?, J. Cuttler, Cuttler & Assoc. Inc.

Individual Radiosensitivity and its Relevance to Health Physics,
K. Scharr, McMaster University

Long-term Management of Canada's Spent Nuclear Fuel: The Nuclear Waste Management Organization's Recommendations to Government, K. Shaver, NWMO

Canada's Approach to the Management of Used Nuclear Fuel: the role of the Advisory Council to the Nuclear Waste Management Organisation, D. Lister, UNB

ACR 1000: Licensing Status, N.K. Popov, AECL

An Integrated Performance Based Management System for Nuclear Organizations and its Compliance with National and International Standards, S.S. Dua, AECL

***Cancer and Low Dose Responses in Vivo: Implications for Radiation Protection**, R.E.J. Mitchell, AECL

Implications of Science and Technology on the Radiological Protection System, R. E. J. Mitchell, AECL

Impacts of Low-Dose Gamma Radiation on Genotoxic Risk in Aquatic Ecosystems, C. Cassidy, McMaster University

AECL's Waste management and Decommissioning Program
W. C. H. Kuperschmidt, AECL

CANDU Reactors with Thorium Fuel Cycles, J. Hopwood, AECL

ACR 1000: Enhanced Response to Severe Accidents
N. K. Popov, AECL

***Molten Fuel Moderator Interaction Program at Chalk River Laboratories,** T. Nitheanandan, AECL

The Current Status on DUPIC Fuel Technlogy Development

K.C. Song, H. Choi, H.D. Kim, J.J. Park, G.I. Park, K.H. Kang, J.W. Lee, M.S. Yang

Korea Atomic Energy Research Institute, Daejeon, Korea

Ed. Note: The following paper was presented at the 15th Pacific Basin Nuclear Conference, Sydney, Australia, October 2006.

1. Introduction

The Direct Use of Spent Pressurized Water Reactor (PWR) Fuel in Canada Deuterium Uranium (CANDU) Reactors (DUPIC) fuel technology has been developed by Korea, Canada and the United States (U.S.) since 1991 in order to utilize the PWR spent fuel in the CANDU reactor [1]. The optimum fuel fabrication process was determined as the Oxidation and Reduction of Oxide Fuel (OREOX), based on the results of a feasibility study performed until 1993 [2]. Because the OREOX process uses only the thermal/mechanical process, the spent fuel standards are maintained throughout the process and the process is recognized as the most proliferation-resistant technology. In addition, because the amount of residual fissile isotopes in the PWR spent fuel is twice that of the natural uranium, the fuel burnup of the DUPIC fuel is twice that of the natural uranium fuel in the CANDU reactor. Therefore, as shown in Fig. 1, a direct disposal of the PWR spent fuel is no longer necessary, the natural uranium resources are preserved, and the amount of spent fuel from the CANDU reactor can be halved in the DUPIC fuel cycle. This paper summarizes the technical feasibility of the DUPIC fuel based on the research results obtained until now.

2. Current status of the DUPIC fuel cycle technology

The DUPIC fuel cycle technology has been developed based on a remote fuel fabrication, in-core fuel performance analysis, and a compatibility of the DUPIC fuel with a CANDU reactor, which are described below.

2.1 DUPIC fuel fabrication

2.1.1 DUPIC fuel development facility

The Korea Atomic Energy Research Institute (KAERI) established the DUPIC fuel development facility (DFDF) in 1999 to process the PWR spent fuel and to fabricate the DUPIC fuel on a laboratory scale. In this facility, about 25 pieces of fuel fabrication equipment are installed as follows:

1) Decladding machine, OREOX furnace, off-gas treatment system, attrition mill and mixer to produce DUPIC fuel powder from the PWR spent fuel
2) Compaction press, high temperature sintering furnace, centerless grinder, pellet cleaner and dryer, pellet stack length adjuster and pellet loader to fabricate DUPIC fuel pellets

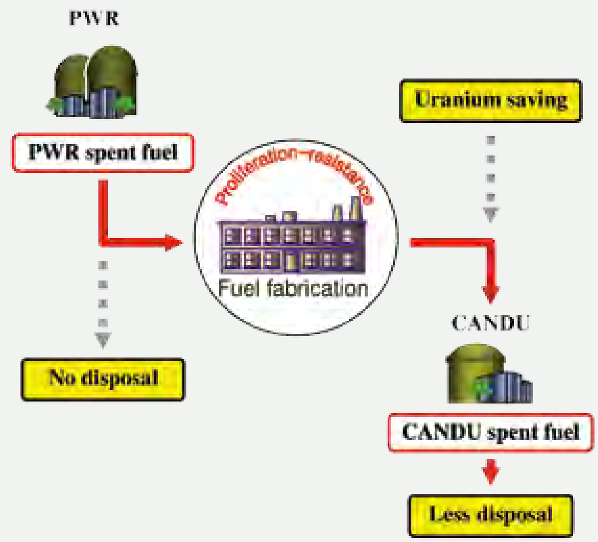

Figure 1: DUPIC fuel cycle concept.

3) Remote laser welder and welding chamber to fabricate DUPIC fuel elements
4) Quality inspection devices to characterize the DUPIC fuel powder, pellets and elements.

2.1.2 DUPIC fuel pellet and element fabrication

In December 1998, a Facility Attachment was put into force after research activities on the spent fuel in the DFDF were approved by the International Atomic Energy Agency (IAEA). In April 1999, KAERI obtained a Joint Determination from the U.S. for the research activities that included an alteration of the forms and content of the U.S.-origin PWR spent fuel. After resolving the international restrictions, KAERI produced the DUPIC fuel powder and pellets in March 2000. In addition, small-size DUPIC fuel elements were fabricated in April 2000 for irradiation tests in the HANARO research reactor. Then, KAERI fabricated real-size DUPIC fuel elements in February 2001.

2.2 Fuel performance assessment

As the DUPIC fuel fabrication technology had been developed, the characterization, performance analysis and the irradiation tests of the DUPIC fuel have been carried out since 1998, which are described in the following sections:

2.2.1 DUPIC fuel pellet material property

The thermal and mechanical properties of the simulated DUPIC fuel were measured and compared to those of the natural uranium fuel. The thermal expansion coefficient is higher for the DUPIC fuel pellet by ~5% in the high-temperature range above 1200 and the thermal conductivity is smaller for the DUPIC fuel by 8~23% in the range up to 1300. The Young's modulus is greater for the DUPIC fuel pellet by ~2%. The high-temperature hardness is almost the same for both the DUPIC and natural uranium pellets in the low temperature range, but the value is higher for the DUPIC fuel pellet by 127~287% for the temperature range of 400~1000. The fracture toughness of the DUPIC fuel pellet is not that different from that of the natural uranium pellet in the temperature range of 20~300. The diffusion coefficient of the fission gas for the DUPIC fuel matrix is estimated to be ~1/3 of that for the natural uranium. The experimental results have been integrated into the DUPIC fuel performance database.

2.2.2 Irradiation and post-irradiation tests

A total of five DUPIC fuel irradiation tests have been carried out in HANARO from 1999 to 2004. The first, second and fourth tests were non-instrumented tests, while the third one was an instrumented test to measure the thermal neutron flux of the irradiation hole and the fifth one was an instrumented test to measure the center temperature of the DUPIC fuel pellet. One fuel element irradiated in the third test was burned again in the fourth test. This element has a fuel burnup of 6700 MWd/tHM, which is the highest among all the fuel burnups obtained until now. The maximum and average linear element ratings of this element were estimated to be 34 kW/m and 25 kW/m, respectively.

A comparison of the pellet centerline temperature between the on-line measurement and the KAOS calculation showed that the calculation result was a little conservative for the 1st cycle of the irradiation but matched the measurement result within 8% for the temperature range of 800~1200 [3]. The post-irradiation examination was performed for the DUPIC fuel pellet which was irradiated to an average fuel burnup of the standard CANDU fuel. A comparison of the optical microscopy photos (Fig. 2) showed that the irradiation behavior of the DUPIC fuel is similar to that of the standard CANDU spent fuel or PWR spent fuel of 40000 MWd/tHM.

2.3 Compatibility with a CANDU reactor

The reference DUPIC fuel composition was determined based on the PWR spent fuel data accumulated in Korea until 1994 under the conditions that the fuel composition variation is minimized. The DUPIC fuel composition was also adjusted such that the DUPIC fuel lattice property, core performance and the fuel cycle cost were optimized [4]. The DUPIC fuel bundle adopts the 43-element CANDU Flexible (CANFLEX) model, of which a compatibility with the fuel channel and fueling machine was already demonstrated in the CANDU reactor.

2.3.1 Reference reactor power distribution

A 2-bundle shift refueling scheme is adopted for the DUPIC fuel [5]. The refueling simulation of the DUPIC fuel core has shown that the peak maximum channel power (MCP) and the maximum bundle power (MBP) are 6998 kW and 827 kW, respectively, which are below the license limits of the natural uranium core (7300 kW and 935 kW). The average channel power peaking factors (CPPF) of both the DUPIC and the natural uranium cores are comparable. Regarding the refueling operation, the DUPIC fuel core requires four channels to be refueled per day. Therefore the total number of fuel bundles loaded per day is approximately 8 for the DUPIC fuel core, while it is 16 for the natural uranium core.

Though the reference DUPIC fuel was determined to have a fixed fissile content, the contents of the fission products and the higher actinides vary depending on the PWR spent fuel condition. This composition heterogeneity of the DUPIC fuel causes variations of the lattice parameters, which in turn result in uncertainties for the core performance parameters. The uncertainties of the core performance parameters were estimated by both the deterministic and statistical method [6,7]. In general, the results of the deterministic analysis were more conservative. As a result, the uncertainties of the MCP, MBP and CPPF were estimated to be less than 1% for the simulated core.

2.3.2 Compatibility with the reactivity devices

The compatibility of the DUPIC fuel with the reactivity devices of the existing CANDU reactor was assessed for the zone controller unit (ZCU), adjuster (ADJ), mechanical control absorber (MCA) and the shut-down system (SDS). For the ZCU, the capability of suppressing a xenon-induced spatial oscillation and the draining effect were confirmed by a refueling simulation [8,9]. The ADJ was assessed for the capability of overriding the xenon load at 30 min after a reactor shutdown, startup after a short shutdown, startup after a long shutdown, shim operation in the event of a loss of a refueling capability, and a power recovery after a step-back. The analysis showed that the ADJ system satisfies all these design requirements for the DUPIC fuel core even though the response time to the transient core condition is a little delayed when compared to the natural uranium core. The MCA possesses enough reactivity to compensate for the reactivity increase following a reactor hot shutdown. The adequacy of the SDS design was assessed by comparing the maximum thermal energy deposited in the fuel during the transient and the threshold value (840 J/g) of the fuel breakup [10]. The shutdown capability of the shutoff rods and a liquid poison injection was confirmed by simulating a 20% reactor inlet header (RIH) break loss of coolant accident (LOCA) and a 100% RIH break LOCA, respectively.

(a) DUPIC Fuel from HANARO Research Reactor *(b) UO_2 Fuel from Douglas Point (CANDU) Nuclear Power Plant* *(c) UO_2 Fuel from Kori (PWR) Nuclear Power Plant*

Figure 2: Comparison of the irradiated fuel pellets.

2.3.3 Compatibility with the reactor trip set-point

The basic regional overpower protection (ROP) system design requirement is that the reactor is tripped for any flux shape and power ripple before any coolant channel reaches its critical channel power (CCP). The flux shapes are obtained by the physics calculations for design-base cases such as the normal operating configurations, single-device abnormal configurations and certain types of double-device abnormal configurations. An on-power refueling is also considered by calibrating the rippled power to a 100% power level by using the CPPF obtained from a refueling simulation. The ROP trip set-point of the DUPIC fuel core was estimated to be 123.4% and 122.9% for the DUPIC and natural uranium fuel core, respectively. Consequently, it is expected that a DUPIC fuel loading in a CANDU-6 reactor does not deteriorate the current ROP trip set-point designed for the natural uranium fuel.

3. Hardware systems for a future DUPIC fuel study

The basic DUPIC fuel technology has been developed through laboratory-scale studies. Before the commercial use of the DUPIC fuel, however, it is highly recommended to conduct an engineering-scale study to accumulate a database and confirm the practicality of the DUPIC fuel. The hardware systems considered for a practical use of the DUPIC fuel in the future include an engineering-scale DUPIC fuel facility, transportation equipment, fuel loading equipment and the nuclear material safeguards system.

3.1 DUPIC fuel fabrication facility

The engineering-scale DUPIC facility will be designed with a capacity of 50 ton/yr and a plant lifetime of 40 yrs. The design also considers the expansion of the facility to a commercial-scale plant. The main process building is located in the centre, surrounded by auxiliary buildings such as a utility facility, health physics buildings, etc. The overall process can be categorized into a DUPIC fuel fabrication, a structural part recycling and a radioactive waste treatment. A detailed flow path of the main processes is as follows:

- PWR spent fuel receiving and storage
- Spent fuel disassembly and decladding (99% recovery of the fuel material from the clad)
- Fuel powder preparation by the OREOX process
- Fuel pellet fabrication with a theoretical density of more than 95%
- Fuel rod fabrication including a surface decontamination and fissile content measurement.
- Fuel bundle fabrication in the CANFLEX geometry.

3.2 Transportation of the PWR spent fuel and fresh DUPIC fuel

The PWR spent fuel and DUPIC fuel should be remotely handled during the transportation. The DUPIC fuel bundles will be placed in a basket, and several baskets are loaded into a shipping cask in the shielded facility. The shipping cask is ground-transported to the CANDU nuclear power plant (NPP), and the fuel bundles are unloaded in the storage room. It is also required to comprehensively analyze the transportation between the DUPIC facility and the CANDU NPP.

3.3 DUPIC fuel loading in a CANDU nuclear power plant

There are two ways of loading the DUPIC fuel into a CANDU reactor depending on the loading route, i.e., front-loading and rear-loading. The front-loading option requires a new hot-cell in the new fuel loading area inside the reactor building. The DUPIC fuel bundles are remotely and automatically pulled out from the cask in the new hot-cell. Extra fuel loading equipment is also required in case of the decontamination and an exchange of the contaminated or failed fuel loading equipment.

The rear-loading option utilizes the existing spent fuel storage bay in the power plant. The DUPIC fuel bundles pulled out from the shipping cask are transferred to the reception bay and loaded into the fueling machine reversely following the existing discharge route of the spent fuel. In this option, the existing dry storage facility in the storage bay area should be modified to be used for the opening of the shipping cask and a handling of the DUPIC fuel bundle. Additional equipment is also required such as a blow-dryer to remove the light water from the DUPIC fuel, a ram device for inserting the DUPIC fuel into the spent fuel discharge port, and a gamma radiation detector for identifying the new and spent fuel.

3.4 Nuclear material safeguards

When the DUPIC fuel is loaded into a CANDU reactor, a new safeguards approach should be deployed because all the monitoring systems are remotely operated and the material flow and classification system are different from those of the current CANDU reactor system. Korea has been negotiating with the IAEA on an integrated safeguards system since the Additional Protocol entered into force in 2004. Therefore it is expected that the current safeguards system can be utilized for the CANDU reactor with the DUPIC fuel if the current system is modified and supplemented through consultations with the main inspection organizations such as the National Nuclear Management & Control Agency (NNCA) and the IAEA.

In order to demonstrate the DUPIC fuel performance under a power reactor operating condition, a lead test assembly (LTA) irradiation test should be performed. For the LTA irradiation, a series of in-pile and out-pile tests is required to prepare the fuel design documents and evaluation reports to be submitted to the regulatory body.

4.1 Physics design verification

The experimental data that can be used for the validation of the DUPIC fuel physics design is limited because of the complexity of the fuel composition. Therefore it is recommended to conduct a few physics experiments by using either the actual DUPIC fuel or simulated DUPIC fuel. The simulated DUPIC fuel should have the reference DUPIC fuel composition of 235U and 239Pu as well as some of the major fission products. The experiments include the measurement of the critical buckling, detailed reaction rates and neutron density distributions across a fuel bundle with and without a coolant in the channel.

4.2 Thermal-hydraulic design verification

The purpose of the fuel channel thermal-hydraulic design is to determine the heat removal capability in all the fuel channels and to meet the performance and safety criteria. For the thermal-hydraulic design of the CANDU fuel, a single channel analysis code is typically used. Because the radial power distribution of a fuel bundle and the axial power distribution in a fuel channel for the DUPIC fuel are different from those for the standard 37-element fuel and 43-element CANFLEX natural uranium fuel, it is recommended to develop a new xc-Lb correlation [11] of the single channel analysis code for various radial power and non-uniform axial power distributions [12]. Based on the water critical heat flux test results, the single channel analysis code should be validated for the thermal-hydraulic design of the DUPIC fuel.

4.3 Mechanical design verification

The DUPIC fuel should be designed to be mechanically compatible with the primary heat transport system, fuel channel, fuel handling system and the fuel management system. Because the DUPIC fuel bundle adopts the CANFLEX geometry, it is believed that the mechanical compatibility can be verified by either the experimental or analytical method. For a compatibility with the primary heat transport system, the pressure tube fretting and spacer grid fretting experiments will be required, while analytical methods can be used for the end plate fatigue and pressure tube corrosion. For a compatibility with the fuel channel, the clearance between the fuel bundle string and the shield plug can be analytically evaluated. For a compatibility with the fuel handling system, it is expected that the cross-flow fretting experiment will be necessary.

In order to assess the in-core integrity and geometrical stability of the DUPIC fuel bundle, the high power and power ramp irradiation tests are required, which are used to produce the stress corrosion cracking (SCC) threshold curve of the DUPIC fuel, typically used to assess the fuel integrity of the CANDU fuel during the normal and operational transients. It is also required to measure the melting temperature of the DUPIC fuel to estimate the safety margin of the DUPIC fuel, because the thermal conductivity of the DUPIC fuel is lower than that of the natural uranium fuel.

4. Conclusion

The DUPIC fuel cycle is a unique spent nuclear fuel management technology that can be implemented in Korea. In the past, the Tandem fuel cycle development project, which recycles mixed oxide fuel in a CANDU reactor through a reprocessing, was frustrated. The utility also tried a reprocessing in a foreign country but it was not successful due to the rising concerns about a proliferation and the non-proliferation treaty in the Korean peninsula. Nonetheless the accumulation of spent fuel is an urgent issue that should be resolved. Therefore a technology should be developed that can be implemented in Korea under the non-proliferation policy. Until now, the DUPIC fuel cycle is known to be the most representative example that has technically overcome the international and domestic restrictions of the Tandem fuel cycle.

Though it is yet too early to launch the commercialization of the DUPIC fuel based on the basic DUPIC fuel technologies developed until now, it is also true that the key technologies have been developed for the DUPIC fuel cycle. Therefore it is expected that there should be no technical problems to develop the commercial DUPIC fuel technology once the DUPIC fuel technology and its performance are demonstrated through a practical use of the DUPIC fuel, which will be an extremely important turning point in the history of nuclear power development. By utilizing spent fuel by an internationally-proven proliferation-resistant technology, it is expected that the burden of a spent fuel accumulation will be relieved not only in the domestic nuclear grid but also in the worldwide nuclear power industry.

6. Acknowledgement

This project has been carried out under the Nuclear Research and Development program by Korea Ministry of Science and Technology.

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Molten Fuel Moderator Interaction Program at Chalk River Laboratories

T. Nitheanandan, G. Kyle, R. O'Connor and D.B. Sanderson[1]

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Further note: As background, this work addresses one of the early "Generic Action Items" (GAI 95 G01) identified by the Atomic Energy Control Board (now Canadian Nuclear Safety Commission) in 1995. The postulation was that a severe flow blockage in a fuel channel of a CANDU reactor could potentially lead to fuel melting, channel rupture and ejection of molten fuel into the moderator. That led to the question of whether the molten fuel / moderator interaction could damage the shut-off rods guide tubes and prevent shutdown system #1 from functioning properly. In answer to a question, the principal author stated that the cost of the program had been "several million" dollars. The GAI is not yet "closed".

1. Introduction

The Canadian nuclear power generation industry, represented by the CANDU Owners Group (COG), has been funding an experimental program at Chalk River Laboratories (CRL) to study the interaction between molten material ejected from a fuel channel and the moderator. These experiments were designed to address one of the very low probability postulated accident events [1] considered for CANDU®[2] Pressurized Heavy Water Reactors. The reactor consists of an array of horizontal fuel channels (Figure 1) that contain the UO_2 nuclear fuel and high-temperature, high-pressure heavy water coolant. Under severely restricted flow blockage conditions, approaching 100% reduction of the flow area, postulated in a fuel channel, the temperature excursion could result in fuel melting, consequential failure of the fuel channel (Figure 2), and ejection of the molten fuel at high pressures into the heavy water moderator at near atmospheric pressure.

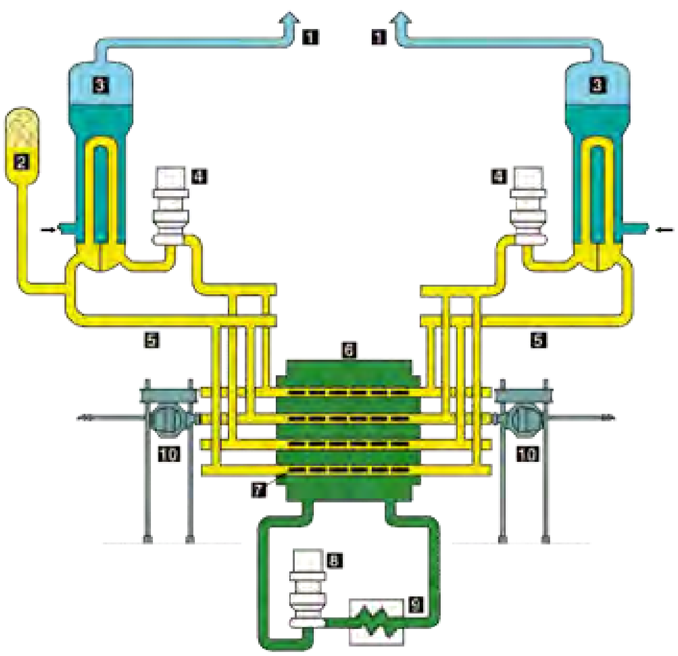

Figure 1: A schematic of a CANDU primary heat transport system (Legend: 1. Steam line leading to electric turbines, 2. Pressurizer, 3. Steam generator, 4. Pumps, 5. Inlet headers, 6. Calandria vessel, 7. Fuel channel, 8. Moderator recirculation pump, 9. Heat exchanger, and 10. Online refueling machines).

In preparation for these tests, a chemical mixture called a thermite, that could produce a simulated molten fuel when ignited, was developed in partnership with Argonne National Laboratory (USA). Following this thermite development, two base-case reference tests were completed. The two base-case reference tests, with no molten material present, were performed in the Molten-Fuel Moderator-Interaction (MFMI) facility at CRL. Following the base-case reference tests, a high-pressure melt ejection test using prototypical corium was conducted. The objectives of this paper are to provide an overview of the MFMI program and present the results obtained from thermite development, base-case and melt ejection experiments.

2. Corium development

The term corium refers to the complex mixtures, originating from the melting of the constituents of a nuclear reactor, at different stages of a severe accident. The generation and ejection of 2400°C molten corium from a 0.1038 m diameter pressure tube at ~10 MPa was made possible by thermite technology developed by Argonne National Laboratory. The thermite is an incendiary mixture of metal powders, oxide and a catalyst powder, which react exothermically when heated to an auto ignition temperature, and produce a molten metal pool (the corium) at elevated temperatures. The target CANDU corium composition is 0.9 UO_2/0.1 Zr (wt%) at 2400°C with limited oxidation of components. Four chemicals, namely uranium metal powder, U_3O_8, Zr metal powder, and CrO_3, were selected as reactants for the thermite. Although Cr is not a major reactor material, CrO_3 was used as an oxidant in the thermite. Chromium is assumed

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

2 CANDU – CANadian DeUterium

Figure 2: Cross Section of a CANDU fuel channel with intact fuel bundle under normal operating conditions (left hand side) and postulated fuel channel failure scenario (centre and right hand side) where molten material is available to be ejected at 10 MPa pressure into Moderator.

to behave similarly to zirconium in its melt-water interaction behaviour.

