CANADIAN NUCLEAR SOCIETY

bulletin

DE LA SOCIÉTÉ NUCLÉAIRE CANADIENNE

October 2001 Octobre

Vol. 22, No. 3

- Annual Conference
- Regulatory Directions
- Nuclear, Hydrogen and Climate Change
- Next Generation CANDU
- McArthur River Mine
- Student Award-winning Papers

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Cover Illustration

The cover photograph is a different view of the Centrale nucléaire Gentilly 2 which emphasizes the environmentally benign characteristic of nuclear power.

(Photo courtesy of Atomic Energy of Canada Limited)

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ISSN 0714-7074

The *Bulletin of the Canadian Nuclear Society* is published four times a year by:

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Le Bulletin SNC *est l'organe d'information de la Société Nucléaire Canadienne.*

CNS provides Canadians interested in nuclear energy with a forum for technical discussion. For membership information, contact the CNS office, a member of the Council, or local branch executive. Membership fee is $65.00 annually, $40.00 to retirees, $20.00 to students.

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. La cotisation annuelle est de 65.00$, 40.00$ pour les retaités, et 20.00$ pour les étudiants.

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Printed by The Vincent Press Ltd., Peterborough, ON

Canada Post Publication Agreement #1722751

EDITORIAL

Challenging Times

The summer months since the last issue of the *CNS Bulletin* have seen a number of happenings and developments affecting the nuclear community. But these were all over-shadowed by the tragic events of September 11, which occurred while this issue was being put together.

Predictably, the terrorist attacks in the United States brought cries from nuclear critics about the vulnerability of nuclear power plants, with spectres of Chernobyl-type catastrophe. This only served to increase the public's apprehension and insecurity. The nuclear industry internationally was slow to respond, and domestically failed to say anything that would ameliorate the concern raised. Eventually, the United States Nuclear Regulatory Commission did issue a statement that gave some assurance, noting that nuclear plants had "robust containment buildings, and redundant safety systems" and were "among the most hardened structures in the country...designed to withstand hurricanes, tornadoes and earthquakes". Other nuclear organizations in that country and abroad made similar comment. In Canada neither our regulatory agency nor the industry said anything.

Obviously, there is no absolute safety with nuclear plants, or any other activity. However, more analysis of possible failures or impacts, more "what ifing", is conducted on nuclear facilities than for any other activity and the design of nuclear plants reflect that extensive precautionary approach. That fact should have been conveyed to the public. Until the Canadian nuclear industry begins to speak with a common voice the nuclear critics will rule the day and the public support for nuclear energy will remain low.

On a positive note it is gratifying to see the Canadian nuclear industry finally responding to the many warnings over the past few years about the declining state of nuclear education and the looming dearth of new graduates to replace the impending swarm of retirements. The scholarships being granted, the chairs being established, the support for the CANTEACH project, all will led to stronger nuclear engineering programs. Combined with more positive views of the future of nuclear power these initiatives should led to more young people being attracted to careers in nuclear science and technology. Nevertheless, that good news is mixed with some irony in the case of the creation of a Centre of Nuclear Engineering at the University of Toronto, the same university that dismantled its SLOWPOKE reactor just last year.

The nuclear community is always interesting.

Fred Boyd

IN THIS ISSUE

Once again we are later than scheduled, for a variety of reasons, and apologize to the organizers of meetings that are now past. But, to make up for it, we have a larger than usual issue.

Many of the papers and articles are drawn from the very successful and informative 22nd CNS Annual Conference held in June. An **Insert** has the winning papers from the 26th CNS / CNA Student Conference that, for the first time, was run in conjunction with the Annual Conference. Choosing from the excellent papers presented at the Annual Conference was difficult and was based on our judgement of broad and topical interest.

The issue begins with a report on the Conference in **22nd CNS Annual Conference,** followed by a list of the **Technical Papers** presented. Then follows two papers selected from the plenary sessions: **Emerging Directions in Regulation** by Linda Keen, president of the Canadian Nuclear Safety Commission, and, **The Next Generation CANDU,** by Jerry Hopwood and others from Atomic Energy of Canada Limited.

As a change of pace we have another photo story on **Servicing and Upgrading the RMC SLOWPOKE** by Dan Arscott, a young summer student involved with the project. Then follows two papers related to global warming and the role of nuclear: **Climate Change - the science,** a reprint of a paper by Henry Hengeveld of Environment Canada, and **Hydrogen Production, Nuclear Energy and Climate Change** by Romney Duffey and Tabitha Poehnell of AECL, one of the many excellent papers in the technical sessions of the CNS Annual Conference. Another selection from the technical papers is **Investigation of Tritium in the Groundwater at Pickering NGS** by John DeWilde of Ontario Power Generation and others.

Turning to the important sector of uranium mining, there is an overview of the **McArthur River Uranium Mine** and its many mining challenges by Martin Quick of Cameco Inc. Rounding out the section of papers and reports is a note on Norman Gentner in **A Canadian at UNSCEAR.**

There follows our usual short package of **General News** with an eclectic selection of items that we hope may be of interest. Indicative of the ageing of our nuclear program there are two more **Obituaries,** for Doug Andrews and Larry Sewchuck.

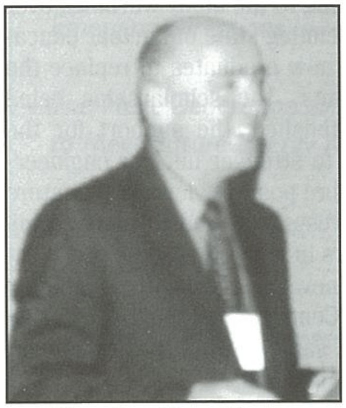
CNS News includes a note on the CNS Annual General Meeting, Awards, and some other related items.

Finally, there is a note on some new publications, the always interesting **Endpoint** commentary by Jeremy Whitlock, an updated **Calendar**, and, on the inside back cover, a new listing of the 2001 -2002 CNS Council.

We hope you find something of interest and invite your comments, input and submissions.

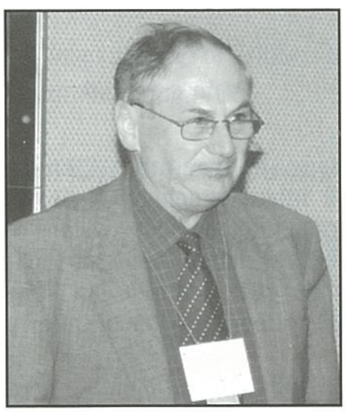
CNS Annual Conference
– excellent organization reflected in upbeat mood

Close to 300 participants attended the 2001 CNS Annual Conference held June 3 to 6 at the Delta Chelsea Hotel in downtown Toronto. The generally upbeat mood and active participation of the attendees matched the chosen theme of "Excellence in the New Millennium".



Douglas Hawethorne

This was the 22nd CNS Annual conference but just the second organized completely by the Society. For 20 years the CNS joined, as a junior partner, with the Canadian Nuclear Association in holding the annual Canadian nuclear gathering. The success of this Conference demonstrated once again the ability and dedication of the volunteer organizers of the Canadian Nuclear Society.



Peter Wigfull

An innovation this year was the inclusion of the 26th CNS Student Conference, which was held on the Sunday. This arrangement proved to be successful with more papers presented and a larger audience. *(The winning papers are included as a special section of this issue of the* CNS Bulletin.*)*

Paul Spekkens

Following the all day student session, the Conference officially opened with a reception on the Sunday evening, June 3. This was a more modest event than in past years but proved a pleasant time for attendees to meet, share stories and prepare for the coming days.

The Conference began on the Monday morning with a Plenary Session on *"Nuclear Power - Current Status and Future Opportunities"*. **Gary Kugler,** vice-president at Atomic Energy of Canada Limited opened the session with a very appropriate paper entitled *"Charting AECL's Future at Home and Abroad"*. AECL, he said, was well positioned to benefit from the renewed interest in nuclear power. In the short term the company will focus on helping CANDU owners extend the lives of their plants. For the longer term AECL is working on the design of a new generation of CANDU, termed CANDU NG. This design will be physically smaller, much less capital intensive and quicker to build, than the current CANDU 6.

The presentation by **Douglas Hawthorne,** recently appointed CEO of Bruce Power, was titled *"Perspective of the Newest Nuclear Plant Operator in Canada"*. He described briefly, with the aid of photographs, the Bruce stations his company had leased from Ontario Power Generation, and noted that Bruce unit 5 had a 91.5% capacity factor last year. He referred to the experience of his parent company, British Energy in the UK, where nuclear is competing successfully against gas and coal. Studies are underway, he reported, for the re-start of two units of the Bruce A station in 2003. In fact, he noted, his company's commercial case is based on these units restarting. The challenge of the coming deregulated electricity market can be met, he stated in closing.

Michel Ross, of Hydro Quebec, in his presentation, *"Gentilly 2 Refurbishment Pre-Project"*, referred to the several studies that had been conducted over the past few years on ageing associated with the Gentilly 2 station. HQ is now in the "pre-project" phase of an analysis to determine whether or not to conduct a significant refurbishment to extend the life of Gentilly 2. A report and recommendation is scheduled to go to the Board of Hydro Quebec in mid 2003.

NB Power vice-president **Rod White** gave a similar paper on, *"Possible Refurbishment of Point Lepreau"*. Well underway is "Phase 1" of a project to produce a business case for the refurbishment of the Point Lepreau station to enable it to run for another 25 to 30 years. A decision will be made in mid 2002.He commented that there is a need for a stable, defined regulatory environment. *(A pre-conference version of his paper was printed in the previous issue of the* CNS Bulletin, Vol. 22, No. 2.*)*

President and CEO of the Canadian Nuclear Safety Commission, **Linda Keen,** spoke on, *"Emerging Directions in Regulation"*. Noting that she had been in her position for less than half a year, she stated her three goals for the organization: to become one of the best nuclear regulators in the world; to ensure the highest level of openness and transparency for all stakeholders; and, to become a preferred career choice for the best and brightest. These goals, she stated, cannot be achieved by the CNSC alone; they must be pursued in tandem with the industry and other stakeholders. *(A slightly edited version of Ms. Keen's address is included in this issue of the* CNS Bulletin.*)*

Rounding out the first plenary session **Gene Preston,** executive vice-president and chief nuclear officer of Ontario Power Generation, titled his address *"Current Status and Future Direction for Nuclear at Ontario Power Generation"* but actually ranged well beyond that scope. He did note that their performance index now stood at 84% but plants in the USA were now at 90%. The first day of hearings before the Canadian Nuclear Safety Commission on the re-start of Pickering A would take place June 28. He then turned to the international scene. The International Energy Agency, he commented, predicts a 60% increase in the world-wide demand for electricity in the next two decades and that 90% of that will be generated by fossil fuels, mostly coal. That raises questions about climate change and air quality. "Nuclear is essential for clean air", he stated in closing.

The first of two conference lunches featured **Jack Brons** of the Nuclear Energy Institute in the USA as guest speaker. Nuclear provides just 22% of the electricity in the USA but the total nuclear generation is greater than that of France and Japan combined. Referring to the energy plan announced by US vice-president Chaney in May he commented that there were six bills before Congress supporting nuclear in various ways. He predicted that there would be 20,000 MW of new nuclear generation in the USA by 2020.

Two more plenary sessions were held, Tuesday afternoon and Wednesday morning. On each of Monday afternoon, Tuesday morning and Wednesday afternoon there were five parallel sessions of technical papers. *(See a list of papers elsewhere in this issue.)* At Tuesday noon hour a special "development seminar" was held, aimed at nuclear professionals under the age of 35. This was organized and chaired by **Mark McIntyre** of the Young Generation Network. *(See a separate account in "CNS News".)*

The first speaker of the second plenary session, which was titled *"Nuclear Industry Update: New Directions and Initiatives"*, was **Ioan Rotaru** of Nuclearelectrica, Romania, whose paper was title, *"CANDU Technology: Benefits and Perspectives in Romania"*. He gave a review of the Cernavoda project and the operating experience with Unit 1. Further nuclear development is necessary in his country, he opined.

Prof. Cai Jianping, of the Shanghai Nuclear Engineering Research and Design Institute, spoke about his institute and China's indigenous 300 MW nuclear power plant design.

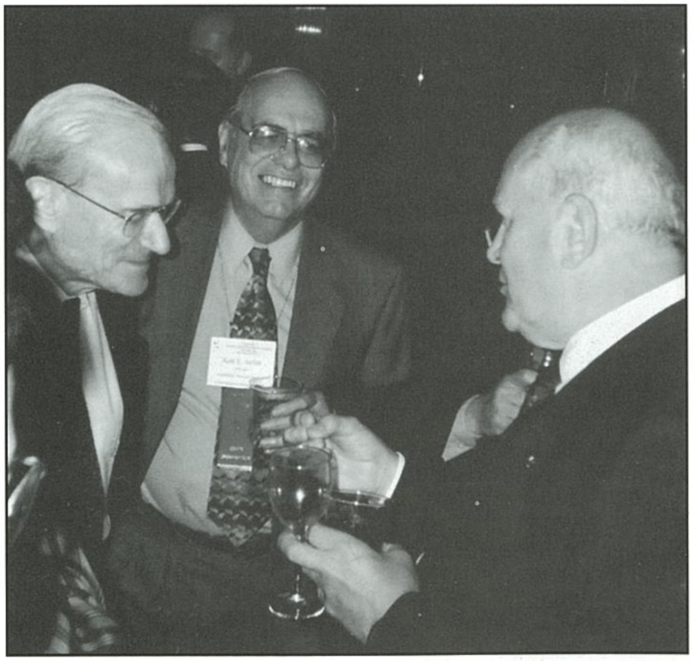
Turning to uranium, **Martin Quick,** vice-president, mining, Cameco Corporation, gave an update on the McArthur River Mine. That mine is based on the world's largest, highest grade, uranium deposit. There are proven reserves of 355 million tonnes with an average grade of 21% U_3O_8 and probable reserves of a further 39 million tonnes at a grade of 23%. Production in 2000 was about 11 million pounds U_3O_8. Special non-entry mining techniques had to be developed to cope with the radiation problems of the high grade ore. Raise boring has been used to date. The mined ore is trucked 80 km. to the previously existing mill at Key Lake. *(See paper in this issue.)*

Dan Whelan, director general at Natural Resources Canada, outlined developments at the federal level related to nuclear. The Nuclear Fuel Waste Act had received second reading and referred to committee. He placed considerable emphasis on public acceptance noting that in considering nuclear matters government leaders are strongly influenced by their perception of public attitudes.

"Nuclear Waste Management" was the subject of the presentation by **Ken Nash,** vice-president at Ontario Power Generation. OPG supports Bill C-27 (the proposed Nuclear Fuel Waste Act) he said and were preparing for its passage.

Bill Clarke, president and CEO of the Canadian Nuclear Association, provided an update on CNA activities. The Association conducted studies and polls over the past several months on public attitudes towards nuclear power and is planning a major information campaign for later this year.

Tuesday evening featured the conference banquet with entertainment by the Ken Edge jazz band and impersonators Barry Moyle and Marilyn.



Frank Stern, Ken Smith, and Dan Meneley discuss a deep technical question during the reception for the CNS Annual Conference June 10, 2001.

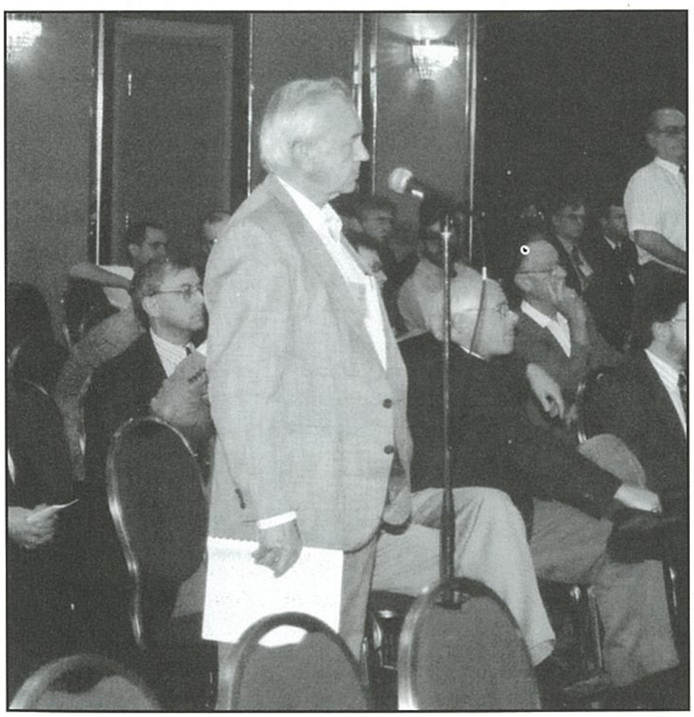
The plenary sessions continued Wednesday morning on the topic *"Maintaining Vital Capability in the Canadian Nuclear Industry"*.

Leading off was **Mohan Mathur** of Ontario Power Generation who presented a paper on behalf of **Pierre Charlebois,** which was focussed on the subject of the session, from the viewpoint of OPG. As the design authority for its stations OPG must maintain the skills to meet its needs or to oversee contract work. OPG is pursuing succession planning, has an active hiring campaign, and is cooperating with other utilities.

Dan Meneley, senior adviser at Atomic Energy of Canada Limited, spoke on *"Education and Training - Back to Basics"*. The current shortages in some professional and technical categories are, he said, a natural consequence of the age of the nuclear industry and present economic and social conditions. Stating that it is a problem that can be managed, he outlined some of programs AECL was pursuing to deal with the challenge.

Another view of education was presented by **Prof. William Garland** of McMaster University in his paper, *"The Role of the Universities and CANTEACH in Succession Planning"*. Student enrolment in nuclear engineering has been declining, he noted, and some universities have closed their programs. Yet, there are signs of a resurgence of the industry leading to the need for new graduates. The CANTEACH program, initiated by the Canadian Nuclear Society and Atomic Energy of Canada Limited, is an attempt to capture the existing teaching material.

Peter Wigfull, a director at the Canadian Nuclear Safety Commission, spoke about the *"Regulator's Perspective"*.



Ken Sedula asks a question during one of the plenary sessions of the CNS Annual Conference, June 2001.

The CNSC has also had problems recruiting staff, he noted. To help overcome that problem it has put in place an internship program which this year has eight new graduates. The CNSC had placed the maintenance of capability high on its regulatory agenda and will be monitoring the industry closely, he said.

Rounding out that session **Bob Menard,** of the Power Workers Union, reported that many of their 15,000 members were nearing retirement. With little support for technical or trades programs in schools there will be shortages of qualified technologists and trades persons, he predicted.

When session chairman and moderator **Pat Tighe,** president of COG, opened the session for questions a vigorous discussion ensued, much of it on the issue of education and training.

An additional plenary session with just two papers was held, after a short break, on the topic *"Looking to the Future"*.

The first paper was presented by **Jerry Hopwood,** of AECL, who spoke on *"The Next Generation of CANDU: Reactor Design to Meet Future Energy Markets"*. The focus of the new design is to achieve a 40% reduction in capital cost, quicker construction time and higher efficiency. Key aspects of the new design include: light water coolant; smaller core; slightly enriched fuel; higher temperature and pressure coolant. Work is well advanced on the preliminary design. *(His paper is included in this issue.)*

The final plenary presentation was by **Peter Barnard,** chairman and CEO of Iter Canada, who reviewed the recent formal bid to host the ITER project. Then followed a fascinating and informative video of the proposed ITER facility as it would be at the offered site adjacent to OPG's Darlington station.

The Wednesday luncheon was the venue for the presentation of CNS awards. *(See a separate article in the "CNS News" section.)*

Augmenting the technical presentations were displays by: Bruce Power; FC Newman Hattersley and Specialty Valves; Ontario Power Generation; Stone & Webster; Summit controls Ltd.; Nuclear Logisitcs Inc.; and Thermodyne Engineering. These were in the lobby area where suitable and ample refreshments were served during breaks.

Sponsors were: AECL; Babcock & Wilcock Canada; Bruce Power; Cameco; CNA; Canatom NPM; CanNuke; GE Canada; Hydro Quebec; NB Power; Ontario Power Generation; Organization of CANDU Industries; Power Workers' Union.

The conference organizing committee included: Paul Spekkens, conference chair; Ken Smith, executive chair; Sadok Guellouz, Nino Oliva and Roman Sejnoha, program co-chairs; Aniket Pant and Jad Popovic, program committee; Hugues Bonin and Bill Garland, student conference; Andrew Lee, treasurer; Ian Wilson secretary; Denise Rouben, registration; Brian Thompson, signs; Denise Brien, Proceedings CD; Ben Rouben, abstract book.

22nd CNS Annual Conference

Technical Papers

Listed below are the technical papers presented at the 22nd CNS Annual Conference held in Toronto, Ontario, 10 - 13 June 2001. The Proceedings of the Conference, which include full versions of the papers, are available in CD format from the CNS office.