A chemical equation that satisfies the target corium composition (and the thermite composition) can be written as:

$4.01\ U + 0.151\ U_3O_8 + 2.72\ Zr + 3.12\ CrO_3 \sim 4.46\ UO_2 + 0.82\ ZrO_2 + 1.90\ Zr + 3.12\ Cr$.

This chemical equation can be expressed in terms of mass as: 0.582 U/0.077 U_3O_8/0.151 Zr/0.19 CrO_3 (wt%) for the reactant chemicals and 0.73 UO_2/0.1 Zr/0.06 ZrO_2/0.10 Cr (wt%) for the product constituents [2]. The product composition is comparable to the target CANDU specific corium composition of 0.9 UO_2/0.1 Zr. Further details of thermite development are provided in Reference 2.

2.1 Thermite reaction tests

The peak melt temperature of the thermite was confirmed from small-scale thermitic reaction tests. The reaction characteristics of the thermite on a larger scale (1 kg) were verified using mass scale-up tests. These tests were also used for qualifying the thermite to ensure that the prescribed mixture would burn completely and provide a coherent solidified melt mass reaching the target peak melt temperature [2].

The mass scale-up tests were conducted in a drop test apparatus; see Figure 3. The thermite was placed in the upper refractory crucible with a hole at the bottom plugged by an aluminum diaphragm and ignited. After thermite ignition, the diaphragm melted through, allowing the melt to pour from the crucible (Figure 3), and land in the catch cup. To provide independent and diverse measurements of melt temperatures for comparison to the thermocouple measurements, three two-colour optical pyrometers were focused on the melt stream. Type-C thermocouples in the crucible and the catch cup also measured the corium temperature. These tests confirmed that the average melt temperature was 2388±24°C.

2.2 Slow heat-up tests

Once the thermitic reaction and mass scale-up tests confirmed that the thermite would ignite and reach the desired temperature range, the next step in the qualification process was to determine the temperature at which it would auto ignite. This ignition temperature is an important indicator of how stable the thermite is and the level of caution required to handle it safely. A thermite that ignites at a relatively low temperature (<200°C) is considered extremely reactive, while one that only ignites if it reaches a relatively high temperature (>400°C) is considered quite stable.

A slow heat-up test was performed using a 100-g sample of the thermite composition to ensure that a safe temperature margin was available to prevent accidental auto-ignition. This test indicated self-heating of the MFMI thermite mixture started at 200°C, and the mixture auto ignited at 400°C. The measured corium temperatures are shown in Figure 4.

3. Base-case reference tests

The base-case reference tests (also called the non-corium commissioning tests) were performed by rupturing empty pressure tubes without the simulated molten fuel. The pressure tubes with a machined flaw were pressurized to ~10 MPa by a mixture of steam and helium inside the steam injection vessel and associated piping. The measured dynamic pressure transients in the water from these tests provided a reference base to be compared against the melt ejection tests. They helped interpret the results of melt ejection tests, and study the effect of molten corium interaction with water, over and above the effect of the shock wave created by the pressure-tube rupture in the absence of corium.

Figure 3: A photographic view of the melt-pour stream dripping out of the crucible.

3.1 Confinement and auxiliary systems

The confinement for the MFMI experiment consists of an outer confinement vessel, and an inner tank. The outer vessel is cylindrical, 1.5 m diameter and 5.0 m high (Figure 5). The confinement vessel has flanged feed-throughs for process and instrumentation. The lines

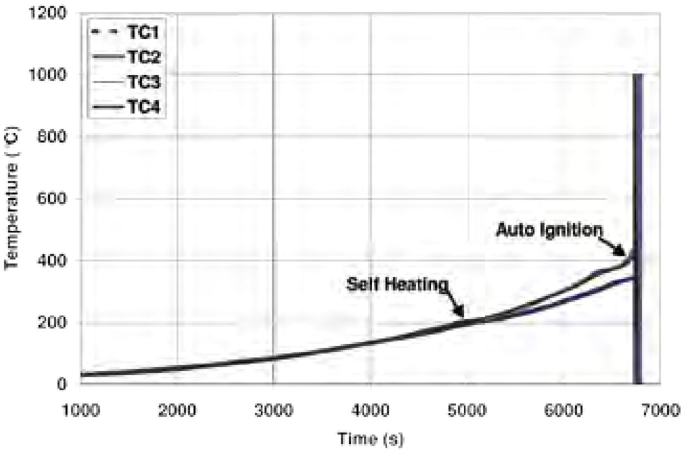

Figure 4: Measured temperatures in the slow heat-up test.

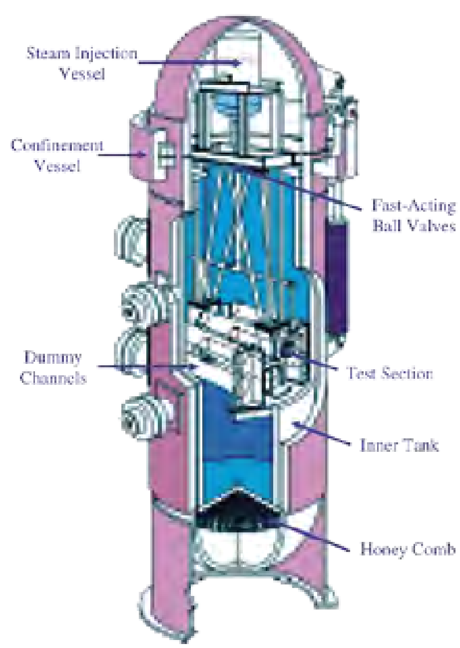

Figure 5: An artistic view of the MFMI facility.

from the pre-heated water supply tank, the helium supply lines, and steam vent lines penetrate the confinement tank via these feed-throughs in the flanges.

The inner tank (Figure 5) holds water (simulating the moderator), instrumentation, simulated adjacent fuel channels, and the structure supporting the test section. It is an open top tank which has an inside diameter of 1.25 m and a height of 2.9 m. Instrument sensors for level, pressure, and temperature measurement are located at various locations inside the tank. Eight piezo-electric and two piezo-resistive dynamic pressure transducers (range 0 to 70 MPa) are used to monitor the pressure within the water and on the walls of the inner tank. The locations of the pressure transducers are shown in Figure 6. Six standard Resistant Temperature Devices (RTDs) are used to monitor the water temperature at various elevations within the inner tank. These RTDs have a maximum operating temperature of 300°C. The concrete filled dummy fuel channels were placed beneath and beside the test section (Figure 5). The steam-injection vessel, designed to provide ~23 L of saturated steam at 10 MPa, is connected to the test section via a steam-injection line that consists of two fast-acting ball valves (Figure 5). The purpose of the steam-injection vessel and piping is to deliver steam to the test section just prior to pressure-tube rupture, simulating the coolant flow to the channel.

3.2 Test section

The test section is a 1. 14-m long section of Zr-2.5 Nb pressure tube (0. 1038-m ID and 0.0043-m thick wall) placed concentrically inside a 1.04-m long, 0.13-m ID, and 3-mm thick quartz tube. The quartz tube insulates the pressure tube from the surrounding water. The pressure-tube/quartz-tube assembly was submerged in 68°C water at a depth of 1.4 m. Two end hubs, attached to the ends of the pressure tube with an O-ring seal between, have penetrations for two pressure transducers, a thermite fill port, two ignition wires, CO_2 gas inlet and outlet ports, steam-injection lines, and two Type-C thermocouples. A schematic of the assembled test section in the MFMI facility is shown in Figure 5. The pressure-tube/quartz-tube assembly was bolted to a stainless steel frame that provided structural support to the steam-injection vessel, the steam-injection line, and the fast-acting ball valves. A V-shaped groove was machined on the outside surface of the pressure tube to weaken a section of the wall at the 6 oíclock position to ensure a predictable rupture at a defined location. The defect is a 450-mm long section with a 60° groove, leaving a wall thickness of 1.03 to 1.06 mm at the weakest section. Further details on the test section and the facility are given in Reference 3.

3.3 Data acquisition and instrumentation

The data acquisition system (DAS) configuration includes both high-speed sampling and low-speed sampling during the test. The low-speed sampling of data occurs at 10 Hz. The high-speed system can acquire 28 channels simultaneously at a rate of 100 kHz.

During the MFMI test, a series of sequential operations were performed remotely using a Programmable Logic Controller (PLC). The entire test sequence is divided into six stages. The PLC is programmed to execute a set of instructions when stage switches are activated. These stages represent discrete operations such as pumping water into the inner tank, pre-pressurization of the pressure tube, injecting steam into the pressure tube, etc.

3.4 Experimental procedure

The following is an overview of the test procedure followed during the non-corium and corium tests. The differences between the corium and non-corium tests are indicated in parenthesis.

1. Connect the test section to the steam-injection vessel, place the apparatus into the inner tank, and close the confinement vessel lid. (For the corium test, mix thermite and load into pressure tube).
2. Turn the power on to the moderator heating system and heat the water to 74°C.

3. Turn the power on to the steam-injection vessel and when the steam-injection vessel reaches 265°C, turn the low-speed DAS on and flip Stage 1 switch to pump water into the inner tank.
4. When steam-injection vessel water reaches 305°C, turn on high-speed DAS.
5. When steam-injection vessel reaches 310°C, turn-on Stage 2 to pressurize the pressure tube to 6 MPa. Turn Stage 3 switch to adjust steam-injection vessel to 11 MPa using helium and supply nitrogen gas to fast-acting ball valves to maintain it in standby mode. (Stage 2 adjusted the steam-injection vessel pressure and Stage 3 supplied nitrogen gas to ball valves in the corium tests).
6. Flip Stage 4 switch to increase the pressure-tube pressure to 9 MPa, wait for 3 s and open the fast-acting ball valves to direct 11 MPa saturated steam into the pressure tube to rupture the pressure tube. (This switch ignited the thermite for the corium test).
7. If pressure tube does not rupture (from pressure-tube pressure), activate Stage 5 switch to automatically bring the Bump system at 13 MPa helium gas pressure to the pressure tube via the steam-injection vessel. (After thermite ignition, pressure tube is pressurized with helium and following a 1.7 s delay, the interconnect ball valves are opened to inject steam into the pressure tube in the corium test).
8. If pressure tube does not rupture with the Bump system, turn Stage 6 switch on to vent the steam injection, pressure tube and the confinement tank.

3.5 Experimental results

The results obtained from the first non-corium commissioning test are described in this section. These tests characterized the pressure pulse generated by the rupture of the pressure tube submerged in water. The results from the second non-corium test are given in Reference [3].

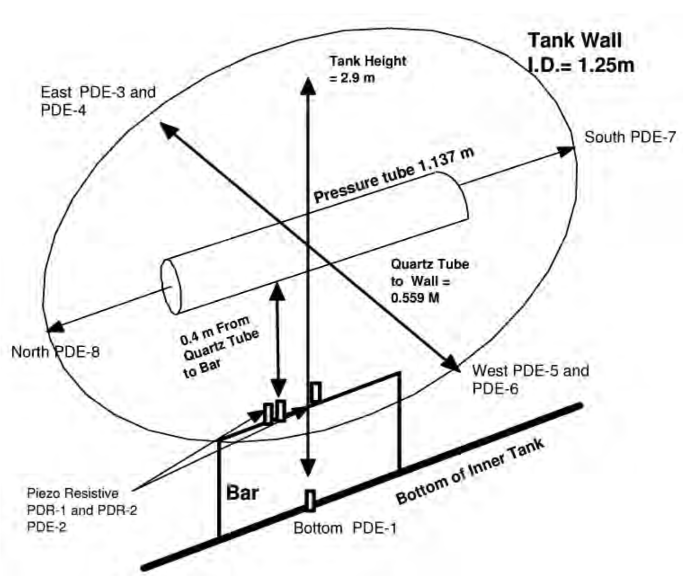

Figure 6: The Schematic showing the dynamic pressure transducer locations named PDE-1 to 8 in the MFMI Facility.

The response of the RTDs placed at different elevations in the inner tank is shown in Figure 7. The Stage 1 switch was turned on (at time = 152 s) and the 74°C water from the insulated storage tank was pumped to the inner tank. The pump took 15 minutes to pump 3100 L of water into the inner tank. As shown in Figure 7, the RTD temperatures started at 30°C (measuring room temperature) when the pump was turned on. When water encountered the first RTD, it began to record a sharp increase in temperature reaching 71°C and then gradually decreasing to 68°C.

The measured steam-injection vessel pressure and the pressure-tube pressure from the low-speed DAS are shown in Figure 8. The pressure tube was pressurized to 6.4 MPa as shown in Figure 8. Once the steam-injection vessel pressure and temperature reached 10 MPa and 3 10°C, respectively, the steam-injection vessel pressure was increased to 12.2 MPa using helium gas. The steam-injection vessel pressure decreased to 8 MPa within 5 s due to condensation when helium gas at room temperature mixed with steam. The steam-injection vessel pressure and temperature recovered back to the value before helium gas was added within 6 s. Once the steam-injection vessel pressure and temperature reached the target values, the pressure-tube pressure was increased to ~10 MPa using helium and the fast-acting interconnect ball valves were opened after a 10 s delay. The pressure in the steam-injection vessel decreased to 10.6 MPa when the interconnect valves opened. The pressure-tube pressure was 0.1 MPa lower than the pressure in the steam-injection vessel. Since the pressure tube did not rupture for approximately 120 s, the bump system was activated. Within 8 s after the bump system activation, the pressure tube ruptured and the test terminated.

The dynamic pressure measured by a transducer placed at the bottom of the inner tank is shown in Figure 9. The pressure pulse resembles a rising and falling half-sinusoid curve. The range of time period (half wavelength) of the pressure pulses was 4 ms. The peak dynamic pressure measured at the bottom was 5.5 MPa in the first pulse. The velocity of the wave front was calculated to be 1180 m/s. The rupture of the pressure tube was a typical "fish mouth" ~0.7 m long opening with the largest width along the rupture being 150 mm.

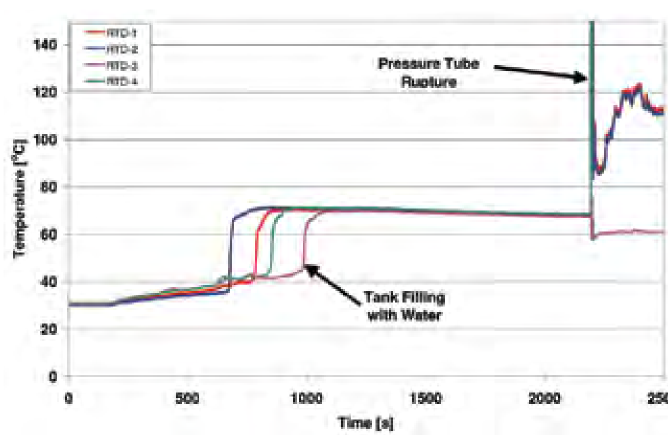

Figure 7: The measured water temperatures in the first non-corium commissioning test.

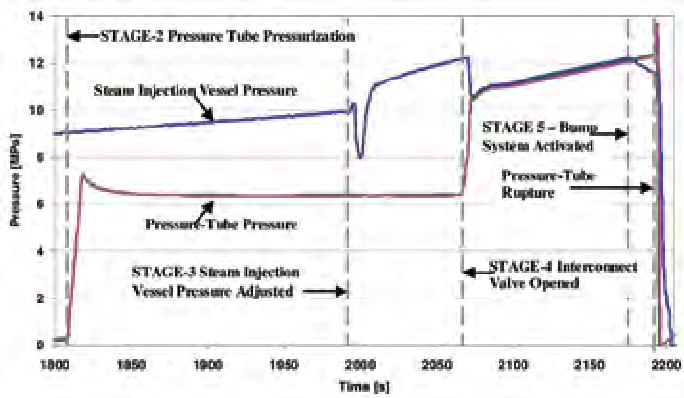

Figure 8: The measured pressure-tube pressure and steam-injection vessel pressure in the first non-corium commissioning test.

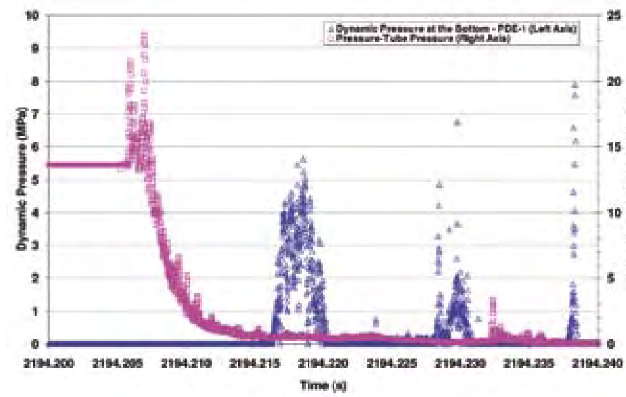

Figure 9: The measured pressure-tube pressure and the dynamic pressure at the bottom of the inner tank in the first non-corium commissioning test.

4. First corium test with 5 kg of thermite

In the corium test, the pressure tube was insulated with zirconia insulation and charged with 4.75 kg of thermite. The thermite was ignited using an electrical circuit and then the pressure tube was pressurized with helium gas and steam. The pressure and the temperature in the pressure tube ruptured the tube, ejecting the molten corium into the inner tank water.

4.1 Steam and water temperature

The Stage 1 switch was turned on at the start of the test and the 74°C moderator water from an insulated storage tank was pumped to the inner tank. The response of the RTDs placed at different elevations in the inner tank was similar to that shown in Figure 7. The average water temperature was 68°C just before pressure-tube rupture. Once the steam-injection vessel pressure and temperature reached 9 MPa and ~300°C, respectively, the Stage 2 switch was flipped. In this stage, the steam-injection vessel pressure was increased to 11 MPa using helium. The steam-injection vessel pressure decreased to 7.5 MPa due to condensation of steam. The steam-injection vessel temperature quickly recovered, reaching 310°C and ~10 MPa before the start of Stage 4. In Stage 3, the nitrogen supply required to turn the ball valves was turned on and maintained in a standby mode.

4.2 Thermite ignition and pressure-tube rupture

Once the steam-injection vessel pressure and temperature reached the target values (10 MPa and 310°C), the Stage 4 switch was flipped to ignite the thermite. The time when thermite ignited was determined from the response of the Type-C thermocouples. Elevated temperature measurements continued for approximately 2 s at which point the thermocouples burnt out and ceased recording corium temperatures. The peak temperature measured was 2477°C. The peak corium temperature has also been previously established using separate effects tests (Section 2.1).

Following thermite ignition, the Stage 5 switch was flipped to pressurize the pressure tube to 11 MPa using helium and activate the fast-acting ball valves on the steam-injection lines after a timed 1.7 s delay. The pressure tube ruptured ~9 s after the steam-injection line was opened. The steam-injection vessel pressure was used as an indication of pressure-tube pressure between the time the quick-acting valves opened and the pressure tube ruptured. The steam-injection vessel pressure decreased from ~11.6 MPa to the confinement vessel pressure within 6 s and the shock wave increased the confinement vessel pressure to a maximum of 188 kPa within 5 s. The confinement vessel pressure reached a steady-state pressure of 46 kPa, approximately 290 s after the maximum pressure was reached. The pressure-tube rupture was a "fish mouth" opening 0.72 m long with the largest width along the rupture being 160 mm.

4.3 Dynamic shock wave pressure

The peak pressure measured by the dynamic pressure transducers was between 2.54 MPa (bottom) and 4.36 MPa (north). A comparison of measured dynamic pressures at the bottom of the inner tank and on the bar below the pressure tube is shown in Figure 10. The dynamic pressures measured on the bar for two non-corium tests and the 5-kg corium test are compared in Figure 11. The pressures in the figure have been normalized to the pressure-tube pressure before rupture. For example, the measured dynamic pressure from the 5-kg corium test was normalized to 11.6 MPa pressure, which was the pressure inside the pressure tube before rupture. The peak dynamic pressure characteristics were similar between the corium test and the non-corium tests. The pulse width in the corium test was wider compared with the non-corium tests. Based on this comparison, it can be concluded that there was no steam explosion when 4.75 kg of corium was ejected into water from a pressure tube at 11.6 MPa driving pressure.

4.4 Debris and post-test analysis

A post-test debris analysis was completed using a set of sieves after the obvious "non-corium" debris was removed. The mean particle size was calculated on a weight basis using the geometric mean

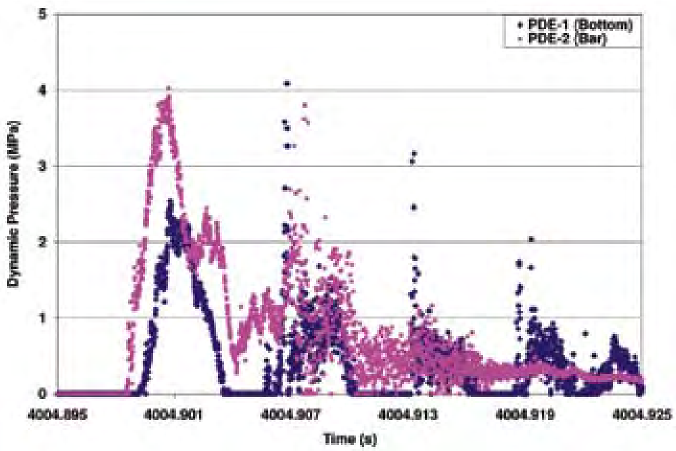

Figure 10: The measured dynamic pressure at the bottom and at the bar in the 5-kg corium test.

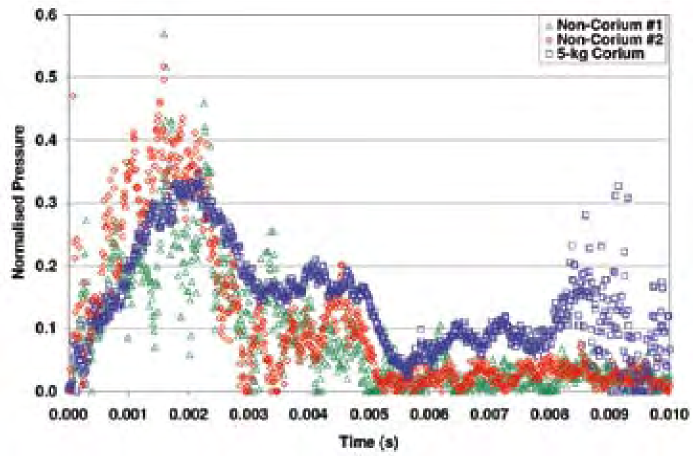

Figure 11: The measured dynamic pressure at the bar for the two non-corium tests and the 5-kg corium test.

of the diameter openings in two adjacent sieves in the stack [4]. The calculated mean diameter of the debris particles was 0.686 mm.

Had the mean particle size been greater than 1 mm, it would be indicative of the potential for spontaneous or triggered fragmentation and subsequent steam explosion in the experiment. Since the mean size of the debris was less than 1 mm and the dynamic pressurization history was below the driving pressure (i.e., pressure-tube pressure), it was concluded that there was no steam explosion in this test.

5. Summary

The CANDU Owners Group representing the Canadian nuclear power generation industry has been funding an experimental program at Chalk River Laboratories to study the interaction between the high pressure molten material ejection and the moderator. A thermite mixture that can auto ignite at 400°C was developed to generate the molten corium at 2400°C for these studies in partnership with Argonne National Laboratory.

Two non-corium commissioning tests were completed with and without target calandria tubes placed beneath and on the sides of the test section to provide a reference base for the melt ejection tests. The pressure tubes ruptured in both tests and produced a dynamic shock wave. The 5-kg corium-commissioning test was completed in the MFMI facility with adjacent calandria tubes. During the test, 4.75 kg of thermite, loaded inside a pressure tube, was ignited producing molten corium at ~2400°C. Following ignition, the pressure tube was pressurized to 11.6 MPa using helium and then steam, forcing it to rupture. The molten corium was ejected into the inner tank water at 68°C. The confinement vessel pressure reached a peak value of 188 kPa within 5 s. The measured peak dynamic pressure in the water ranged between 2.54 MPa and 4.36 MPa, which were below the pressure-tube pressure. The mean size of the debris was calculated to be 0.686 mm. The measured response of the system indicated that an energetic interaction between the melt and the water did not occur in this test.

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7. Acknowledgement

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Ensuring Reliable Medical Isotope Supply

K. Hedges[1] and G. Malkoske[2]

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1. Introduction

This paper describes the role of MDS Nordion and AECL in ensuring a reliable global supply of medical isotopes. The first part of the paper discusses the uses of medical isotopes, their importance to the medical community, and the benefits to patients of a secure supply of medical isotopes. The second part describes the role of the NRU reactor and the future role of the MAPLE reactors and New Processing Facility being commissioned at AECL's Chalk River Laboratories for production of medical isotopes to meet the world market demand for for the next 40 years.

MDS Nordion is the world's leading supplier of medical isotopes. These isotopes are used to conduct some 34,000 nuclear medicine procedures performed every day around the world, such as determining the severity of heart disease, the spread of cancer, and diagnosing brain disorders. These medical isotopes are currently produced primarily by AECL in the NRU reactor at Chalk River, Ontario, Canada.

2. Maintaining an Essential Source of Global Supply

Every day more than 34,000 nuclear medicine procedures take place using medical isotopes supplied by MDS Nordion and produced in reactors owned by Atomic Energy of Canada Limited (AECL). Sustaining this daily supply stream of medical isotopes requires a commitment to patients around the world to meet their healthcare needs. Essential criteria for the supply of medical isotopes includes reliable and continuous supply, proven product quality and timely delivery for patient use (Table 1). These factors drive the safe, production, processing, and timely delivery of medical isotopes from AECL's reactor facilities and MDS Nordion's processing operations.

Essential Criteria for Medical Isotope Supply

- Reliable and continuous product supply
- Proven quality and product characteristics
- Predictable and consistent product yields
- Economical supply and timely delivery
- Meets all regulatory requirements

➡ ***patient healthcare needs must be met, every time, all the time***

Table 1: Essential Criteria for Medical Isotope Supply

The NRU reactor located at Atomic Energy of Canada's (AECL's) Chalk River site in Ontario, Canada has been, for many years, the world's largest supplier of Molybdenum-99, and several other medical isotopes. Over the last decade, supply reliability has been excellent. NRU, which started operation in 1957, has been upgraded with a number of significant safety enhancements and a remaining life assessment is well advanced. Based on these factors it is anticipated that NRU will continue to reliably operate until at least 2012.

2.1 Importance of nuclear medicine

For physicians and patients, molybdenum-99 is the world's most important medical isotope. Eight out of ten nuclear medicine diagnostic procedures depend on this isotope. It has particular significance in diagnosing cancer and heart conditions.

Other isotopes produced in the NRU reactor are iodine- 131 used for a variety of treatment applications including thyroid cancer therapy and diagnostic imaging, iodine-125 used for treating prostate cancer and xenon-133 used for lung ventilation studies. The MAPLE facilities will be dedicated to the production of these key isotopes (Figure 1).

Figure 1: MAPLE production: key radioisotopes

There are some 100 applications of medical isotope scans used in today's medical procedures. More than 34,000 patient proce-

1 Atomic Energy of Canada Limited, Mississauga, Ontario, Canada
2 MDS Nordion, Ottawa, Ontario, Canada

dures are performed daily worldwide using medical isotopes supplied by MDS Nordion (over 12 million procedures annually). Overall, some 60 countries globally rely on Canada for a substantial portion of their reactor-produced isotope needs.

Some of these procedures are performed using medical isotopes that have left the NRU reactor only 41 hours earlier. This is truly a just-in-time business and a global endeavour (Figure 2). As the radioisotope decays, MDS Nordion must deliver the product to the customer as quickly as possible. Over 5000 hospitals in North America depend on this supply each week. Other examples of hospitals around the world that rely on the supply of medical isotopes currently produced at AECL's NRU reactor include 850 hospitals in Germany, more than 1000 hospitals in Japan, and 250 hospitals in Argentina.

MDS Nordion's medical isotope supply and isotope technology continues to be the foundation for the discovery of new ways to diagnose and treat disease. Today, molybdenum-99 is the most extensively used isotope. However, new medical techniques are providing oppor-

Figure 2: Supply Chain

tunities for iodine- 131, iodine- 125 and xenon-133. Radioisotope technology is being applied to develop new ways to target and treat cancer. It is now possible to deliver the radiation right at the cellular level from within the body. Known as radioimmunotherapy, monoclonal antibodies are used to carry the radioisotope to the cancer cell where radiation destroys the individual cell and largely spares healthy cells. The treatment is offering new hope for conditions like non-Hodgkin's lymphoma. MDS Nordion is a supplier of the medical isotope, iodine-131, being used in this product. Canadian enterprise has become an essential partner for biotechnology companies to develop their leading-edge treatments by radiolabelling molecules.

Medical isotope innovation continues to unfold. Recently the USFDA has unveiled their Critical Path Opportunities List to advance innovation in medical products as part of the USFDA Critical Path Initiative. The importance of bringing new drugs to market faster will have a direct application to the use of nuclear science to support public health needs. "Molecular imaging" is leading to new ways to develop drugs. Molecular imaging is the term used for an emerging set of drug development tools that are based on nuclear technologies and are anticipated to help bring drugs to market faster, more economically and with a greater probability of success.

For example, at the developmental stage, it allows researchers to track the bio-distribution of a drug in animals and therefore, to better translate the results into humans. Molecular imaging could also be used at the clinical and commercial stages of drug development to identify which patients could benefit from a particular drug before they take it and then monitor how well it performs. This can be used for diagnosing or treating heart disease, cancer and neurological disorders. MDS Nordion is positioning itself as a leader in this area because of its expertise in radiation technology and access to radioisotope supplies.

Some other recent examples of innovative developments include the development of iodine- 131 labeled antibody for a severe form of brain cancer and an iodine-13 1 labeled fatty acid for neuroblastoma, an often fatal childhood cancer.

2.2 Canada's important role in ensuring isotope supply

MDS Nordion's distribution to top export destinations (Table 2) reveals an interesting picture of the relative importance to Canada of this global supply chain, which starts at Chalk River Laboratories and Ottawa and extends to many locations around the world.

If today for whatever reason, the Chalk River Site and NRU reactor were not available for isotope production, there would be a shortage in global supply of medical isotopes. Collectively, all other reactor producers of isotopes in the world cannot fill the supply gap that would be created by the unavailability from NRU. MDS Nordion does maintain supply agreements to back up short-term isotope requirements from the handful of reactors in other countries that produce reactor-isotopes. But, if NRU is unable to supply isotopes for an extended period, beyond a routine maintenance shut down, there is not enough global capacity to supply the world's demand for reactor-produced medical isotopes.

<u>MDS Nordion's Distribution of Exports</u>

- Europe 17%
- United States 50%
- South America 80%
- Japan 85%

(Source: figures are estimated; MDS Nordion data for medical isotopes, 2005.)

Table 2: MDS Nordion's Distribution of Exports

3. The role of the NRU reactor

NRU, which has played a key role in supplying medical isotopes to date, has been in operation for a period of time approaching 50 years. AECL continues to invest in safety system upgrades, plant life extension programs, and performance improvement initiatives for the NRU reactor. AECL has spent more than $30 million Canadian over the past 15 years upgrading the reactor's safety systems to current standards and has increased the spending rate for reactor operations by about 25% to improve safety and performance.

These increases are in the areas of staffing level, training, spare parts, life cycle management work, safety assessments, and improvement plans.

AECL has proactively undertaken the NRU reactor Improvement Initiative Program Plan to industry best practices. The Program was developed from peer review and is presently focused on eight areas for improvement:

- Human Performance,
- Operational Decision Making,
- Plant Status Control,
- Housekeeping,
- Learning Organization,
- Foreign Material Exclusion,
- Conduct of Maintenance, and
- Management Effectiveness.

The reactor continues to operate with a high degree of assurance of safety and reliability. AECL has requested, and the Canadian Nuclear Safety Commission (CNSC) staff have recommended at Commission Hearings on April 26, 2006 and June 28, 2006, that the Commission extend the Chalk River site licence, which include the operation of the NRU reactor for a time period of 63 months, to October 31, 2011. A Commission decision on the Chalk River site licence is expected in July 2006.

Over the past five years, the performance of the NRU reactor to meet market demand for Mo-99 has exceeded 97%. This performance was measured over 1700 shipments from AECL to MDS Nordion and is calculated as follows:

Performance (%) = (1 ñ number of short or late shipments / total number of shipment) x 100

However, replacing isotope production in this aging reactor with production in the MAPLE facilities continues to be a priority for AECL and MDS Nordion in order to assure the global nuclear medicine community that Canada can continue to be a dependable supplier of medical isotopes for the world. From radiopharmaceutical companies, who are MDS Nordion's customers, to nuclear medicine physicians, the health care system depends on Canada to supply medical isotopes reliably and routinely.

4. The new Dedicated Isotope Facilities

To ensure a reliable, continuous supply of medical isotopes, two MAPLE reactors and a New Processing Facility are being built at Chalk River. In August 1996, MDS Nordion contracted AECL to build these facilities and the project was initiated in September 1996. The objectives of the project were to design, build, and commission two identical 10 MW MAPLE reactors and a processing facility that would start commercial production of medical isotopes in calendar year 2000.

The environmental assessment for the project was approved in April 1997, construction approvals were granted in December 1997, and all construction work was completed in 29 months by May 2000. Figure 1 shows the MAPLE reactor and the isotope processing facility buildings (these are the buildings with beige siding). The photograph also shows the NRU reactor in the background and the NRX reactor, which was shut down in 1992, to the right in the photograph.

Today, the two MAPLE reactors and New Processing Facility are collectively referred to as the Dedicated Isotope Facilities (DIF). This is the only worldwide large-scale facility dedicated to isotope production.

Medical isotope supply will continue from NRU until the Dedicated Isotope Facilities (DIF) are brought into operation.

Commissioning of the facilities has been on-going and over the last year significant progress has been made in resolving technical issues. Once commissioning of the DIF facilities is complete in 2008, there will be a gradual transition from the current NRU stream to the DIF stream. The capacity of DIF is significantly greater than the current NRU stream and this capacity supports the expected growth in isotope demand.

The MAPLE 1 reactor has been commissioned to a power of 8 MW. Commissioning was interrupted in June 2003 after the measured power coefficient of reactivity was found to be of a small positive value and different from the predicted negative value of about 0.1 mk/MW for the reactor's initial core. This difference has consequences on the assumptions made in the safety case supporting the operation of the MAPLE reactors.

AECL has deployed significant efforts to analyze the cause for the difference between the measured and predicted values for the power coefficient of reactivity. External organizations such as Idaho National Laboratory, Brookhaven National Laboratory and INVAP are engaged in studies to arrive at causes for the difference. The CNSC has recently authorized AECL to resume low-power operation of the MAPLE 1 reactor. The reactor resumed low-power operation in June 2006. AECL has requested CNSC approval to increase the reactor power to 5 MW and conduct tests to resolve the positive power coefficient of reactivity issue. These tests are scheduled to be completed in 2007 after which the commissioning of the DIF facilities will be completed in 2008.

In support of the international efforts to minimize civilian commerce in Highly Enriched Uranium (HEU), AECL and MDS Nordion are engaged in a stakeholder review to determine the feasibility of converting their large-scale, commercial molybdenum-99 production process to Low Enriched Uranium (LEU) targets in a dedicated LEU processing facility. At this time, only approximately 2-4% of the world's molybdenum-99 production is based on LEU targets. While significant progress has been made in developing LEU target technology for molybdenum-99 production, the transferability from low volume to high volume production processes and facilities is yet to be developed and realized. AECL and MDS Nordion remain committed to convert isotope production from HEU targets once a large-scale, commercial LEU target technology has been developed that can be implemented in a technically and economically feasible manner, while meeting the Essential Criteria for Medical Isotope supply as set out in Table 1.

Figure 3: MAPLE reactors and isotope processing facility

5. The MDS Nordion/AECL business relationship

MDS Nordion and AECL entered into an agreement in 1996 to construct, license, and commission new medical isotope production facilities at AECL's Chalk River Laboratories. This project, comprised of two 10 MW MAPLE Reactors and a New Processing Facility, were to be owned by MDS Nordion. The operation and licensing of the facilities would be done by AECL on behalf of MDS Nordion. The facilities would be dedicated solely for isotope production for MDS Nordion. Originally, these Dedicated Isotope Facilities were to start commercial production of medical isotopes in the year 2000.

As noted previously in the paper, the project was substantially delayed to resolve certain technical issues. To resolve the mounting costs and ongoing operation obligation, MDS Nordion and AECL entered into a comprehensive mediation process. The mediation reached a successful conclusion on February 21, 2006 and MDS Nordion and AECL entered into a new agreement related to completion of the project and supply of isotopes. Under the new agreement AECL will assume complete ownership of the MAPLE facilities and be responsible for all costs associated with completing the project and the production of medical isotopes. MDS Nordion will continue to provide the medical isotopes for medical imaging for patients around the world.

The press releases issued by MDS Inc. and AECL are an excellent testimony to the willingness of the parties to move forward together in this important initiative.

"I am very pleased with the outcome of this process. This new agreement provides a solid basis for both parties to move forward and successfully complete this project. It protects MDS shareholders from further capital costs related to the commissioning of MAPLE and creates a more economically viable relationship going forward that allow us to continue to provide these important medical imaging products to patients around the world," said Stephen P. DeFalco, President and Chief Executive Officer, MDS Inc.

"This is obviously a very positive outcome that strategically aligns the interests of both companies and allows each of us to focus on our core competencies while creating a stronger commercial arrangement," AECL chief executive Robert Van Adel said in a release.

Under the new agreement, AECL will complete commissioning of the MAPLE 1 reactor and New Processing Facility by October 31, 2008. MAPLE 2 is to be commissioned and in-service by October 31, 2009. Also, MDS Nordion and AECL have entered into a 40 year supply agreement on terms similar to the NRU supply agreement. This important development will further ensure the global nuclear medicine community of Canada's role in ensuring a reliable supply of medical isotopes.

6. Conclusion

Operation of the Chalk River Site is vital to support Canada's role as an essential link in global medical isotope supply. The NRU reactor continues to play a key role in producing medical isotopes. At times, when NRU's operation is disrupted beyond what is planned, our customers have temporarily been short of key products. This underscores the importance of an Operating License Renewal. This renewal will ensure NRU's place as the pre-eminent global producer of medical isotopes until such time as the MAPLE facilities assume this role.

MDS Nordion expects that AECL, as the licensed operator of the Chalk River Site and the NRU reactor, will operate these facilities with paramount consideration to safe and reliable production of medical isotopes. Safety, quality and reliability of operation will enable Canada to remain as a premier supplier of medical isotopes for the international health care community. These hallmarks will ensure the global nuclear medicine community that MDS Nordion and AECL will continue with a reliable supply of medical isotopes.

Cancer and Low Dose Responses *In Vivo:* Implications for Radiation Protection

by R.E.J. Mitchel[1]

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1. The LNT hypothesis, risk prediction and radiation protection

The linear no-threshold (LNT) hypothesis is the fundamental basis for the prediction of risk from radiation exposure, and forms the basis for radiation protection practices [1]. Dose limits for human exposure reflect this assumption that risk is proportional to total dose, without a threshold. However, radiation protection practices also utilize a number of additional concepts, derived from or auxiliary to the hypothesis, to predict the risk of radiation exposure. The most basic concept presumes that since risk is proportional to dose, then dose (normalized as Sieverts using radiation weighting factors, W_R) can be used as a surrogate for risk. Additionally, since each dose is assumed to create some risk, those doses, and hence risks, are treated as additive. Therefore, with the absence of a threshold, risk can only increase with each dose, and this assumption applies to low as well as high doses. Importantly however, radiation protection practices [1] recognize the observation that different tissues respond differently to radiation, and, based only on the tissues actually exposed, individually contribute different fractions to the total risk of radiation. In practice, different tissue types are assigned tissue weighting factors (W_T) that reflect their relative fractional contribution to the total cancer and non-cancer radiation risk. The W_T for each tissue is held to be constant, independent of dose, since every tissue is assumed to obey a linear no threshold response. Another concept, also derived from observation and not the LNT hypothesis, is an assumed 2-fold reduction in the risk of a high dose/high dose rate exposure, if that exposure is received at low dose or low dose rate [1]. Recently, serious concerns have been raised about the appropriateness of many of these assumptions [2,3].

2. Epidemiological basis for radiation protection practices

In the development of the current radiation protection system, the main source of information on radiation induced human cancer risk has come from epidemiological data on exposed populations. However, these data are mainly from medium to large doses, and for low LET radiation epidemiological studies do not show an increased cancer risk in adult humans below about 100 mSv for an acute exposure [2]. A linear extrapolation has therefore been used to estimate the cancer risk at the lower doses relevant to the general population and radiation workers. Uncertainties in dosimetry of epidemiological studies make it more difficult to observe a dose response, which in turn tends to lead to lower risk estimates. Other problems associated with the epidemiological studies include the comparison of the results obtained for different exposure patterns (for example, acute external irradiation versus protracted internal irradiation) and/or for different types of radiation (for example, rays versus particles) and/or for exposures of mixed LET.

3. Adaptive response and carcinogenesis

The term adaptive response refers to biological responses whereby the exposure of cells or animals to a low dose of radiation induces mechanisms that protect the cell or animal against the detrimental effects of other events or agents, including spontaneous events or subsequent radiation exposure [4]. Adaptive responses occurs in situations where all cells receive one or more radiation tracks at low dose rate, but also where the dose is too low for all cells to be hit. In the latter instance, the protective effect is amplified by chemical signals sent to other "bystander" cells [5, 6]. For low LET radiation, the first ionisation track through the cell (a dose of about 1 mGy) appears to produce the maximum increase in DNA repair capacity and protective effects, and further tracks, if delivered at low dose rate, neither increase nor decrease that maximum response [5, 7]. For malignant transformation in human and rodent cells, the protective effect of low doses is dose *independent* for all doses up to about 100 mGy, when given at low dose rate. Above about 300 mGy, these protective effects give way to an increased risk of malignant transformation, suggesting detrimental effects outweigh protective effects at this point [8, 9]. The (unknown) signal(s) for adaptation can be transmitted through the medium that surrounds the cells. In human cells, there was no difference between gamma rays and tritium beta particles for the induction of the adaptive response [5], and low doses of low LET radiation protect against the detrimental effects, including detrimental effects of high LET exposure. High LET radiation apparently does not induce the adaptive response in mammalian cells.

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

For low doses to induce an adaptive response, cells or animals require a functional copy of the *TP53* gene, responsible for the control of several processes critical to the risk of carcinogenesis. In animals with full *TP53* function, and in cancer-prone animals with partial *TP53* function a single low, whole body dose of low LET radiation, increased cancer latency and restored a portion of the life that would have been lost due to either spontaneous or radiation-induced cancer in the absence of the low dose [10, 11, 12, 13). An increase in tumor latency but not frequency, suggests that adaption to radiation *in vivo* acts primarily by slowing the multi-step process of carcinogenesis.

In *TP53* normal mice, protective effects against radiation-induced cancer occur up to at least 100 mGy [10]. In the cancer prone mice protective effects give way to increased risk between about 10 and 100 mGy [12]. However, different tissues appear to have different thresholds at which protection turns to detriment [11]. The results suggest that protective adaptive responses may predominate at typical public and occupational exposure levels, but that at doses around 100 mGy detrimental effects may overcome the protection. High doses at high dose rates do not induce the protective response, although relatively high total doses received at low dose rates may be effective.

Adaptive responses to low doses (typically 1-100 mGy) have been shown to increase cellular DNA doublestrand break repair capacity, reduce the risk of cell death, reduce radiation or chemically-induced chromosomal aberrations and mutations, and reduce spontaneous or radiation-induced malignant transformation *in vitro.* Elevated DNA repair capacity after low dose exposure is a response that has been tightly conserved throughout evolution, appearing in single-cell eukaryotes, simple eukaryotes, insects, plants, amphibians, and mammals including human cells, suggesting that it is a basic response critical to life [14].

4. Implications for radiation protection

4.1 Dose additivity

Cancer is considered to be the most important risk associated with radiation exposure. If the LNT hypothesis is correct, sequential exposures to radiation should increase cancer risk for all types of exposures. However, cell and animal experiments indicate that adaptive responses occur after low dose exposures, and that, as a consequence, responses to radiation are not linear.

A fundamental principle of radiation protection is the assumption of a linear dose response and dose additivity. The universally observed phenomenon of the adaptive response, as exemplified by the cell and animal experiments described above, indicate that for low LET radiation, the risk of cancer is not linear with dose. In fact, increasing dose by adding low doses to high doses decreases risk. The concept of dose additivity, when at least one exposure is to a low dose at low dose rate, did not hold, These data indicate that at the low doses and dose rates typical of public and occupational exposures, the radiation protection principle of dose additivity, and the concept that risk can only increase as dose increases are not justified. In general, the use of dose as a surrogate for risk needs re-evaluation. However, once past the upper dose threshold, increased dose could increase risk, as currently assumed. It is also apparent, however, that genetic variations in cancer proneness can influence these thresholds.

If different exposures (e.g. internal / external, chronic / acute, low/high, low LET / high LET, etc.) can not be summed to estimate an individual's total detriment / risk, or even if, more simply, several specific types of exposure can not be summed, then we may need to develop a new approach to radiation protection, in order to protect against each specific type of exposure separately [15]. Ultimately, that approach may need to be tailored to individual genetics.

4.2 Tissue weighting factors

At high doses, different tissues are known to respond differently to radiation and are assigned constant, dose independent tissue weighting factors (W_T) that reflect their relative fractional contribution to the total risk. However, experiments at low dose indicate that individual tissue risk is not a constant with dose, and exhibits a dose threshold below which risk is less than spontaneous risk. Different tissues appear to have different dose thresholds below which detriment turns to protection, indicating that individual tissue weighting factors (W_T) vary from zero to positive values as dose increases. These observations indicate that tissue weighting factors are neither constant nor dose independent, and the current assumptions used for radiation protection are not appropriate.

4.3 Radiation weighting factors and Sieverts

The currently accepted W_R factors have been determined by comparisons of Relative Biological Effect (RBE) at high doses, where all cells are hit by radiation and each cell receives multiple tracks of radiation. However, current animal and mammalian cell research is assessing the risk of low doses of low LET radiation down to and below a dose that represents an average of one track per cell. This is important as at these radiation levels epidemiological studies do not have sufficient power to provide risk data. Since the dose to a single cell from a single high LET track is much higher than the dose from a single low LET track, these measurements of RBE (and therefore W_R) are valid only when there are sufficient tracks of low LET per cell to provide enough physical dose to match the effect, at a minimum, of one high LET track per cell. At lower doses, however, these concepts break down. At lower doses of high LET most cells are not hit, yet those that are hit still receive the high dose delivered by one track. At similar doses of low LET radiation all cells may still receive multiple tracks. At even lower doses, low LET radiation, like high LET radiation, will not hit all cells. At these levels, typical of public and occupational exposures, the use of WR derived from high dose exposure assumes that the biological mechanisms responsible for the observed difference in biological response to different radiation types are the same mechanisms that operate at low doses. This has clearly been shown to be incorrect, since low doses induce protective effects. Even at the level of the response of individual genes, different genes activated at high versus low doses. These results therefore call into question the use of current W_R factors at low doses.

Animal and cell based experiments show that low doses reduce cancer risk below the level observed in the unexposed cells or animals; i.e. below the spontaneous risk. If the radiation weighting factor (W_R) for high doses of low LET radiation is taken as 1, then these data suggest that the W_R is a variable with dose, and can be zero at low doses. Since the W_R for high LET radiation is based on a reference to the same level of effects at low LET, the W_R for high LET also cannot be a constant. This, together with the physical impossibility of delivering the same dose per cell at low doses and the mechanistically different cellular response to high and low doses, suggests that the use of normalised dose (Sievert) at low doses is inappropriate, and that the risk or benefit of exposure to radiations of different quality needs to be understood and assessed independently, on the basis of physical dose.

The realities of human radiation exposures present an additional problem. Current cell based research indicates that a prior or concurrent exposure to low LET radiation is able to induce adaptive responses which mitigate much or all of the detrimental effect of exposure to high LET radiation. Since virtually all public (and much occupational) exposure to high LET radiation is accompanied by exposure to low LET radiation, and if the cell based studies apply to organs and whole organisms, then radiation protection policies and risk assessments also need to consider the effect of combined exposures to these different radiation types.