Session 2A: Physics I

Development of the CANDU 66-Group SN Transport Library, *K.T. Tsang (AECL)*

Uncertainty in the Burnup to Lanthanum Concentration Ratio for CANDU Fuel, *R.E. Donders (AECL)*

Calculation of Power Distributions for Experimental Bundles in the NRU Loops, *M.D. Atfield (AECL)*

A Methodology for Estimating Error in the Computed Maximum Fuel Bundle Power, *P. Sermer (OPG), F.M. Hoppe (McMaster University), and C.G. Olive (OPG)*

Fuel Temperature Reactivity Coefficient of a CANDU Lattice - Numerical Benchmark of WIMS-AECL (2-5d) Against MCNP, *M.A. Lone (AECL)*

High Temperature Physics Experiments Using UO_2 and Simulated Irradiated CANDU-Type Fuel in the ZED-2 Reactor, *M.B. Zeller, A. Celli, R.S. Davis, S.R. Douglas, R.T. Jones, and G.P. McPhee (AECL)*

Session 2B: Thermalhydraulics I

Experimental Characterization of a Turbulent Round Jet in Support of Validating the CFD Code MOD-TURC_CLAS, *H.F. Khartabil (AECL), D. Novog and J. Szymanski (OPG)*

A Statistical Estimator for the Boiler Power and Its Related Parameters, *H. Tang (New Brunswick Power)*

Review and Assessment of Heavy Water Transport Properties for Accident Analysis at High Temperature Conditions, *J.C. Luxat (OPG)*

Darlington Primary Heat Transport System Hot Waterhammer Analysis: Lessons Learned, *E. Zaltsgendler, P.T. Wan, W.S. Liu, S. Ho, D. Cheng and R.K. Leung (OPG)*

Fuel Cooling Analysis in Support of Operating the Universal Delivery Machine for Channel Inspection and Maintenance in Planned Outages at Bruce B, *Q.M. Lei, R.T. Murdock, M. Tabatabai, A. Tahir, K.K. Fung, M.H. Bayoumi, D. Austman, K.E. Locke and M.B. Furniss (OPG)*

Session 2C: Advanced and Research Reactors

Development and Field Application of a Leak Sealant for the NRU Water Reflector, *M. Porringa (AECL)*

The Next Generation CANDU Evolution in Safety, *D.J. Wren and F.J. Doria (AECL)*

Reactor Physics of NG CANDU, *P.S.W. Chan, K.T. Tsang and D.B. Buss (AECL)*

Next Generation CANDU Heat Transport System Parameter Assessment, *K.F. Hau, J.W. Love, M. Vadera and J. Vecchiarelli (AECL)*

Nuclear Power: Obstacles and Solutions, *R.S. Hart (R.S. Hart & Associates)*

The Modular Helium Reactor and a Review of Applications with a Focus on the Tar Sands, *A.S. Shenoy (General Atomics) and R.S. Hart (R.S. Hart & Associates)*

Session 2D Reactors and Operations I

COG's Role in Operational Excellence in the New Millennium, *C. Guiry (CANDU Owners' Group)*

Improving Fire Protection in Ontario Power Generation Nuclear Power Plants, *F.K. Fitzsimmons (OPG)*

Implementation of Reliability Centred Maintenance into Current CANDU 6 Plant Programs, *R. Dam, J.H. Nickerson, and J. Hopkins (AECL), A.L. DeLong (New Brunswick Power)*

Configuration Control During Maintenance of Safety Related Equipment, *C.S. Irish (Nuclear Logistics Inc.)*

Safeguards Spent-Fuel Bundle Counter for CANDU 6 Reactors, *K.M. Aydogdu (AECL)*

Corrosion of the Tube-Tubesheet Crevices in the Presence of Impurities and Deposits, *D. Lucan , I. Pîrvan, M. Fulger, and C. Anghel (Institute for Nuclear Research), Ghe. Jinescu (University Polytechnic Bucharest)*

Session 2E Safety I

Prototype Application of Best Estimate and Uncertainty Safety Analysis Methodology to Large LOCA Analysis, *J.C. Luxat and R.G. Huget (OPG)*

Assessment of Effects of Pressure Tube to Calandria Tube Contact Caused by Relocated Garter Springs on Safety Analysis Results, *Q.M. Lei and M.H. Bayoumi (OPG)*

Coolant Void Reactivity Transient in a Gentilly-2 Loss of Flow Event, *A. Baudouin (Hydro-Québec), K. Joober (ENAQ), T. Sissaoui and H. Chow (AECL), G. Hotte (Hydro-Québec)*

Application of Best Estimate and Uncertainty Safety Analysis Methodology to Loss of Flow Events at Ontario Power Generation's Darlington Nuclear Generating

Station, *R.G. Huget (OPG), D.K. Lau (Candesco Research Corporation), and J.C. Luxat (OPG)*

Demonstration of Fuel Channel Integrity in Case of Reverse Flow Bundle Impact During Fuelling or Defuelling with Flow, *Q.M. Lei, N.N. Wahba and M.H. Bayoumi (OPG)*

Bruce NGS B Core Conversion - Endshield Response to Impact Velocity Due to Reverse Flow Resulting from Large LOCA, *N.N. Wahba and M.H. Bayoumi (OPG)*

Session 3A: Physics II

Validation of RFSP-IST, *M. Ovanes, D.A. Jenkins, F. Ardeshiri, A.C. Mao, M. Shad, T. Sissaoui, H.C. Chow (AECL)*

Validation of DRAGON End-Flux Peaking and Analysis of End-Power-Peaking Factors for 37-Element, CANFLEX and Next-Generation CANDU Fuels, *W. Shen (AECL)*

Generalized Perturbation Theory in DRAGON: Application to CANDU Cell Calculations, *T. Courau and G. Marleau (École Polytechnique de Montréal)*

Sensitivity Studies for the Modeling of Core Reactivity Devices and Structures, *C.G. Olive (OPG), F.M. Hoppe (McMaster University) and P. Sermer (OPG)*

Delayed Photo-Neutron Yields in D2O from Fission in 235U, 238U, 239Pu, 240Pu and 241Pu, *M.A. Lone (AECL)*

Recommended Delayed Photo-Neutron Data for Use in CANDU Reactor Transient Analysis, *R.T. Jones (AECL)*

Parallel Coupling of Thermal-Hydraulics and Reactor Physics for Applications in a CANDU-6, *B. Dionne, J. Koclas and A. Teyssedou (École Polytechnique de Montréal)*

Session 3B: Environment I

The Five Year Review of the Canadian Environmental Assessment Act, *J. Clarke (Canadian Environmental Assessment Agency)*

Hydrogen Production, Nuclear Energy and Climate Change, *R. Duffey and T. Poehnell (AECL)*

Scientific Issues Around the Priority Substance Assessment of Radionuclides from Nuclear Facilities, *D. Hart, P. McKee and D. Lush (Beak International Inc.)*

Use of Self-Powered Detectors for Near-Containment Gamma Monitoring, *J. Kemp and M. LaFontaine (IST Canada), H. Sharma (University of Waterloo)*

ALARA Initiatives in Support of the Pickering-A Return to Service, *A. Khan (OPG)*

Development of a Real-Time, Neutron & Gamma Dosimeter, *R. Aryaeinejad (Idaho National Engineering & Environmental Lab.) and M. LaFontaine (IST Canada)*

Session 3C: Reactors and Operations II

NDE Inspection Qualification - an OPG Perspective, *J.A. Baron, B. Bevins, T. Harasym, and N. van den Brekel (OPG)*

Evolution of Bruce B Digital Control Computer Software Quality Assurance, *P.J. Gribbons and A. Kozak (OPG)*

Testing the Dynamics of Shutdown Systems and Their Instrumentation in Reactor Trip Measurements, *O. Glöckler (OPG)*

An Approach to Infer the Moderator Temperature of a CANDU Reactor from Measurements Inside a Vertical Flux Detector, *M. An and W. Thompson (Atlantic Nuclear Services Ltd.) and R. Gibb (New Brunswick Power)*

A Proposed Method for Assessing In-Core Flux Detector Dynamic Compensation Adequacy Over a Range of Trip Times, *C.M. Bailey (CANTECH Associates), M. Nguyen (Hydro-Québec) and B. Sur (AECL)*

Session 3D: Control Room

Regulatory Perspectives on Human Factors Validation, *F. Harrison and L. Staples (CNSC)*

Human Factors Engineering in Nuclear Plant Rehabilitations, *K. Berntson, M. Remisz and S. Malcolm (AECL)*

Lessons Learned in Applying Function Analysis, *G.R. Mitchel (AECL), E. Davey (Crew Systems Solutions) and R. Basso (AECL)*

Operator Error and Psychological Error Mechanisms, *B.K. Patterson (Human Factors Practical Inc.), M. Bradley (University of New Brunswick) and D. Packer (Biron Engineering International Ltd.)*

Realizing the Benefits of Improved Plant Monitoring in DCC Upgrade Applications, *K.L. Stephens (AECL)*

Updated Requirements for Control Room Annunciation: An Operations Perspective, *E. Davey (Crew Systems Solutions) and L. Lane (OPG)*

A Strategy for the Phased Replacement of CANDU Digital Control Computers, *G.A. Hepburn (AECL)*

Session 3E: Into the Future

Protecting the Principles During Progress, *W.K.G. Palmer (Bruce Nuclear)*

The Balanced Scorecard Advantage - Driving Strategic Change into Canada's Nuclear Laboratory Site Operations, *P. Lafrenière (AECL) and D. Weeks (Haggarty's Cove Ventures (2001 Ltd.))*

Why Are We So Afraid of Nuclear Radiation? *J.M. Cuttler (Cuttler & Associates Inc.)*

Future Prospects for Development of Nuclear Power: Good or Bad? *J.V. Jovanovich (University of Manitoba)*

Research and Development and Related Capabilities for Safety and Licensing of Nuclear Power Reactors: A Regulatory Perspective, *D.B. Newland (CNSC)*

Nuclear Education and Training in the Internet Age, *G. Bereznai (AECL, Chulalongkorn University, Thailand) and Wm.J. Garland (McMaster University)*

Measurement of Radiation Dose to Ovaries from CT of the Head and Trunk, *M.A.M. Al-Habdhan and A.R. Kinsara (King Abdul Aziz University, Saudi Arabia)*

Session 6A: Safety II

A Risk-Informed Process for Managing Nuclear Safety Issues and Periodic Safety Report Revisions, *W. Bowman, R. Chun, K. Dinnie, E. Panyan, D.G. Parkinson, D. Rennick and C. Slongo (OPG)*

Bruce NGS B Risk Assessment (BBRA) Peer Review Process, *S. Kaasalainen, W.P. Crocker and W.A. Webb (OPG)*

Reducing the Cost of Probabilistic Risk Assessment Modeling by Taking Advantage of the Advances in Information Technologies, *R. Greszczuk (OPG)*

The Use of CASE Tools in OPG Safety Analysis Code Qualification, *J. Pascoe and A. Cheung (OPG), C. Westbye (Geodesic Consulting)*

MAAP4-CANDU V4.04A, A Computer Code for Severe Accidents in CANDU Nuclear Generating Stations, *M.T. Kwee, F.I. Iglesias and S.G. Lie (OPG)*

LOCA Power Pulse Evaluation for CANFLEX-NU Core, *M.Y. Ohn, C.J. Bae, J.H. Choi, H.R. Hwang and J.T. Seo*

Session 6B: Plant Aging and Rehabilitation

Experiments on Feeder Thinning and Their Implications for CANDU Reactors, *D.H. Lister (University of New Brunswick), F.R. Steward (Center for Nuclear Energy Research), W. Cook (University of New Brunswick) and J. Slade (New Brunswick Power)*

Measurement of Oxide Loadings Within Steam Generator Tubes at CANDU Nuclear Stations, *J. Krasznai and A. Husain (Kinectrics Inc.)*

Gentilly-2 Steam Generator Primary Side Cleaning by SIVABLAST, *S. Plante (Hydro-Québec)*

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22nd CNS Annual Conference

Emerging Directions in Regulation

by Linda J. Keen[1]

***Ed. Note:** Following is s slightly edited version of the notes used by Ms. Keen for her talk to the 22nd CNS Annual Conference, June 11, 2001, in Toronto, Ontario.*

Introduction

This is an excellent opportunity for me to continue my introduction to Canada's nuclear industry and to discuss emerging directions in nuclear regulation in Canada.

Since I became President and CEO of the Canadian Nuclear Safety Commission six months ago, I've met with many industry representatives and other stakeholders as part of building a comprehensive knowledge of nuclear safety and regulatory issues.

In this talk I would like to discuss some of the things I've learned and talk about my vision for the future of the CNSC. But first, I should talk about the current state of the CNSC and the environment in which it regulates.

Canada has a very diverse nuclear industry, covering virtually all peaceful applications of nuclear materials. The CNSC administers approximately 4,500 licences, in every province and territory, covering everything from uranium mining to the medical use of radioactive materials to waste storage. Our mandate is to regulate the use of nuclear energy and materials to protect health, safety, security and the environment and to respect Canada's international commitments on the peaceful use of nuclear energy.

For the past year, the CNSC has been governed by new legislation - the Nuclear Safety and Control Act. We just celebrated the first anniversary of the legislation coming into force on May 31st. This has given us the opportunity to reconsider and revitalize the CNSC in terms of our goals, objectives and strategic priorities. With these in mind, I have put together a vision of the CNSC for the next few years. My goals are threefold:

- to make the Canadian Nuclear Safety Commission one of the best regulators in the world
- to ensure the highest level of openness and transparency in our organization, and
- to make the CNSC a preferred career choice for the best and brightest.

Making the CNSC one of the Best Regulators in the World

In speaking with other nuclear regulators, it is apparent to me that we all face similar tasks. We must prepare for challenges facing the industry and, at the same time, prepare our agencies for other forces of change, both internal and external.

The CNSC is currently facing several major forces of change within Canada. These include the deregulation of electricity markets and subsequent emergence of private, foreign-owned licensees such as Bruce Power, and the proposed Act Respecting the Long-Term Management of Nuclear Fuel Waste. Keeping these developments in mind, improving regulatory effectiveness and efficiency is a focus of attention for the CNSC as we continue to implement our new legislation and regulations.

A key element is clarity of requirements and expectations

Our first priority is to maximize the effectiveness of our regulations. A key element of this is clarity of requirements and expectations. Regulatory clarity has been raised by our stakeholders, and we have already begun to initiate many changes to achieve our goals.

We are reviewing our ratings of safety performance. Our aim is to produce clearer and more objective terminology that will be more useful in decision-making and more understandable for all stakeholders. For example, what exactly does it mean when the CNSC currently says a laboratory is "operated in a satisfactory manner?". Does this

1 Ms. Linda Keen is President and CEO of the Canadian Nuclear Safety Commission.

imply that many improvements are needed, or that no improvements are needed? In addition, we are revamping our compliance program to provide more predictability for licensees, CNSC staff and the public by offering more direction and clarifying expectations.

We are also looking at the structure and scheduling of the commission hearing process, with a view to improving efficiency and fostering easier access and understanding for anyone who wishes to participate.

Our new legislation also improves the CNSC's ability to reduce overlap and duplication and to harmonize requirements between jurisdictions in Canada. This will lead to greater efficiencies for both the regulator and industry.

As we strive to meet these goals, we must also look beyond our borders. Keeping abreast of developments in other markets helps us learn from best practices and be aware of changing attitudes and perceptions. For example, we are monitoring recent developments in the US energy policy as they may have some effect, direct or indirect, on the Canadian nuclear power industry.

Beyond monitoring other markets, we are also working with our colleagues in other countries to explore international benchmarks to monitor our performance as regulators. I also believe we need to strive for greater international harmonization of nuclear safety standards, which I know is of great interest to the industry.

I attended my first meeting of the International Nuclear Regulators Association earlier this year, and discussed common regulatory challenges and opportunities that we face. Sharing views on best practices and learning from the experience of others is an important part of our commitment to continuous improvement. For example, INRA has created 60 "Concepts Fundamental to the Delivery of Nuclear Safety Regulation." We are reviewing ourselves against these concepts, and identifying areas for improvement.

We have seen significant reductions in R&D funding by industry over the past few years

We are also reviewing our research and development function and capacity. This, among other things, will be spearheaded under the direction of our recently appointed Executive Director of Regulatory Affairs, Mr. Mike Taylor.

At the same time, I must note, the CNSC's R&D role is only one very small piece of Canada's entire nuclear R&D pie. As with safety, the majority of responsibility to perform research and development lies with licensees. We have seen significant reductions in R&D funding from the industry side over the past few years. This is cause for concern, as a robust R&D program is essential to maintaining a safe operating envelope. A viable R&D program is a key element of a healthy safety culture. A healthy safety culture is the primary concern of the CNSC. The facts show that, at least within the power reactor industry, there has been a sharp decline in safety research and development funding. If not addressed, this may ultimately impact on the medium- and long-term safety of the industry. In addition, there is evidence that R&D funding cuts have resulted in valuable highly skilled people leaving the nuclear industry for greener pastures. It will not be easy to lure them back.

However, there are reasons to be optimistic. I have noted, and applaud the fact that the CANDU Owners Group and its members have already recognized this problem, have studied it and have reported their findings in the "CANDU Research and Development Capability Review." The COG report is a healthy step towards stabilizing the future of Canada's nuclear power R&D capacity, but it must be acted upon. I challenge licensees to ensure the long-term viability of research and development programs and the safety of the nuclear industry.

There are no easy solutions to these R&D issues. There needs to be a cooperative effort from all parties to solve the equation. Together, we have many questions to answer. What is the minimum research capacity needed to maintain a safe operating envelope? How is it determined what regulatory-focused research should be carried out? Do we have a clear strategy for R&D in Canada?

The CNSC is doing its part to answer these questions. I will be meeting with my international colleagues at a meeting of the Nuclear Energy Agency of the OECD, to discuss "The Role of Research in a Regulatory Context." In preparation for this workshop, we have completed a review of, and will continue to evaluate, the CNSC's own R&D program. At the same time, we will be engaging industry to discuss the issue of investment in research and development. We are investigating the R&D situation because, indeed, there is a minimum R&D capacity necessary for safety, and achieving the highest safety standards and promoting a safety culture are 'job one' for the CNSC.

While safety remains primarily the responsibility of the licensee, the new Act requires us to be more rigorous and assertive in measuring how licensees fulfill this responsibility. We expect nuclear executives to demonstrate how safety culture is of primary and strategic importance. Licensees must assure us that a healthy culture of safety permeates every aspect of their operations and management.

In addition, the CNSC must also ensure Canada's nuclear industry acts within both the spirit and the letter of our international treaty obligations with respect to non-proliferation and security of nuclear materials. To better address this, I have created a new Office of International Affairs, under the direction of Mr. Ken Wagstaff. This responsibility is particularly challenging, given the diversity of Canada's nuclear industry. However, by ensuring that Canada meets its international obligations, we demonstrate to the world our commitment to internationally agreed-upon standards for safety and security.

The CNSC intends to become one of the best regulators in the world. At the same time, our licensees must foster and implement a strong safety culture with the goal of becoming the world's best, and safest, nuclear industry.

Openness and Transparency

Internationally, Canada is seen as having one of the world's most transparent nuclear regulatory processes. This is something Canadians can be justifiably proud of but it needs constant attention because the bar of public expectation is always being raised. Ensuring openness and transparency means we must be accountable, open to scrutiny and actively seek input from all stakeholders on how we can do a better job.

We have accelerated production of regulatory documents needed to communicate the CNSC's expectations to licensees, staff, and the public. I am pleased to inform you that in our first year as the CNSC, we published 22 regulatory documents. This compares to 18 over the previous decade. However, we must continue to increase the rate of production while ensuring documents remain of high quality and are fully available for stakeholder input.

The CNSC must always operate with the public interest in mind.

The CNSC must always operate with the public interest in mind. However, this goal must be balanced with the need for security, personal privacy, corporate confidentiality and our international obligations.

Regulatory transparency cannot occur in a vacuum. There is an increasing onus on the nuclear industry to become more open and transparent. For example, the new Act requires licensees to address public communications when undertaking major projects. Forthright and open public communications and consultation is a factor which must now be considered in licensing matters. This will be an area of work for the CNSC in terms of specifying guidelines for public information programs.

Recent experiences with the environmental assessment process and our own hearing process have made it very clear that Canadians want to be fully informed and involved. We - both the regulator and industry - have a duty to meet these expectations.

Making the CNSC a Preferred Career Choice

Our goals of openness, transparency, and regulatory effectiveness and efficiency can be achieved only if the CNSC is staffed by a motivated and high-calibre team. However, we are confronted with a unique human resources challenge that is shared by other science-based organizations, our licensees and other nuclear regulators. There are two primary obstacles to our goals for employee retention and recruitment. We are experiencing a high rate of attrition through retirement, and we are not attracting new recruits as successfully as we would like. With a limited pool of potential employees due to the highly technical nature of the field, the industry, regulator and educators are all robbing from each other to fill vacant positions. We must attract, retain and motivate our share of the best and brightest talent on the market.

Unfortunately, there is a perception that the nuclear industry has no future. Students do not see a viable career path in the nuclear field, and many universities are downsizing or canceling programs in this area. This problem is growing with each passing year. In order to increase the pool from which we can draw, and to make the CNSC more attractive, we have developed and joined several initiatives to attract new recruits and strengthen nuclear education programs. We have a pilot internship program for regulation of power reactors called the Career Challenge. Our first eight interns began a two-year training program on June 4th. Upon completion of the program, interns will be offered a full time position with the CNSC.

The CNSC is also working in partnership with academia and industry. As you may be aware, the CNSC is supporting CANTEACH - a joint initiative of five universities, four utilities, the CANDU Owners Group and AECL. We are also supporting the Canadian Universities Network of Excellence in Nuclear Engineering. This is an excellent example of the cooperation needed to ensure the survival of nuclear engineering programs.

I want the CNSC to be recognized as an employer that offers challenging work, opportunities for career advancement and a continuous learning culture. The CNSC needs to be seen as offering a promising and rewarding career.

Conclusion

The CNSC has a vision for becoming a "best in class" regulator. We are taking steps to achieve this goal. A strong regulator is in the best interest of all stakeholders. By having a strong and impartial regulator, industry is afforded more trust and credibility in the public's eye. An effectively regulated industry, and one recognized for its safety culture, is an industry which the public will trust.

The Next Generation of CANDU: Reactor Design to Meet Future Energy Markets

by J. M. Hopwood, J. W. Love, D. J. Wren

1. Introduction

Today's operating nuclear power plants were primarily developed for electricity utilities, often state-owned or directed, with a mandate to ensure reliable supply at appropriate cost. The existing fleet of plants has contributed strongly to this mandate, but construction of new nuclear power plants has been limited in recent years. However, recent changes in the energy supply marketplace present new challenges and opportunities for the construction of new Nuclear Power Plants (NPP's). Interest in the nuclear option is reawakening, in North America and elsewhere.