4.4 DDREF

It is widely accepted that a radiation dose delivered at a low dose rate produces fewer late effects than the same dose delivered at a high dose rate. This is in a large part due to the fact that dose protraction facilitates a more effective repair of cells, including DNA damage. The ICRP therefore defines a Dose and Dose Rate Effectiveness Factor (DDREF) to allow for the reduced effectiveness of low dose rate radiation doses. The DDREF factor represents the ratio of the slope of the linear no threshold fit of high dose, high dose-rate data to the slope of the linear no threshold fit of high dose, low dose-rate data. For radiological protection the ICRP recommend a DDREF factor of 2. The utility of the DDREF coefficient depends upon the assumption that, for exposure to low doses at low dose-rate, the dose-response is linear, continuous with the slope of the high dose, low dose rate response and has a slope that is less than the corresponding slope of a linear high dose, high dose rate response.

However, low dose and low dose rate studies using low LET radiation in cells and in adult animals have shown that below a threshold dose (about 100mGy in human cells, rodent cells and normal mice) the detrimental effects of a radiation exposure disappear and are replaced by protective effects, manifested in cells by decreases in transformation frequency and in animals by increases in cancer latency. These observations show that low dose responses are non linear and that the biological processes occurring in cells in response to low doses and dose rates can be fundamentally different from those that result from exposure to high doses, These observations undermine the concept of DDREF and indicate that at low doses DDREF becomes infinite.

These experiments indicate that the linear no threshold hypothesis, and the associated dose and dose rate reduction factors derived from high dose experiments are inappropriate for use at low doses and low dose rates. There may be no constant and appropriate value of DDREF for use in radiological protection.

4.5 ALARA

Cell and animal based experiments indicate that low doses of low LET radiation induce a protective effect that reduces the risk from spontaneous cancer and the risk of cancer from further exposure. If this is also true for humans, then radiation protection policies that endeavour to reduce exposures to the lowest possible dose,or entirely eliminate the exposure, may need to be reconsidered since they may prevent the induction of this protective response. For a public exposure, this could result in the otherwise reduced risk rising to the spontaneous level of the unexposed population. Such radiation protection policies could then be viewed as “withholding benefit”. For persons who may be occupationally exposed, prevention of the induction of protective responses would result in a higher than necessary risk if that person were then accidentally exposed to a high dose. In this circumstance, such a radiation protection policy could be viewed as increasing occupational risk.

5. Summary implications for the radiation protection system

At low doses,

- The conceptual basis of the present system appears to be incorrect
- The belief that the current system embodies the precautionary principle and that the LNT assumption is cautious appears incorrect
- The concept of dose additivity appears incorrect
- Effective dose (Sieverts) and the weighting factors on which it is based appear to be invalid
- There may be no constant and appropriate value of DDREF for radiological protection dosimetry.
- The use of dose as a predictor of risk needs to be re-examined
- The use of dose limits as a means of limiting risk need to be re-evaluated

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Preserving Technical Knowledge – When Technology's Lifetime Exceeds The Human Life Span

by D. Menely[1], W. Garland[2], M. Lightfoot, and M. Safa[3]

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1. Introduction

Industry is being challenged by the departure of experienced managers and workers. The loss of skills and the difficulty of finding qualified replacements can negatively affect operations, environment, safety, and economics. There is a need to capture, preserve and pass along both documented and undocumented knowledge before aging workers depart the workplace.

How to do it? Our ancestors faced the same problem, and they often solved it in a personal way through a Master-Journeyman-Apprentice system. Our modern education system is an extension of that system, augmented by extensive use of textbooks. This system now is stretched to its limits by two factors, (a) the need to update the teacher's knowledge, and (b) the need to update high quality textbooks. Modern Masters are so busy doing their work that they have no time to pass knowledge on in an effective manner. When they retire, their knowledge often is lost.

The CANTEACH project was initiated to fill this gap. The essence of this knowledge capture process is acquisition of archival documents that are relevant to current practice in the field – in our case, CANDU power plant engineering. This project is made possible by voluntary contributions from Masters in the field; it can proceed only by avoiding the pitfalls of excessive security and intellectual property rules. This paper describes the mechanisms used to make this archival knowledge openly available for operators, designers, educators, and students of this technology.

2. The CANTEACH Concept

The archive was conceived as a knowledge repository that should provide high quality technical documentation relating to all facets of the CANDU nuclear energy system. This information is public and is intended for use in various aspects of education, training, design and operation. The project, underway for nearly five years, has the objective of building this knowledge repository.

The original project agreement (signed on July 21, 2001 and revised on April 1, 2002) states the basic goal:

> "The CANTEACH Partners agree to develop a comprehensive set of education and training documents prepared according to the highest academic standards to describe the various aspects of CANDU power plant technology. These documents will be subjected to planning and review by the Academic Director and the Project Director, and then will be recommended to the Board of Directors for incorporation into the set of deliverables of the project."

Annex B to the Agreement refers to potential source materials such as course notes from AECL, Universities, and Utilities as well as to a collection of monographs developed in China. The original CANTEACH project agreement expired in March 2005. The project has been sustained by Canadian COG[1] members since that date. Much of the conceptual structure of the original project has been validated. Some weak areas have been revealed, as discussed herein.

3. Why Do We Need a Knowledge Archive?

This part is simple. The operating lifetime of a modern nuclear plant will extend possibly 60 to 100 years beyond the date at which the conceptual design is completed, or 50 to 90 years past the plant's first startup.

The working life of an engineer is judged to be about 30-40 years, an optimistic estimate because a professional engineer normally works in his or her discipline for much less time than this before moving on to non-engineering or supervisory jobs. The long time span of these projects raises the issue of the location and possession of design authority for plant systems. The original plant designer is the obvious authority during the early years. But after several decades, staff of the design organization probably has moved on to work on new designs, and is no longer devoted to maintenance and refurbishment of the company's old plants. In these circumstances, design authority must pass to the Chief Engineer of the operating company. The problem of knowledge transfer remains the same; only the location of the expertise changes.

As a consequence of this long time span we must sustain the communication of high quality plant information over three or four generations of professionals, allowing for some overlap between generations. Staff overlap is essential because it gives an opportunity for informal transfer of knowledge, akin to the old Master-Apprentice system. Courses, procedures and other "third person" methods usually cannot transfer all of the essential knowledge – this may be possible in a theoretically ideal documentation system, but is impossible to achieve in practice. Two-way communication between established stations and new stations also is required, to take advantage of lessons learned during operation as well as design. For example, a principal mandate of the CANDU Owners Group[1] is aimed exactly at this aspect of information exchange from operating experience and general knowledge preservation.

1 Atomic Energy of Canada Ltd. (Retired), Mississauga, ON, Canada
2 McMaster University, Hamilton, ON, Canada
3 CANDU Owners Group, Toronto, ON, Canada

Retraining programs, properly conducted, offer an opportunity to keep plant information fresh over the long term. Trainers must first be trained, thereby suggesting close contact with educators in academic institutions. Preparation and modification/updating of training materials is a continuous process, and provide a natural procedure for incorporating the lessons learned as operating experience accumulates.

Sixty-six years have passed since the nuclear energy venture began in Canada. Fifty-four years have gone by since the founding of Atomic Energy of Canada (AECL). Tens of thousands of dedicated people have forged a new and successful primary energy supply. CANDU technology is well launched into the first decade of the 21st century. This specialty within the world's technology community is unique, first because it was established as a separate effort very early in the history of world fission energy, and second because it grew in an isolated environment with tight security requirements, in its early years. Commercial security rules later sustained a considerable degree of isolation. As a result, many of the correct answers to the important "Why?" questions are different for CANDU than for other reactor types. While standardization of lessons learned across different reactor types is often useful, it is important to guard against situations in which the correct answer for one reactor type is the wrong (or irrelevant) answer for another type.

The pioneers of CANDU development have finished their work. Most of the people of the second generation also have moved on. And yet, up to this time we cannot point to a consistent and complete record of this remarkable achievement. We, as a nuclear enterprise, have not captured the knowledge legacy in a form readily accessible to current and future generation of professionals involved with CANDU reactors -- students, designers, operations staff, regulators, consultants or clients. This is a serious oversight.

Young people entering our field of study must make do with one or two textbooks and a huge collection of diverse technical papers augmented by limited-scope training materials. General textbooks include much of the basic information, but there is not a single definitive text or handbook specifically aimed at the details of CANDU technology as it is applied today. Those employed in the various parts of the nuclear industry rely mostly on a smaller set of CANDU-related documents available within their own organization; documents that sometimes are rather limited. University professors often have even more limited access to in-depth and up to date information. In fact, they often depend on literature published in other countries when preparing lectures, enhanced by guest lecturers from various parts of the industry. Because CANDU was developed mostly inside Canada and because the system is unique in many aspects of its design, few of these non-Canadian text materials contain useful data describing processes important to the CANDU system.

For many years it has been recognized that a "CANDU Textbook" is needed. However, other work priorities and intense work activity within the industry have prevented the completion of such a reference volume. There is, in fact, a large volume of existing documents describing CANDU systems and operation. Much of this documentation is repetitious and contains less depth than is desirable. Very few of the documents detail why CANDU is designed the way it is. How can designs evolve appropriately and how can

retrofits and design changes be implemented correctly if the 'whys' are not elucidated? How are the graying experts passing on their knowledge and wisdom? It is this need that the CANTEACH project strives to fill.

4. Intellectual Property

The first and only purpose of the CANTEACH project is to preserve the knowledge base on which the technology of the Canadian Deuterium-Uranium energy system is founded. The chosen means of preserving this knowledge is to establish an open-source archive, as complete and comprehensive as possible. The chosen origins of this archive material are the writings, lessons, and publications of the professionals involved in the research, development, design, and operation of the CANDU energy system.

One of the first questions that many people have is "How about my intellectual property rights?" The best answer to this question can be found[2] under the title "Why it Makes Sense to Give Stuff Away". The essence of the argument lies in the distinction between (a) fundamental training and education and (b) the applied world in which application of knowledge is part of a commercial enterprise. On the fundamental level there is no need to give away secrets in the process of training and education. On the applied level information belongs to two or more parties exchanging technology for money, and so become true secrets.

On the level of training and education, the project aims to provide a technical library that is open, and freely available to all. As such it helps to maintain the sense of community that once enabled the success of the remarkable achievement that is known under the mnemonic of CANDU and gives those people who may choose to work in this field the best way for them, as individuals, to contribute to its further development. As previously described[2], the CANTEACH project addresses all three dimensions of human empowerment (competence, relatedness, and autonomy). People are empowered through education, and professionals emerge. The basic human characteristic, that a person is motivated to do something if that person is good at it, if the activity is meaningful in some way, and if he or she has personally decided to do it[3] results in the motivation so essential to success of the larger enterprise. Using other language, the success of the nuclear enterprise depends on maintenance of a safety culture in which an individual habitually does the right thing even when nobody is looking. This goal can be achieved only through individual behaviors and motivation.

Here is the reason for establishing an open source archive. Also, here is the reason that agencies and companies should freely contribute to that archive. What about the security of sensitive information?

5. Information Security

Obviously, it is wise to restrict the distribution of some specific information regarding any facility. This is a vital part of defence in depth, whereby several barriers are established between a valuable facility and any potential threat, either natural or human. Distribution of information that threatens any of these barriers should be discouraged. Unfortunately, defence is often taken to mean overt, physical defence in the form of guards and weapons as well as fences and ramparts of all sorts.

The most important element of defence is often neglected. This is the group of people always present and in control of the facility itself. Their attitudes and motivations lie at the very core of defence. Do these people care? Are they vigilant? Do they feel a sense of community with their co-workers and with the objectives of the enterprise? Will they risk harm to themselves to maintain the overall security of the facility?

It is a realistic presumption that security depends to some extent on the ignorance of the threatening agent as to the specifics of the facility. Locations of, and specific procedures for, operation of plant systems should not be common knowledge. As noted already it is completely unnecessary to give away such secrets while providing the education and training of professional individuals who have the option of entering the field of nuclear engineering. Specific plant-related knowledge is best communicated at the appropriate time by professionals already familiar with, or responsible for, operation of the facility.

Information donated to the CANTEACH archive comes, as it must, from people inside the organizations and those working in the field. These individuals carry the primary authority and responsibility for retention of sensitive information. Project staff will ensure that information received has passed normal review and approval by these donating organizations. Further, it may at some time be appropriate (as judged by the sponsors of this project) to establish a second, confidential, archive containing information valuable to the users but which is deemed sufficiently sensitive that it should not be distributed widely.

6. Target Audience

Understanding the limitations imposed both by commercial value, intellectual property claims and by information security we must define, at least in general terms, the audience to whom these works are directed. The CANTEACH project aims to provide the information necessary to attract, then to educate and train, professionals in the broad aspects of CANDU technology.

Reference 4 summarizes some of the basic causes of the known shortages of skilled manpower in the Canadian nuclear industry as existed at that time. Written today, that summary would be more optimistic with regard to future prospects, given the present resurgence in the number of plant life extensions and potential “new builds”. It is expected that the demand for new nuclear capacity will grow very rapidly of the next few decades. However, the basic problems of staffing will not change greatly, and in fact will be exacerbated by the demands for staff to accomplish these new tasks as well as by the steadily increasing requirements of operating facilities as the nuclear industry grows over the next few decades.

Reference 4 outlines the needs of the nuclear industry’s “supply chain” for new staff. A typical example of staff demand ratios is about 1000 2-year community colleges graduates, about 100 Baccalaureate engineers, about 10 MSc graduates, and about 2 doctoral graduates. Given this distribution, it is obvious that the first level of CANTEACH information should be usable by students 1 or 2 years beyond high school. Given the associated need to give their instructors a firm grounding in nuclear energy technology, at least a second level of documentation is essential. Students who will eventually graduate with higher degrees also will begin at level 1. Their instructors and professors must, of course, be highly qualified. There will be a somewhat higher demand for PhD graduates in the near future simply to fill professorial openings.

Staff entering the CANDU program will undergo in-house education and training beyond graduation, to improve their specific knowledge of operating systems. Operating companies may choose to do this job through their own schools or via contracts. Security and intellectual property restrictions force this separation between the academic world and the practical world of industry. Our conclusion is that the main thrust of CANTEACH archive material should be directed to the general public and to “Entry Level” students and their instructors. A proper definition of this beginner’s level is important – because of the advanced knowledge of physics, chemistry, mathematics, material science, and diverse other fields that are essential to understanding of nuclear plant engineering, the “entry level” for this discipline may be at the baccalaureate or post-graduate stage of an individual’s education.

7. CANTEACH Archive Elements

Collecting information from contributors is the first and most important step. We welcome contributions from companies, agencies and individuals; the only requirement is relevance to some aspect of the CANDU energy system, ranging from exploration, research, development, design, manufacturing, construction, operation, decommissioning, and management of radioactive materials. All aspects are considered for inclusion in the archive, from education to economics to public relations. The most directly useful materials are formal course notes that have been proven through presentation and re-examination.

When received the materials are scanned into pdf format files, converted to searchable format, indexed and bookmarked. They are catalogued by name of the contributing organization or individual. A keyword-based search system has been introduced recently. At the present time, work is proceeding on collection and classification of photographs, diagrams, and descriptive presentation materials for use by educators and instructors. The next step will be to review each contribution and incorporation of the “best” set of materials into evaluated information files. Up to this stage of the project we have done no editing of the material except for organization, sorting, and correction of substantial errors.

The products of the CANTEACH archival process are located on a website maintained by the CANDU Owners Group, at <http://canteach.candu.org>. Approximately 1400 documents containing a variety of archival information are grouped into .pdf files, bookmarked, and indexed. This website is completely public at the present time, however there is provision for establishing a confidential site available only to authorized individuals. This second website will allow the project to broaden the scope and to increase the depth of detail in description of components and systems utilized in CANDU reactor systems.

8. Accomplishments and Present Status

Figure 1 shows the "entry " page of the CANTEACH archive. The best way to discover what is available on the web site, and also what is missing, is to "walk around" the website guided by this starting page. The "Search" category is still under construction, with only a fraction of the total entries having been populated with keywords. It is usable, but limited in scope. The Documents Library is organized by contributing organization and individual. The layout follows the pattern of the original lecture course or technical paper/conference. This archive changes when new documents are added, as indicated in New Arrivals. The Image Library is the newest major component of the archive. It now contains only a few images, but hundreds of new images are in process of being added. Material in this section will be extracted from existing documents, revised as necessary to make them more accessible with highest achievable resolution.

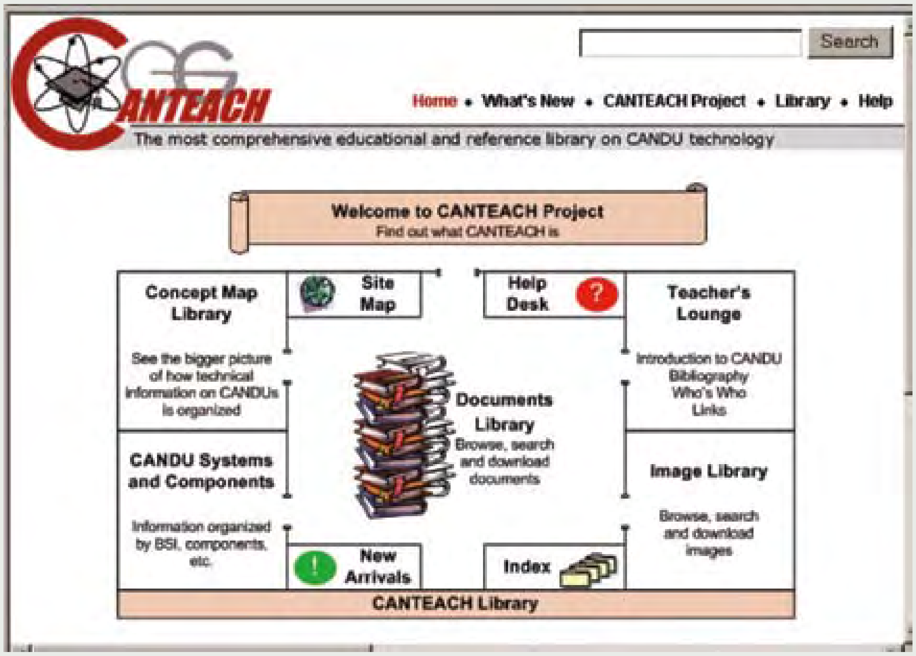

Figure 1: The starting point of a search for CANTEACH information

CANTEACH is a work in progress. Immediate tasks, now underway, include extension of document search capability using a keyword search system for the library. We also plan to refine and post several thousand pictures and other figures and make them available to CANTEACH users. Over the next three years, in addition to collection and posting of new archival files, staff intend to undertake editing and refinement of all existing files to improve their overall quality of the content and presentation.

9. Current Developments and Improvements

There are weaknesses in the current archives in breadth, depth, and content. Regarding breadth, essentially no project files exist covering areas of the CANDU enterprise such as fuel resources, mining, decommissioning, and waste disposal as well as several aspects of electrical, civil, and mechanical design. The numerous subjects concerning operations are not covered at all – for example load following, load cycling, maintenance, refurbishment, and economics. Regarding weaknesses in depth, the whole archive is weak in descriptions of **why** equipment and processes are as they are in CANDU plants. Also, in some respects only the general aspects of plant systems and operation are presented, without any deeper examination. Some aspects of systems are treated repetitiously, while other aspects are not even mentioned.

Several potential contributors have personal files and records that would be very valuable to the next generation of CANDU personnel – but whose contributions have not yet been collected, due to a lack of project manpower. These skilled individuals are now mostly retired or are nearing retirement – time is short. Today's plan includes a proposal to initiate a series of task-specific contracts with experts who are willing and able to improve the CANTEACH archive. These contracts will be administrated by COG.

Finally, the underlying rationale for continuing this work is that the CANDU enterprise must continue to serve the people of Canada and the world for generations to come. For a variety of reasons, neither the academic, the commercial, the industrial, nor the academic participants in this enterprise have produced a comprehensive set of education and training documents prepared according to the highest standards to describe the various aspects of CANDU technology. Current deficiencies in staffing have stimulated education efforts such as those recently undertaken by UNENE and via utility support of community college training programs. These programs need comprehensive documentation in order to be effective.

10. New Contributions

1) Populate existing documents with keywords, to take advantage of the new search engine.
2) Refine, identify, index, and post to the website, several hundred pictures and graphics with.
3) Increase the breadth and depth of document acquisition from companies and Universities.
4) Issue task-specific contracts to experts – to correct, sort, and resolve differences between different presentations and courses on the same general topic (e.g. reactor physics, safety).
5) Expand the archival record on the subject of radioactive waste management.

Tasks 4 and 5 represent our first moves toward upgrading the quality of the existing archive. It is the area which will require additional resources and, consequentially, additional funding.

It is proposed that staff plan and conclude a sequence of small contracts (200-800 hours each) with very specific goals, schedules, and deliverables. The scope of these tasks will be limited, of course, by available funding.

The full duration required for completion of the CANTEACH project is somewhat difficult to determine. The original estimate was about ten years, and it appears that this is still valid. Of course, the actual end of the project will depend on the need as indicated by the usage level and the number of requests for new information. Neither of these measures shows any sign of declining up to this time.

11. Summary

The project will continue until the users decide that the archive is sufficient to fulfill their objectives. It is hoped that professionals who work in this field of engineering will continue to contribute to this body of knowledge for many years to come.

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Nuclear Undergraduate Programs at The University of Ontario Institute of Technology

by G.T. Bereznai[1]

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1. Introduction

Currently Canada has 18 operational CANDU (*CAN*ada-Deuterium-Uranium) nuclear power plants, comprising of two units each at Pickering A and Bruce A, and four units at each of the Pickering B, Bruce B and Darlington sites. Two of the Bruce A units are under refurbishment and the two remaining Pickering A units are in voluntary lay-up. The generating capacity and in-service dates of these units are given in reference [1].

The first of these units, at Pickering, came into service in 1971, and have already undergone major refurbishment that is designed to extend the operating life of these units to 50 years. The commitment to refurbish the Bruce A units will have these reactors operational well into the 2030s, at a projected cost of 4.25 billion Canadian dollars. The Government of Ontario has recently announced its intent to have the present share of electricity generation from nuclear plants (~51%) maintained, implying the need to refurbish all the currently operating units in Ontario, as well as to construct new nuclear units. The two CANDU power plants operating outside Ontario are also expected to have their operating lives extended. Estimates for all these projects range from 20 to 40 billion Canadian dollars.

The large projected increases in expenditures in Canada's nuclear industry comes at a time when most of the people involved in the design and operation of the currently operating units are reaching retirement age, or have already retired. Ontario Power Generation, which operates the Pickering and Darlington nuclear electric generating stations, has been hiring in the order of 100 engineers per year and plans to continue at that space for several more years. Recognizing this demand, the University of Ontario Institute of Technology (UOIT), which is located within 25 kilometres of the Pickering and Darlington plants, initiated undergraduate honours degree programs in nuclear engineering and science [1].

2. Bachelor of Engineering in Nuclear Engineering

UOIT had first intake of undergraduate students in September 2003, by offering eight honours degree programs. In the nuclear field, students could choose between nuclear engineering and radiation science. The nuclear engineering program was designed principally to produce graduates for the nuclear power industry, while the radiation science program targeted the wide range of applications of nuclear technology outside the electrical generation specialty. The expectation was that there would be approximately equal interest in these two programs, but the actual enrolment was 98 students in nuclear engineering and only 12 in radiation science.

The development of the nuclear engineering program and the list of courses comprising it were presented at the 14th PBNC [1]. While the overall program has been delivered much as it was originally planned, the sequencing of some of the courses has changed, as well as some movement between the required and elective subjects. The revised program map, highlighting the courses that have changed from the original plan, is shown in Table 1. The changes fall into three categories, as described below.

2.1 Changes in course content

As a result of faculty, student or external feedback the contents of six courses were changed. These courses are shown highlighted in Table 1. In year 3 semester 1, the course in Computer Aided Design, was designed primarily for students in the manufacturing and mechanical engineering programs. These students had taken additional CAD related material in the second year of their studies, which the nuclear engineering students did not. As such, our students in effect did not have the desired prerequisite knowledge for the course. The replacement course, Fundamentals of Computer Aided Design Tools was developed to recognize that the nuclear engineering students had taken only the first year Engineering Graphics and Design course, as well as selecting examples and projects that better reflect applications relevant to nuclear engineering.