New nuclear plants can be competitive if they respond to these issues:

- New plant financing will likely depend increasingly on private equity, where higher rates of return are demanded;
- The greater volatility of the market will also drive shorter payback times during operation, complemented by shorter project durations, to reduce financial risk.
- Project sponsors will expect clear and straightforward licensing (based on a strong and well supported licensing case), and reliable, high capacity-factor performance.

These challenges generate, in particular, a requirement for large reductions in initial capital cost. Can this be achieved by manageable development steps? For the CANDU system, evidence from design studies indicates the answer is "yes".

So far, AECL has achieved significant incremental improvements to the current CANDU 6 design through successive projects, both in design and in project delivery. The CANDU 9 design incorporates proven advancements in a single-unit adaptation of the Darlington reactor. AECL believes that major additional improvements will be needed for nuclear power to reach its full potential in the emerging market. This can be achieved, by developing an innovative next generation CANDU design building on traditional CANDU strengths.

Since the beginning of year 2000, AECL has been studying possible characteristics of a next generation CANDU design (Reference 1). Building on innovative concepts to extend the CANDU design, this program is aimed at developing and confirming a series of key enabling technologies, and applying these to the design for a next generation family of CANDU plants. The key technologies have been carefully assessed, and the nominal design concept for a 600 MWe class Next Generation CANDU plant has been established to confirm concept practicality. Continuing work is aimed at achieving the ambitious capital cost target reduction of 40% compared to today's CANDU 6.

2 Next Generation CANDU Development Approach

As noted above, nuclear power plant designs for the future must respond to increasingly demanding market requirements. This means that value can be gained from substantial product development directed at these requirements. For the CANDU system, AECL has adopted the evolutionary approach, accommodating significant changes to design while retaining traditional CANDU strengths:

- Modular horizontal fuel channel core
- Available simple, economical fuel bundle design
- On-power fuelling
- Separate cool, low-pressure moderator with back-up heat sink capability
- Relatively low neutron absorption for good fuel utilization

Based on these principles, AECL has developed a number of enabling technologies at the component level (described in the next section), which together are being applied in conceptual design studies for the next step in CANDU design - the Next Generation CANDU. The design offers the opportunity for reduction in capital cost, reduction in schedule, and enhancements in inherent safety. At the same time, the design is firmly rooted in the principles and characteristics of the CANDU system, and takes full benefit from the extensive knowledge base in CANDU technology built up over many decades.

The following key development steps, derived from the enabling technologies below, are incorporated into the nominal design concept for the Next Generation CANDU:

- Slightly enriched uranium fuel at increased burnup
- Light water replacing heavy water as primary coolant
- More compact core design with reduced lattice pitch, reducing heavy water inventory and giving highly stable core neutron flux
- Higher coolant system and steam supply pressure and temperature.

3. Development of Enabling Technology

While the next generation CANDU design involves significant change from the traditional CANDU - NU design, each of the changes noted above is supported by an extensive base of R and D knowledge, and component testing, as described below:

1 Atomic Energy of Canada Limited

3.1 Advanced Fuels

Current CANDU reactors are designed to cost-effectively use natural uranium (NU) fuel. This has necessitated design to achieve very low neutron absorption in the core. In general, CANDU plants can also use Slightly Enriched Uranium (SEU) fuel to achieve significantly higher burnup than NU fuel. AECL has carried out development of higher burnup fuels over many years. The CANFLEX fuel bundle has been developed and irradiation-tested specifically with the intent of high burnup use (Reference 2). The CANFLEX bundle has 43 elements compared with original CANDU 6 fuel at 37 elements. In addition, element sizes are graded to reduce peak-to-average fuel rating. This reduces fuel temperatures, which ensures high design margin through to high burnup, and also increases fuel operating thermal margins. Fuel tests and fuel management studies indicate that the traditionally extremely low CANDU fuel defect rates will be achieved for burnups three times NU burnup or beyond.

In general, CANDU's fuel cycle flexibility has many advantages for the future, when plant owners and national institutions may need to take advantage of this flexibility to assure economical fuel supply (Reference 3). From the viewpoint of reactor development, the availability of high-burnup SEU fuel enables design optimization to improve core economics, while obtaining advantages such as reduced spent-fuel volume.

3.2 Reactor and Coolant System

AECL's R and D into reactor components has generated a large knowledge base, in particular for fuel channel design. Incremental design and manufacturing improvements for pressure tubes enable the choice of a small increase in thickness to enable higher operating pressure and temperature. This allows, in turn, higher turbine steam pressure that significantly improves operating efficiency and reduces cost per MW. Optimizing the core design for SEU fuel allows the selection of light water coolant in the place of heavy water used in operating CANDU's. This enables a significant reduction in initial capital cost and leads to further opportunities to greatly simplify heavy water management systems.

3.3 Reactor Core Components

In addition to fuel channel development, AECL has also made improvements to key core components, in particular reducing component sizing to enable a more compact core configuration. For example, the end-fitting sections, which connect each end of the fuel channels to feeder pipes, have been adapted to a smaller outer diameter, and to include a channel closure seal that resides inside the bore of the end fitting. Figure 1 illustrates this new bore-seal closure plug. This closure, together with a smaller, more efficient connecting "snout" on the fuelling machines, enables the lattice pitch (distance between fuel channel centres) to be reduced to 80% of current CANDU cores. This has several advantages; calandria vessel size, weight and complexity can be reduced;

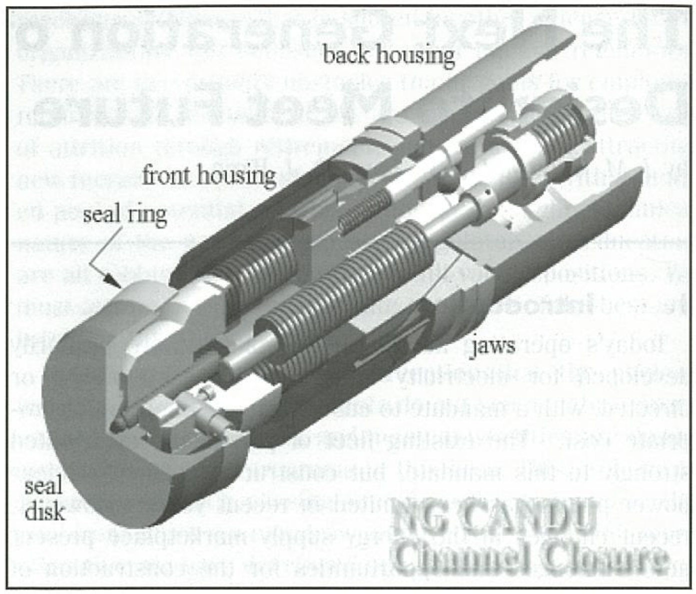

Figure 1: Bore seal closure plug.

the inventory of heavy water for the reactor moderator and reflector is almost halved; and further improvements to the fuelling machines can be incorporated, such as simplified ram design.

The compact fuel channel core, with SEU fuel, at about 1.6% enrichment, also offers unique reactor physics advantages. The core exhibits a naturally very even flux shape across all fuel channels, achieved without the need for local absorbers, while maintaining exceptional flux stability. This is driven by a high generation of thermal neutrons in the reflector. The result is a core that extends the traditional CANDU advantages of consistent control characteristics throughout the fuel cycle, to include very low reliance on external reactivity control.

3.4 Inherent and Passive Safety Characteristics

The CANDU system incorporates a number of inherent safety advantages, which are retained in the next generation design: Special Safety Systems are rigorously designed to be completely independent of all power production systems, and of each other. This minimizes the potential for common mode failures, and ensures that the day-to-day routines of operation have no impact on safety functions.

Two separate, independent and functionally diverse shutdown systems are retained in the nominal design for Next Generation CANDU. Each shutdown system and all other reactivity mechanisms, are located in the low pressure and temperature moderator, eliminating the possibility of accidents such as rod ejection.

The CANDU reactor type also features the inherent ability of the cool, low-pressure moderator to act as an emergency heat sink, in the event of a loss of coolant coincident with postulated complete failure of the ECC system.

As a further step, AECL has been carrying out enabling R and D to develop test applications of passive decay heat removal to CANDU (Reference 4). Coupled with inherent safety of a fuel channel core, long-term passive containment heat removal reduces the probability of large radioactive release from containment, even after severe, beyond-design-basis accidents, to the point where credible scenarios can be all but eliminated.

Enabling technologies have been developed so that passive heat removal for the moderator system, steam-feedwater system and containment building can be applied as appropriate to CANDU designs. Figure 1 illustrates such passive heat sinks incorporated into an Advanced CANDU 6 concept. The designer then has the choice of applying traditional engineered heat sinks, passive heat sinks, or a combination, to meet deterministic and probabilistic safety targets.

3.5 "Smart CANDU" Operating Support Technology

AECL has increasingly emphasized developing technologies to support nuclear plant operation, both via CANDU Owners' Group (COG) programs, and through AECL's own R and D programs. In particular, as the current group of operating NPP's increases in age, technologies to improve the efficiency and effectiveness of equipment monitoring have been increasingly in demand. AECL is developing a suite of technologies both to enhance in-field equipment and system performance measurement, and to develop information analysis software to support the operator. The first integrated operating support package, the ChemAND Health Monitor for optimised system chemistry control, has been developed and implemented at the Gentilly-2 CANDU 6 unit in Canada. ChemAND provides chemistry monitoring and control measurement and software for major plant systems, and is demonstrating benefits in improved operator effectiveness (Reference 5). This package is being expanded to the ChemAND package for plant-wide equipment monitoring building on the results of cooperative programs supporting Plant Life Management at CANDU Stations ComAND will provide information to the operations staff throughout the plant via internal LAN, or to any off-site support entities via an Extranet.

4. Conceptual Design: The Next Generation Mid-Sized CANDU

Conceptual design work for a next generation CANDU design was initiated at the beginning of year 2000, after feasibility studies had demonstrated the powerful benefits from applying the enabling technologies described above. The design approach has been to exploit the cost reductions; inherently available from the choice of light water coolant and higher steam pressure, while maintaining a high degree of proveness in design features, and maintaining or enhancing safety margins. This has meant applying key enabling technologies above, in a way that retains ample design margin. It also means adopting a conservative approach to any uncertainties arising from innovation; to ensure that key design parameters will be well supported throughout the complete design process through to first plant construction. (One example is the selection of fuel conditions. A discharge burnup of 20,000 MWd/TU has been chosen, which sets the nominal value of fuel enrichment, since this burnup is approximately the maximum seen in a significant number of CANDU fuel elements. In fact the ratings and power boosts seen by NG fuel will be significantly smaller than the range of CANDU experience, which promises that, as further experience is gained in the future, increased burnup will be achievable.).

The design process started with reactor physics, by establishing a core geometry, which leads to a favourable neutron flux behaviour (stable flux, benign reactivity coefficients). A companion paper (Reference 6) describes the reactor physics basis for the next generation design. Advances in compact fuel channel, end fitting and fuelling machine have been applied to establish the compact fuel channel lattice required to achieve the required core geometry. The next step was to develop a reactor coolant system and steam/turbine system design to achieve the higher efficiency targeted. Reference 7 describes the optimization studies, which were carried out to support coolant system design. Based on these and many other supporting studies, a nominal configuration for a 600 MW class design has been established. The configuration has the following characteristics:

- Nominal output of approximately 600 MW (e) net, dependent on site conditions
- Light-water coolant hot leg pressure of approximately 13MPa
- Steam outlet pressure of 7MPa, allowing turbine cycle efficiency of approximately 37%.
- Reactor core configuration consisting of 256 fuel channel locations in a square lattice.

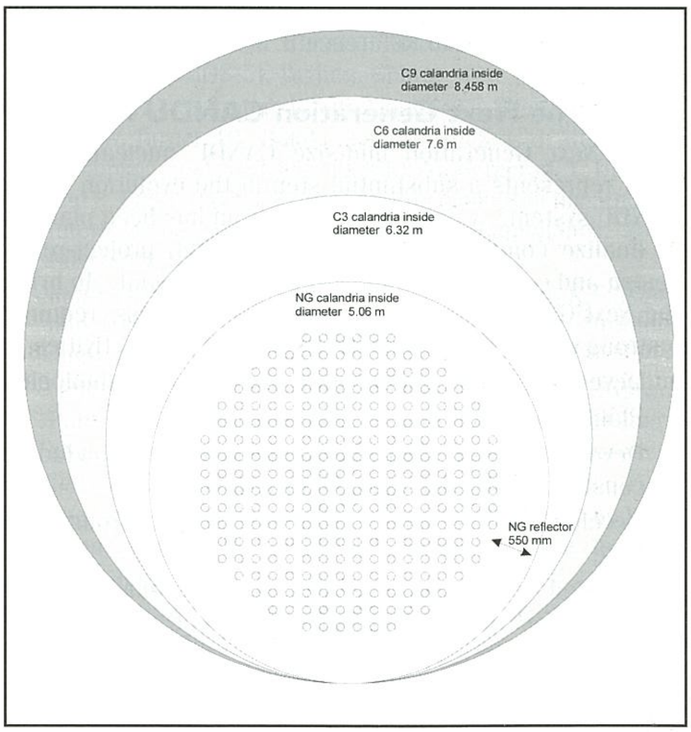

Figure 2: End view of NG/C6/C9/C3 reactors.

- Average channel power increased from 5.8MW (CANDU 6) to 6.8MW, primarily from increased core radial form factor of 0.93.
- Thanks to inherently even core flux shape (reflector-driven thermal flux), estimated peak bundle power is 850kw compared to 875kw for CANDU 6, while peak fuel element ratings are 14% lower than CANDU 6, due to CANFLEX fuel design
- UO2 fuel in CANFLEX fuel bundles enrichment nominally 1.65%, with burnup of 20,000 MW/TU
- Reactor coolant system in a single-loop, figure of eight configuration with two steam generators.
- Double-ended refuelling employing two fuelling machines and 2-bundle shift.

A comparison of the next generation CANDU core end view versus previous AECL CANDU designs is shown in Figure 2. CADDS model of the reactor and coolant system main components is shown in Figure 5.

The nominal safety systems design follows well-established CANDU practice, adapted to the next generation reactor characteristics. An array of gravity-driven shut-off rods forms shutdown system #1, using plate-type rod cross-section to meet the more compact core geometry requirements. Liquid gadolinium solution injection into the moderator forms shutdown system #2. Injection tubes are located in the reflector; since this is the location where neutron poison injection is most effective for this core type (see Reference 6). Emergency core cooling system design benefits from a simpler interface to the reactor coolant system, (in the absence of a light water/heavy water boundary). The single unit containment structure benefits from a significantly reduced diameter and height, owing to the more compact reactor/coolant system design. A more detailed discussion of safety considerations in the conceptual design is given in Reference 8.

5. The Next Generation CANDU Program

The Next Generation mid-size CANDU nuclear power plant represents a substantial step in the evolution of the CANDU system. A development program has been planned to finalize concepts generate the detailed, project-ready design and component qualification for this plant. To bring the Next Generation CANDU to market readiness requires a strong emphasis on concurrent development activities:

- Development and qualification of enabling technologies
- Plant conceptual and detailed design
- Development of improved project delivery including constructability and manufacturability
- Development of safety, licensing and environmental case
- Detailed implementation of design to assure effective operations and maintenance for good performance throughout design life.

The Next Generation CANDU program represents a major step in the continuing process of development of the CANDU system. As longer term applicable technologies are developed, they can be incorporated into future modifications of the Next Generation design. Looking farther ahead, AECL also maintains a program of "CANDU X" studies, defining concepts to reach the ultimate potential of the CANDU system. (Reference 9) Continuing work to define and prepare a Next Generation CANDU will emphasize inter-organizational collaboration. Close cooperation with potential customers, suppliers, partners and regulators, will be an essential ingredient in a successful program.

In general the CANDU system is designed and applied in accordance with IAEA Safety Standards and Guides, and has been shown to be consistent with the objectives of EPRI and EUR utility requirement compilations. In practice, earlier application of detail design requirements to the CANDU system has been done by utilities and regulators on a case-by-case basis for individual projects. More recently, within AECL's CANDU 9 design program, agreement on a specific set of customer requirements and licensing basis was done at the pre-project stage during detail design. For a Next Generation CANDU, incorporating utility and regulatory feedback through multi-organization participation would further extend this approach. This would ensure that, once the plant design is project ready, specific implementation is straightforward, rapid and low-risk.

In order to retain the benefit of the proven CANDU design "pedigree", emphasis is being placed, in AECL's reactor development activities, on comprehensive development and prototype testing of any new components or features. Test programs have been completed or are under way to ensure readiness of these Next Generation technologies:

- CANFLEX Fuel: After a multi-year design, development and prototype irradiation, production CANFLEX bundles have now successfully completed power reactor irradiations at Pt. Lepreau NGS in New Brunswick, Canada. CANFLEX-NG irradiations at NRU are in preparation.
- Fuel Channels: The Next Generation fuel channel represents the next step in the evolution of CANDU pressure tube and other components. Manufacturability, endurance and irradiation tests are under way or in preparation.
- Fuel Channel Closure Seal: The Next Generation bore-seal closure has completed initial prototype testing successfully. Interface tests with fuelling machine components are under way.
- Fuelling machine. Development tests on adaptations of current fuelling machine components are under way.
- Passive heat sinks. AECL has carried out an extensive range of proof-of-concept tests for passive moderator, steam system and containment cooling, and has developed generic conceptual designs. Evaluation of applicability to the Next Generation CANDU is under way and prototype test planning has begun.
- SMART CANDU: The rollout of the first element of SMART CANDU operational support (ChemAND) has been successfully accomplished at Gentilly-2 in Canada. Development of the comprehensive ComAND system is under way.

6. Next Generation Product Delivery

The CANDU system is particularly suited to rapid project execution, because of the modular nature of the fuel-channel reactor design. This is an important benefit, in terms of reduced Interest During Construction (IDC) costs, and reduced time-to-payback, important to success in arranging project financing. The recent Wolsong-3 CANDU 6 unit was completed in 69 months from the Contract Effective Date (CED) to being placed in-service-a highly competitive accomplishment for today's generation of power plants.

The Next Generation CANDU will include product delivery evolutions which, added to the natural benefits of the Next Generation design, will enable further significant reductions in project delivery schedule.

For the longer term, collaborative development work will continue with an ambitious target of a 48-month total schedule (CED to in-service) for an N'th unit. This target is a major challenge, but is seen as achievable, in the context of a regular order series and an established standard licensing case.

To achieve this, the advances in project delivery, already being implemented at Qinshan in China, will be further extended, in the areas of:

- Comprehensive engineering/delivery electronic models; 3D CADDS models of plant design linked to equipment supply, delivery and installation, and to project management licensing and operations software.
- Modular construction; further emphasis on assembly of pre-fabricated equipment modules for simple, cost-effective site installation
- Open-top construction; extensive use of open top placement of equipment and modules, with reactor building top-off afterwards.

The Next Generation CANDU design is readily adapted to faster project schedules. In comparison to the (already rapid) CANDU 6 schedule, the Next Generation Schedule will have improvements due to:

- Smaller number of fuel channels, hence faster reactor vessel manufacture and installation
- Two-steam generator design, simplifying steam system manufacture, installation and commissioning
- Light-water coolant, simplifying heat transport system commissioning.

7. Conclusion

As air pollution and climate change issues become more important, the opportunity for nuclear energy to play a large role in the coming decades also increases. However, the emerging energy market also presents a stringent economic challenge. Current NPP designs, while established as reliable electricity producers are seen as being limited by high capital costs. In some cases, the response to the economic challenge is to consider radical changes to adopt new design concepts, with attendant development risks and difficulties in prototyping.

Because of the flexibility of the CANDU system, it is possible to significantly extend the mid-size CANDU design, creating a Next Generation product, without sacrificing the extensive design, delivery and operations information base for current generation CANDU plants. This enables designers to select a design with superior safety characteristics while at the same time meeting the economic challenge of emerging markets.

8. Acknowledgements

The Next Generation CANDU concepts described here are a result of much original work and research that has been undertaken by the physicists, scientists, engineers and designers of AECL over many years. In particular, the authors would like to acknowledge the contributions from original Next Generation studies by the CANDU-X and Advanced CANDU 6 teams in 1999, under the leadership of AECL's Principal Scientist, Romney Duffey.

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Twenty-Third Annual Conference of the Canadian Nuclear Society

40 Years of Nuclear Power in Canada: Celebrating the Past, Looking to the Future

2002 June 02-05
Holiday Inn on King, Toronto, Ontario, Canada

Call for Papers

The Canadian Nuclear Society's 23rd Annual Conference will be held in Toronto, Ontario, Canada, 2002 June 02-05. The location is the Holiday Inn on King, close to the heart of Toronto's theatre and restaurant district.

The main objective of the Conference is to provide a forum for discussion and exchange of views on the technical aspects, challenges and opportunities for nuclear technology in what appears to be a new dawn for nuclear power. As usual, papers are solicited on technical developments in **all** subjects relating to nuclear technology. **In addition, because the refurbishment of older plants is very topical, papers related to this topic are particularly encouraged.** The following list of topics is therefore meant as a general guide only:

- Operational excellence, plant reliability and competitiveness
- Plant aging, maintenance and life extension
- Operation of aging reactors
- Plant rehabilitation and refurbishment
- Medical and other applications
- Reactor physics
- Fuel cycles, fuel design
- Thermalhydraulics
- Safety and licensing
- Computer-code validation, software QA
- Manufacturing
- Radiation transport, shielding, health physics
- Probabilistic risk assessment
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- Advanced reactors, research reactors
- Operator training, simulators, robotics
- Nuclear waste management, transportation and storage of nuclear material
- Environmental issues
- Industrial irradiation
- Uranium mining
- Fusion

Information for Authors

- Deadline for **receipt** of summaries: 2002 January 12.
- Notification of acceptance: 2002 February 12.
- Firm deadline for **receipt** of full papers: 2002 April 21.
- When submitting the summary, please attach a 50 - 100 word abstract to be included in the abstract booklet distributed at the time of the conference

Content of Summaries

Summaries should be approximately 750-1200 words in length (tables and figures counted as 150 words each). They should present facts that are new and significant or represent a state-of-the-art review. Proper reference should be made to all closely related published information. The summaries should include:

- an introductory statement indicating the purpose of the work
- a description of the performed work
- the achieved results

Technical Program Co-Chairs:
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Submissions should be made, preferably by e-mail, in MS Word or PDF format, to nichitae@aecl.ca.

Hard-copy submissions should be mailed to:

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Servicing & Upgrading the RMC SLOWPOKE - a photo story

by Daniel Arscott

Ed. Note: *Dan Arscott was a student employee with Merlin General Corporation during the summer of 2001.*

Merlin General Corporation, which is based in Kincardine Ontario, acted as the general contractor for the upgrade of the control console to the SLOWPOKE 2 reactor at the royal Military College in Kingston, Ontario..The analog controls were removed, and the new digital SIRCIS control panel was installed in late May / early June 2001. Merlin General also serviced the control rod mechanism, and performed reactor reactivity adjustments, during July and August.

We thank Dan for his article, Merlin for the photographs and its president Jack Richman for the original suggestion.

Background

The SLOWPOKE 2 reactor, with a maximum power of 20 kilowatts (17.7kW at RMC), is recognized as being fail safe, and was in fact developed to be user friendly. The reactor pool is quite small, as it measures 6.4 metres (21 feet) deep, and has an inside diameter of only 2.5 metres (8.2 feet). Since dimensions are so small and radiation is minimal, no special building is required for the SLOWPOKE 2 reactor. With 10 easy to access irradiation sites, simple shutdown procedure, flux stability and reproducibility, SLOWPOKE 2 is so safe and uncomplicated that students can operate the reactor themselves while conducting experiments under the direct supervision of a current Licenced Operator. These experiments include biological tracers, radiochemical separations, and specific activity studies (not necessarily performed at RMC, but at various SLOWPOKE facilities) allowing students to learn principles of reactor physics, radiochemistry, and nuclear engineering.

With SLOWPOKE 2, no special physical protection other than radiation measuring devices is required, and there are no special power or water requirements. The reactor is also licensed to operate for periods of up to 24 hours in the remote attendance mode, further adding to the ease with which SLOWPOKE 2 can be operated. In August/September 1985, the SLOWPOKE 2 reactor at RMC was installed. The SLOWPOKE 2 at the RMC is still fully functional and operating with minimal maintenance 15 years after it's installation and should continue to do so for years to come.

Upgrading Process

Merlin General Corporation received the contract for the reactor upgrade from Atomic Energy of Canada Limited (AECL), Chalk River and began assembling the SIRCIS team. Dr. Les Bennett, Director Kathy Nielsen and SIRCIS developer Lt(N) Lloyd Cosby of RMC were present. Mr. George Burbidge and Mr. Manfred Mueller, sub-contracted to Merlin General from AECL, Chalk River, who performed the upgrade, were members as well. Lt(N) Cosby lead a training seminar during the upgrade to fulfill CNSC requirements for Licenced Operator upgrade for the new SIRCIS control system. The CNSC sent a person to Kingston to observe the SIRCIS training session. Also present for the training were Mr. Keith Greenfield and Mr. Pat Charette of AECL who assisted on the project.

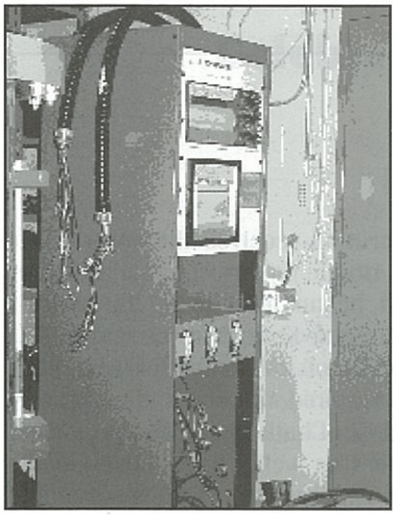
SIRCIS had been connected to a simulator and its digital performance observed and tested over a period of several months. All tests were passed by the system and installation began. The old system was removed and the new one connected, but initially did not properly perform. The simulator had not corrected for a floating ground, thus when the system was introduced to actual conditions, setting were not accurate. This problem was corrected by Mr. Burbidge who ensured that SIRCIS function as it should.

Since the upgrade was completed in June, Merlin General returned to RMC, in July and August, to further service the reactor. Difficulty had arisen in the operation of the vertical control rod mechanism, such that it did not properly function. Merlin General proceeded to investigate the mechanism, and search for possibilities for the failure. The motor and the setscrew were examined, but were seen to be in working order. The Oscillator / Microstepping Drive Unit however needed replacement, and the new unit was installed and configured by Mr. Mueller and Mr. Reid. After this installation, the vertical control rod mechanism responded to commands from the SIRCIS control panel, confirming that the mechanism was once again operational.

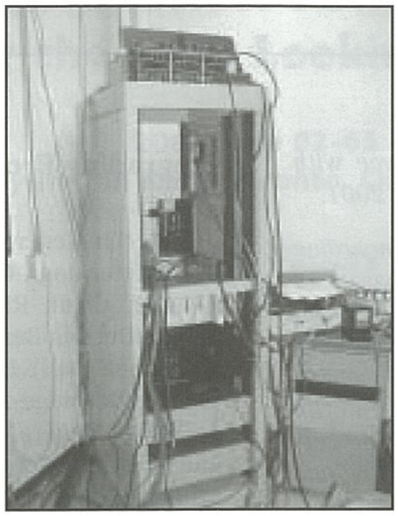
Reactor reactivity adjustment services were then provided to RMC's SLOWPOKE 2 reactor, to improve neutron economy and extend the life of the reactor. Mr. Mueller removed the old shims, and installed the new ones, while Mr. Burbidge, using the new SIRCIS operating system, monitored the reactor and ensured that the system recognized that new shims were being installed.

Normal operation of the reactor resumed shortly thereafter and experimentation for which the reactor is required, resumed also.

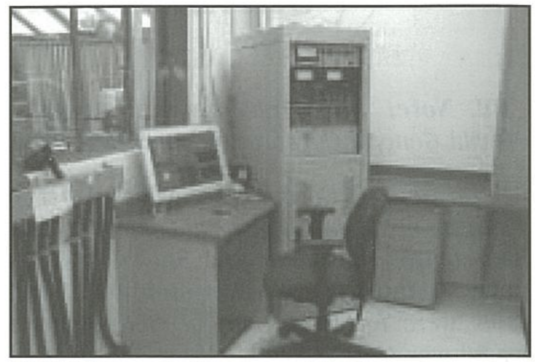
The accompanying photographs depict various stages in the upgrading process, and reactor servicing.



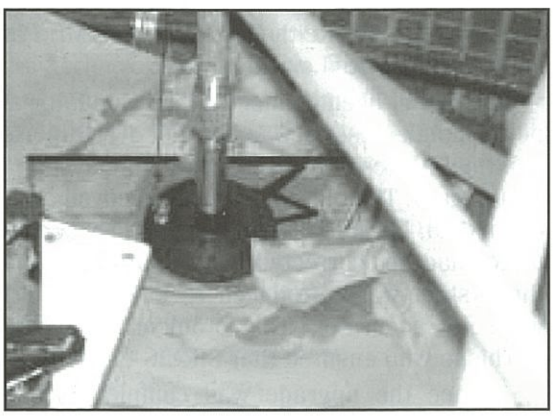
The disconnected analog system.



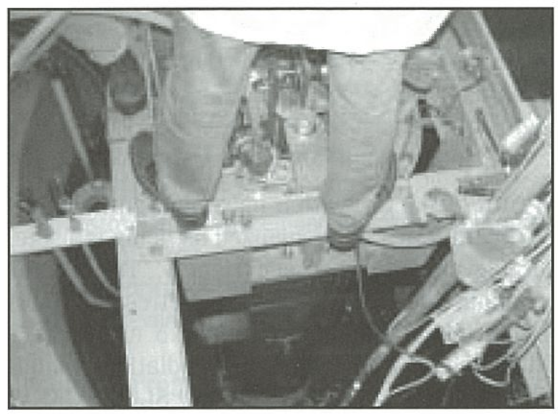
The digital system during installation.



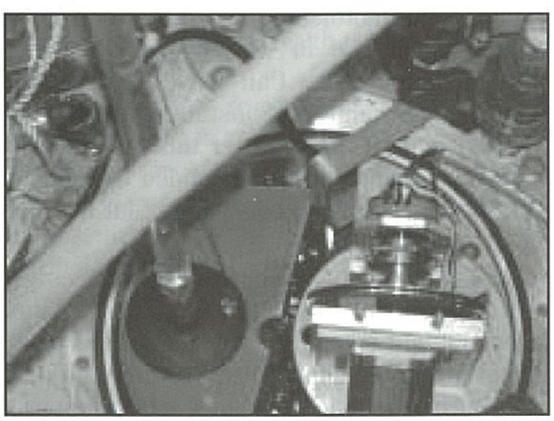
SIRCIS installation completed.



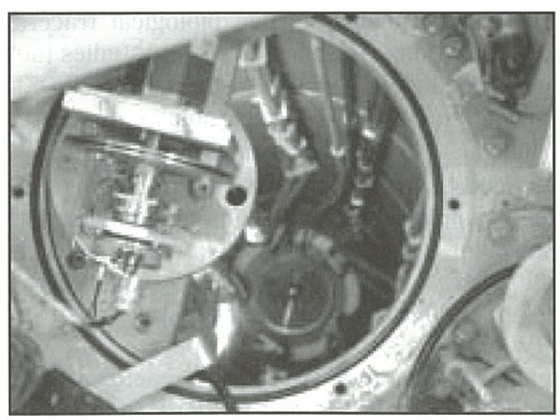
The semi-circular shim is attached to the suction cup end of an extension pole in order to lower the shim into place.



The shim is lowered to the bottom of the tube, which is seen in the reactor pool. The new Oscillator/Microstepping Drive Unit is obscured by the technician.



The shim enters the top of the reactor tube, with pole attached. The top of the tube has been unbolted and removed to allow for this procedure.



The shims are detached from the pole after being properly placed. 2-1/4" shims are seen inside the tube, across from one another.

Climate Change - the science

There is a scientific basis for the concern over climate change. It rests in the fundamental principles of physics and chemistry.

by Henry G. Hengeveld[1]

***Ed. Note:** The following article is reprinted from the June 2001 issue of Canadian Chemical News. It provides, in our view, a needed scientific perspective on the climate change issue. We thank the editor, Dinah Laprairie, and the author for their permission to reprint.*

In the early months of 2001, the United Nations Intergovernmental Panel on Climate Change (IPCC) and its Working Groups convened a series of meetings in Shanghai, Geneva, Accra and Nairobi to finalize its Third Assessment Report on the science of climate change. The culmination of a two-year process involving more than 2,000 scientific and technical experts and intensive peer review, this report provides the most up-to-date and comprehensive assessment of the science of climate change currently available. It will now serve as the scientific basis for ongoing international negotiations on climate change mitigation.

Some argue that the IPCC process is flawed by its emphasis on consensus, contrary to the adversarial process of debate normally used within the scientific community. The scientific community, at the request of the IPCC, has attempted to address these concerns by carefully documenting both the uncertainties as well as the key points of agreement. Uncertainties are particularly important when it comes to the discussions of rates and regional characteristics of projected climate change. However, more importantly, there is good agreement between scientists on the fundamental principles of physics and chemistry behind the climate change issue and the scientific basis for concern. They agree, for example, that the climate is already changing, that expected changes in the future will be large and potentially problematic, and that the related risks to humanity and ecosystems already justify mitigative actions beyond simple precautionary measures. The rationale behind these conclusions, as well as the uncertainties associated with them is discussed in more detail in the following sections.

Our Changing Climate

Climatologists have been monitoring the Earth's climate with meteorological instruments for more than a century. These data, collected from many thousands of land and ocean stations and corrected as carefully as possible for biases due to urbanization and other non-climatic influences, suggest that the average surface temperatures around the world have warmed by about 0.6±0.2°C since 1860. Retreating alpine glaciers, thinning and retreating sea ice in the Arctic Ocean, and other forms of proxy data support the conclusion that this change is real. Furthermore, comparison with temperature records reconstructed from geophysical indicators of climate conditions, such as tree ring characteristics and chemical composition of polar ice cores and ocean corals, indicate that, at least in the Northern Hemisphere, the twentieth century was the warmest of the past millennium, the 1990s the warmest decade, and 1998 the single warmest year (Figure 1).

Attributing the changes in climate of the past century to specific causes, however, is a more complex challenge. There is increasing evidence that internal variability within the climate system can cause significant oscillatory shifts in climate that can last for at least several decades. Natural causes of climate change, particularly the effects of variations in solar intensity over time periods of decades and centuries or longer and the large eruptions of volcanoes, which release sunlight-filtering aerosols into the atmosphere, can also cause climates to vary with time. Finally, there is increasing evidence of changes in the compositions of the atmosphere due to human emissions of greenhouse gases (which heat the planet) and aerosols (which tend to cause surface cooling). Concentrations of CO_2, for example, have increased by 31 percent since pre-industrial conditions, while that for methane has more than doubled.

These possible causes of climate change, whether natural or human-induced, are referred to as climate forcings. To help sort out this complicated interplay of different climate forcings, scientists turn to the combination of statistical analysis of observed climate data and computer simulations of the climate system. The latter use fundamental laws of physics and chemistry and advanced mathematics to replicate how the various components of the climate system interact and respond to changes and are first tested against climate observations to assess their performance. Once the models can realistically reconstruct current climate behaviour, they can then be used to both study past climates and project how future climates might change due to changing climate forcings. The results of studies into the behaviour of the climate over the past century using these tools suggest that the changes in the early part of the twentieth century were likely due to a combination of increasing solar intensity, increasing greenhouse concentrations and possibly reduced volcanic aerosol concentrations due to paucity of major volcanic eruptions during that time period.

1 Dr. Henry Hengeveld is a scientist with the Meteorological Service of Canada, a branch of Environment Canada.

However, for the last 50 years, it now seems likely that most of the warming has been caused by human factors. Furthermore, these changes appear to be unprecedented in at least the past millennium.

Projecting our Future Climate

Atmospheric scientists use the same computer models, together with other assessment tools, to project how climate may evolve over the next century or so in response to continued human interference with the climate system. To do so, they must address three key questions: how will the evolution of human society affect greenhouse gas and aerosol emissions?; how will these emissions alter the composition of the atmosphere?; and, how will such atmospheric change alter the climate?

To address the first question, experts use integrated economic, social and physical models to estimate future trends in greenhouse gas and aerosol emissions in response to a range of plausible changes (regional and global) in five key socio-economic variables: population, economic growth, energy efficiency, technology and land use activity. Out of 40 some possible futures that have emerged out of recent analyses (known as SRES scenarios) six representative scenarios are used for further scientific investigation and as references for policy discussions. Global carbon budget models and similar models for other greenhouse gases and aerosols are then used to estimate how these six scenarios will alter the composition of the atmosphere. For CO2, for example, they suggest that, without climate policy initiatives to mitigate emissions, concentrations by 2100 will almost certainly be twice pre-industrial levels, and could triple.

Finally, the projected changes in atmospheric composition can be applied to climate models to estimate how the climate may change over time. Results suggest that, within the next 100 years, global average temperatures are almost certain to increase by at least 1.4°C, and could rise by 5.8°C. Even the lower limit would be unprecedented in at least the past 10,000 years. At the upper limit, the magnitude of change would be similar to that between the peak of the last glacial maximum some 25,000 years ago and today, but at rates of change several orders of magnitude greater.

Projected climate changes during the next century involve much more than a simple increase in average global temperatures. While models disagree on the details of the regional characteristics of future climates, they agree on several key points: continents will warm more than oceans; high latitudes will warm more than low latitudes; and warmer temperatures means a more active hydrological cycle, with both greater evaporation and precipitation. The altered map of temperature distribution around the world in turn causes changes in wind currents (which are driven largely by temperature patterns) and hence in the distribution of rainfall. Most models also predict that ocean circulation in the North Atlantic will slow down, causing a slower Gulf Stream and possible cooling in the northwest Atlantic, and that interior continental regions of the Northern Hemisphere will become drier in summer. Thermal expansion of ocean waters as they warm, together with melting ice on land, will add to ocean levels by some 9 to 88 cm by 2100, and more in subsequent centuries (even if the climate begins to stabilize).

Impacts of Climate Change

Climatologists use a variety of analysis tools to assess how such changes might affect people and ecosystems. Because the details of future climate change remain rather fuzzy, particularly at the regional and local scale where the impacts of climate change are especially important, such studies can only give an approximate sense of possible impacts, and results must still be used with caution. These suggest, however, that the consequences will be unevenly distributed, with wealthier countries in temperate to cool latitudes least troubled and tropical regions and small islands, where many of the world's poorest nations are located, much more likely to be faced with danger. A one metre sea level rise, for example, could threaten the very existence of small island states such as the Maldives or Tuvalu, and displace many millions of people in countries with heavily populated coastal regions, such as Bangladesh, China, Japan and Egypt. Projections also suggest risks of decreased food production in tropical countries, many of which already face food shortages and have low adaptive capabilities. For these countries, almost any significant change in climate can substantially increase the risk of disaster.

However, for Canada, like other cold region countries, climate change will provide both benefits and liabilities. Warmer temperatures, for example, mean less harsh winters and longer and warmer summer growing seasons, with their attendant benefits. Offsetting these are the risks of dryer summers, lower lake and river levels in the south, risks of increased intensity and severity of extreme weather, and the gradual mismatch between slow moving ecosystems and the prevailing climate. Hence some regions and some economic sectors will benefit, and others will lose. Anticipation and preparation for these changes (that is, adaptation) can further help to maximize the benefits and minimize the losses. IPCC analysts estimate that, for countries like Canada, the net economic impact of climate change will be unlikely to exceed those due to other socio-economic factors as long as global temperatures changes within the next century do not exceed 2°C to 3°C. Above this level, the rate of change is likely to be too rapid for effective adaptation, and significant net losses may result.

Slowing Down Climate Change

In 1992, nations around the world signed on to the United Nations Framework Convention on Climate Change. It includes an ultimate objective of stabilizing atmospheric concentrations of greenhouse gases at a level that would prevent dangerous human interference with the climate system. Studies suggest that, to achieve such a goal, greenhouse gas emission levels at a global scale would eventually need to decrease to some 50 percent below current levels. In 1997, developed nations party to the Convention agreed, under the Kyoto Protocol, to take the first small step towards that goal by collectively reduced their emissions by 5.2 percent below 1990 levels by 2010. However, full implementation of the Kyoto Protocol agreement would only delay attaining the various climate change thresholds of the future by a decade or so. Even if the international community were able to eventually reach agreement on how to fully stabilize concentrations at below a doubling of pre-industrial CO_2 (a major challenge for technological change towards an almost totally renewable energy future), models suggest the earth would still likely warm by 2°C to 3°C. In other words, it is too late to stop climate change. This is a reminder that adaptation to climate change must be a key part of response strategies.

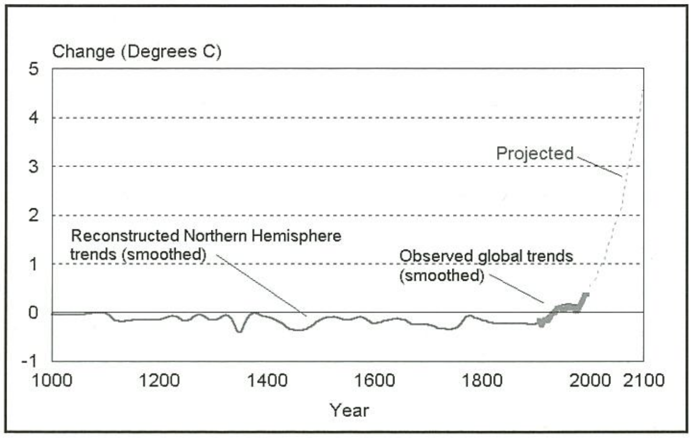


Figure 1. A composite graph showing past and projected trends in average global temperatures. Thin solid line is smoothed pattern of change over the past millennium reconstructed from proxy data, thick sold line is instrumental data for the past 140 years, and the dashed line represents Canadian model projections for the next century.

However, reductions of global greenhouse gas emissions can slow down the rate of climate change, thus buying more time to prepare for and adapt to the changes. To do so within a time frame that would not jeopardize the well-being of future generations will require international statesmanship that places the interest of these generations at par with those of today, that recognizes that, in an increasingly interactive global village, a disaster anywhere in the world also affects the rest of the world, and that measures to protect the environmental well-being of our planet can also be measures that make economic sense. Such statesmanship, in a democratic world, also demands a supportive electorate – something that still seems to be largely absent in North America. Perhaps it is indeed time for the science community to make a fuss!