Also in year 3 semester 1 the contents of the course titled Digital Electronics was too narrow to cover the needs of both nuclear engineering and radiation science students. The revised course that replaced it, and named Scientific Instrumentation, includes digital and analogue transducers and instruments, A/D and D/A conversion, multiplexing, data conversion and analysis, with relevant applications from the nuclear field.

In year 3 semester 2 virtually all the students selected Reactor Instrumentation and Control as their Engineering Design Elective, and it was decided that this subject should be part of the core program. At the same time feedback from students indicated only a limited interest in the fourth year semester 2 subject Principles of Fusion Energy, so this course was changed to an Engineering Science Elective.

1 University of Ontario Institute of Technology, Oshawa, ON L1H 7L7

Year Semester	Subject	Subject	Subject	Subject	Subject	Subject
1-1	Calculus I	Linear Algebra for Engineers	Physics 1	Engineering Graphics and Design	History of Science and Technology	Technical Communications
1-2	Calculus II	Biology for Engineers or Environmental Science	Physics II	Chemistry of Engineers	Introduction of Programming	Impact of Science and Technology on Society
2-1	Differential Equations for Engineers	Fluid Mechanics	Problem Solving, Modelling and Simulations	Structure and Properties of Materials	Introduction of Nuclear Physics	Liberal Studies
2-2	Advanced Engineering Mathematics or Numerical Methods	Thermodynamic Cycles	Statistics and Probability for Engineers	Radiation Protection	**Nuclear Reactor Kinetics**	Collaborative Leadership
3-1	Fundamentals of Computer Aided Design Tools	Heat Transfer	Scientific Instrumentation	Environmental Effects of Radiation	**Nuclear Plant Operation**	Safety and Quality Management
3-2	Corrosion for Engineers	*Electric Circuits*	Nuclear Reactor Design	*Strength of Materials*	Reactor Instrumentation and Control	Engineering Economics
4-1	Risk Analysis Methods	Engineering Science Elective	Nuclear Plant Design and Simulation	Thesis Design Project I	**Radioactive Waste Management Design**	Strategic Management for Professionals
4-2	Nuclear Plant Safety Design	Engineering Science Elective	Nuclear Fuel Cycles	Thesis Design Project II	Engineering Design Elective	Ethics, Law and Professionalism for Engineers

Table 1: Nuclear Engineering program map

Economics for Professionals in year 3 semester 2, and Ethics and Law for Professionals in year 4 semester 2, were initially planned to be taught by the Faculty of Business and the Faculty of Social Science, but a review of the requirements for the accreditation of engineering programs indicated that these courses needed to have an engineering focus. The revised courses will be taught by the Faculty of Engineering and reflect the accreditation requirements.

2.2 Changes in course delivery sequence

Companies interested in hiring nuclear engineering students for summer jobs and longer work terms noted that students having finished second year have taken only two nuclear specific courses, namely Introduction to Nuclear Physics and Radiation Protection, and the course in Nuclear Plant Operation, which would be very useful for students hired after completing third year, was not offered until fourth year. The subsequent review by faculty members also identified the desirability to have Nuclear Reactor Kinetics offered in year 2 semester 1, and the Nuclear Plant Operation course in year 3 semester 1, providing continuity in the delivery of nuclear courses from the introductory level in year 2 semester 1 to Nuclear Reactor Design in year 3 semester 2.

Radioactive Waste Management Design was initially scheduled to be taught in year 3 semester 2, in parallel with the course in Corrosion for Engineers. It was subsequently realized that substantial portions of the Corrosion course are needed for the design of nuclear waste containers and depositories, so the Radioactive Waste Management Design course was moved to year 4 semester 1. The new positions of the three courses that were moved are shown in bold in Table 1.

2.3 Changes to balance the course load

The nuclear engineering program carried the heaviest course load of all the programs initially offered at UOIT: 48 courses, each with three hours of lectures per week, in a program of eight semesters each of 13 weeks in length. As well, the majority of the courses have laboratory and/or tutorial sessions. The heavy course load did not permit more than six courses per semester, so the rearrangement of the courses described above had to be accompanied by moving other courses to balance the course load. This was accomplished by moving Electric Circuits from the second semester of year 2 to that of year 3, and Strength of Materials from the first semester of year 3 to the second semester. These course changes are shown in italics in Table 1.

3.

Year Semester	Subject	Subject	Subject	Subject	Subject
1-1	Calculus I	Linear Algebra for Engineers	Physics 1	Engineering Graphics and Design	Technical Communications
1-2	Calculus II	Environmental Science	Physics II	Chemistry of Engineers	Introduction of Programming
2-1	Differential Equations for Engineers	Fluid Mechanics	Structure and Properties of Material	Introduction to Nuclear Physics	History of Science and Technology
2-2	Electric Circuits	Thermodynamics and Heat Transfer	Radiation Protection	Nuclear Reactor Kinetics	Collaborative Leadership
3-1	Nuclear Steam Supply Systems	Electric Power Systems	Radioactive Waste Management	Nuclear Plant Operation	Strategic Management for Professionals
3-2	Nuclear Plant Steam Utilization Systems	Technical Elective I	Mechanical Equipment and Systems	Reactor Instrumentation and Control	Engineering Economics
4-1	Nuclear Plant Electric and Auxiliary Systems	Technical Elective II	Safety and Quality Management	Thesis Design Project I	Introduction to Operations Management
4-2	Nuclear Plant Safety	Technical Elective III	Nuclear Fuel Cycles	Thesis Design Project II	Introduction to Project and Supply Chain Management

Table 2: BASc in Nuclear Power program map

Bachelor of Applied Science in Nuclear Power

The nuclear engineering program described above was established to meet the industry's need for engineers with specialized knowledge in the design, commissioning, maintenance, operation and decommissioning of nuclear power plants and related facilities. As soon as the nuclear engineering program was announced, inquiries were being received from people in industry who had taken post-secondary training and education courses but did not have an engineering degree. They were hoping to get credit for the courses and qualification they have acquired, and complete the remaining requirements for a nuclear engineering degree in part time. A review of the Canadian Engineering Accreditation Board's requirements showed that while some people may get advanced standing in a few courses, none of the applicants would be able to gain a degree without at least three years of full time university attendance.

The Bill of the Ontario Legislature that established UOIT has as one its many stipulations that the "special mission" of UOIT is "to design and offer programs with a view to creating opportunities for college graduates to complete a university degree." In Ontario "college" refers to the community college system that awards trade certificates, technician and technologist diplomas to students completing two or three year post-secondary programs. The entry requirements to these programs are lower in terms of the level of mathematics, science and other academic subjects, as compared with admission to university. A review of the academic content of these college programs showed that there would be very few if any subjects in which such a graduate could gain advanced standing towards an engineering degree.

An increasing number of jurisdictions that operate and regulate nuclear power plants world wide require operators, maintenance and planning supervisors, and other technical and supervisory positions to be filled by people with a technical degree, but not necessarily professional engineers. A number of universities as well as community colleges in Canada have been authorized to offer technical programs that, while not meeting the accreditation requirements of the professional engineering bodies, do provide a strong technical degree that meet the needs for many industrial jobs.

The above considerations resulted in UOIT developing the Bachelor of Applied Science (BASc) in Nuclear Power program, as shown in Table 2.

In comparison with the nuclear engineering degree, the most obvious change is that there are eight fewer courses. While out of the 40 courses in the BASc program 25 are the same as for the BEng, several of the remaining technical courses are lighter in terms of the design component.

So far there has not been sufficient demand for this program for us to offer it. A key missing component has been defining the advanced standings that graduates of various college programs would receive, as well as designing bridge programs that would help many of the college graduates to gain the mathematics and science course credits so that the remaining degree requirements could be completed in four semesters of

Year Semester	Subject	Subject	Subject	Subject	Subject	Subject
1-1	Calculus I	Linear Algebra for Engineers	Physics 1	Chemistry I	History of Science and Technology	Technical Communications
1-2	Calculus II	Biology for Engineers	Physics II	Chemistry II	Introduction of Programming	Impact of Science and Technology on Society
2-1	Differential Equations for Engineers	Cell and Molecular Biology	Problem Solving, Modelling and Simulations	Introduction to Organic Chemistry	Introduction of Nuclear Physics	
2-2	Advanced Engineering Mathematics or Numerical Methods	Statistics and Probability for Engineers	Environmental Science	Radiological and Health Physics	Health Physics Laboratory	Collaborative Leadership
3-1	Radiation Detection and Measurement	Anatomy and Physiology I	Scientific Instrumentation	Medical Imaging	Introduction to Nuclear Reactor Technology	
3-2	Radiation Biophysics and Dosimetry	Radioisotopes and Radiation Machines	Science OR Engineering Elective	Engineering Economics	Liberal Studies Elective	
4-1	Risk Analysis Methods	Industrial Applications of Radiation Techniques	Environmental Effects of Radiation	Thesis Project I	Safety and Quality Management	
4-2	Senior Science OR Engineering Service	Medical Applications of Radiation Techniques	Senior Science OR Engineering Elective	Thesis Project II	Liberal Studies Elective	

Table 3: Health Physics and Radiation Science program map

full-time attendance, or in a reasonable time-frame if attending part time. Once the bridge programs are implemented, it is expected that the BASc in Nuclear Power will have a key role in producing the next generation of nuclear plant operators, maintenance and technical supervisors.

4. Bachelor of Science in Health Physics and Radiation Science

As noted in section 2, one of the initial degree programs offered by UOIT was the BSc in Radiation Science. The low level of student interest was in part due to the lack of understanding most high school students had of the potential career opportunities, and the ones with specific career interests were looking for programs leading the radiation technologist qualifications. However, for a program to be accredited for this purpose, it had to have a significant clinical component both within the university as well as in clinics and hospitals. Such placements could not be achieved in the short term.

In order to broaden the career appeal of the Radiation Science program, and at the same time address the need for health physics professionals in not only the nuclear power plants but in many research, industrial and health care applications, an option in health physics was developed to complement the core radiation science program. To our surprise, every student already in the radiation science program, and all new applicants, selected the health physics option. It was both logical and necessary to terminate the original radiation science program, and to offer a single program called health physics and radiation science. The program map is shown Table 3. The program design allows students through their choice of electives to emphasize either the health care sector or the material uses in industry.

Having 26 of the 43 courses in the Health Physics and Radiation Science the same as in the Nuclear Engineering helps to minimize the delivery costs. Financial help has also been received from the nuclear industry, which is the key beneficiary of the nuclear programs offered at UOIT. Application is also being made for a research chair in health physics and environmental safety, which will further enhance the viability of the program.

5. Future Plans

Broadening the appeal and applicability of the BASc in

Nuclear Power program by making it available, through a bridge program, to collage graduates, is one of the current initiatives. Discussions are being held with members of the nuclear industry to offer a co-op program to candidates who meet the hiring requirements of the company as well as the academic requirements of UOIT. This would be of particular benefits for entry level jobs that require both a technical degree and some practical experience. Having sufficient numbers of staff who have satisfied the nuclear regulatory requirements has been a constant challenge for the Canadian nuclear industry. At the crux of the problem is that candidates for the operator or shift supervisor licence are already well paid and have excellent job security, and do not have sufficient incentives to undertake the strenuous studying required to pass the licensing examinations, while facing the negative consequence of possible failure in meeting the regulatory requirements. Having potential employees complete the academic requirements of the licensing exams prior to being given a permanent job is expected to significantly increase the number of employees who succeed in achieving the operator and shift supervisor licences.

Graduate programs are currently being designed, and it is expected that a research-based MASc degree program in nuclear engineering, health physics and radiation science, as well as a course-based MEng in nuclear engineering will be offered starting in 2007.

6. Conclusion

The University of Ontario Institute of Technology has successfully developed and implemented Canada's only nuclear engineering undergraduate honours degree program, with the first graduations taking place in June 2007. Complementing the nuclear engineering program is a BASc in Nuclear Power that is designed to meet specific needs of the nuclear industry for technical graduates, particularly in operations and maintenance. Completing the trio of undergraduate honours programs is the BSc in Health Physics and Radiation Science. Once the graduate programs have been developed, UOIT will be able to offer the full range of degree programs that meet Canada's needs for engineers and scientists in the nuclear field.

7. References

[1] Bereznai, G.T., "Start-up of a Nuclear Engineering Undergraduate Honours Degree Program in Canada", *Proceedings of the 14th Pacific Basin Nuclear Conference,* Honolulu, March 2004.

Dr. E. Weller, second from right, is seen instructing nuclear engineering students in the Radiation Protection Laboratory at the University of Ontario Institute of Technology. PHOTO COURTESY OF UOIT

UOIT Nuclear – a student's perspective

by Safwan Amin

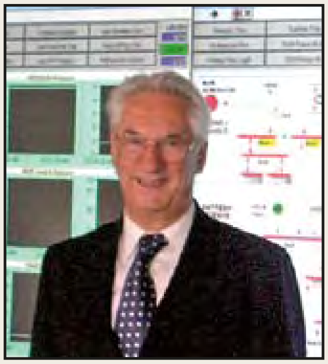
***Ed. Note:** When Safwan Amin, a third-year student at UOIT, School of Energy Systems and Nuclear Science and a member of the Canadian Nuclear Society, offered to help with the CNS Bulletin, we jumped at the chance to obtain a "student's perspective" of the School to accompany the formal paper by George Bereznai. Following is his contribution.*

The School of Energy Systems and Nuclear Science (SESNS) [at the University of Ontario Institute of Technology] has lot more to offer than just a long name! All the programs in this faculty are designed to provide its students with a competitive edge, with the Nuclear Engineering degree carrying the heaviest course load in the University. As a 3rd year student in the Nuclear Engineering program, I have truly begun to appreciate the course material and the knowledge imparted upon us.

In early stages of UOIT's development, the outcome of this program was unclear and we, as students, were unsure about what our role in the industry would be upon graduation. Slowly we received answers from our second year courses like Nuclear Physics, Radiation Protection and Nuclear Reactor Kinetics. Once we have reached third year, with courses like Nuclear Plant Operation and Environmental Effects of Radiation, all students are familiar with the plant layout and challenges we may face in the field environment. By this time, in year 3, we have become comfortable with the courses and how they connect to each other; so we are able to realize the value that a nclear engineer will have in the prospective job market.

This university is very inviting to students and it is always appreciated that the professors make the effort to learn your name, and do not refer to their students by number. This is made possible at UOIT with its small class sizes and tight-knit, friendly campus. The professors here have an extensive knowledge of their subject and are all well connected with the industry. This laptop-based program is first of its kind in Canada and is guided by the SESNS Dean, Dr. George Bereznai. Dr. Bereznai has 35 years of experience in this field, and his insight will give UOIT graduates an advantage in the numerous job openings in various facets of the energy industry. In fact, the work environment of a nuclear plant can become second nature to you, as most of us have had the opportunity to work in a power plant as a student intern or in a co-op position.

UOIT is also a great place for students with research interest in the nuclear industry. Some of our renowned professors are currently engaged in innovative research projects including modelling, simulation and numerical computations using high-end workstations. A few research projects that are currently underway include the determination of hazards from airborne contaminants, and radiation based methods used to see through visual impairments (such as walls).



Dean George Bereznai is seen in front of a simulated panel of the proposed CANDU 9 nuclear power plant control room at the University of Ontario Institute of Technology.

Our first batch of nuclear engineers will graduate the spring of 2007. They will definitely set a benchmark for the future graduates of this program and establish the University's reputation for skilled and knowledgeable graduates.

The Canadian Nuclear Society Chapter at UOIT is working with the students to encourage them to become members of the CNS because it is a great way to start a network with industry leaders and to learn about latest developments. The official website of the chapter will be launched in January 2007, and as an active member of the CNS it gives me great pleasure to be a part of the CNS Bulletin.

A group of nuclear students compare notes on the campus of the University of Ontario Institute of Technology

(Photos by Safwan Amin)

PHYSOR 2006

Reactor physicists from around the world meet in Vancouver

Almost 400 reactor physicists, including about 50 students, from 26 countries descended on Vancouver, September 10 to 14, 2006 for PHYSOR 2006. This was the largest attendance of the series of PHYSOR meetings.

"PHYSOR" (an acronym for physics of reactors) is a series of topical meetings held every two years under the auspices of the American Nuclear Society. This was the first time a PHYSOR meeting has been held in Canada, a result of lobbying by **Ben Rouben,** senior reactor physics consultant at Atomic Energy of Canada Limited, a former president of the Canadian Nuclear society and currently chair of the ANS Physics Division. As a "reward" for his efforts, Rouben ended up as General Chair of the meeting. **Ken Kozier,** also of AECL, was the senior co-chair of the Program Committee, coordinating the input of 174 members from 25 countries. **James Lake,** of Idaho National Laboratory in the USA, was Honorary Chair.

Although there were well-attended workshops on the codes TRITO, PARCS and DRAGON, on the Sunday, most of the delegates arrived that afternoon. With a significant number not being pre-registered this caused a challenge for those manning the registration desk under the direction of **Denise Rouben,** CNS administrator.

Nevertheless, the opening reception that evening proceeded, allowing delegates to renew acquaintances or, in many cases, meet others with whom they had been corresponding.

The meeting proper opened early Monday morning. Noting the "overwhelming" response, Ken Kozier pointed out that the schedule would be tight. Ben Rouben welcomed everyone and invited Honorary Chair, James Lake, to open the meeting. Lake noted the development of physics analyses and commented that the new designs of reactors being developed require validation. He welcomed the almost 50 students registered and the more than 350 papers to be presented.

Then Rouben called on **Romney Duffey,** senior scientist at AECL, to chair the opening plenary session, which was titled *"Advantages in Generation III Reactors"*. Leading off was **Jerry Hopwood,** vice-president, reactor development at AECL, who provided an overview of AECL's ACR 1000 reactor design, which continues the CANDU concept of fuel channels and heavy water moderator but employs light water coolant and slightly enriched uranium fuel. Hopwood stated there were three key areas of improvement: enhanced safety; cost reduction; improved operability. The compact core with reduced pitch between channels and a flat flux has required considerable reactor physics analyses, he told the receptive audience.

Ben Rouben

James Lake

Ken Kozier

Dwight Willett

Presenting another new design, **Martin Parece,** of AREVA, described the work going on to modify the EPR design (being built in Finland) to meet the requirements of the United States market. Although the PWR design originated in the USA it was developed further in France and Germany, he commented, and is now being reintroduced to that country. It is an evolutionary design, he stated, which offers enhanced ability to withstand extreme accidents. It can use up to 5% enriched fuel or mixed oxide (MOX).

After a break there was another short plenary session, titled *"Advances in Analysis Methods"*. **Jess Gehin,** of Oak Ridge National Laboratory began with a presentation on *Advances in Analysis Methods and Reactor Simulation* in which he spoke about "super big computers". Even with these machines, he said, we need: experts; careful assessment of predictive capability; more realism and less conservatism; and improvements in "deterministic" approaches. In conclusion he stated that we need a good understanding of the fundamental physics involved. Licensing based on simulations is a challenge, he suggested.

At the only conference luncheon, on the Monday, **Dwight Willett,** executive vice-president, corporate services at Bruce Power, was the guest speaker. He was introduced as having an interesting background, beginning as a teacher, then with Ernst & Young consultants, and moving to Consumers Gas before joining Bruce Power.

Willett began with a brief description of Bruce Power which is owned by a consortium of: Cameco Corp., TransCanada Pipelines, OMERS (Ontario Municipal Employees Retirement System) and two unions, Power Workers Union and Society of Energy Professionals. It has leased the two four-unit nuclear stations, Bruce A & B, and the large 2300 acres site

Titles of Technical Sessions

Transport Methods

Fuel/Core Design and Analysis

Multiprocessing Methods and Algorithms for Nuclear Applications

Advances in Reactor Assembly & Core Analysis Methods

Critcality Benchmarks & Experiments

Physics& Modelling of Research Reactors

Neutron Physics

International Reactor Physics Experiment Evaluation Project

3-D Neutron Transport Methods

Uncertainty analysis Methodologies & Applications in Reactor Safety

Nuclear Data

Nuclear Methods for Non-Proliferation & Homeland Security

Lead-Fast-Reactors Physics

HTR Numerical Benchmarks & Studies

Monte-Carlo Methods & Developments

Accelerators, Transmutation & Spallation

Advanced Reactor Designs

Reactor Physics Experiments & Analysis

Covariance Data Generation for Nuclear Applications

Fusion Blanket Physics

Reactor Analysis Methods

Multi-Physics Coupled Code Systems & Multi-Scale Computation

Advanced Fuel Cycles for Fuel Management

Nuclear Standards

Regulatory Perspective on Analysis & Simulation

In-Coe Fuel-Management Optimization

Detector Technology

Nuclear Safety

Nuclear Safety Validation & Performance of ENDF/B-VII

Reactor Physics

Very High Temperature Reactor Physics

Nuclear Criticality Safety

Nuclear Engineering Distance Education

International Collaboration in Reactor Physics

on the shores of Lake Huron where they are located. There are currently about 3600 full-time employees and 1800 on the refurbishment projects underway.

He then turned to an overview of the Bruce A restart program and the refurbishment of units 1 and 2. This includes a new simulator building, he commented. He veered off to the Ontario electricity situation, the need for more generation, the demand for skilled workers, and other challenges. Bruce Power is considering building 4,000 MW of new nuclear generation over the next 10 to 12 years, he stated. The Environmental Assessment will begin soon and is expected to take three years. The technology has not been decided, he said, with Bruce Power looking at: ACR 1000, AP 1000, EPR, ESBWR and enhanced CANDU 6. To a question he acknowledged that the EPR 1600 might be too large for the Ontario system.

Although a few technical sessions had been held in the last part of the morning, the intensive program began in earnest after lunch, with 10 parallel sessions. That challenging format continued for the next two and a half days with a brief respite early Tuesday afternoon for another short plenary and an optional tour of the TRIUMF accelerator facility on the campus of the University of British Columbia on the Thursday morning.

The Tuesday plenary session, on ***Advances in Nuclear Data Libraries,*** had four speakers. Claes Nordborg, from the OECD-NEA, spoke about the new improved versionof the OECD Nuclear Energy Agency's co-ordinated Joint Evaluated Fission and Fusion (JEFF) data library. Pavel Obloûinsk˝, from the National Nuclear Data Centre at Brookhaven National Laboratory described the staus of the new version of the U.S. Evaluated Nuclear Data File, ENDF/-VII. Alan Nichols, of the Department of Nuclear Sciences and Applications at the International Atomic Energy Agency, described the broad effort of the IAEA to assemble international data bases. Finally, Keiichi Shibata, of the Japan Atomic Energy Agency, spoke of the most recent version o their JENDL General-Purpose File which was first compiled in the late 1970s.

The conference banquet was held on the Wednesday evening, with **David Sanborn,** founding director of the Institute for Integrated Systems at the University of Victoria and a long-time proponent of the use of hydrogen, as the guest speaker.

Sanborn began by quoting the saying, "wisdom is all context". We can predict the "deep" future better than the short future, he stated, noting the widespread expectation of the depletion of oil and gas and possible economic disarray this will cause. He then turned to describing the energy system chain of: service; service technology; currency; transformer; source. Focussing on currency he emphasized the use of hydrogen. Using nuclear for its production the use of hydrogen for transportation could replace the current dependence on oil. He offered a historic list of fuels for land transportation as: 1770 – hay; 1840 – wood; 1910 – coal; 1980 – oil; 2050 – hydrogen.

After thanking the speaker, James Lake called upon Rakesh Chawl, of EPFL, Switzerland, to extend an invitation to PHYSOR 2008 to be held in Inerlaken, Switzerland in September 2008.

An optional dinner at the Vancouver Aquarium was held on the Tuesday evening with a large number of the delegates participating. After being transported to the Aquarium by bus those attending enjoyed a "private" viewing of the many aquatic displays before enjoying an extensive buffet dinner.

The list of the topics of the parallel sessions (see sidebar) gives an insight into the diversity of the reactor physics discipline and the intense specialization that has developed over recent years.

A poster session was held, emphasized by a pre-banquet reception in the poster area, on the Wednesday evening. There were 42 poster presentations on display giving the judges a definite challenge. Finally, they awarded two prizes rather than the one planned.

The meeting ended early Thursday afternoon with the presentation of prizes for the best student papers and the best poster.

The poster winners were:

Maria Pázsit, Carl Sunde, Imre Pázsit:
Chalmers University of Technology, Göteborg, Sweden
"Beam Mode Core-barrel vibrations in Ringhals 2 – 4 PWRs"

D. W. Nigg, P. E. Sloan, J. R. Venhuizen, C. A. Wemple, G. E. Tripard:
Idaho National Laboratory; Department of Nuclear Engineering, University of Illinois; Nuclear Radiation Center, Washington State University
"Computational and Experimental Physics Performance Characterization of the Neutron Capture Therapy Research Facility at Washington State University"

Three awards were also granted for the best student papers. The student winners were:

1st Massimiliano Fratoni, University of California at Berkeley
"Optimal Hydride Fuelled BWR Assembly designs"

2nd Romain le Tellier, École Polytechnique de Montrèal
"Benchmarking of the Characteristics Method combined with Advanced Self-Shielding Models on BWR-MOX Assemblies"

3rd Angel Papukchiev, Technische Universität München
"Impact of Boron Dilution Accidents on Low Boron PWR Safety"

A CD, with most of the technical papers, can be purchased from the American Nuclear Society.

The meeting had a large number of sponsors: Argonne National Laboratory, Atomic Energy of Canada Limited, Battelle, Bruce Power, Cnadian Nuclear Safety Commission, Canadian Nuclear Society, Candesco Corporation, Hydro-Québec, Idaho National Laboratory, New Brunswick Power Nuclear, Nuclear Safety Solutions, Ontario Power Generation, Pacific Northwest National Laboratory.

PHYSOR-2006 Badge-Draw Winners

At the end of PHYSOR-2006 in Vancouver, seven prizes were awarded by random draw from among badges returned by attendees. The prizes were CNS silk ties or attractive souvenirs from Vancouver or Canada.

The winners, in alphabetical order:

- Forrest Brown, Los Alamos National Laboratory, USA
- Ron Dagan, Forschungszentrum Karlsruhe, Germany
- Steve Goodchild, Ontario Power Generation, Canada
- Jaakko Leppänen, VTT Technical Research Centre, Finland
- Tran Hoai Nam, Tokyo Institute of Technology, Japan
- Shawn Pautz, Sandia National Laboratories, USA
- Anssu Ranta-aho, Technical Research Centre, Finland

Scenes from PHYSOR 2006

OCI Annual Meeting
Mini seminar augments business meeting

To add interest to its Annual General Meeting, the Organization of CANDU Industries invited several leaders of the Canadian nuclear business to address the meeting, held the afternoon of November 16, 2006, at McMaster University.

Rae Watson, chairman of the OCI Board of Directors began the meeting by introducing the directors. In presenting the financial report, General Manager Martyn Wash noted that the organization now had reserves equal to a yearís operating budget.

In his chairmanís report Watson reported that there are now 84 member organizations, up from 59 last year. Board members had visited all of the nuclear power sites and held a reception for Ontario MPPs. Saying that the organization had outgrown the original Charter and By Laws of 1979 Watson reported they have been significantly revised. They now allow the Board to have directors from up to 20 percent of the membership. Six new directors were added to the Board:

Gary Brown	Summit controls
Frank Didomizio	GE Canada
Spencer Fox	E.S.Fox
Richard Goodman	Merlin General
Andrew Oliver	Zircatec
Denzil Prabhu	Sulzer

He then called on Gerry Waterhouse to speak about the OCI bursary program. OCI has created endowments at University of Ontario Institute of Technology and McMaster University to encourage students to pursue nuclear-related programs. The bursaries are named after Jack Howett, the first and long-serving General Manager of OCI. He then called on Howett to present a plaque commemorating the award to Karl Kazlowski, a student at McMaster.

Following a short pause Watson introduced the first of the invited speakers, John Kim of Babcock & Wilcox Canada. B & W is continuing with its contract to build 24 replacement steam generators for the Bruce a refurbishment, Kim reported, noting that the first unit was shipped in August. The company is also manufacturing two, "very large" units for the Crystal River PWR plant in Florida.

He identified the key issues for the company as: resource planning; supply chain capability; risk management; standardization; competition for resources and materials. Two key questions, he said, are: will nuclear attract suppliers?, and, can suppliers meet the challenge? Skilled trades people are limited, he commented in closing.

The flow of speakers was broken briefly to allow Dr. Peter George, president of McMaster University, to extend his greetings. He commented that McMaster had recently acquired the former Westinghouse plant in Hamilton which will be transformed into a research center for materials and nano-technology.

Jack Scott, Atomic Energy of Canada Limited, the next invited speaker, began by referring to "Team CANDU", the alliance of six companies prepared to offer "turn-key" projects. OCI members back up Team CANDU, he commented.

Next was David Bothers of the Association of Power Producers of Ontario (APPrO) who mentioned the meeting his organization held earlier in the week. He described the current arrangement for electricity in Ontario as a "hybrid market" which had a number of problems but was still better than the previous one. To a question he qualified his comment saying that it was better then the system immediately after the (Harris) government deregulation and break-up of Ontario Hydro.

The final two speakers gave perspectives of the utilities. First was Gregory Smith, of Ontario Power Generation, who stated that public or private ownership did not matter. The key factor was "how the business is run". Further, he said, technology was less important than people, noting that nuclear requires far more people (per megawatt produced) than any other form of electricity generation.

Last was Keith Wettlaufer, of Bruce Power, who briefly described the company and the refurbishment which is about to proceed now that all of the preparatory work has been done, noting in particular the challenge of replacing the steam generators and all of the fuel channels..

The day concluded with a reception to which McMaster students had been invited, providing an opportunity for students to seek summer or permanent positions.

Jack Howett presents a plaque accompanying the OCI bursary award bearing his name to Karl Kazlowski, a student at McMaster University

Douglas Point commemorated

On September 27, 2006, close to 150 people, mostly retirees once associated with the plant, gathered at the Visitors' Centre of Bruce Power for a ceremony to commemorate the Douglas Point Nuclear Power Plant, the first large scale nuclear power plant in Canada.

This was roughly the 40th anniversary of the first criticality of the Douglas Point reactor in November 1966 and paralleled a similar ceremony for the prototype NPD plant in 2002. Douglas Point entered commercial operation on September 26, 1968 and continued to supply up to 220 megawatts to the Ontario grid until it was retired on May 5, 1984.

The plaque, which was authorized by the Ontario Heritage Trust, the official agency of the Ontario government, was erected outside the Visitors' Centre after the closing of the ceremony.

Guest speakers and dignitaries pose following the Douglas Point plaque unveiling, September 29, 2006: (Left to right) David Harrington, AECL Project Director; Glenn Sutton, Mayor, Town of Kincardine; Fred Eaton, Vice Chairman, Ontario Heritage Trust; Jeremy Whitlock, Past-President, Canadian Nuclear Society; Ken Ellis, Vice President Engineering, Bruce Power; Lorne McConnell, Vice President (retired), Ontario Hydro; and Ron Oswald, Warden, Bruce County.

The bilingual plaque reads:

DOUGLAS POINT NUCLEAR POWER PLANT

The Douglas Point Nuclear Power Plant began generating electricity in 1967 and continued until 1984. This joint project between Atomic Energy of Canada Ltd. and Ontario Hydro was the first commercial-scale Canada Deuterium Uranium (CANDU) reactor. The Nuclear Power Demonstration (NPD) reactor in Rolphton, Ontario had proven the CANDU concept in 1962 and the 200-megawatt Douglas Point plant, ten times larger than NPD, demonstrated that a CANDU nuclear power plant could be scaled up for commercial power generation. The advances made at Douglas Point provided the province with a growing and reliable energy supply and contributed to the success of larger CANDU plants in Canada and abroad.

CENTRALE NUCLÉAIRE DE DOUGLAS POINT

La Centrale nucléaire de Douglas Point a commence a produire de l'électri-cite en 1967 et ce, jusqu'en 1984. Ce projet conjoint d'Énergie atomique du Canada limitée et d'Ontario Hydro a été le premier reacteur nucléaire commercial CANDU (Canada Deuterium Uranium). Le réacteur nucléaire de démonstration (réacteur NPD) de Rolphton, en Ontario, a validé le concept CANDU en 1962 et la centrale de Douglas Point de 200 mégawatts, dont le réacteur était dix fois plus puissant que celui de Rolphton, a prouvé qu'une centrale nucléaire CANDU pouvait étre aménagée a des fins de production commerciale d'électricité. Les progrès accomplis à la centrale de Douglas Point ont permis d'offrir à la province une source croissante et fiable d'ap-provisionnement en énergie et ont contribué a assurer le succès de centrales nucléares CANDU plus puissantes au Canada et à l'étranger.

Chaired by Fred Eaton, vice-chairman of Ontario Heritage Trust, the speakers at the ceremony included:

- Dr. Norman Ball, a historian commissioned by the Trust to prepare a historical statement and the citation on the plaque,
- Jeremy Whitlock, former president of the Canadian Nuclear Society, who had been instrumental in convincing the Trust to erect the plaque,
- Lorne McConnell, former vice-president of Ontario Hydro, who was in charge of Ontario Hydro's nuclear program,
- David Harrington of Atomic Energy of Canada Limited, who had worked on the Douglas Point design, and,
- Ken Ellis, vice-president, engineering, Bruce Power, who had joined the Douglas Point staff in 1982.

In his offical note Ball commented, "the most important legacy of douglas Poijht is that expensive lessons were learned in time to apply them to large commercial stations being built in the late 1960s and early 1970s".

Ball concluded his opening address by commenting, large technical enterprises stand on many supports. Nuclear, especially, needs public support, he said. We have the technology, can we convince the public? he asked in closing.

After the speeches, Frank Baker and Doug Stewart, two retirees who had worked many years at Douglas Point, performed an original song they had written for the occasion.

Bruce A Refurbishment
– Preparatory work completed, major tasks to begin soon

by Fred Boyd

Prologue: Over the past year Bruce Power has been planning and organizing for an extensive refurbishment of the Units 1 and 2 of the Bruce A station. Now the company and its several major contractors are ready to proceed with the most challenging aspects of the actual work. The largest tasks are the replacement of the 8 steam generators and of the 480 complete fuel channels in each unit. Bruce Power has created a separate website connected to their basic one to provide ongoing information about the progress of the work. The following brief note is intended to provide an outline of this challenging refurbishment program and to invite readers to visit this website to follow its progress. To provide background the writer was accorded an informative and interesting tour of the units by Rob Liddle, of Bruce Power, on September 28, 2006, the day after the ceremony commemorating the Douglas Point station held at the Bruce site.

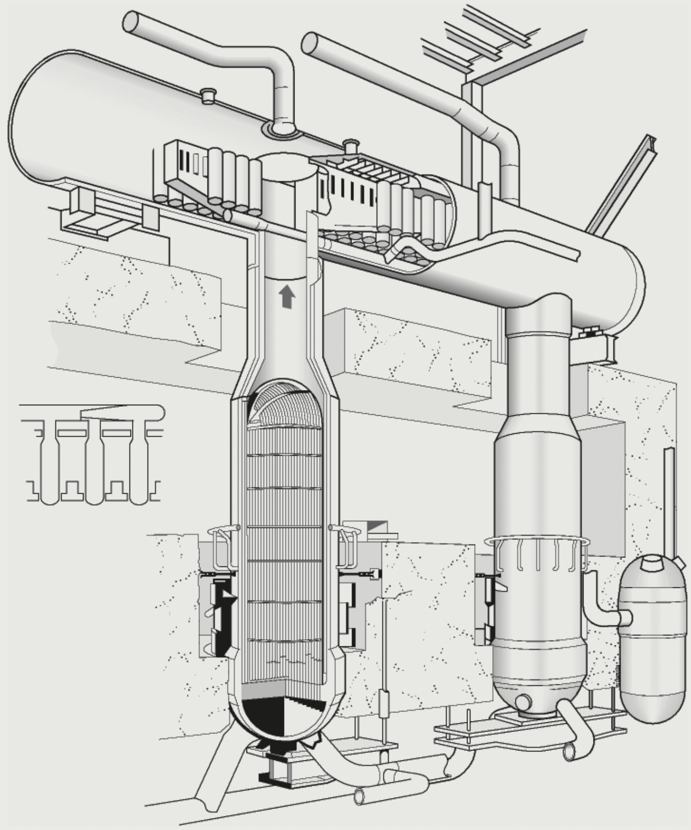
Just over a year ago, in October 2005, Bruce Power announced its intention to conduct an extensive refurbishment of the Units 1 and 2 of the Bruce A nuclear power station. Included in this $2.75 billion project was replacement of all of the steam generators and all of the fuel channels.

After completing their in-house studies, Bruce Power engaged AMEC NCL to be the project management contractor with Kevin Routledge taking the role of Project Director. *(See article on Routledge in Vol. 27, No.2 June 2006 issue of the CNS Bulletin.).* Major contracts were then awarded for the largest tasks. Babcock & Wilcox was assigned the work to fabricate and deliver new steam generators, as well as bulkheads to isolate Units 1 and 2 from the stationís common containment system. SNC-Lavalin Nuclear was chosen to carry out the difficult task of replacing the steam generators. Atomic Energy of Canada Limited was selected to replace the fuel channels. Both of these large tasks were first of their kind.

The other major contractors are: Siemans who will overhaul the turbine generators and auxiliary electrical esystems and E.S.Fox who will manufacture and install new lower segments on the feeders. (AECL has the task of removing the old segments.)

Additional contractors include:

- Aecon Group, in a 50 / 50 association with SNC-Lavalin Nuclear, will deal with upgrades in the balance of plant.
- ASLF, a joint venture of Hatch-Acres, Sargent & Lundy and E. S. Fox will conduct engineering and construction to upgrade the fire protection system
- RCM-Fox. RCM Technologies Canada Corp., a subsidiary of RCM Technologies, Inc., in a joint venture with E.S. Fox Ltd., will provide engineering analysis, design and field modifications to ensure components that are critical to safety will function properly in the event of adverse environmental conditions.



A drawing of part of a steam generator arrangement in Bruce A units)

Steam Generators:

Each unit has eight steam generators, four in each loop. In a unique design, four steam generators are connected to one steam drum. Most of the steam generators are outside the compact containment of the Bruce design. *(See drawing)*. The common steam drums have been determined to be in good condition and will be reinstalled.

Four slots will be cut in the roof over each steam generator / drum assembly. Two of these will be elongated. The steam generators will be cut away from the steam drum and from the piping connecting to the main circulation pumps at the bottom. Then, using the recently acquired heavy lift crane *(see photo)*, slings will be placed through the elongated slots, placed around the drum and it will be moved just far enough to enable the generators to be lifted out one at a time. The vessels will be sealed and taken intact to the Western Waste Management Facility operated by Ontario Power Generation on the Bruce site. During the installa-

A view of the massive Mammoet crane to be used for the replacement of the steam generators.

tion, there will be only centimetres of clearance and the generators, in banks of four, must line up precisely with their inlet and outlet nozzles as well as the steam drum connections.

The steam drum weighs about 250 tonnes and is about 30 m. long. Each steam generator is about 12 m. high and weighs about 100 tonnes. The large Mammoet crane has a lifting capacity of 1600 tonnes.

Babcock & Wilcox Canada delivered the first replacement steam generator in August 2006. *(See Vol. 27, No. 3 August 2006 issue of CNS Bulletin.)* It is expected that eight will be on the Bruce site by the end of 2006.

Fuel Channels

Although pressure tubes have been replaced in other CANDU reactors, this will be first time that the entire fuel channel, including the calandria tubes will be replaced en masse. The existing channels will be cut away from the feeders and disconnected from the calandria end shields. They will be extracted using multi-purpose machines and tooling operated remotely from a Retube Control Centre between the two reactor vaults. The calandria and pressure tubes will be cut up into small pieces by the same tooling inside the reactor vaults and placed in retube waste containers before also going to the Western Waste Management Facility. The same machines will be used to replace the channels.

AECL crews have been using a feeder disconnect tool to shear the bolts that connect the feeder pipes to the Grayloc fittings on the fuel channels. This work was completed in Unit 2 on Dec. 2 and is expected to commence in Unit 1 in May.

Existing bulkheads were installed by B&W in Unit 2 last summer to isolate the Unit 2 reactor vault from the stationís common containment system. B&W has manufactured new bulkheads for Unit 1 and installation is currently underway to prepare for a vault pressure test in January.

Other Work

Among the many other tasks underway, a "West End Complex" is being built at the southwest end of Bruce A to provide better access to the Construction Island for employees working on Units 1 and 2 and to minimize disruption for employees in the adjacent operating units (3 and 4). Phase A of the complex with parking, an enclosed walkway over the stationís intake channel and a security facility was placed in service Nov. 22. Phase B, to be completed by year-end, will add new lunchrooms and additional office space.

Bruce Power reports that as of November 2006 there are about 1,200 contract workers on site and that the project is on schedule and on budget. However, Duncan Hawthorne, Bruce Power President and CEO, is quoted as saying that the next six months will be critical.

Regulatory Process

The Bruce Power refurbishment program passed its first regulatory hurdle when the Canadian Nuclear Safety Commission accepted the Environmental Assessment for the project on July 5. The next formal step is the Operating Licence. To obtain that, Bruce Power will have to submit a revised safety analysis and conduct an Integrated Safety Review (ISR), which is an assessment of design and operation in accordance with the document, Periodic Safety Review of Nuclear Plants, Safety Guide, Safety Standards, No. NS-G-2.10 of the International Atomic Energy Agency. The CNSC has issued its own draft guide G-360, for review and comment. *(See paper "Regulatory Approach for Life Extension of Nuclear Power Plants in Canada", by D. G. Miller et al of the CNSC in Vol. 27, No. 3, September 2006, issue of the CNS Bulletin.)* The detailed requirements that may come from these studies and the subsequent CNSC reviews remain to be seen.

For up-to-date information and some interesting animations of the steam generator removal and retube go to the Bruce Power website at www.brucepower.com and then proceed to the sub site on "Bruce A Restart".

McMaster University ENGINEERING

McMASTER UNIVERSITY
DEPARTMENT OF ENGINEERING PHYSICS

TENURE-TRACK FACULTY POSITIONS AT THE ASSISTANT/ASSOCIATE PROFESSOR LEVEL IN ENERGY STUDIES

The Department of Engineering Physics at McMaster University and the McMaster Institute for Energy Studies are undergoing a significant expansion of research and teaching in the area of Energy Studies. There are two positions available at the Assistant/Associate Professor level. Candidates should have proven excellence in one of the following areas:

Area 1. Photovoltaics – technology development and/or systems design. The successful applicant is expected to have expertise in advanced photovoltaic materials and state-of-the-art devices. He/she will become part of a strong team in the department with active research in photonic materials, devices and technologies. Significant facilities are available for device fabrication and characterization.

Area 2. Nuclear Reactor Physics and Reactor Engineering. This position will build upon existing departmental expertise in nuclear thermalhydraulics, reactor physics, and safety analysis and energy systems. The applicant should have advanced knowledge of nuclear power plant fuel cycles and advanced reactor concepts.

Area 3. Nuclear Reactor Fuel Cycles and Lifecycle Management. Building on the departmental strengths in nuclear engineering, the focus of this position is on nuclear fuel cycles, specifically in the processing and/or disposal of spent nuclear fuel as well as other irradiated materials.

Applicants must have a PhD in Engineering, Applied Physics or a closely related discipline. They will be expected to have proven research excellence in the area to which they are applying and the ability to develop an effective research program. They must also demonstrate a strong commitment to teaching and curriculum development at both the undergraduate and graduate levels. The Department will provide assistance to the successful candidates for them to become registered as a Professional Engineer in the Province of Ontario.

Interested applicants should send a letter of application stating the area applied for, curriculum vitae, statements of teaching and research interests, a selection of research publications, and the name and addresses of at least three references to:

Dr. Paul Jessop, Chair
Department of Engineering Physics
McMaster University
Hamilton, ON. L8S 4L7, Canada.

These positions are available immediately and will remain open until filled. Applications by e-mail will not be accepted.

All qualified applicants are encouraged to apply; however, Canadian Citizens and permanent residents will be given priority. McMaster University is strongly committed to employment equity within the community, and to recruiting a diverse faculty and staff. The University welcomes applications from all qualified applicants, including women, members of visible minorities, Aboriginal persons, members of sexual minorities, and persons with disabilities.

GENERAL news

CNSC's Keen Re-emphasizes International Standards

(The following is extracted from the official CNSC media release.)

Linda Keen

In a follow-up to her talk to the Canadian Nuclear Association meeting last February, on October 30, 2006, Linda Keen, President and CEO of the Canadian Nuclear Safety Commission (CNSC), met with CEOs of major licensees to provide an overview of the CNSC's commitment to international standards in view of current industry growth.

Keen outlined the strategic direction being taken by the CNSC in moving towards an internationally benchmarked regulatory framework. She also emphasized that the CNSC approach for new nuclear facilities is clearly committed to moving towards adopting and/or adapting international standards, particularly those of the International Atomic Energy Agency, for assessing future nuclear facilities in Canada.

She reiterated [her earlier statement] that the future for regulation of new nuclear reactors in Canada would be based upon expanded use and alignment with international standards. "This will be a technology neutral approach," said Ms. Keen, "to ensure Canadians are assured of high standards for health, safety and the protection of the environment."

Keen also reviewed current security requirements and issues.

Nuclear facilities have put security measures in place that are in line with international standards, she noted. The new measures involve such areas as: having an on-site armed response force, implementing enhanced security screenings of employees and contractors, establishing systems to protect against forced vehicle penetration and improving physical identification checks of personnel.

The coming into force of amendments to the Nuclear Security Regulations on November 27th of this year will solidify Canada's implementation of strengthened nuclear security measures in Canada. "These security measures are in line with international standards and are an essential part of the Canadian nuclear regulatory regime." said Ms. Keen. "They compliment our long standing efforts in safety, health, environmental protection, and the control of nuclear material."

In September 2005, the IAEA reported that all Canadian nuclear material remains in peaceful activities.

Links to related documents:

Licensing Process for New Nuclear Power Plants in Canada
http://www.nuclearsafety.gc.ca/eng/regulatory_information/other/licensing_process.cfm

News releases for New Build Applications
http://www.nuclearsafety.gc.ca/eng/media/news/news_release.cfm?news_release_id=244
http://www.nuclearsafety.gc.ca/eng/media/news/news_release.cfm?news_release_id=247

Modern Nuclear Regulation & Responding to Industry Growth: Notes for an address to the Canadian Nuclear Association
http://www.nuclearsafety.gc.ca/eng/media/speeches/2006_02_23.cfm

Nuclear Security Regulations
http://www.nuclearsafety.gc.ca/eng/media/news/news_release.cfm?news_release_id=246

IAEA Broader Safeguards Conclusion
http://www.nuclearsafety.gc.ca/eng/media/news/news_release.cfm?news_release_id=126

AECL Signs Agreement with Argentina on Expanded CANDU Program

Atomic Energy of Canada Limited (AECL) has signed an agreement with Nucleoeléctrica Argentina S.A. that will advance co-operation in Canadian-developed CANDU nuclear power.

The federal Minister of Natural Resources, Gary Lunn, announced the agreement on November 27, 2006.

The agreement covers the refurbishment of Argentina's first CANDU power station, Embalse, and includes a feasibility study for another 700-megawatt CANDU 6 power station.

Argentina's nuclear power program is centred on heavy water reactors, including the very successful Embalse, an AECL CANDU 6 power reactor that was connected to the grid in 1983, and the German designed, pressure vessel PHWR unit Atucha 1.

The agreement specifies a number of nuclear-related projects for joint co-operation. These include:

A view of the Embalse nuclear power station

- the refurbishment of Embalse,
- a feasibility study by 2007 for another CANDU station to go into service around 2015, and
- assistance to NucleoelÈctrica Argentina S.A. in completing the Atucha 2 reactor originally supplied by Germany whose construction was halted in 2000 when Argentina suffered an economic crisis.

The agreement will also create commercial opportunities for Argentina to supply services and heavy water to international CANDU markets.

Headframe of Cigar Lake mine

CAMECO working on water ingress at Cigar Lake

On November 20, 2006 Cameco Corporation announced that remediation work is under way at Cigar Lake uranium project in northern Saskatchewan following a water inflow that filled the underground development on October 23, 2006.