Hydrogen Production, Nuclear Energy and Climate Change

by Romney B. Duffey[1] and Tabitha G. Poehnell[2]

Ed. Note: *The following paper was presented at the 22nd CNS Annual Conference held in Toronto, Ontario, June 10 - 13, 2001.*

Abstract

Present nuclear power plants (NPPs) are reliable, efficient and cost-competitive power producers. The Next Generation NPP design concepts will produce power cost-competitively well into the 21st Century. Currently, the use of nuclear energy is projected to decline in the United States, Canada and Europe, and to increase in Asia, the Pacific-Rim and other rapidly developing regions. Fluctuating rising fuel and energy costs, and concerns about finite energy supplies, however, have brought renewed focus on the contribution of nuclear energy to sustainable global development.

Despite Herculean efforts to adopt alternate energy strategies without damaging the national or global economies or energy-intensive industries, harmful global emissions of greenhouse gases (GHGs) are projected to increase.

We show the potential contribution of nuclear energy in reducing GHG's from the generation of electric power and from transportation, owing to the production of hydrogen fuel by nuclear energy. By analyzing the impact on the Intergovernmental Panel on Climate Change's 2000 global scenarios and altering the scenarios to incorporate recent cost reductions in nuclear power, we show the direct benefits of the nuclear energy contribution in reducing GHG and transportation emissions. The results indicate the possible large contribution of nuclear energy to sustainable energy use, and the effects on both managing and avoiding potential climate change.

"Forget gas, this is an environmental revolution"
Ottawa Citizen January 26, 2001

1. Switching to Hydrogen for Zero Carbon Dioxide Emissions: Does It Make Sense?

Energy fuels the world's economic growth. Fluctuating and rising energy prices, regional power shortages, predicted increases in global emissions and resulting climate change, all point to a vital need for safe, secure, cheap and sustainable energy sources. To reduce GHG emissions humans must use alternative (non-carbon) energy sources to feed their global energy appetite. Nuclear energy is a cheap energy source, and today provides 7% of world energy use and 17% of total electricity generation [1]. Hydrogen is now receiving a great deal of attention from the auto manufacturers for use in the automobile, either in a fuel cell or in a modified internal combustion engine. The manufacturer's intent is to produce a "zero emissions" vehicle, since hydrogen is clearly recognized as a pollution-free fuel whose low-temperature combustion produces only water:

$$2H_2 + O_2 = 2H_2O \qquad (1)$$

Currently, hydrogen is usually produced in industrial quantities by steam-methane reforming (SMR) according to the reaction:

$$CH_4 + 2H_2O = 4H_2 + CO_2 \qquad (2)$$

The byproduct carbon dioxide (CO2) is discharged freely to atmosphere, thus adding to atmospheric greenhouse gas (GHG) concentrations. The motive power of hydrogen as a transportation fuel has been well demonstrated at a full-scale level using hydrogen in fuel cells to produce electricity. So the potential application of hydrogen as a transportation fuel has been proven and the full cycle is:

$$2H_2O + \text{electricity in} \longrightarrow 2H_2 + O_2 \longrightarrow 2H_2O + \text{electricity out} \qquad (3)$$

The overall efficiency of the process is fairly low (the efficiency of electricity production times the efficiency of electrolysis cells ~ 25%), but hydrogen electrolysis is a direct cycle without intermediate steps, has negligible emissions, recyclable by-products and a limitless supply of a sustainable fuel (water). The only real technical (as opposed to social, political or infrastructural) challenge is to reduce the cost of producing the hydrogen. When one analyses the CO_2 produced from all activities required to produce an energy source, both nuclear and renewable energy sources have life-cycle emissions of 1-2% of those from carbon-based fuels, and are on the order of ~10 gCO_2/kWh, which are clearly negligible. So this technological option for hydrogen production is sound, sustainable

1 Atomic Energy of Canada Limited, Chalk River, Ontario
2 Atomic Energy of Canada Limited, Mississauga, Ontario

and environmentally attractive.

2. The Source of Electricity: What is the Cost?

We may set the use of electricity, production of hydrogen and avoided carbon emissions targets.

As noted above, there are two effectively zero emission sources for the electricity: nuclear and renewable energy. Renewable proponents argue that solar photovoltaics and wind turbines operated in conjunction with electrolysis cells are a hydrogen fuel source that can be distributed fairly efficiently, since their large land use (low energy intensity) favors distributed renewable generation. The unreliable and variable nature of the wind and sun mean that energy storage, batteries, back up generators, and/or an electric grid are also needed for alternate supply, reverse metering and electricity supply.

Reviewing the data we see that electrolysis requires ~50 kWh/kgH_2 [2], so with the lowest cost wind power at ~4¢ CDN/kWh (as for a typical power contract) which with a capacity factor of 40% or less, implies an effective hydrogen cost of:

$$50\ \frac{kWh}{kgH_2} \times 0.04\ \frac{\$CDN}{kWh} \times 1000\ \frac{kgH_2}{tH_2} \times \frac{1}{0.4} = \sim\$5000\ CDN/tH_2 \quad (4)$$

For a nuclear plant at ~3 ¢CDN/kWh (the current Next Generation target and close to the actual generating cost in the U.S. and Canada) with a capacity factor of 80%, this implies an effective cost of:

$$50\ \frac{kWh}{kgH_2} \times 0.03\ \frac{\$CDN}{kWh} \times 1000\ \frac{kgH_2}{tH_2} \times \frac{1}{0.8} = \sim\$1875\ CDN/tH_2 \quad (5)$$

Using off-peak power for both nuclear and wind options can reduce these electricity (and subsequently hydrogen) costs by a factor of two or more, bringing hydrogen costs into the range of \$900 to 2500 CDN/tH_2, respectively.

The excess, or differential cost of this non-carbon hydrogen production over the hydrogen cost using conventional SMR is the cost or trading value of the avoided CO_2. This is a cost, at peak power, in the order of \$600 - \$3800 CDN/tH_2, for nuclear or wind generated electricity respectively and it is also already competitive for off-peak power. A typical hydrogen fueled vehicle using 0.4 kgH_2/d/vehicle needs 146 kgH_2/y/vehicle, which in turn avoids ~5 tCO_2/y/vehicle. The lowest avoided carbon cost, for peak power, is then ~\$44/y or ~\$9/tCO_2 avoided, for nuclear electricity. This value is a very reasonable market number in a carbon credit-trading scheme if such a scheme were ever to be adopted. Even for wind power, the avoided carbon cost is ~\$54/tCO_2, still not an unreasonable value.

Therefore, there are no insurmountable economic barriers to the technology, other than the actual will to begin implementation of hydrogen's displacement of the existing carbon-energy based economy.

3. Nuclear Energy Reduction in Global Emissions: How Soon?

A key question is how soon do humans have to start using hydrogen as an alternative transportation fuel if the switch is to have an impact on the global GHG emissions stemming from the use of carbon fuels for electrical energy production and transportation.

The Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES) [3] has recently published a large range of future energy and emissions scenarios, that show a large growth in energy use and potential adverse climatic impacts. Since the future is uncertain, the IPCC carefully avoids endorsing any given set of assumptions or scenarios. One thing is clear: to reduce GHG emissions, and consequently, the threat of adverse climate change, a large switch (>60%) to non-carbon energy sources is required. For most of the scenarios the use of nuclear energy and renewables are both assumed to increase in an effort to avoid adverse climate change as the 21st Century unfolds.

We can estimate how, through the use of nuclear energy, global emissions can be reduced even further than the levels predicted by the IPCC scenarios. Unfettered by artificial policy constraints to quantify the full nuclear potential, we may analyze many options. Our preferred scenario is the IPCC B2 case. In our judgment this appears to be the most realistic reflection of possible global future economic and energy path. Case B2 is largely an extrapolation of the carbon-rich past (Figure 1), not requiring or assuming any major shifts in economic and energy growth, technology innovations or energy use patterns.

Predicted Global Economic Growth and Energy Use
(Historical projection 1987-1998 and IPPC 2000-2100 future scenarios)

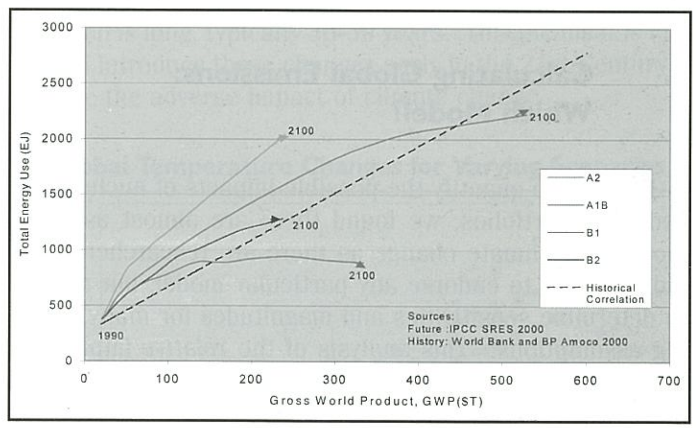


Figure 1: Typical IPCC global energy-economic scenarios for the 21st Century, and the historical path from 1987 to 1998 projected to 2100 [data from [3]]

Nowhere in the IPCC scenarios do they consider the effect of large-scale nuclear penetration in the energy markets (~80%), or large-scale adoption of hydrogen fuel switching in transportation. We decided to conduct precisely that calculation for the plausible nuclear plus hydrogen (N+H2) scenario.

We assumed and can justify adopting 80% as the maximum nuclear electric penetration based on the target CANDU generating cost with an *advantage* exceeding 2 ¢US/kWh [4] compared to Integrated Gas Combined Cycle (IGCC) and coal plants at 7.8 to 8.6 ¢/kWh [3] (excluding fuel costs). This should be compared to the IPCC nuclear Levelized Unit Energy Cost (LUEC) estimate (largely based on Light Water Reactors (LWRs)) of 7.2 - 9.7 ¢/kWh (SRES Table 4-13b, [3]). When compared to IGCC and coal, these costs and a >1 ¢/kWh cost *disadvantage*, which hence severely limits nuclear and wind deployment. The Next Generation nuclear cost reduction targets (as taken from the DOE Generation IV requirements [5] gives nuclear a >4 ¢/kWh advantage. Similarly wind power has a >3 ¢/kWh advantage. Thus, the 80% potential electric market penetration was assumed to occur by 2020 using advanced (i.e., Next Generation CANDU) nuclear technologies with a cost advantage of >3 ¢/kWh. For the same scenario a significant renewable contribution is also occurring.

As a test or limit case, we took the maximum for the hydrogen fuel switching as 80% of the transportation energy use; transportation energy was assumed to be ~20% of carbon energy use. The hydrogen fuel switching was assumed to begin by 2020 and its maximum use for transportation energy by 2040, based on the expected development of fuel cell vehicles, fleet turnover rates, and carbon fuel prices.

These timeframes are clearly relevant to making an impact on 21st Century climate change scenarios and therefore worthy of further quantification.

4. Calculating Global Emissions: Which Model?

In order to quantify the possible impacts of nuclear and hydrogen portfolios, we found there are almost as many models for climate change as there are researchers. We did not want to endorse any particular model, but needed to determine sensitivities and magnitudes for many differing assumptions. This analysis of the *relative* impacts of differing nuclear and hydrogen portfolios can be pursued using the climate change freeware MAGICC/SCENGEN Version 2.4 [6] which was developed for the express purposes of "vulnerability and adaptation assessments" by Wigley and co-workers. This software is a very useful and powerful scoping tool.

To determine the relative impacts, we ran all the major IPCC marker scenarios (A1B, A2, B1 and B2) and two additional IPCC scenarios (A1FI and A1T) in MAGICC, and then adapted the energy inputs for the conbined assumption of increased nuclear electricity and hydrogen fuel use. The penetration fractions for the energy markets and technology timescales were as assumed in Section 3 above, and 30% of renewable energy was contributing to the electricity market.

It is entirely reasonable to perform such comparative analyses to determine the potential for actually reducing the projected IPCC climate change and GHG emissions increases.

5. Results: What are The Emissions Reductions?

Analyses were performed using MAGICC for all six of the main IPCC scenarios (A1B, A1F1, A1T, A2, B1, and B2) since between them the spectrum of alternate energy use futures is covered. The reduction in GHG emissions was significant, as the fraction of carbon energy use decreased. This reduction was not unexpected since we had found that for all the IPCC scenarios the relation between CO2 emissions and carbon energy use was linear at high confidence, i.e.,

$$\text{Emitted CO2}\left(\frac{\text{GtC}}{\text{y}}\right) = 0.02 \text{ x Carbon Energy (EJ)} \qquad (6)$$

However, this type of linear relation was found not to hold true for other GHG emissions (e.g., methane (CH4), SOX and NOX).

Assumptions made for the overall global analysis include:

1) 5% of transportation energy using hydrogen fuel introduced by 2020
2) 80% of transportation energy using hydrogen fuel introduced by 2040
3) 20% of carbon energy is used for transportation worldwide, and
4) 80% of electricity will be produced by either nuclear or renewables power by 2020.

Item three above is derived from the IPCC SRES [3]. Additional nuclear energy proportionally reduces the use of all three of the carbon energy sources (coal, oil and natural gas), and no changes from the deforestation data is given in the scenarios. There is no double accounting in a given scenario for either nuclear power or hydrogen energy already being produced by nuclear power.

Our results show that the introduction of increased nuclear use and nuclear generated hydrogen fuel will result in a decrease in overall GHG emissions. There will still be a net increase in GHG emissions over the next century, however. In several scenarios (especially the IPCC 2000 scenarios that focus on technology improvements and environmental issues) the increased use of nuclear and the use of nuclear generated hydrogen fuel helped to stabilize the atmospheric concentrations of GHGs and contributed to the reduction of CH_4 concentrations (Figure 2). The impact of the increased nuclear usage and hydrogen fuel resulted in a decrease of the atmospheric concentrations of CO_2 by up to ~100 ppmv by 2100 for the marker scenarios (even more for the more extreme scenario A1FI) compared to the original scenarios.

Atmospheric Methane Concentrations for Varying Scenarios

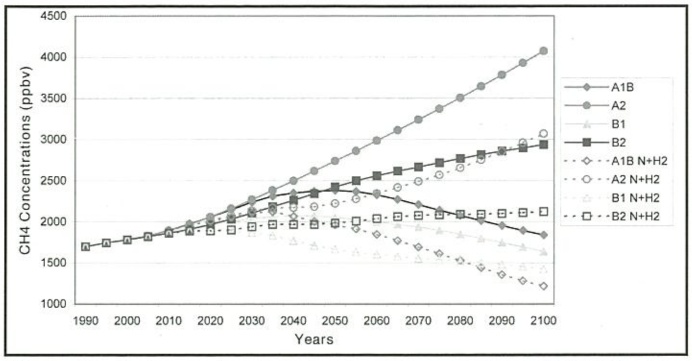


Figure 2: Estimated atmospheric concentration of CH4 for the original IPCC marker scenarios and the scenarios that assume an increase in nuclear power and the introduction of hydrogen fuel produced by nuclear energy (shown by the "N+H2" lines).

The typical results for the four IPCC marker scenarios, including reference case B2, are shown in Figure 3. Scenarios for the projected nuclear and hydrogen technologies are also shown.

Atmospheric Carbon Dioxide Concentrations for Varying Scenarios

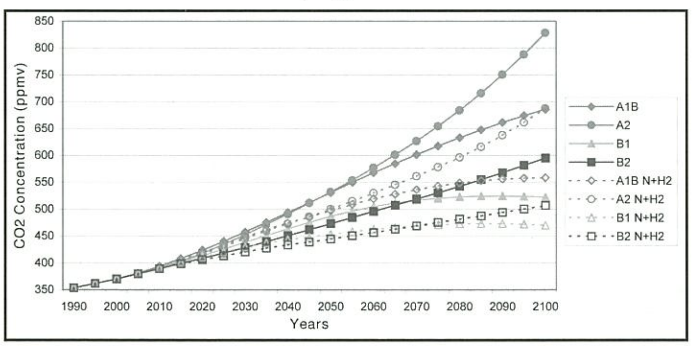


Figure 3: Estimated atmospheric concentration of CO2 for the original IPCC marker scenarios and the scenarios that assume an increase in nuclear power and the introduction of hydrogen fuel produced by nuclear energy (shown by the "N+H2" lines) analysis.

The reduction in sulfur dioxides (SO_X) with nuclear and hydrogen energy use is also environmentally significant, and an example of the potential reduction was produced for scenario B2, shown in Figure 4. We conclude that there is indeed a large and quantifiable reduction in emissions due to the combination of the introduction of nuclear produced hydrogen fuel for transportation and the increased use of nuclear energy to meet future energy needs. In conjunction with other non-carbon energy sources, that reduction is extremely helpful in mitigating and managing total atmospheric concentrations and in enabling sustainable growth in energy use.

Total SOx emissions reduction IPCC scenario B2

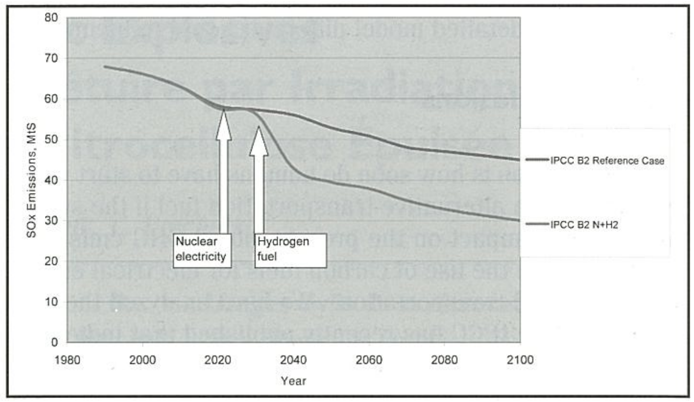


Figure 4: Typical reduction in emissions for the advanced nuclear and hydrogen fuelled transportation (N+H2) scenario (green lower line) using IPCC scenario B2 as the base case (red upper line).

In regards to climate change, the analyses are somewhat more uncertain due to the complexities of the issues and the limitations of the models. However, it can be said that the nuclear plus hydrogen future scenario reduces the estimated global warming up to 30% of the projected rise, but more importantly, by 2100 the combined assumption scenario helps to stabilize the temperature increase (Figure 5) in several of the scenarios. The time lag from when the global energy use changes are introduced to when the beneficial impact on the atmospheric CO_2 concentrations is realized is long, typically 30-50 years. This means it is critical to introduce these changes early in the 21st Century to reduce the adverse impact of climate change.

Global Temperature Changes for Varying Scenarios

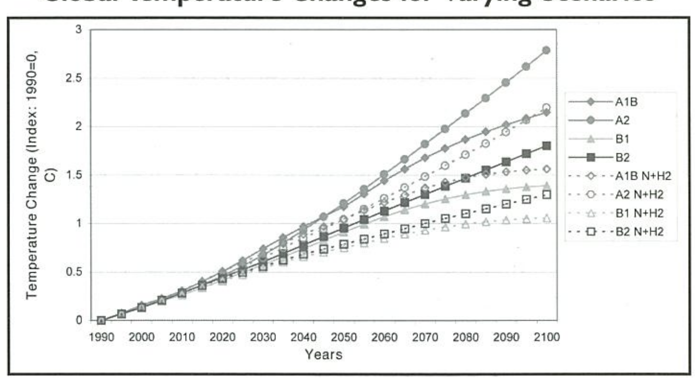


Figure 5: Estimated temperature increases for the original IPCC marker scenarios and with an increase in nuclear power and the introduction of hydrogen fuels produced by using nuclear energy (shown by the "N+H2" lines).

This analysis confirms the large potential impact of both increased nuclear usage and an introduction of nuclear produced hydrogen fuel for transportation; however, this analysis used only one particular numerical model (MAGICC). There are many variations in both global climate change factors and emissions models. However, we expect the trend of reduced emissions to be real, and the relative impacts and trends have been found to be largely unaffected by detailed model differences and refinements.

6. Conclusions

A key question is how soon do humans have to start using hydrogen as an alternative transportation fuel if the switch is to have an impact on the present global GHG emissions stemming from the use of carbon fuels for electrical energy production and transportation. We have analyzed the scenarios that the IPCC has recently published that indicate a large growth in energy use and potential climatic impacts. Nuclear energy and renewables are both assumed to grow in use to avoid climate change as the 21st Century unfolds.

We have estimated a greater potential for nuclear energy to reduce global emissions above and beyond what the IPCC has estimated. Unfettered by artificial policy constraints to quantify the full nuclear potential, we did not want to endorse any particular model, but to determine sensitivities and magnitudes for many differing assumptions. We used a consistent set of market energy cost advantages for nuclear energy and Next Generation nuclear designs, and also examined the impact of large-scale fuel switching to hydrogen.

The results show that even though the increase in nuclear power and introduction of hydrogen fuel results in a decrease in GHG emissions, there will still be a net increase in GHG emissions over the next century. In several of the scenarios (especially the IPCC 2000 scenarios that focus on technology improvements and environmental issues) the use of nuclear energy and hydrogen fuel contributed to stabilizing the GHG concentrations and to actually reduce SO_X emissions and CH_4 concentrations. The potential impact is ~100 ppmv reduction, from the base case, in CO_2 by 2100, and a significant reduction in other emissions. The timescale needs to be relatively short (~20 years) for the large-scale introduction of advanced nuclear technology and hydrogen fuels, as well as the contribution from other renewable sources. The potential contribution of nuclear and hydrogen energy sources to stabilizing global emissions is calculated to be significant, and also larger than previously estimated by the IPCC. We expect this result to be largely independent of the exact global model chosen.

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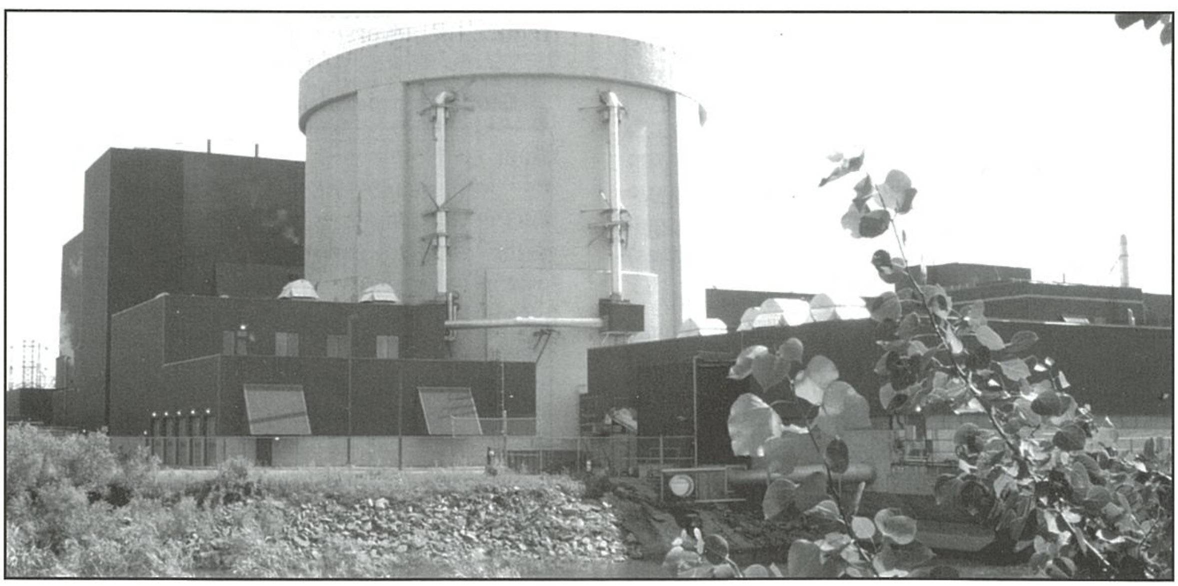

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The Design of An Irradiation Facility for The Destruction of Spent Nitrocellulose Plastic Explosives
Désign D'une Installation pour Détuire par Irradiation Les Explosifs Plastiques Fait en Nitrocellulose Épuisée

by J.O.A. Kim, M. L'Italien, P. Nault, C. Prechotko[1]

Abstract

Nitrocellulose samples were irradiated in the SLOWPOKE-2 reactor to determine the required dose to lower the nitrogen content from 13% to 11%. That weight content of nitrogen in nitrocellulose permits recycling of nitrocellulose while neutralising the explosive characteristics of the polymer. The lowering of the nitrogen content was detrmined using a Nicolet FT-IR. The lowering of the areas under the peaks corresponding to the NO_2 groups were measured and related to the content of nitrogen in the molecule. That enabled us to estimate the dose required to lower the nitrogen content in the nitrocellulose. A facility capable of delivering 1.85 kGy of gamma irradiation to the spent nitrocellulose propellant was designed, using Cobalt-60, a radioisotope that decays through emission of gamma photons. The facility design incorporated a batch process, which irradiated twelve nitrocellulose filled aluminum tote boxes per batch. The tote boxes were designed to be of 52cm x 50cm x 20cm (length, height, thickness) in dimensions, and were optimized in geometry for high dose uniformity and low cycle time. The facility incorporated radiation shielding to protect the surrounding environment and personnel from the harmful gamma radiation emitted during irradiation processing, including an above ground concrete enclosure, and a underground water filled pool. With a total source activity of 3.70 x 10^{15}Bq, the facility would be able to process 8.58x 103 metric tons of nitrocellulose per year.

I. La Nitrocellulose

A. Synthétisation de la nitrocellulose

La nitrocellulose est produite de plusieurs façons. La plus courante est de la synthétiser à l'aide d'hémicellulose, qui est trouvée dans le bois naturel, et avec de l'acide nitrique (HNO_3) et de l'Acide sulfurique (H_2SO_4). La molécule de cellulose n'a que trois sites où la nitratation est possible. Par conséquent, la fraction massique maximale d'azote à l'intérieur de la molécule de nitrocellulose est de 14,14%.

B. Usages civils de la nitrocellulose

La nitrocellulose a plusieurs applications. Elle peut être utilisée dans les industries de peintures, de laques et dans l'industrie des cartouches sportives [1]. En général, pour ces applications, on utilise de la nitrocellulose qui a une teneur en azote entre 10,9% et 12,0%.

C. Usage militaire de la nitrocellulose

Le premier usage historique de la nitrocellulose a été pour la fabrication de poudres à canon. Cet usage découle du fait que la nitrocellulose qui a une teneur en azote de plus de 12,0% possède des caractéristiques explosives très intéressantes. pour des applications militaires. En effet, la nitrocellulose à teneur d'azote élevée possède une très haute énergie de combustion, alors qu'elle est facile à produire et à entreposer. La nitrocellulose fait encore partie de plusieurs propergols militaires à ce jour dans les Forces canadiennes.

1. Problèmes associés à l'usage militaire de la nitrocellulose

La nitrocellulose à teneur élevée en azote est très instable. Si la poudre n'est pas mouillée, la nitrocellulose peut devenir explosive à la moindre étincelle. Lorsque la nitrocellulose à teneur élevée en azote est produite à des fins militaires, on y ajoute des additifs afin de stabiliser la molécule et pour avoir les qualités explosives recherchées. Après un nombre d'années déterminés, la nitrocellulose devient périmée, et elle doit être détruite.

D. Méthodes actuelles de destruction de la nitrocellulose

Plusieurs méthodes de destruction de la nitrocellulose périmée existent. La méthode couramment utilisée dans les Forces canadiennes est la combustion à ciel ouvert.

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Plusieurs problèmes existent avec cette méthode. Premièrement, la combustion de la nitrocellulose produit des gaz toxiques à l'environnement, tel le NO_x et le CO_2. Deuxièmement, le transport de la nitrocellulose pose un autre problème, car les explosifs deviennent moins stables avec l'âge, et un accident de la route pourrait avoir des conséquences dangereuses. Une autre méthode envisagée par les Forces canadiennes est la combustion de la nitrocellulose périmée dans un four. Cette méthode est avantageuse parce que tous les produits de la combustion sont recyclés et traités, donc l'environnement est protégé. Par contre, cette méthode est très coûteuse.

E. Méthode proposée de destruction de la nitrocellulose périmée

La méthode que nous proposons afin de se débarrasser de la nitrocellulose périmée est l'irradiation des stocks. En effet, des expériences précédentes ont démontré que sous l'effet de radiations gamma, la teneur en azote de la nitrocellulose diminuait. Il serait donc possible d'irradier les stocks de nitrocellulose périmée afin d'abaisser leur teneur en azote, et ainsi les rendre recyclable. Cette méthode a l'avantage d'abaisser dramatiquement les gaz toxiques émis en atmosphère, tout en trouvant un usage alternatif à la nitrocellulose.

II. Expérience

A. Méthodologie

Le but de l'expérience était de calculer la dose nécessaire pour abaisser la teneur en azote de la nitrocellulose en bas de niveau explosif, c'est-à-dire en bas de 12,0%. Pour ce faire, de la nitrocellulose mouillée à 13,1% de teneur an azote fût séparé en 40 échantillons. Il fût jugé nécessaire d'étudier l'effet du poids de l'azote sur la dénitratation par irradiation. Donc, 5 échantillons de 0,15 g et 5 échantillons de 0,3 g furent irradiés pendant 10, 15 et 30 minutes. 5 échantillons de chaque masse furent également irradiés à puissance réduite pendant 10 minutes. Les échantillons furent ensuite analysés à l'aide d'un spectrographe FT-IR, et la teneur en azote fût déduite après irradiation.

1. Procédure expérimentale

Les échantillons furent pesés, puis mis en capsules et ensuite insérées dans un support spécialement conçu. Le support fût descendu dans la piscine du réacteur SLOWPOKE-II au Collège Militaire Royal du Canada, et furent laissé pendant la période de temps déterminée. Le support fût ensuite remonté à environ mi-chemin dans la piscine et laissé reposer pendant une période d'environ 48 heures, afin d'éliminer les produits radioactifs qui auraient pu se former à l'intérieur de nos échantillons. Les échantillons furent ensuite dissous dans du Tétrahydrofurane (THF) à 0,5% pour en faire l'analyse à l'aide d'un spectrographe FT-IR. Les spectres obtenus après l'analyse furent examinés à l'aide du programme d'ordinateur *Peak-fit* afin de mesurer l'aire sous la courbe de deux pics. Les pics à 1660 cm^{-1} et à 1284 cm^{-1} furent choisis, car ils sont représentatifs de la présence de NO_2 dans la molécule. Le pic situé à 1660 cm-1 correspond à la région d'absorption asymétrique des groupes NO2. Cette région varie normalement entre 1661 cm^{-1} et 1499 cm^{-1} et dépend de la substitution et de l'insaturation du groupe NO_2. Le pic à 1284 cm^{-1} quant à lui correspond à la région d'absorption symétrique des groupes NO_2. Afin de déterminer le taux de nitration dans nos échantillons irradiés, deux techniques furent utilisées. La première consiste à fabriquer une courbe de calibration en analysant plusieurs échantillons de nitrocellulose non-irradiée et de construire une courbe de calibration avec ceux-ci. La nitrocellulose non-irradiée fut diluée à différentes concentrations dans du THF et l'aire du pic représentant les groupes nitrates fut évalué. La loi de Beer-Lambert nous permet ainsi de porter en graphique l'aire du pic étudié en fonction de la concentration et de calculer le pourcentage d'azote d'un échantillon en sachant l'aire de son pic. La deuxième méthode fut de prendre plusieurs échantillons de nitrocellulose non-irradiée dissoute à un pourcentage donné (0.5% fut choisi). Une moyenne d'aire du pic des échantillons non-irradiés peut ainsi être faite et comparée avec nos échantillons irradiés pour déterminer la variation du pourcentage d'azote.

B. Résultats

Temps (min)	Taux d'azote (%N p/r au pic à 1660 cm^{-1})	Taux d'azote (%N p/r au pic à 1284cm^{-1})
10	7,76	9,67
15	14,28	15,08
30	9,07	7,94
10, puissance réduite	12,85	8,75

Ces résultats ont été obtenus à partir de la deuxième méthode d'analyse, c'est-à-dire celle de la comparaison avec un échantillon de 13,1% N à une concentration de 0,5% dans le THF.

C. Discussion

En analysant les résultats, il est remarquable que le taux d'azote semble augmenter après 15 minutes d'irradiation. En se basant sur les recherches accomplies précédemment [2], il est clair que cette situation doit être causée par une défaillance dans la procédure expérimentale. Il fût donc jugé nécessaire de ne pas tenir compte de ces résultats et de se concentrer sur les résultats obtenus après 10 minutes, 30 minutes et 10 minutes à puissance réduite. En examinant ces résultats, il devient clair que l'irradiation pendant 10 minutes à intensité réduite est la dose optimale pour l'abaissement de la teneur en azote de la nitrocellulose. Par contre, une dose exacte n'a pu être déterminée, à cause de la nature trop séparée de nos résultats. Pour cette étude, nous avons donc considéré qu'une dose de 1,85 kGy serait acceptable pour rendre la nitrocellulose en état d'être recyclée, c'est-à-dire avec un taux de nitration qui serait plus bas que 12,0%.

III. Radiosotope Selection

The radioisotope selected to provide the source of radiation was Cobalt-60, a radioisotope well known for its reliability as well as its safety in industrial applications such food irradiation. Cobalt-60 possesses many advantages as a source. Firstly, Cobalt-60 decays strictly through a beta and gamma decay chain that produces two gamma photons with each disintegration. The absence of neutron decay from the Cobalt-60 decay chain allows materials to be irradiated without imparting any degree of radioactivity to the processed material, and eliminates the need to store the processed products in a cooling facility in order to allow the products' imparted radioactivity to subside. Secondly, Cobalt-60 spontaneously produces two gamma photons at 1.33 and 1.17MeV with each radioactive disintegration. These two gamma photons are easily capable of passing through the nitrocellulose material and doing useful denitration work. Thirdly, with its convenient 5.24 year half life, a Cobalt-60 based irradiator would require little or no maintenance. In fact, it is feasible that the Cobalt-60 source could remain useful for up to ten years without any extensive maintenance, depending on the tolerances of the irradiation process and the preferences of the operator. Finally, Cobalt-60 is produced in Canada, and is locally availability through suppliers such as MDS NORDION, at a reasonable cost of $2.00 CAD/Currie. This makes Cobalt-60 based irradiation a highly economically attractive endeavour.

IV. Cobalt-60 Sources

The type of Cobalt-60 source selected for use in the irradiation facility is known as the C-188 source [3]. The C-188 is comprised of a stack of Cobalt-60 pellets that are doubly encapsulated into an inner cylindrical tube made of a zircaloy as well as a corrosion resistant outer tube made of ASTM 316 stainless steel. The C-188 is a rod shaped source that stands 451.5mm tall with a 11.1mm diameter. The activity[2] of each C-188 source can be custom manufactured to a maximum of 4.81×10^{14} Bq (13 kCi).

The C-188 source was selected for a number of reasons. Firstly, being a Canadian product, the C-188's are easier to procure than foreign sources since transportation and licensing would involve only one government. As well, the C-188 was selected due to its exceptional safety record that it has achieved over the past 35 years which has consistently meet IAEA[3], CSA[4], and ISO[5] specifications.

C-188 sources are not intended for use as stand alone sources, but rather they are intended for use as the building blocks of larger gamma irradiation sources, called source racks. Common arrangements of source racks include curtain-like arrangements, where irradiated products pass on either side of the curtain, or ring arrangements, where irradiated products pass through a tunnel made of C-188 sources.

V. Source Rack Configuration

The source rack configuration chosen was a 2 x 3 (two row by three column) arrangement of the sub-modules (Fig. 1). The 2x3 design geometry allows for simple calculation of the dose delivered to the nitrocellulose, since it can be represented as a large rectangular source that is the aggregate of the six sub-modules. The 2x3 configuration also incorporates geometric symmetry; a property which, when managed properly, allows to the operator to overcome problems of dose uniformity in the irradiated samples.

The total activity of the source rack was chosen to be 3.70×10^{15} Bq (100kCi), a relatively small amount of activity. The source rack's activity was chosen to be small, since nitrocellulose possesses a relatively low density (between 1.55-1.66 g/cm^3), and also requires a fairly small dose to achieve proper denitration (1.85 kGy).

VI. Tote Containers for Irradiation

Due to the symmetry inherent in the source rack configuration, simple rectangular totes were chosen as a means of containing the nitrocellulose during their irradiation processing. In order to maximize irradiator efficiency, it was decided to have twelve identical tote boxes, six totes on either face of the source curtain (Figure 2).

Ten diffferent tote geometries were devised and scrutinized using a series of Microshield 5™ simulations. The end goal of the tote simulations was to determine the optimum geometry to minimize the max-to-min dose ratio inside of the totes, as well as maximize processing rates. It should be noted that these dose rate simulations, using the ten tote configurations, were done in accordance with a mechanical tote interchange process where totes spend half of their irradiation time on one side of the source rack, and then are repositioned on the opposite side of the source rack for the rest of the irradiation time.

The behaviour of the ten different tote configurations in the dose rate simulations illustrated some very important trends. The first trend observed was that thinner totes corresponded to smaller max-to-min dose ratios along the z-axis of the tote. As well, the difference in the max-to-min dose rate ratio between the totes with 1600.0cm2 to those with 2500.0cm^2 of surface area exposed to the source rack was relatively small at smaller z-axis dimensions (smaller than 25cm), see Figure 3.

At Z-axis values smaller than 20cm, the difference observed in maximum-to minimum dose ratio values

2 units of activity: 1 Currie (Ci) = 3.7 x1010 Becquereles (Bq)

3 International Atomic Energy Agency

4 Canadian Standards Association

5 International Organization for Standardization

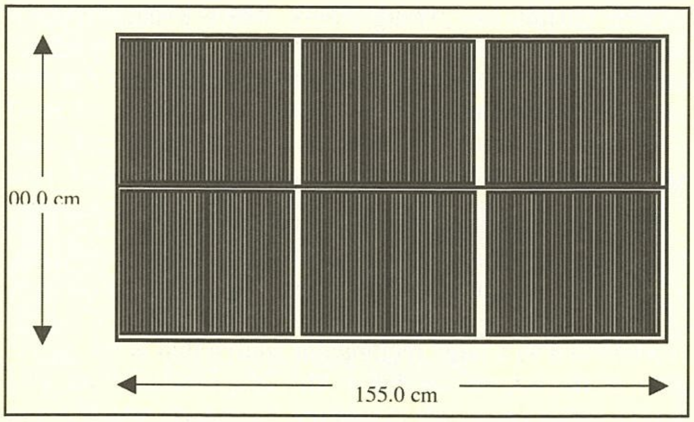

Figure 1 – The 2x3 Source Rack Design with Total Activity of 3.70 x 1015 Bq (100 kCi)

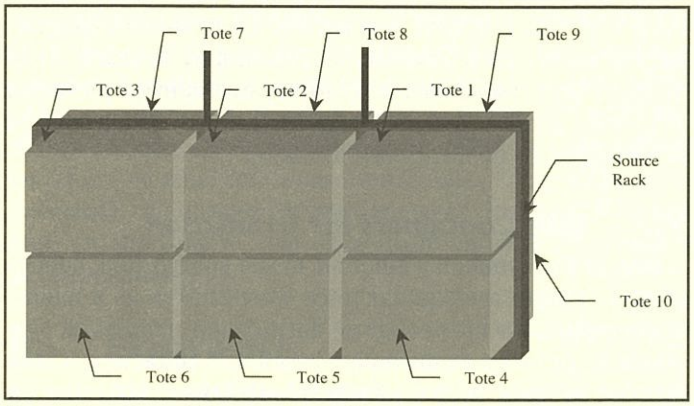

Figure 2 – Spatial Orientation of Tote Boxes with Respect to the Source Rack

between the two variant cross sections was minimal, however the corresponding difference in processing rate was of disproportionately large. For example at Z = 20cm, the max-to-min dose ratio values for the totes of cross sections of 1600cm2 and 2600cm2 were 1.85 and 1.88 respectively while the processing rates were 8.58x103 metric tonns/yr and 1.15x104 metric tonns/yr respectively (Fig 4).

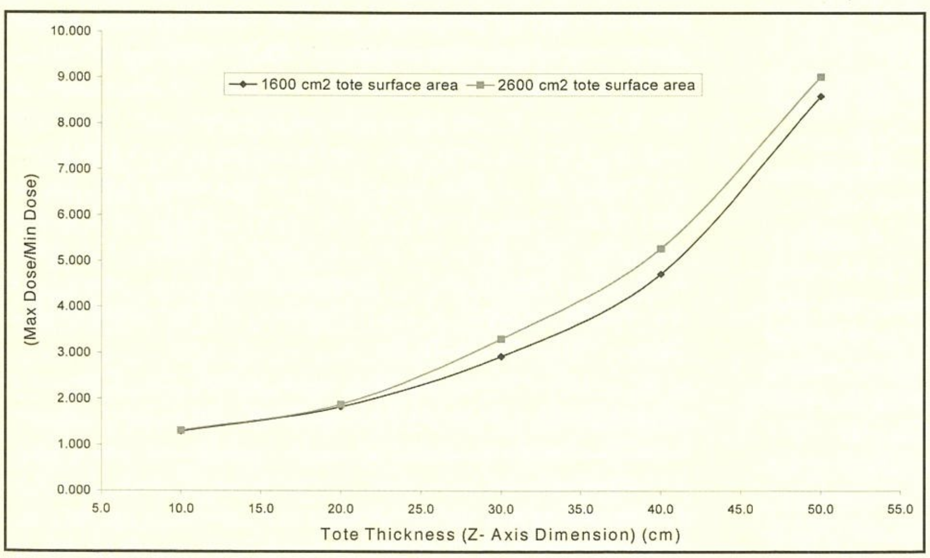

Figure 3 – (Max/Min) Dose Ratio as a Function of Tote Thickness

This large difference in processing rate has great economic repercussions that far outweigh any marginal improvement in dose uniformity. Since the irradiated nitrocellulose can be sold to manufacturers as a recyclable material, the rate at which the nitrocellulose can be processed translates into revenue rates. Therefore, since the nitrocellulose's processing rate reaches a maximum at a tote thickness near 20cm, the tote's thickness was selected to be 20cm. Thus the dimensions of each tote box was chosen to be 52 cm x 50 cm x 20 cm (X,Y,Z) respectively (fig 5)

With this tote configuration, the axis containing the largest maximum-to-minimum dose ratio gradient is still the Z-axis (Fig. 5). Thus if one determined that the tote arrangement lacked the appropriate dose uniformity as per required by a nitrocellulose recycler, a decrease in the tote's Z-axis dimensions would be in order (see Fig 6 & Fig 7)

VII. Radiation Safety Standards and Shielding

For the design of the radiation shielding of the facility, the authors endeavored to ensure that the shielding met the civilian requirement of 5mSv/year with a ten times safety factor. Thus shielding was designed such that the maximum allowable dose received by an individual standing directly outside of the shielding enclosure for the entire year would not exceed 0.5mSv. Shielding was thus built for a 1.480x1016 Bq (400 kCi) source.

Since the irradiator would operate as a batch process, shielding had to be designed such that no gamma radiation exposure could possibly occur when the batch's totes are being exchanged at the beginning and end of each cycle. In order to accomplish this, the source rack as well as a small section of the containment shielding was chosen to be a moveable. The movement of the source rack, at the beginning and end of each batch, thus called for the design of two sets of shields: one for when irradiation is occurring, and another for when the irradiator is not in use or undergoing source rack maintenance.

The simplest shielding solution for our facility would be an above ground/underground combination enclosure (Fig. 8 & Fig.9) to provide shielding for when the irradiator is in use, and when it is not in use. The centerpiece of the shielding arrangement would be an open air, water filled pool.