Cameco, with assistance from international experts, is developing a comprehensive remediation plan including fallback options.

Currently, Cameco is proceeding with the most conventional option to restore the underground workings in phases. The first phase includes surface drilling using oil field rigs and grouting to seal the inflow. This phase was approved by the Canadian

Nuclear Safety Commission (CNSC) on November 2, 2006, and subsequently by the joint venture partners. Drilling is now under way. Phase one work is anticipated to take at least 60 days based upon current plans.

Phase one involves drilling holes down to the access tunnel at the 465 metre level in the vicinity of the source of the inflow. Concrete will be pumped through the drill holes into the tunnel to create a plug downstream from where the rockfall and inflow occurred. Once the plug has solidified, it will be grouted by pumping cement under high pressure into cracks in the rock and concrete mass to seal them off. Subsequently, the area of the rockfall itself will be filled with grout. Progress will depend on the successful completion of each step of the plan for phase one.

Drilling crews involving 40 to 50 workers have been at work on the site since November 9, 2006. They will be working three shifts per day, seven days per week on the remediation drilling.

Detailed planning is now under way for the next phase that includes pumping the water out of the mine, verifying the integrity of the plug and the mine workings, restoring underground pumping capacity and ventilation systems and assessing and repairing the bulkhead doors. Planning continues for subsequent phases that include ground freezing in the area of the inflow, restoring other underground areas and resumption of mine development.

Regulatory approval is required for each phase of the remediation plan.

The Cigar Lake project, which has the world's largest undeveloped uranium deposit, is a joint venture owned by Cameco Corporation (50%), AREVA Resources Canada Inc. (37%), Idemitsu Uranium Exploration Canada Ltd. (8%) and TEPCO Resources Inc. (5%).

New Chair of AECL Board

Michael C. Burns has been appointed Chair of the Board of Directors of Atomic Energy of Canada Limited (AECL). The announcement was made by the federal Minister of Natural Resources, Gary Lunn on October 31, 2006

Mr. Burns is currently Chair of NaiKun Wind Development in Vancouver, British Columbia. Previously, he was a senior executive with BC Gas Inc., where he served as Executive Vice President and Chief Financial Officer. He was also President of Inland Pacific Enterprises, a subsidiary of BC Gas. For 10 years, he acted as a consultant to senior management in a variety of public and private enterprises. He also held senior positions with IBM Corp.

Mr. Burns has extensive corporate and public-sector board and governance experience, including serving as a member of AECL's Board of Directors from 1987 to 1990. He continues to sit on a number of corporate, community and association boards in Canada.

Mr. Burns will take over the position as Chair from Mr. Jean-Pierre SoubliËre, who has been Acting Chair since August 2005.

MDS Nordion receives US approval for innovative cancer therapy

In September 2006, MDS Nordion received approval from the U.S. Food and Drug Administration (FDA) to begin the first clinical trial for a non-invasive, innovative cancer therapy.

This treatment called TheraSphere® has been developed for patients with liver cancer. The clinical trial will enrol up to 150 patients with secondary liver cancer from five existing TheraSphere® treatment centres in the United States.

TheraSphere® offers another option to the limited number of treatments available for patients suffering from secondary liver cancer. With this treatment, tiny radioactive glass beads attack cancerous tumours in the liver, while minimizing the impact on the patient's healthy tissues. Unlike chemotherapy, it has few side effects. Patients rarely experience extreme fatigue, nausea and vomiting usually associated with high-dose, systemic chemotherapies. The treatment can generally be administered on an outpatient basis, as it does not usually require an overnight hospital stay.

TheraSphere®, Yttrium-90 glass microspheres, is a low toxicity, out-patient liver cancer therapy that consists of millions of small glass beads (20-30 micrometers in diameter). Each bead has radioactive Yttrium-90 in it. The physician injects TheraSphere® into the main artery of the patient's liver through a small tube (catheter) and the tiny radioactive glass beads are delivered directly into the liver tumour via blood vessels. The radiation delivered destroys the tumour cells from within the tumour, with minimal injury to surrounding health liver tissue. The Yttrium-90 in TheraSphere® becomes Zirconium-90 as it loses radioactivity. The radioactivity half-life of Yttrium-90 is 64.1 hours resulting in most of the radioactivity disappearing in approximately 10-12 days following treatment with TheraSphere®.

For more information on TheraSphere®, visit www.therasphere.com

Canadian Light Source receives $25.8 Million for Major Projects

The Canada Foundation for Innovation (CFI) has awarded $25.8 million for three projects to be built at the Canadian Light Source (CLS) national synchrotron facility at the University of Saskatchewan.

The projects are led by teams from three universities: the University of Guelph, the University of Saskatchewan, and the University of British Columbia. Construction and operation will be done in collaboration with CLS scientists.

The three projects together comprise five new beamlines. Construction is expected to begin in early 2008, with some of the new facilities operational as early as 2011.

CFI will provide up to 40 per cent of the total $64.5 million in funding for the beamline projects, with the balance to be made up from other partners. Operating costs will be covered by CFI and the CLS operating budget. The CFI funding is part of more than $422 million in investments to support 86 projects at 35 institutions across Canada.

The new beamlines include:

- **The Brockhouse X-ray Diffraction and Scattering Sector:** Under the leadership of Stefan Kycia from the University of Guelph, this $27.8-million project includes two beamlines which will be devoted to characterizing the structure of a wide variety of materials for applications such as advanced alloys and polymers, novel batteries, food science and petroleum products.
- **BioXAS: Life Science Beamline for X-ray Absorption Spectroscopy:** Led by University of Saskatchewan Canada Research Chair Graham George, this $20.6 million project will develop two beamlines to be used to study biological and health-related metals, in diseases such as Alzheimer's, as environmental toxins, in metal-containing drugs, and as essential constituents of living systems.
- **The Quantum Materials Spectroscopy Centre:** Under the leadership of Andrea Damascelli, Canada Research Chair in Electronic Structure of Solids at the University of British Columbia, this $16.1-million project is expected to propel Canada into the forefront of research into the electronic properties of novel materials, with applications from high-performance computing to energy storage technologies.

The projects announced today bring to 19 the number of beamlines in various stages of planning, construction, commissioning and operation at the CLS. There is room for about 30 beamlines at the national synchrotron facility. A backgrounder on these latest projects is available at www.lightsource.ca.

The Canada Foundation for Innovation (CFI) is an independent corporation created by the Government of Canada to fund research infrastructure. The CFI's mandate is to strengthen the capacity of Canadian universities, colleges, research hospitals, and non-profit research institutions to carry out world-class research and technology development that benefits Canadians. More information is available at www.innovation.ca.

Bruce Power and PWU offer apprenticeship scholarships

Bruce Power has teamed with Power Workers' Union Training Inc. (PWUTI) to offer scholarships and potential co-op work placements for up to 25 students in an apprenticeship program at Fanshawe College.

The Huron Shores Scholarships are worth $4,600 per student each semester and open to anyone enrolled in the January 2007 class of the Mechanical Technician (Millwright) apprenticeship program at the London, Ont. college.

Including wages paid during four-month work placements, it is estimated that the program represents roughly $750,000 commitment to help Ontario meet its growing need for skilled trades.

"As companies like Bruce Power continue to expand, it's vital that young people understand there are exciting, long-term opportunities within the trades," Duncan Hawthorne said. "I began my own career working on the tools as an apprentice, which gave me credibility as I took on various roles within the business. Acquiring a trade can open a lot of doors for students willing to work hard and learn a craft."

Through joint scholarships and co-operative training initiatives, Power Workers' Union President Don MacKinnon said labour, business, government and academia can work together to manage a shortage of skilled workers that is expected to grow significantly in Canada over the next 10 years.

CNSC gives SRB two-month extension

Following a two-day public hearing held on October 25 and November 27, 2006, the Canadian Nuclear Safety Commission (CNSC) announced its interim decision to extend the current operating licence of SRB Technologies (Canada) Inc.'s (SRBT), located in Pembroke, Ontario, by two months until January 31, 2007.

Following the proceedings, the Commission determined that additional time was needed to complete its deliberations before it could make a final decision on SRBT's application. As the current operating licence expires on November 30, 2006, the Commission decided to extend the licence for two months to ensure continued regulatory oversight of the facility. The operating restrictions contained in the Designated Officer Order issued on August 15, as amended by the Commission on August 30, 2006, will also continue to be in effect.

The Commission heard from CNSC staff, SRBT and an intervenor on Day One. On Day Two the Commission heard from 93 intervenors and received supplementary information from CNSC staff and SRBT. The Commission is now continuing its consideration of this matter. The Commission is of the opinion that the continued operation of the facility, under operating restrictions, will not pose an unreasonable risk to the environment, persons or security during the extended licence period.

SRBT uses tritium to manufacture illuminated emergency signs. Evidence of excessive levels of tritium in the groundwater on the plant property last summer led to CNSC staff imposing a "cease and desist" order. This was amended by the Commission to allow limited operation while the hearing above proceeded.

(See note in Vol. 27, No. 3, September 2006 issue of CNS Bulletin.)

AECL Annual Report on web

An electronic version of the 2006 Annual Report of Atomic Energy of Canada Limited (AECL), covering the fiscal year of April 2005 to March 2006, can be downloaded through AECL's website at www.aecl.ca. The report was officially released in September 2006.

Following are highlights of the report

- Revenue from Commercial Operations increased $19 million in 2005-2006, and net income was $47 million.
- Consolidated orders-on-hand at the end of 2005-2006 were $1,278 million (2004-2005: $190 million), reflecting two major refurbishment and retubing contracts awarded during the year.
- AECL invested $60 million in the ACR-1000 program in line with government funding support of $60 million in 2005-2006, consequently enabling the achievement of planned milestones.
- Entered a formal agreement with Babcock & Wilcox Canada, GE Canada, Hitachi Canada, and SNC-Lavalin Nuclear to create Team CANDU. Together, these five world-leading nuclear technology and engineering companies will present a turnkey service and competitive solution for building new nuclear power plants in Ontario.
- The Technology segment maintained a $39 million investment in support of the safety and performance of the CANDU fleet.
- Overall, AECL's cash position (including cash and cash equivalents, segregated cash and short-term investments) at March 31, 2006 increased to $111 million (compared to $67 million in 2004-2005), mainly due to cash generated from operating activities.
- AECL signed a new agreement with MDS Nordion, relating to the long-term supply of isotopes.

NB Power launches construction of International Power Line Construction

On November 28, 2006, NB Power officially launched the construction of the International Power Line with an event that took place in Lepreau, New Brunswick.

The 345 kV International Power Line will run 95 kilometres from the existing Point Lepreau terminal to the border of Maine. Its construction is a primary means to enhance the reliable and efficient operation of the transmission grid and improve market development.

The IPL Project commenced in April 2001 with applications to the National Energy Board and the New Brunswick Department of Environment to construct and operate the line. Since that date, the project has achieved significant milestones, including a detailed route hearing before the National Energy Board, receiving all Canadian and US regulatory approvals and the commencement of clearing of the right of way.

NB Power, which will construct the line using its own resources supplemented with third-party resources, has partnered with Bangor Hydro for the U.S portion of the project.

The line is scheduled to be in-service by December 2007, increasing New Brunswick's export capacity from 700MW to 1,000 MW and increasing import capacity from a conditional 100MW to 400MW.

CNSC Creats "New Reactor Licensing Division"

The Canadian Nuclear Safety Commission (CNSC) has created a new unit, the New Reactor Licensing Division (NRLD), effective November 24, 2006.

This is a result of two applications to prepare sites for the potential construction of new power reactors, from Bruce Power and Ontario Power Generation.

The new division will be the focal point for the CNSC regulatory program for new power reactor licensing and will be accountable for leadership and management and will be responsible for ensuring the horizontal coordination necessary to provide consistent delivery of the regulatory program.

It will also will provide program and project management and technical integration services, coordinate program planning, monitor and track program delivery, report and evaluate results and handle official correspondence with proponents and other stakeholders.

Intervenors Flock to CNSC Hearing in Port Hope

CNSC Commissioners listened to 128 oral submissions regarding the Cameco conversion plant and the Zircatec fuel manufcturing plant during a three-day hearing held in Port Hope, Ontario November 28 – 30, 2006.

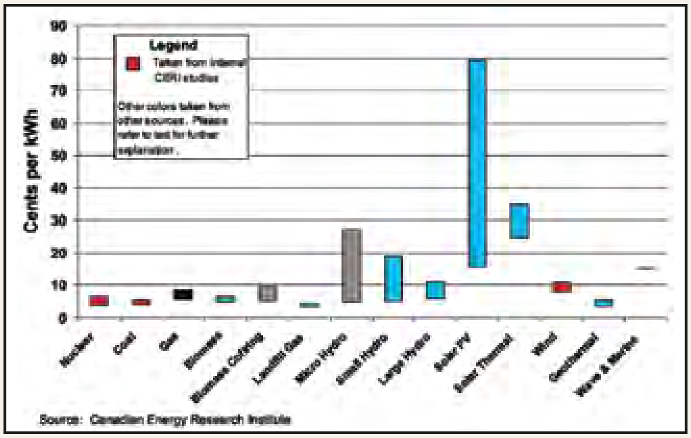
In addition there were 87 written submissions on Cameco and 79 for Zircatec. Reportedly, the presentations were mixed, with some being in favour of the renewal of licences for the two plants.

Emissions, of various kinds, and fire-fighting, were the two top topics regarding the Cameco conversion plants. A group called Families Against Radiation Exposure (FARE) (See article in Vol. 27, No. 3, September 2006, issue of the CNS Bulletin) was not satisfied that emissions of uranium had declined, rew-questing that they be zero.

Cost of Generating Electricity

The Canadian Nuclear Association has put the summary graph comparing the cost of generating electricity by various means, as evaluated by the Canadian Energy Research Institute, on its web-site, www.cna.ca, for downloading. It is reproduced below.

Relative Costs of Electricity Generation Technologies
(2003 Canadian cents per kilowatt-hour)



CNS Membership Renewal Time

Time to renew your CNS membership for 2007! By the time you read this, you will probably have already received your CNS membership-renewal form. And you certainly don't want your membership to lapse! If you have not yet returned your renewal form, please take a moment to do it now. If for any reason you have not received a renewal form, you can simply copy one from the CNS website at www.cns-snc.ca.

Thank you!

Note: Your individual CNS ID number is shown on your renewal form, and it also appears on the CNS membership card which you receive every year. Keep your card and ID number handy – it is proof of your membership, and you are asked for it when you register to a CNS Conference or Course!

Ben Rouben
Chair, Membership Committee

Renouvellement d'adhésion à la SNC

C'est le moment de renouveler votre adhésion à la SNC pour 2007 ! Quand vous lirez ceci, vous aurez sans doute déjà reçu votre formulaire de renouvellement. Et vous n'aimeriez certainement pas perdre les bénéfices de votre adhésion ! Si vous n'avez pas encore renvoyé votre formulaire, veuillez prendre un petit moment pour le faire tout de suite. Si par hasard vous n'avez pas reçu de formulaire de renouvellement, vous pouvez en copier un du site web de la SNC, à www.cns-snc.ca.

Merci bien !

Ben Rouben
président du comité d'adhésion

N.B.: Votre numéro de membre de la SNC appara"t sur votre formulaire de renouvellement, ainsi que sur votre carte de membre, que vous recevez chaque année. Veuillez garder votre carte et votre numéro de membre à portée de la main – c'est votre preuve d'adhésion, et on vous le demande quand vous vous inscrivez à une conférence ou à un cours de la SNC !

CNS news

CNS at PBNC 2006

Canadian Nuclear Society president, Dan Meneley, represented the society at the 15th Pacific Basin Nuclear Conference (PBNC 2006) held in Sydney, Australia, 16 – 20 October 2006 (largely at his own expense). He also attended the meeting of the Pacific Nuclear Council (the authorizing organization for the PBNC series of conferences), of which the CNS is a member, held on October 15, immediately prior to PBNC 2006.

He presented his own paper *"Preserving Technical Knowledge – when Technology Lifetime Exceeds the Human Life Span"* and one on behalf of George Bereznai of the University of Ontario Institute for Technology, *"Nuclear Undergraduate Programs at the University of Ontario Institute of Technology"* (which is reprinted in this issue of the CNS Bulletin).

Other members of the CNS at PBNC 2006 included: Jerry Cuttler (who organized a session on "Effects of Low Doses of Radiation"); Romney Duffey; Paul Fehrenbach; Miklos Garamszeghy; Ian Hastings; Jerry Hopwood; Derek Lister; Ron Mitchell, Fred Boyd.

CNS meets science teachers

Largely through the efforts of Bryan White, co-chair of the CNS Education and Communication Committee the society was represented at a meeting of the Science and Technology Awareness Network (STAN) and had a display at the conference of the Science Teachers Association of Ontario (STAO), both held in November 2006. Following is his report.

The CNS Education and Communication Committee (ECC) received special project funding from CNS Council to participate in the Science and Technology Awareness Network (STAN) annual meeting in Ottawa on November 10th, and to sponsor an exhibit booth at the Science Teachers' Association of Ontario (STAO) Annual Conference in Toronto held November 16-18.

Fred Boyd attended the STAN meeting, and Bryan White lead the team who volunteered to staff the CNS booth at STAO 2006. STAN is an association of associations. The one-day STAN meeting discussed the challenges of raising awareness of the importance of science and technology among politicians, business people, the general public, and, especially, young people.

The CNS stand at STAO, November 16.
(Left to Right): Tracy Gagne, Bob Walker, Peter Lang, Ginni Cheema

The CNS booth space at STAO was shared with Visions of Science and the Deep River Science Academy. Francis Jeffers of VoS and Dale Torgerson of the DRSA were both pleased with the interest they received.

Over the 2-1/2 days the CNS booth was staffed by Tracy Gagne (AECL, WiN Canada, PWU), Peter Lang, Bob Walker (OPG, PWU), Constantin Banica (OPG), and a contingent from Candesco: Ginni Cheema, Evan Houldin, and Julie West.

The CNS booth offered the science teachers information on the nuclear industry provided by AECL, the PWU, and the CNA. The booth featured a simple demonstration of monitoring background radiation using an Aware Electronics RM-80 Geiger detector interfaced to a laptop computer running the Aware RADW software. The teachers were shown that with this system a weak radiation source, such as a container of *NoSalt*® – KCl, about 4.8 kBq of K-40 that one may purchase in most grocery stores – can be used to demonstrate gamma and beta radiation in just a few minutes. The system was also shown to be able to detect the 60 keV gamma from the Am-241 source in a household smoke detector. Many teachers expressed interest in obtaining such a system for their schools and they were encouraged to contact the nearest CNS Branch to request assistance.

Over 150 teachers took the time to enter the draw to win one of six CNS sweatshirts, one of six copies of *Canada Enters the Nuclear Age,* and/or the Grand Prize – the Aware RM-80 Geiger system (excluding the laptop computer). Shoba Thomas of Lester B. Pearson Secondary School in Burlington won the Geiger system.

The entries included teachers from schools as far east as

MontrÈal, as far west as Kenora, and as far north as Moose Factory. The information gleaned from the entry forms and discussions with teachers is being assessed to advise CNS Council of the effectiveness of this exhibit.

The CNS "fact sheets" that were available for the teachers may be downloaded from the "Education" page of the CNS web site (near the bottom).

Following is the status of other activities being pursued by the ECC.

World Nuclear University Bursary

The application for the 2007 CNS Bursary for attending WNU in 2007 is available on the CNS web site.

CNS Undergraduate Scholarship

Dr. David Novog of McMaster University will administer the CNS Undergraduate scholarship program in 2007. The application information is posted on the CNS web site. The submission deadline has been changed to February 28, 2007.

CNS Speakers' Bureau approved

CNS Council has approved a proposal from Elizabeth Muckle-Jeffs of "The Professional Edge" (www.theprofessionaledge.com) to develop and administer a CNS Speakers' Bureau. One of the first activities in implementing this proposal is to establish a small panel of CNS members who will perform the following three general duties:

(1) Agree on a set of criteria to be used to choose speakers from the list of volunteers. The proposal suggests that a "short list" be developed first, which would then be submitted to a professional communications consultant who would make the final assessment of the Phase 1 speakers.

(2) Review the data on volunteers and come up with the "short list". The data would include that obtained from a follow-up survey to be sent out by the consultant.

(3) Determine the "key messages" that the CNS would like to see represented in the material that speakers will present. The ECC would then ensure the incorporation of these key messages.

Jeremy Whitlock, co-chair of the Education and Communication Committee, who will chair the panel, reports he already has enough volunteers.

BRANCH NEWS

CHALK RIVER - Blair Bromley

Since the last branch update, the following events occurred:

- Gary Dyck, AECL, spoke on the GNEP program and how CANDU reactors might fit into it at branch seminar on October 26, 2006.
- The CNS Chalk River Branch held its AGM. Two new members have been added to the executive, Chris Canniff (AECL) – member-at-large, and Tracy Gagne (AECL) who is the Chalk River Chair of WIN, and who will be our liaison with WIN. We are looking to recruit a few more members-at-large, and a liaison for NA-YGN.
- The PEO/CNS-CRB organizing committee has met a couple of times to plan and assign tasks for the planned symposium on discussing the feasibility of a new NPP in Renfrew County. We are currently looking for speakers who can give presentations to cover the various topics of the symposium.
- Periodically we put up posters in the community to advertise the essay contest. Newspaper ads for the essay contest were also sent out to several newspapers throughout Renfrew County.
- Blair Bromley (Chair) met with Jennifer Layman, a marketing consultant hired through a Trillium Grant to help promote the Renfrew County Science Fair. The goal of her activities is to boost the participation by high school students in the RCSF, and also to raise funds to help support the initiative to eventually bring the Canada-Wide Science Fair to Renfrew County. Part of that activity is raise funds, and Jennifer has invited the Chalk River Branch of the CNS to be a sponsor. The level of sponsorship that we are considering is on the order of $1600 per year. With this sponsorship, the RCSF will help promote and advertise all CNS activities and events.

The Chalk River Branch is currently planning (or thinking about) the following activities for the November 2006 to May 2007 period:

- **Two more seminars are planned for the fall of 2006, including:**
  1. David Mosey, New Brunswick, will speak on Reactor Accidents on November 23, 2006..
  2. Professor Jan Veizer (U of Ottawa), will speak on Global Warming, on December 8, 2006.
- **Four or five seminars are tentatively planned for the first half of 2007, including:**
  1. Jintong Li, AECL, will speak about China's nuclear program in January.
  2. Dan Meneley, CNS President, will give guest lecture at annual CNS-CRB dinner meeting in mid-February (before the CNA seminar).
  3. Barclay Howden (CNSC) will give a talk in late April, 2007.
  4. Madiba Saidy (AECL) will give a talk in April or early May, 2007.
  5. Colin Allan (INPRO) will give a talk in May or June of 2007.

- **Establish a Nuclear Science and Technology prize for the Renfrew County Science Fair.**
  - Perhaps two $100 prizes for the best two science projects illustrating directly or indirectly an application of nuclear science and technology.
- **Establish a scholastic award for graduating high school students in Renfrew County.**

- Perhaps two $100 prizes for the students with highest combined grades in senior physics, senior chemistry, and two senior math classes. There are up to 9 high schools, so this could be an investment of $1800. We might target just two schools this year for $400.

- **Set up a poster contest for grade school students (Grades 7/8) – due date in late April.**
  - Perhaps four prizes ($100, $80, $60, $40), and up to 10 grade schools will be targeted. We will be looking for the best poster that illustrates an application of nuclear science and technology.

As mentioned in the previous updates, a major initiative underway is to set-up and co-sponsor a one-day symposium in Renfrew County with municipal government representatives, local employers, and community members to discuss the viability of building a new nuclear power plant in Renfrew County. The target date is less certain now, due to various delays, but in should be in early 2007, perhaps late February or late March. **We will be looking to recruit speakers, so help from the CNS membership would be appreciated.** Letters were sent out to prospective guests by the end of September. We're waiting for feedback, and our sub-committees are working on organizing the event.

Many thanks are expressed to members Uditha Senaratne, Ragnar Dworschak, Morgan Brown, Marcel Heming, Jintong Li, Bryan White, and Jeremy Whitlock for their efforts.