The movement of the mobile section of the facility's shielding and the tote boxes, would be accomplished through the use of a system of rails. This would also allow access into the irradiation inclosure at the beginning and end of each batch of irradiation processing.

The dimensions and specifications and schematics of each of the shielding enclosure's components were determined using a

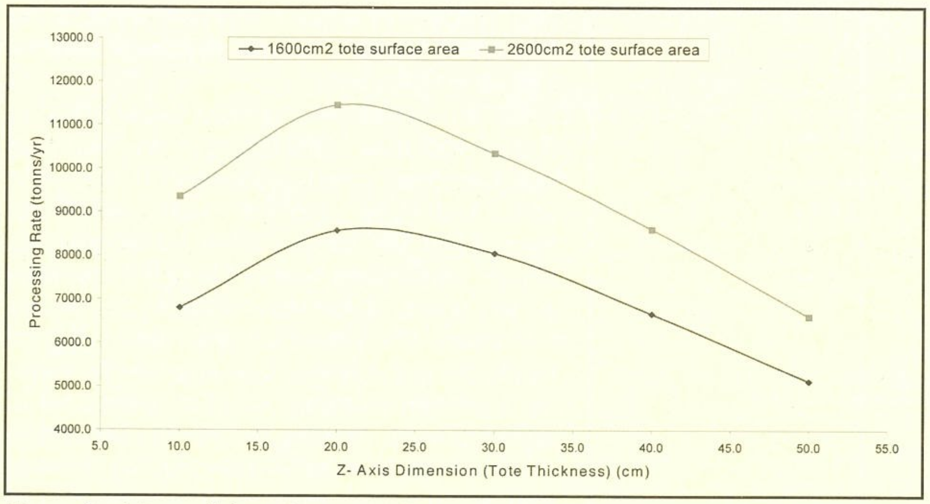

Figure 4 – Nitrocellulose Processing Rate as a Function of Tote Thickness

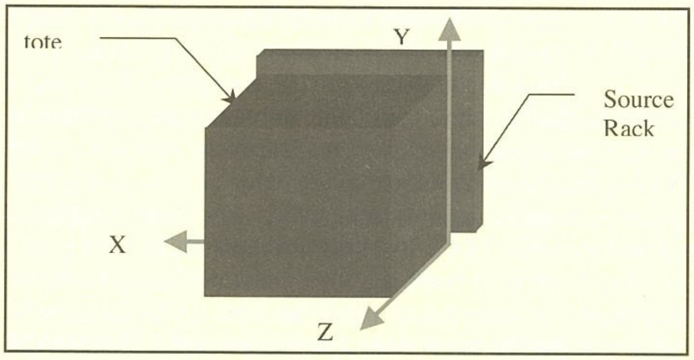

Figure 5 – Spatial Orientation of Tote Box used in Optimization Trials

series of Microshield 5™ calculations, and were omitted from this paper for the sake of brevety.

VIII. Process Quality Insurance Through Use of Dosimeters

The verification of dose uniformity and the quality of the irradiation processing during the operation of the facility needs to be performed on the outgoing processed materials, especially if the processed material were to be sold as recyclable materials.

An alternative to FTIR testing to determine the level of denitration would be to use commercially available Polymethylmetha-crylate (PMMA) dosimeters. Dosimeter manufacturers, such as Harwell Ltd. who manufactures the Perspex™ line of dosimeters, provide calibration curves which relate the irradiation doses as a function specific absorbance. Thus in order to determine the degree of denitration achieved during processing, a calibraion curve would need to prepared which relates the degree of denitration to dose. With this done, the determination of the level of denitration would be a matter of taking a simple specific absorbance reading (using a spectrophotometer) of a dosimeter that was in the same tote as the nitrocellulose of interest. It should be noted that the dosimeter method of quality assurance would offer a considerable cost advantage to the operators of the facility, as it significantly reduces the need for costly FTIR testing.

IX. Source Activity Decay & Irradiation Periods

The total activity of the source rack decreases as a function of time. This has practical implication on the operation of the facility. In order to compensate for this loss of activity, the users of the irradiator would need to increase the period of irradiation at regular intervals. Although recalculating the ideal irradiation period each day, or for each batch would be a simple task, implementing those changes on the production line would be somewhat more difficult a task. With each change in the batch irradiation period, facilty workers must change the rhythm and intensity of work, thus increasing the risk of workplace accidents or mistakes. It is thus suggested that the period of irradiation be set and changed on a monthly basis, beginning the month with the irradiation period that is ideal for the last day of the month in question.

The effect of the decrease in total source activity on the quality of the irradiation processing was also investigated. Five Simulations were performed in Microshield 5™, in order to determine the effects of decreased source activity on the max-to-min dose ratio inside of the tote boxes. It was found that the max-to-min dose ratio increases by small values as a function of time (Fig. 10). The replacement schedule of the source rack will thus be a function of the range of nitrogen content that is considered acceptable for recycling purposes, since the larger the max-to-min dose ratio, the larger the range of nitrogen content of the nitrocellulose inside of the tote box.

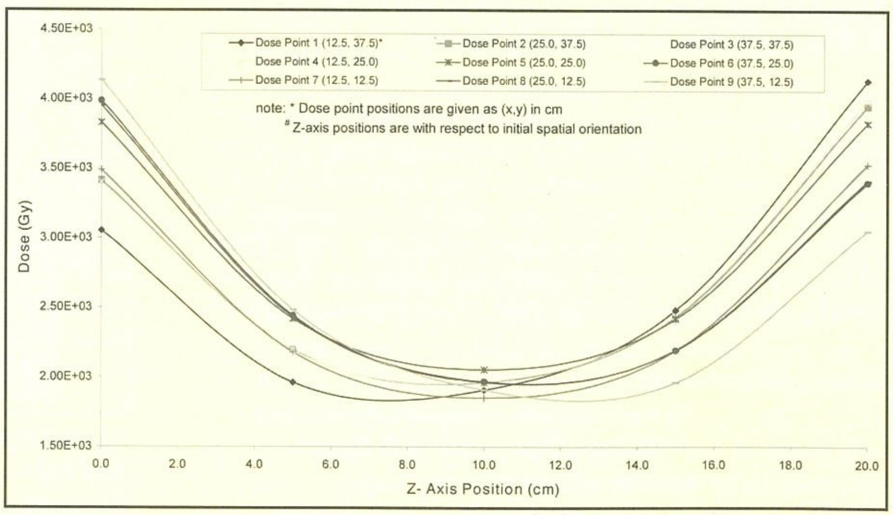

Figure 6 – Dose in tote I as a function of Z-axis position

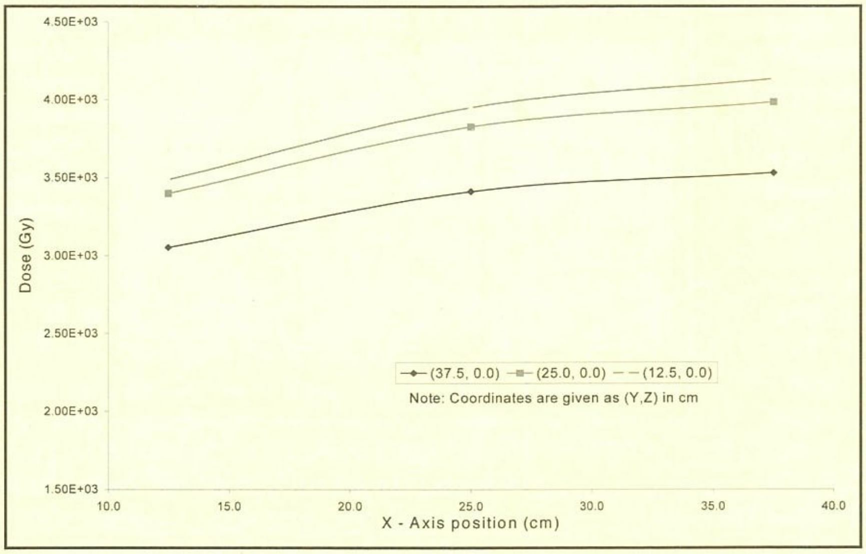

Figure 7 – Dose in Tote I as a function of X-axis Position

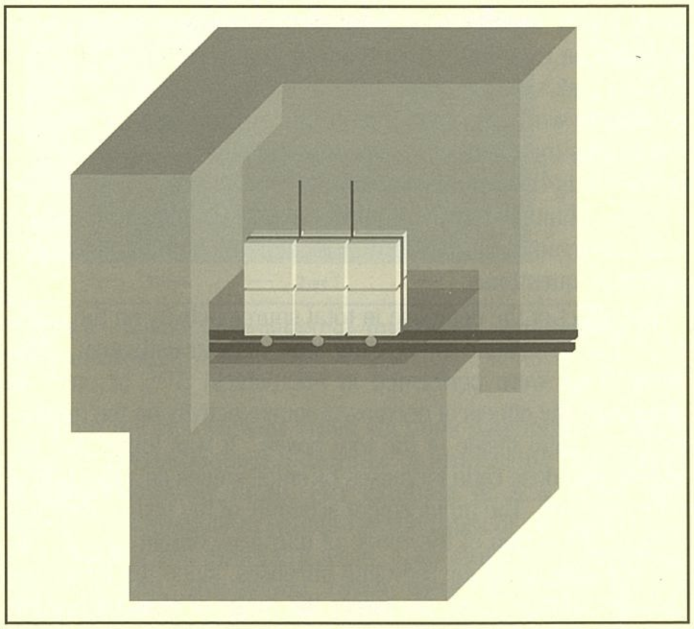

Figure 8 – Cutaway View of Above Ground & Pool Shielding Enclosures with Tote Boxes, Source Rack and Mobile Section of Shielding Enclosure in Operating Positions

A simple manner of increasing the dose uniformity, while not having to replace the entire source rack would be to use totes of smaller surface area, such as a tote which has a surface tote surface area of 1600cm^2 as opposed to 2600cm^2. By switching to a smaller tote, the edge effects of the source become less important a factor on dose uniformity, thus the max-to-min dose ratios improve slightly.

X. Discussion

A. Systematic Uncertainties Associated With Tote Optimization & Design In Microshield 5™

The use of Microshield 5™ as a means to determine the dose received by the nitrocellulose inside of the tote boxes presents several sources of systematic uncertainties.

The primary purpose of Microshield 5™ is to design radiation shielding and to "estimate exposure from gamma radiation"[5] to people and materials beyond that shielding. Microshield 5™ does not allow for calculations of dose points immersed inside of objects, such as the doses of radiation received inside our tote boxes. The simulation of the nitrocellulose inside the tote box was thus achieved by creating a custom shielding material (composed of nitrocellulose), creating two shields (one made of aluminium in order to represent the tote box wall, and the other made of nitrocellulose), and placing the dose point directly behind the nitrocellulose shield. The thickness of the nitrocellulose shield was made to be equivalent to Z-axis position of the dose point inside the box. Thus in order to determine the dosimetry of the tote's entire thickness, the size of the nitrocellulose shield was incrementally increased in 5 cm intervals until the entire thickness of the box was represented.

The systematic uncertainty for the dose values calculated using Microshield 5™ stem from the inability of the program to "represent back-scatter from materials immediately beyond the dose point" [4]. The size of this systematic error can not be accurately determined using Microshield 5™ alone, but one would need to conduct physical experiments with case geometries, materials, and dimensions similar to those of our facility. The difference between the actual doses received and those computed using the Microshield™ method would constitute the exact magnitude of the uncertainty.

Although the magnitude of the uncertainty in the doses received in the nitrocellulose cannot be calculated without

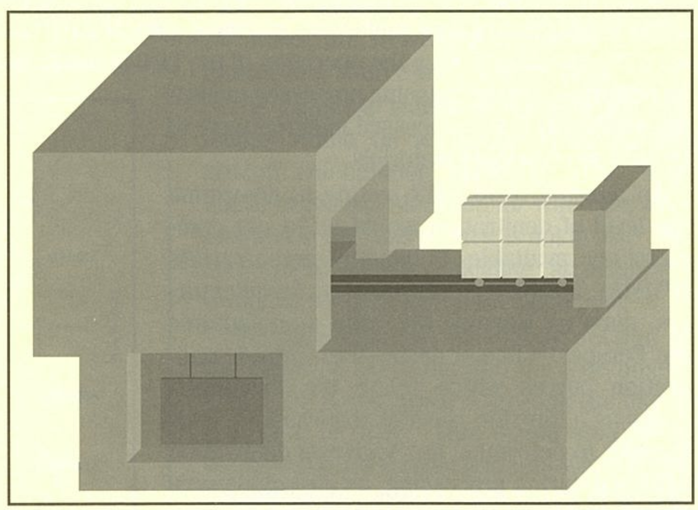

Figure 9 – Above Ground & Pool Shielding Enclosures with Tote Boxes, Source Rack, and Mobile Section of Shielding Enclosure in the Loan/Unload Position

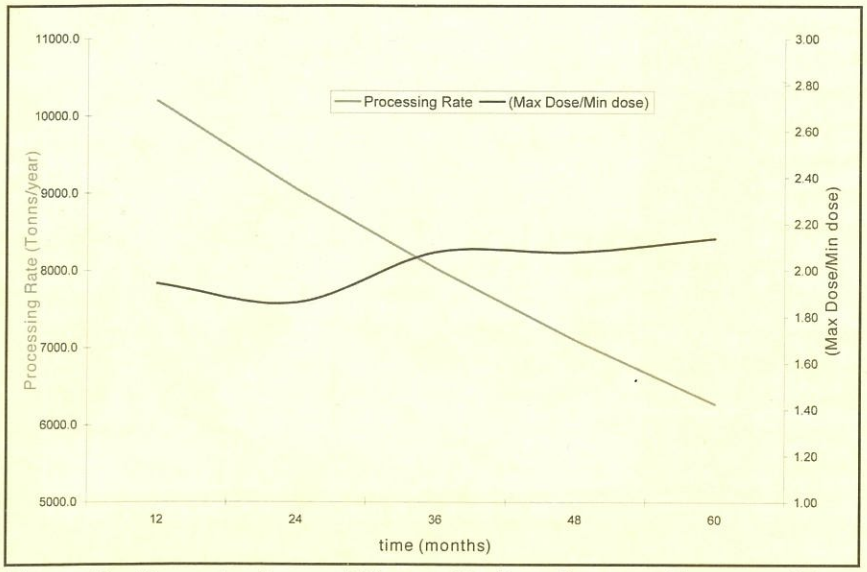

Figure 10 – Processing Rate and Max-to-Min Dose Ratio as a Function of Time
Note: Tabular forms of this data is found in Appendix B

further experimental lab work, the order of magnitude of the uncertainty associated with gamma photon back-scattering is known to be in the order of 12 to 15 percent [4] for applications not unlike this facility. Thus the actual dose received in the totes would be 12 to 15 percent larger than those calculated using Microshield 5™.

In addition to the last form of uncertainty discussed, Microshield 5™ itself has its own level of uncertainty associated with all of its calculations. The magnitude of the program's uncertainty is "known to be within 10 to 15% of the true situation"[4]. This range of uncertainties applies to all of the dose point exposure rates, and the values calculated as a function of those values including: the cycle times, processing rates, exposure rates, and the max-to-min dose ratios.

The last source of uncertainty stems from the source rack geometry that was used in the Microshield 5™ simulations. Microshield 5™ does not allow for more than one source in the calculation of doses at a given dose point. Although in reality, the source rack would be a composed of some 240 C-188 sources, it is not possible to simulate for each individual C-188 source, thus a single rectangular source of dimensions 155 cm x 100cm x 1.11 cm (x,y,z) was made in order to represent the entire source rack and all of the C-188 sources. This approximation imparts uncertainties as large as large as -15.9%, where the rectangular geometry gives rise to a dose rate that is larger in magnitude in the dose that would result from cylindrical geometry. Thus the real dose rates at the dose points in the nitrocellulose filled totes would be smaller than their values calculated using the Microshield 5™ simulations.

B. Production of Ions, Gases, and Heat During Facility Operation

Two gaseous products, NO_2 and O_3, would be produced as a result of interaction of the gamma photons with the nitrocellulose and surrounding air. These products would need to be managed through proper ventilation of the facility or perhaps, in the case of NO_2, captured for recycling purposes.

The water filled pool shield for the source rack would also need to be protected from the build-up of ions. This would serve to protect the C-188 sources from corrosion, among other things. The simplest manner in which to achieve ion-free water in the pool would be to cycle the pool's water through ion-exchange resins.

The source would also produce heat, which would need to be removed from the above ground shielding enclosure during irradiation as well as from the pool when the source is in storage. The magnitude of the heat produced by Cobalt-60 decay is known to be 1.54 x10^{-2} watts per curie, thus our source rack would produce a maximum of 1.54x10^{3} watts of heat energy. This heat removal could be achieved through ventilation or heat exchangers.

C. Computer Controls & Instrumentation

Computer controls and instrumentation would be required to control the the mechanical interchange of the tote boxes, as well as the raising and lowering of the source. Computer controls and instrumentation would offer a safety advantage over manual operation of the facility, as specific safety precautions, protocols, and procedures for irradiation cycles could be programmed and executed flawlessly. This, however, is beyond the scope of this project and it would most likely be subject to work by a computer engineer.

XI. Conclusions

1. Le pourcentage d'azote dans la nitrocellulose diminue clairement avec l'irradiation
2. Une dose d'environ 1,85 kGy serait nécessaire pour abaisser le taux d'azote dans la nitrocellulose de la façon désirée.
3. The Canadian Forces surplus of nitrocelluose does not validate the need to build such a facility, however, the Canadian Forces could build such a facility to process all of NATO's spent nitrocellulose propellant. By selling excess irradiator time and the processed nitrocellulose to industry, such a facility could become a very profitable investment. This facility's design should be brought to the attention of the Canadian Forces for review and consideration at an official level, as a means of disposing future Canadian and International stocks of spent nitrocellulose.
4. Des expériences plus approfondies sur la nitrocellulose seraient nécessaires afin de déterminer plus précisément la dose nécessaire.

5. Des expériences sur l'irradiation des autres constituants des propergols seraient necessaires avant de pouvoir mettre le projet en oeuvre.
6. A computer code which accounts for back-scattering effects from material beyond the dose point should be created, in order to properly determine the dose rates of irradiation at the dose points inside of the tote box.

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Slowpoke Integrated Reactor Control and Instrumentation System (SIRCIS)

by Lt(N) L.R. Cosby[1]

I. Abstract

A Commercial Off-The-Shelf (COTS) digital control and instrumentation system was developed for the SLOWPOKE-2 reactor at RMC using the LabVIEW Professional Development System. The resulting software was deployed on a PowerMac G4 computer using Mac OS 9.1. Several techniques were used to enhance the robustness of this COTS system.

II. Introduction

SLOWPOKE is a small, inherently safe, pool-type research reactor that was engineered and marketed by Atomic Energy of Canada Limited (AECL) in the 1970s and 80s. The original reactor, SLOWPOKE-1, was moved from Chalk River to the University of Toronto in 1971 and was operated until upgraded to the SLOWPOKE-2 reactor in 1976. In all, eight reactors were produced and six are still in operation today, two having been decommissioned. All of the remaining reactors are designated as SLOWPOKE-2 reactors.

In total, three variations of control systems were used for SLOWPOKE reactors:

- the original control system for SLOWPOKE-1;
- the Mark 1 (MK1) control system, installed at the University of Toronto, Dalhousie University (Dal), École Polytechnique (EP), the University of Alberta (U of A); and
- the MK2 control system (Figure 1), installed at the University of the West Indies (UWI), Saskatchewan Research Council (SRC), and the Royal Military College of Canada (RMC).

The SLOWPOKE-2 research reactor at RMC was commissioned in 1985 with the MK2 control console, which includes auxiliary equipment located in a rack mount cabinet. Although it is called a controller, it has several functions, which include:conditioning of transducer signals, monitoring and display of measured parameters and, closed feedback control of a single control rod.

The system is thus a combined system that performs both control and instrumentation roles.

The reactor is currently in its 16th year of operation, which may be considered to be approximately mid-life for the reactor. The reactor as a whole has operated reliably, as have the other SLOWPOKE reactors, partly due to the simplicity of the reactor. There is only one moving part and that is the cadmium control rod, which is suspended inside the core by a wire attached to the control motor.

The weakest link with SLOWPOKE reactors is the control system, which has reliability, availability and maintainability issues. Essentially, as the system ages, parts fail more frequently and the system becomes increasingly more difficult to maintain. Based on these facts, an investigation was conducted to determine the feasibility of implementing a new control system for the reactor. The result of this effort is known as the SLOWPOKE Integrated Reactor Control and Instrumentation System (SIRCIS).

A commercial control system or some variant thereof was entertained for some time. However, the cost of a commer-

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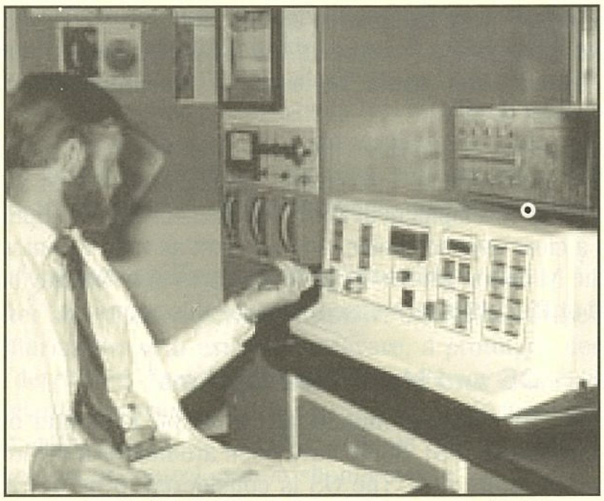

Figure 1 - SLOWPOKE-2 Control System at RMC

cial system was determined to be likely in excess of $500k for a turnkey solution. An expenditure of this level would not have been easily justified in view of the commercial income that the SLOWPOKE-2 Facility can dependably generate yearly. It must be understood that universities in general cannot easily afford large capital projects of this nature without significant commercial return. For these reasons, it was decided to approach the development of a new control system with COTS components. The intent with SIRCIS was to transfer the main functionality from the MK2 control system, while improving on functionality and interaction where practical and desired. Also, it was necessary to upgrade the system to reflect additions to the Facility, e.g., the Neutron Beam Tube (NBT), as well as improve safety-related functions.