GOLDEN HORSESHOE – Dave Novog

We have agreement from Kevin Routledge - CEO NSS and Project Manager for the Bruce 1 and 2 consortium to come down and give a seminar on refurbishment issues and opportunities.

MANITOBA – Jason Martino

After receiving funds from CNS the Branch forwarded a contribution to the Deep River Science Academy, Whiteshell Campus for the amount of $500.

NEW BRUNSWICK - Mark McIntyre

Dr. David Mosey, formerly of Ontario Hydro and author of the book "Reactor Accidents" spoke to the New Brunswick Branch in Saint John on November 2, 2006 on the topic of "Institutional Failure."

David defined the term Institutional Failure and illustrated it extensively with reference to the most egregious examples in the last 30 years. Those failures being: Three Mile Island, *Herald of Free Enterprise* ferry - Britain's greatest peacetime maritime loss since the *Titanic,* the space shuttle *Challenger,* major railway accidents, in England each claiming more than thirty dead and the *Hinton* collision in Canada, the *Piper Alpha* drilling rig, Chernobyl, Columbia, the Toki-mura (Japan) criticality accident and the Mihama (Japan) condensate pipe failure.

David brought the whole thing home to the CANDU audience by reviewing the Pickering Unit 2 Pressure Tube G-16 Failure of August 1983; the small LOCA of December 10, 1994 when Unit 2 at Pickering experienced a liquid relief valve on the primary heat transport system fail open while the reactor was at 100 percent full power; and the March 1993 incident when Bruce A and Bruce B reactors were at once derated to 60 percent full power when it was discovered that in the Bruce A, Bruce B and Darlington reactors an inlet header failure could cause *en masse* movement of fuel which would give rise to a significant reactivity addition.

David identified four problem areas that promoted these examples of institutional failure: Misperception of hazard, controlling the production imperative, safety responsibility and authority, and operating experience: unrecognized, misunderstood or ignored.

He then finished the presentation by presenting these six barriers to institutional failure: establishing a positive safety culture, recording decisions and their rationales, tracking processes, maintain integrity of information flow, alternate communication paths, and management health.

CNS New Brunswick recommends that CNS members consider purchasing David's updated book "Reactor Accidents" published by Nuclear Engineering International.

OTTAWA – Jim Harvie

On October 12, 2006, the Ottawa Branch held a successful meeting, at which Ian Grant, Director General of Power Reactor Regulation at the Canadian Nuclear Safety Commission, spoke about "Current Developments in Canadian Nuclear Safety Regulation".

On November 24th a meeting was held over lunch, with David Mosey addressing "The Role of Institutional Failure in Reactor Accidents". *(See NB report above.)*

QUEBEC – Michel Rheaume

The CNS Quebec Branch has prepared and presented before the CNSC at Becancour, a brief supporting the Hydro-Quebec Project : Enlargement of Nuclear Waste Facilities and Refurbishment of Gentilly-2 NGS. Public Hearings (on the Screening Report) were held on November 8 and 9, 2006 at which Dr. Elisabeth Varin presented the brief prepared by a team composed by: M. Jaroslav Franta, M. Michel St-Denis, M. Gilles Sabourin and Dr. Varin.

You can read this brief on the CNS Quebec Branch Web Site Section.

SASKATCHEWAN – Walter Keyes

Consideration is being given to some possible education project involving kids from schools in Saskatchewan investigating the operations of a uranium refinery. Other than that, our branch is pretty dormant.

SHERIDAN PARK – Adriaan Buijs

The Sheridan Park branch organized a seminar at the U of T together with the Toronto Branch and the Sigma-Xi society on November 2nd. The seminar was entitled "The Chernobyl Accident, 20 Years Later", and given by Dr. Burton Bennett, the chairman of the Chernobyl Forum, a UN sponsored forum, which had recently brought out a report on the health effects of the Chernobyl accident in 1986. The seminar was very interesting and well attended.

TORONTO BRANCH – Nima Safaian

On September 28th the Toronto Branch held a meeting at the former OPG HQ with about 50 people attending at which David Mosey spoke on the topic: The Role of Institutional Failure in Nuclear Accidents. (See NB report above.)

UOIT Branch – Nafisah Khan

The CNS Branch at UOIT has a new executive.

Chairperson:	Nafisah Khan
Vice-Chair:	Kelvin Auyeung
Secretary:	Ruth MacLeod
Treasurer:	Mohamed El-Mansi

A Students Seminar took place on October 5, 2006 featuring our Dean, Dr. George Bereznai as a guest a speaker, and Nuclear Engineering students who have worked in a co-operative or internship positions in the industry, shared their work experiences.

An extension to the present CNS-UOIT Branch website will be launched soon. This site will feature various information about our Branch.

COURSES

The CNS organizes courses on a number of topics.

The following two courses are being run back to back, both at the Hilton Garden Inn, Cambridge, Ontario.

January 29, 30, 2007
Chemistry of Preservation; Degradation and Activity Transport

Course Objectives

To present to those who have an interest in the design, operation, maintenance, manufacture and repair of CANDU power reactors, their systems and equipment:

- CANDU chemistry fundamentals
- Activity transport (new)
- Overview of plant systems
- Current chemistry practice and specifications for the major process systems, including:
  - Primary Heat Transport System, Auxiliaries
  - Moderator System and Auxiliaries
  - Steam, Feedwater and Condensate System
  - Service Water Systems

This course content was developed in February 2001 by people expert and active in the field and has been given in 2001, 2003 and 2005.

January 31, February 1, 2007
Eddy Current for Engineers

Course Objectives

The objective of this course is to introduce eddy current theory and practice to ECT non-specialists (all the rest of us) who will never be ECT experts but who need to understand the fundamentals of the method, what it can do, what it cannot do, the limits of its accuracy, the probability of detection and the methodologies of data analysis, resolution, presentation and storage.

This course has previously been given in 2003 and 2005.

For further information on the courses contact: Bill Schneider, tel. 519-621-2130 x 2269, e-mail: wgschneider@babcock.com.

To register contact Denise Rouben at the CNS office, tel. 416-977-7620, e-mail: cns-snc@on,aibn.com

Draw Winners

At CNS courses and conferences it has been the custom to hold a draw of returned name tags. Following are the winners at recent events.

2006 CNS Reactor Safety Course in Kincardine

At the end of the fall CNS CANDU Reactor Safety Course in Kincardine, on September 27, 2006, 7 prizes were awarded by random draw from among badges returned by Course attendees.

The winners:

- Adam Gavey and Dave Shaw, of Bruce Power, and Scott Gilchrist, of AECL, each won a CNS silk tie
- Anand Panditrao, of Bruce Power, won a CNS multitool
- Mike Diebel, of Bruce Power, won a book
- Sanjay Kalra and Ken Sedman, of Bruce Power, won a complimentary CNS membership, good to end of 2007.

2006 CNS CANDU Fuel Technology Course, in Mississauga

At the end of the fall CNS CANDU Fuel Technology Course in Mississauga, on November 17, 2006, 6 prizes were awarded by random draw from among badges returned by Course attendees.

The winners:

- Mahmoud Karam and Daniel Dai each won a CNS silk tie
- Claire Simister won a CNS sweatshirt
- Albert Sun, Ghulam Khawaja, and Stephen Livingstone each won a complimentary CNS membership, good to end of 2007.

By coincidence [the draw was not fixed:)], all winners are from AECL!

31^{st} ANNUAL CNS/CNA STUDENT CONFERENCE

St. John Hilton, St. John, New Brunswick

2007 June 03 – 06

CALL FOR PAPERS

Again this year, the 31^{st} Annual CNS/CNA Student Conference will be embedded within the 28^{th} Annual CNS Conference. As usual, there will be a Best Paper competition for the students with awards at each level (undergraduate, Master's degree and Ph.D. levels).

STUENDT CONFERENCE TOPICS

The topics acceptable for Annual CNS/CNA Student Conference include any subject related to nuclear engineering, nuclear science and nuclear medicine.

CHOICE OF PAPER CATEGORIES

Student participants have two choices for the category of their presentations: either a fully refereed paper or a student (not refereed) presentation. In the first option, the paper may have as co-authors the student's supervisor(s) and other researchers who are not themselves students. The submission must then be made directly to the organizers of the CNS Annual Conference and the rules of the Annual Conference should be followed, including the 01 December 2006 deadline for notice of intent to present a paper (cf. CNS web site www.cns-snc.ca). The papers submitted in the first category will be included in the regular sessions of the CNS Annual Conference. Papers submitted for the student conference must be authored or co-authored by students only. To be considered as students, participants must be registered in a nuclear science or engineering program at a post secondary teaching institution at the time they submit their abstracts. Please indicate the level of the paper (Undergraduate, Master's or Ph.D.) and the names of the supervisor(s) and send the notification and short abstract by email to either:

Professor D. H. Lister dlister@unb.ca or
Professor W. G. Cook wcook@unb.ca

Submission Deadlines:

Submission of a short abstract (100-150 words):
05 January 2007

Notification of acceptance:
23 February 2007

Submission of conference papers:
06 April 2007

AWARDS FOR BEST PRESENTATIONS

Student presentations (non-refereed) will be assessed on the basis of technical and communicative merit by a committee of industry and academic representatives. Best papers awards will be given at each of the three levels Undergraduate, Master's and Ph.D. The exact nature of the awards will depend on the resources available at the Conference.

FINANCIAL ASSISTANCE

It is important that as many students as possible participate in the conference. For students presenting non-refereed papers within the Student Conference, conference registration fees will be waived and accommodation will be provided by the Conference. It is planned that a significant portion of the travel costs will be covered by the Conference and/or refunded to the student participants. Students who are not presenting papers at the Student Conference may register at the CNS Annual Conference at reduced rates.

28th Annual Conference of the Canadian Nuclear Society and 31st Annual CNS/CNA Student Conference

"Embracing the Future: Canada's Nuclear Renewal and Growth"

"Saisissons l'avenir: Renouvellement et croissance du nucléaire au Canada"

2007 June 03-06
Saint John Hilton, Saint John, New Brunswick, Canada

Call for Technical Papers

The Canadian Nuclear Society's 28th Annual Conference will be held in Saint John, New Brunswick, Canada, 2007 June 03-06, at the Saint John Hilton.

The central objective of this conference is to provide a forum for exchange of views, ideas and information relating to application and advancement of nuclear science and technology, and energy-related issues in general.

- Invited speakers in Plenary sessions will address broad industrial and commercial developments in the field.
- University students in Student sessions will talk about their research and academic work.
- Speakers in ***technical sessions*** will present papers on industrial, research and other work in support of nuclear energy.

Conference Website:
http://www.cns-snc.ca/conf2007.html

Deadlines

- **Receipt of Abstracts: 2006 December 01.****
- **Receipt of full papers: 2007 March 01.**
- **Notification of accepted paper: 2007 April 01.**

(** Abstracts will be considered after this date until the quota for the conference is filled.)

Paper abstracts (<100 words) should be submitted to the Conference Website. Please note that the abstract submission represents the author's commitment to submit a full paper on or before 2007 March 01 and, if the paper is accepted by the Conference Paper Review Committee, to present it at the Conference.

Guidelines for Full Papers

Papers should present facts that are new and significant, or represent a state-of-the-art review. They should include enough information for a clear presentation of the topic. Usually this can be achieved in 8-12 pages, including figures and tables. The use of 12-point Times New Roman font is preferred. Proper reference should be made to all closely related published information. The name(s), affiliation(s), and contact information of the author(s) should appear below the title of the paper.

NOTE

For a paper to appear in the Conference Proceedings, at least one of the authors must register for the Conference by the "early" registration date (2007 April 15).

Paper Submission Procedure

The required format of submission is electronic (Word 2000). Submissions should be made through the Conference Website by 2007 March 01.

Questions regarding papers and the technical program should be sent to:

V.S. (Krish) Krishnan
CNS 2007 Technical Committee Chair
e-mail: cns2007@aecl.ca
Tel: 905-823-9060, Ext. 4555

General questions regarding the Conference may be addressed to:

Denise Rouben, CNS Office Manager
e-mail: cns-snc@on.aibn.com
Tel: 416-977-7620

It's A Wonderful Half-Life

by Jeremy Whitlock

True to Canadian form, the major nuclear achievements of this country are about as familiar to its citizenry as the name of its second Prime Minister (or third, or fourth, or fifth...).

Of course everyone knows that we're famous for inventing the heavy-water reactor, even if that's not quite true. Almost as many know of our traditional status as a nuclear weapons-free country. Also untrue.

A good number of other things are quite demonstrably true, however, so in the spirit of stimulated nationalism that has held this country together for almost 140 years, the Special Patriotic Subcommittee of the Society for the Recognition of Nuclear Scientists and Engineers as a Nation Within a Unified Canada presents herein (after much debate) the "Top Ten Canadian Nuclear Achievements", in no particular order of importance:

1. ***Rutherford Was Here:*** Long before joining the exalted ranks at the Cavendish, Lord Rutherford first proposed the concept of radioactivity, and coined the term "half-life", during nine prolific years at McGill University. This earned Rutherford a well-deserved Nobel Prize in 1908, albeit one that is seldom associated with Canada since he had departed these shores a year beforehand.
2. ***First Graphite Nuclear Pile:*** Before the Manhattan Project and Fermi, there was Laurence. Starting in 1940, PEI-born George C. Laurence, while heading the National Research Council's radiation laboratory, built a 10-tonne graphite nuclear reactor in his spare time, under high security at the Sussex Drive laboratories in Ottawa. Although failing to achieve a self-sustained chain reaction, it was a world first and a precursor of Canada's major wartime role to follow.
3. ***First Nuclear Reactor Outside the U.S.:*** By the end of World War II Canada hosted the world's second-largest nuclear infrastructure, including the only operating reactor outside the U.S. Designed, built, and commissioned in less than a year at Chalk River, ZEEP was a low-power heavy-water reactor initially intended to test the instrumentation, materials, and physics of the behemoth NRX reactor under construction next door. It gracefully retired in 1970 and is currently displayed at the Science and Technology Museum in Ottawa.
4. ***First Large-Scale Research Reactor:*** When it started up in July 1947 NRX was the biggest, baddest research reactor on the planet. Designed by the NRC's wartime Montreal Laboratory, NRX surpassed all expectations and operated for the next 45 years. It made Chalk River the "Place to Be" for nuclear and solid-state physics for many years, and launched Canada's radioisotope industry. Among its achievements was John Robson's 1951 determination of the half-life of a free neutron (approximately 13 minutes: fortunately much longer than the fraction of a millisecond they last in a power reactor).
5. ***First Cobalt Cancer Therapy:*** In 1951 two parallel Canadian teams developed the world's first cobalt cancer "beam therapy" units. In October Roy Errington's team from Eldorado Mining and Refining treated the first patient in London, Ontario. Harold Johns' team followed less than two weeks later in Saskatchewan.
6. ***First Recovery from a Major Reactor Accident:*** The 1952 partial core rupture in NRX was a classic case of misfortune breeding opportunity. The post-mortem of the event spawned several new fundamental concepts in reactor safety, and made Canada a leader in the field. The reactor itself became the first to be totally refurbished and was restarted a remarkable 14 months later, with upgrades that allowed it to operate at higher power.
7. ***First On-Power Refuelling of a Large Reactor:*** Chalk River's NRU reactor regained the research-reactor limelight for Canada when it started up in 1957. Among its engineering distinctions was the first on-power refuelling of a large reactor, using a double-barreled flask that conceptually finds itself in the fuelling machines of CANDU reactors today. NRU continues to serve science and industry as it approaches its 50th birthday.
8. ***First Nuclear-Weapons-Capable Country to Renounce the Capability:*** At the close of WWII Canada was one of three countries on the planet with atomic weapons capability, but (unlike Britain and the U.S.) the only one to pass in favour of peaceful applications alone. Canada's leadership in global non-proliferation included a significant role in the formation of the UN's global watchdog, the International Atomic Energy Agency (IAEA).
9. ***First Computer Control of a Power Reactor:*** Solid-state electronic computing was only four years old in 1962 when the unprecedented decision was made to include limited digital control in the design of the Douglas Point CANDU prototype. The bar was raised again when the Pickering station became the first in the world to be totally controlled by a digital computer.
10. ***Multiple "Firsts" in Particle-Beam Physics:*** From Brockhouse's Nobel-winning Triple-Axis Neutron Spectrometer in the mid-1950s, to Bigham et al's Superconducting Cyclotron in the mid-1980s, Chalk River blazed a trail of ingenuity in the science of subatomic particles. That trail includes the world's first "Tandem" accelerator in the 1950s, and a cornucopia of custom instrumentation which set the standard ñ including the first lithium-drifted germanium detectors (for many years the workhorse of gamma spectrometry), developed by Ewan and Tavendale at Chalk River in the 1960s.

2007

Jan. 29 - 30 **Course: Chemistry of Preservation, Degradation and Activity Transport**
Cambridge, Ontario
website: www.cns-snc.ca

Jan. 31 - Feb. 1 **Course: Eddy Current for Engineers**
Cambridge, Ontaro
website: www.cns.snc.ca

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

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

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

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

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

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

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

CANADIAN NUCLEAR ACHIEVEMENT AWARDS
CALL FOR 2007 NOMINATIONS

The Canadian Nuclear Society and the Canadian Nuclear Association jointly announce a call for nominations for the Canadian Nuclear Achievement Awards for 2007.

A brochure, giving details of the awards and the procedure for nominations, is enclosed with this issue of the CNS Bulletin and can also be downloaded from the CNS website: www.cns-snc.ca

Although the deadline for all nominations is 2007 March 1, CNS members and others associated with the Canadian nuclear program are urged to consider colleagues who deserve to be recognized.

The Honours and Awards are in the following categories:

- W. B. LEWIS AWARD
- IAN MACRAE AWARD
- FELLOWS OF THE CANADIAN NUCLEAR SOCIETY
- INNOVATIVE ACHIEVEMENT AWARD
- OUTSTANDING CONTRIBUTION AWARD (individual and organization categories)
- JOHN S. HEWITT TEAM ACHIEVEMENT AWARD
- EDUCATION/COMMUNICATION AWARD
- CNS PRESIDENT'S AWARD
- R.E. JERVIS Awards (two awards, each with a $1,000 bursary)

For early information contact the chair of the CNA / CNS Honours and Awards Committee, Bob Hemmings, at e-mail: michelineandbob@sympatico.ca

2006-2007 CNS Council • Conseil de la SNC

Executive / *Exécutif*

President / ***Président***	Dan Meneley 705-657-9453
e-mail	mmeneley@sympatico.ca
1st Vice-President / ***1ier Vice-Président***	Eric Williams 519-396-8844
e-mail	canoe.about@bmts.com
2nd Vice-President / ***2ième Vice-Président***	Bob Hemmings
e-mail	michelineandbob@sympatico.ca
Secretary / ***Secrétaire***	Prabhu Kundurpi 416-292-2380
e-mail	kundurpi@sympatico.ca
Treasurer / ***Trésorier***	Jim Harvie 613-833-0552
e-mail	jdharvie@rogers.com
Past President / ***Président sortant***	John Luxat 905-525-9140
e-mail	luxatj@mcmaster.ca
Executive Administrator / Administrateur exécutif	Ben Rouben 905-823-9060 x4550
e-mail	roubenb@aecl.ca
Financial Administrator / Administrateur financier	Ken Smith 905-828-8216
e-mail	unecan@echo-on.net

Members-at-Large / *Membres sans portefeuille*

Neil Alexander 905-827-5323
Glenn Archinoff 905-761-7573
Charles Gordon 416-592-9059
Ed Hinchley 905-849-8987
Dave Jackson .905-525-9140
Krish Krishnan 905-823-9060
Prabhu Kundurpi 416-292-2380
Andrew Lee 905-270-8239
Kris Mohan 905-332-8067
Dorin Nichita .905-721-3211
Jad Popovic 905-823-9060
Ben Rouben 905-823-9060
Bill Schneider .519-621-2130
Roman Sejnoha. 905-822-7033
Ken Smith 905-828-8216
Murray Stewart 416-590-9917
Jeremy Whitlock. 613-584-8811
Syed Zaidi 506-849-8862

Committees / Comites

Branch Affairs / ***Affaires des sections locales***
Eric Williams. . . . . . . 519-396-8844 canoe.about@bmts.com

Education & Communication / ***Education et communication***
Bryan White . . . . . 613-584-4629 bwhite_cns@sympatico.ca
Jeremy Whitlock. . . 613-584-8811 whitlockj@aecl.ca

Finance / ***Finance***
Jim Harvie. . . . . 613-833-0552 jdharvie@rogers.com

Fusion / ***Fusion***
Bob Hemmings . . 613-342-2193 michelineandbob@sympatico.ca

Honours and Awards / ***Honneurs et prix***
Bob Hemmings. . . . . 613-342-2193 michelineandbob@sympatico.ca

International Liaison / ***Relations Internationales***
Kris Mohan . . . . 905-332-8067 mohank@sympatico.ca

Internet/
Morgan Brown . . . 613-584-8811 brownmj@aecl.ca

Inter-Society / ***Inter-sociétés***
Parviz Gulshani . . . . . . 905-569-8233 matla@vif.com

Membership / ***Adhesion***
Ben Rouben . . . . 905-823-9060 roubenb@aecl.ca

NA YGN
Brent Williams . . . . . 519-396-4461 brent.williams@brucepower.com

PAGSE
Fred Boyd. . . . . 613-592-2256 fboyd@sympatico.ca

Past Presidents / ***Presidents sortont***
John Luxat . . . . 905-525-9140 luxatj@mcmaster.ca

Program / ***Programme***
Dan Meneley . . . . . . 705-657-9453 mmeneley@sympatico.ca

Universities / ***Universites***
John Luxat . . . . 905-525-9140 luxatj@mcmaster.ca

CNS Division Chairs / *Presidents des divisions techniques de la SNC*

- Design & Materials / Conception et materiaux
  Prabhu Kundurpi 416-292-2380 kundurpi@sympatico.ca or kundurpip@acel.ca
- Fuel Technologies / Technologies du combustibles
  Joseph Lau 905- 823-9060 lauj@aecl.ca
  Erl Kohn 416-592-4603 erl.kohn@nuclearsafetysolutions.com
- Nuclear Operations / Exploitation nucleaire
  Peter Gowthorpe 905-689-7300 pgowthorpe@intech-intl.com
- Nuclear Science & Engineering / Science et genie nucleaire
  Dorin Nichita 905-721-3211 eleodor.nichita@uoit.ca
- Environment & Waste Management / Environnement et Gestion des dechets radioactifs
  Michael Stephens 613-584-8811 stephensmi@aecl.ca

CNA Liaison / *Agent de liaison d'ANC*

Colin Hunt (613) 237-3010 huntc@cna.ca

CNS Office / *Bureau d'ANC*

Denise Rouben (416) 977-7620 cns-snc@on.aibn.com

CNS Bulletin Editor / *Rédacteur du Bulletin SNC*

Fred Boyd (613) 592-2256 fboyd@sympatico.ca

2007 Conference Chair

Eric Williams (519) 396-8844 canoe.about@bmts.com

CNS Branch Chairs • Présidents des sections locales de la SNC

2006

Bruce	John Krane	519-361-4286	john.krane@brucepower.com
Chalk River	Blair Bromley	613-584-8811	bromleyb@aecl.ca
Darlington	Jacques Plourde	905-623-6670	jacques.plourde@opg.com
Golden Horseshoe	Dave Novog	905-525-9140 ext 24904	novog@mcmaster.ca
Manitoba	Jason Martino	204-345-8625	martinoj@aecl.ca
New Brunswick	Mark McIntyre	506-659-7636	mmcintyre@ansl.ca
Ottawa	Jim Harvie	613-833-0552	jdharvie@rogers.com
Pickering	Marc Paiment	905-839-1151	marc.paiment@opg.com
Quebec	Michel Rhéaume	819-298-2943	rheaume.michel@hydro.qc.ca
Saskatchewan	Walter Keyes	306-536-6733	walter.keyes@sasktel.net
Sheridan Park	Adriaan Buijs	905-823-9060	buijsa@aecl.ca
Toronto	Nima Safaian	416-592-9939	nima.safaian@nuclearsafetysolutions.com
UOIT	Nafisah Khan	905-721-3211	nafisah.khan@mycampus.uoit.ca

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