An analog system was never seriously considered for this upgrade since the advantages of digital control were quite clear from the outset:

- most new or replacement control and instrumentation systems for reactors today are software-based digital systems (e.g., MAPLE, NRU, Penn State Breazeale, Darlington CANDU);
- analog systems are not easily reconfigurable once built, whereas digital systems can be readily modified;
- software-based solutions are more suitable to rapid prototyping methods, thus reducing development time and cost considerably;
- software-based control systems have fewer failures once the code is debugged; and
- digital systems generally enjoy reduced maintenance costs.

Once it became evident that a digital software-based system was the best general option to pursue, development options were considered. All options were based on Commercial-Off-The-Shelf components and technology.

III. COTS

The cornerstone of using a COTS approach in a control and instrumentation application lies in using commercially available components, both hardware and software. The reason that COTS has garnered such support in recent years is that there are several distinct advantages to applying COTS principles:

- lower cost hardware and software;
- lower development cost;
- decreased development risk;
- larger supplier market; and
- improved availability of parts.

However, the COTS approach is not without detractors, especially in a nuclear control system application. The main disadvantage is that many COTS items are not developed with the robust reliability and fault tolerance attributes that are essential to success. However, as will be seen with SIRCIS, the key is to integrate multi-level fault tolerant protection into the system.

IV. OASES CAT III Standard

The standard for the development of real-time protective, control and monitoring software in Ontario CANDU nuclear power plants is the Ontario Power Generation and Atomic Energy Canada Limited Software Engineering Standard (OASES) [1]. Although the OASES standard was developed with CANDU plants in mind, it was considered that the standard was scalable to meet the needs of a much smaller reactor such as SLOWPOKE.

There are four standards in the OASES family and they are defined as Categories I through IV. Category I is deemed to have the most significance to safety while Category IV is deemed to have no significance to safety.

There were two approaches that were contemplated for categorization. The first approach was that both control and instrumentation would be integrated together into one package. The categorization for the product would be attributable to whichever of the two aspects rated a high category, in this case control. The other approach was to split control and instrumentation functionality into separate entities and apply only the lowest applicable category to each. In all likelihood, control would be Category III whereas instrumentation would be Category IV and require considerably less effort. In the end, it was decided to administer one standard (Category III) for the entire upgrade, thus assuring that both functions of SIRCIS were subjected to a clear, precise and rigorous development process.

V. Development Options

Three potential paths for the development of a new digital control and instrumentation system for SLOWPOKE were originally considered. They were:

- development by a third party external to the university;
- development in partnership with a third party; or
- development entirely in-house at RMC.

Only the last two paths were explored further as the budget for a turnkey solution from a third party would have been expensive relative to the worth of the reactor and was thus not feasible. Considering that the original cost of the reactor in 1985 was ~ $1.3M, a new replacement console (in 2001) could be about $0.5M.

The obvious choice for a third-party solution was with the original reactor vendor - AECL. Their proprietary language called PROTROL (PROtection and conTROL) had been successfully used in numerous nuclear applications including:

- DFCS (Digital Feedwater Control System) at Peach Bottom (2x1000 MWe BWR) Atomic Power Station owned by Philadelphia Electric Co;
- DFCS and DRCS (Digital Recirculation Control System) at Oyster Creek (680 MWe BWR) owned by GPU Nuclear;
- Neutron Generator Control and Safety Interlock System for KFUPM (King Faud University of Petroleum & Metallurgy), Saudi Arabia;
- Reactor Control and Safety System Upgrade, Pennsylvania State Brezeale Reactor (PSBR), Pennsylvania State University; and
- several real-time control system testbeds (running real-time models of Maple X10, Oyster Creek (BWR), etc.), in use at AECL at AECL-CANDU and CRNL [2] .

In addition, the SLOWPOKE Energy System (SES) was also considered a candidate for PROTROL [2] before the SLOWPOKE Demonstration Reactor (SDR) was shut down in 1989.

Most of these systems were developed in the late 1980's and they typically used 80286 or 80386 Intel processor computers with clock speeds between 6 and 20 MHz. PROTROL programs were developed in Pascal and run under a DOS operating system. The interfacing hardware that is supported by PROTROL is Computer Products Inc. RTP I/O product or Opto-22 I/O.

Another choice was Siemens Moore's QUADLOG® Safety System. This is a Programmable Logic Controller (PLC) that can be integrated with another of their products, called the APACS+® Process Automation System, in order to provide an integrated control and/or instrumentation system. This combination is being used extensively for the MAPLE reactors that were built for Nordion Ltd. by AECL at Chalk River Laboratories (CRL). In addition, the QUADLOG/APAC+ system is being implemented at the AECL NRU (Nuclear Research Universal) reactor at CRL. Since AECL CRL has already extensively qualified and developed two different reactor control systems using these products, it may have been possible to take advantage of the lessons learned to speed development of SIRCIS.

The third choice examined was National Instruments (NI) LabVIEW (Laboratory Virtual Equipment Workshop) product and their Signal Conditioning eXtensions for Instrumentation (SCXI) system. In 1990, LCdr Greg Cottingham developed a software based SLOWPOKE-2 simulator at RMC as part of a M.Eng. thesis in Nuclear Engineering. He used a first generation LabVIEW product to create his reactor simulator and demonstrated that LabVIEW was a viable development system for control [3]. If LabVIEW were to be used again, then it might be possible to incorporate portions of the simulator into an operator trainer that could be used to transition Licensed Operators to SIRCIS.

An analysis of the three solutions was conducted and concluded that National Instruments products were best suited for SIRCIS development at RMC. The Siemens-Moore approach was a close second choice, and was just as valid a contender as the NI option. However, as NI products were already being used at RMC, it made sense to choose this approach.

VI. OS and Hardware Options

There are several commercially available computer operating systems (OS). Some have been around for a while and some are quite new. The OS is considered to be a critical component for any computer system. Its stability and effectiveness is paramount to system operation.

There are essentially two types of real-time operating systems: hard and soft. A hard real-time OS guarantees event timing within a certain interval while soft real-time systems cannot. The majority of personal computers have these general purpose, soft real-time systems. While there are COTS hard real-time OS environments available, the SIRCIS problem domain does not require such determinism due to the relatively slow changing processes within SLOWPOKE. Thus it was decided to use a general purpose, soft real-time OS.

The operating systems that work with LabVIEW were examined and Mac OS 9 was found best suited for implementation in SIRCIS. Microsoft Windows 2000 was also a reasonably strong contender, but was not the first choice.

Once the OS was chosen, AECL's Guide for the Qualification of Software Products [4] was used to ensure that the chosen commercial software was of sufficient quality for use in this particular application and categorization.

The computer hardware decision became relatively simple since the OS is only supported on computers manufactured by one manufacturer, Apple Computer. While it may seem a design weakness to sole source supply of the control computer to one manufacturer, a closer examination revealed that there are positive benefits. For example, the Mac OS is tightly integrated with the Apple hardware, since the hardware manufacturer and the software developer are contained in the same company. This level of integration is not always possible in the Windows and Intel (WINTEL) environment.

Another consideration was that, once computer hardware has been chosen, the control computer cannot be arbitrarily switched once the system is validated. That is, once a specific model of computer is validated, introducing a new (albeit similar) computer would likely necessitate repeating major portions of the test procedures. Therefore, a decision to source with one manufacturer would more than likely necessitate staying with that manufacturer and product. The key to mitigating the risks associated with a sole-source supplier is to shelve spares that are adequate to meet the maintenance requirements for the intended life of the product.

While there are several types of computers manufactured by Apple (e.g., portables, desktops etc), it was decided to use the most powerful desktop available at the time. This was the 500 MHz Power Mac G4. A cursory review of hardware specifications for the control computer verified that there should be no problem meeting computing performance requirements as specified in the requirements documentation.

VII. Human Factors Engineering

After an extensive review of SLOWPOKE-2 literature and familiarization with existing hardware, a prototype design was developed. This initial design was shown to operators on several occasions in order to receive their input, especially with respect to the MK2 console and how this next generation of control system should evolve.

There is no unique Canadian HFE standard used in the design of CANDU nuclear power plants. Rather, the Canadian nuclear industry relies upon the American Nuclear Regulatory (NUREG) Commission (NRC) standard, and to a smaller degree on IEEE standards. It was decided that, for SIRCIS, the NUREG standards would be considered the primary standard while the IEEE documents would be used strictly for comparison. The HFE Design & Implementation Process outlined in NUREG-0711 was followed in order to expedite HFE work.

These standards were not implemented rigorously as they were considered to be too onerous for such a small reactor as SLOWPOKE. Rather, the spirit of the standard and guideline were followed in order to ensure a logical and coherent approach to the task. The design standards that were consulted were NUREG-0700 Vols. 1 & 3 [5,6] and IEEE Std 1289-1998 [7].

VIII. SIRCIS Overview

Most SIRCIS components are housed in a 19" rack mount cabinet that is located in the control room. The rack contains the necessary hardware for SIRCIS. A 22" flat panel display is located adjacent to the rack at the operator workstation. The operator interacts with the system using an optical mouse; there is no keyboard input.

IX. COTS Enhancements

As mentioned earlier, the main disadvantage with COTS items is that many are not developed with the robust reliability and fault tolerance attributes that are essential in a nuclear application. The key to success is to build in multi-level, fault tolerant protection.

It is important to understand the terms, Fault Tolerance and Graceful Degradation, as they apply to computer control systems. Fault Tolerance is the built-in capability to provide continued correct execution, such as the provision of service as specified, in the presence of a limited number of hardware or software faults [1]. Graceful degradation is a stepwise reduction of functions in response to detected failures while essential functions are maintained [1]. One way to achieve these goals is through redundancy, which is the presence of auxiliary components in a system to perform the same or similar functions as other elements for the purpose of preventing or recovering from failure. Fault tolerance and graceful degradation features that are found in SIRCIS include:

- redundant displays
- redundant hard drive storage
- hot swappable input device
- Triple Redundant Power Supply
- gravity-based control rod insertion

In SIRCIS, three watchdogs are used to provide redundant "health" monitoring of applications and processes such as:

- the main application;
- the Operating System; and
- the process.

The third watchdog monitors SIRCIS processes to ensure that they operate uninterrupted. The program must regularly reset a hardware counter to prevent it from "barking" (expiring). This must occur in less than 0.5 seconds or a power relay will be opened causing a gravity-based control rod insertion. The power relay is also opened if power to the SCXI or control computer fails (e.g., blown fuse, electrical short etc.),

This triple redundant approach to health monitoring ensures maximum reliability and availability of the system.

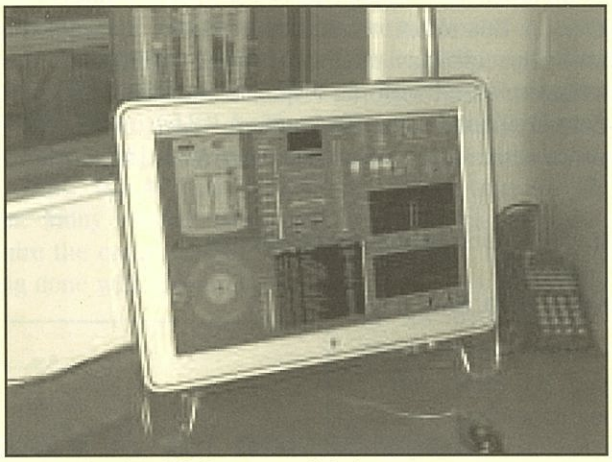

Figure 2 - SIRCIS Operator Workstation

This is especially important during remotely attended operation when no Licensed Operator is required to check on the system for periods of up to 24 hours [8].

Should SIRCIS fail to operate properly, the operator can also trip the reactor by turning a key switch that controls the power to the control rod motor. The control rod would then undergo a gravity based control rod insertion into the core and the reactor would shut down.

Although SIRCIS has some redundancy and fault tolerance capabilities, it is important to note that there are single points of failure within SIRCIS. For example, there is only one DC power supply, one computer, one data acquisition chassis and a single neutron flux channel. A failure of any one of these items would result in varying degrees of failure within SIRCIS.

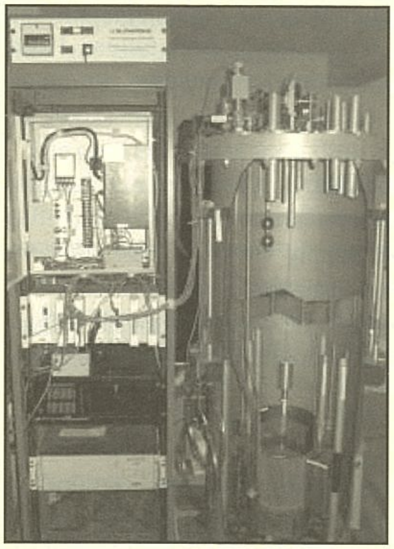

Figure 3 - Control System Test Bed

It must be understood that this is the same situation as with the MK2 control system, and does not represent a departure in design philosophy. The safety of the reactor does not depend on the control system, be it analog or digital; it relies upon the physical characteristics of the reactor to make it inherently safe.

X. Validation and Verification

All work for SIRCIS was conducted with a view towards eventually receiving permission from the Canadian Nuclear Safety Commission (CNSC) for the implementation of SIRCIS. An independent third party conducted the Validation and Verification phase in order to satisfy the requirements for the Category III standard [1]. A contract consisting of two parts, document review and testing, was awarded work to an experienced software testing company.

To aid in this effort, a test stand (Figure 3) consisting of a full-scale cut-away model of the SLOWPOKE-2 reactor was instrumented with the required hardware. The reactor model, previously used to promote sales of SLOWPOKE reactors when it was a commercial product, is shortened in the vertical scale to approximately 2 m in height. A 19" rack was used to house the control computer, UPS, SCXI hardware and test stand wiring panel. The test stand was also useful for practicing installation and maintenance procedures, and in the future will be used for reactor operator training and demonstrations.

Once V&V efforts were successfully completed, the test stand was moved back to RMC in April 2001 where further trials were conducted pending approval of the Commissioning Plan that had been submitted to the CNSC.

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CNS/CNA 26th Student Conference
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Winning Ph.D. level paper

Foundation for A Visual Reactor Simulation Toolkit

by David Gilbert[1]

Abstract

The current research goal is to implement a well structured object based simulation system, for use by the scientists, operators and engineers at the McMaster Nuclear Reactor. Neutron flux, poison buildup, and coolant flow are modeled using finite difference equations. A Cartesian grid with variable resolution, is used to represent the model's geometry. Each grid may directly represent an array of partial differential equations or may be composed of sub-grids, each being treated internally as a separate computational object. The final project will handle model configuration, integration of related simulations, code generation, execution, and output rendering. The simulation tool kit is not yet complete, this paper represents a description of the preliminary status of the project.

I. Introduction

The purpose of the current project is to develop a programming tool for physics models capable of simulating neutron flux, poison buildup, and water fluid flows within the McMaster Nuclear Reactor (MNR) a small light water moderated research reactor located on the McMaster campus. During early conversations about the form of the design several goals were identified.

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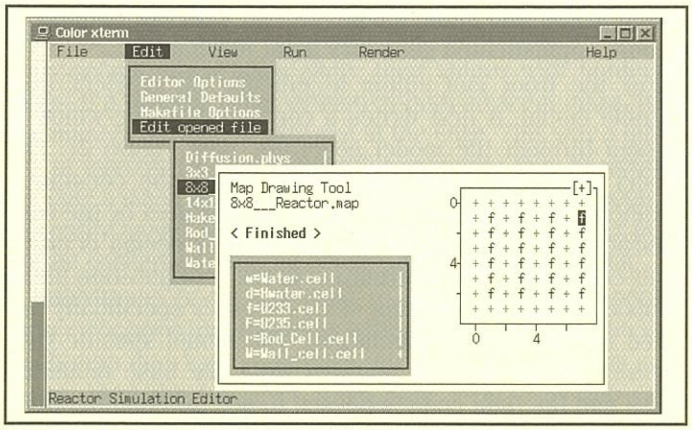

Figure 1: Cell editor

1. Model's physics must be fully configurable.
   (a) Physical laws should be expressed in a mathematically natural way.
2. Model's geometry must be fully configurable.
   (a) A Cartesian mesh with variable granularity is used.
3. Libraries should be easy to edit and extend, and should help the beginner not limit the expert.
4. Physical laws and geometrical structures should have a natural or 1:1 association.
5. The model should be capable of running in real time, so that it will provide a virtual window into the reactor at all times.

Along with these very general goals additional requirements include input and output mechanisms which can work over the Internet, so that scientists may rely on a central server to share their information. Model states must be checkpointed from time to time, to build up a history database, and the model must be able to communicate with standard codes approved by the AECL, already in use at the MNR, including CATHENA, 3DDT, WIMS and ASSERT [1].

Many general purpose fluid flow packages are already available (Fluent [2] for example). Commercial and industrial packages have several disadvantages which prevent the MNR from using them. Many computational fluid dynamic packages are designed to solve a specific set of problems, and are not generic enough for modeling a multigroup neutron diffusion problem. Since commercial packages are sold for profit, source codes to the packages are not always available. Without source codes fine tuning the problem and code verification is impossible.

At the opposite extreme general numerical libraries are available for the efficient solution of sparse matrices. Netlib[3] is an excellent repository of libraries and numerical solving tools, although these libraries require a great deal of programming in order for the user to take advantage of them. A problem's specification may be more difficult to organize than the code which is used to generate the solution.

Several general packages for the specification of reactor models already exist. The Modular Modeling System (MMS) [4] is an example of a nodal system which allows the user to draw on a library of prebuilt objects (pumps, valves and pipes for example) constructing a reactor cooling model in a schematic fashion. A modeling system described by Nilsson [5] follows the same object oriented approach. Both models use Microsoft Windows front end editors to organize the reactor components, and both models are written in specialized modeling languages, MMS is written in ACSL, and Nilsson's model components are written in an object-oriented modeling language called OMOLA. The Modular Modeling System is described in [4] as a more accessible supplement to codes like TRAC, RELAP and RETRAN [6], rather than a replacement. Many reactor monitoring and analysis jobs do not require the complexity of codes like RETRAN, and are either being done with the overly detailed codes, or not being done at all because of the great expense involved.

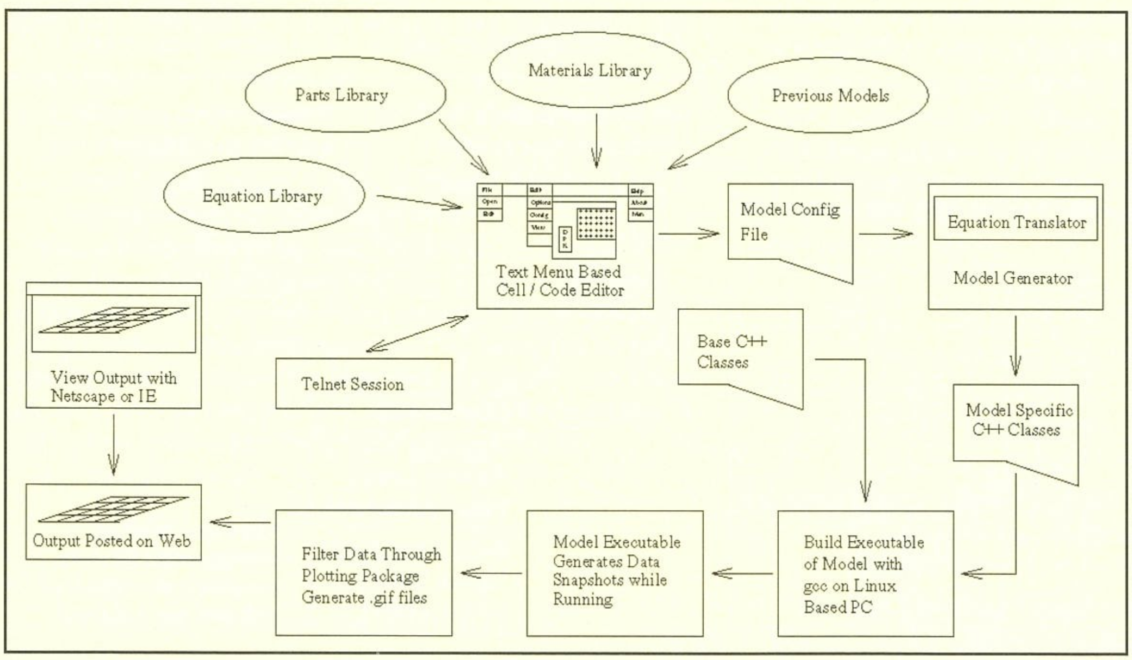

Figure 2: Model data flow overview

The MARS [7] project aims to combine two standard codes (RELAP and COBRA-TF) into a single multi-dimensional fluid flow analysis tool. Dynamic memory allocation features of FORTRAN90 were used, and a graphical user interface was added to the final code combination to make it easier for eng neers to work with the codes.

At this time the codes used for licensing the MNR (CATHENA, WIMS) do not have an easy to use interface, and there is also no general purpose code in use at the MNR to perform routine or experimental analysis. The proposed simulator aims to fill this need. The interior of the prototype model is exposed to the user, in the form of partial differential equations to allow maximum flexibility. A front end editor organizes the equations for the user and associates them with a geometry simplifying the job of model configuration, the cell editor is shown in Figure 1.

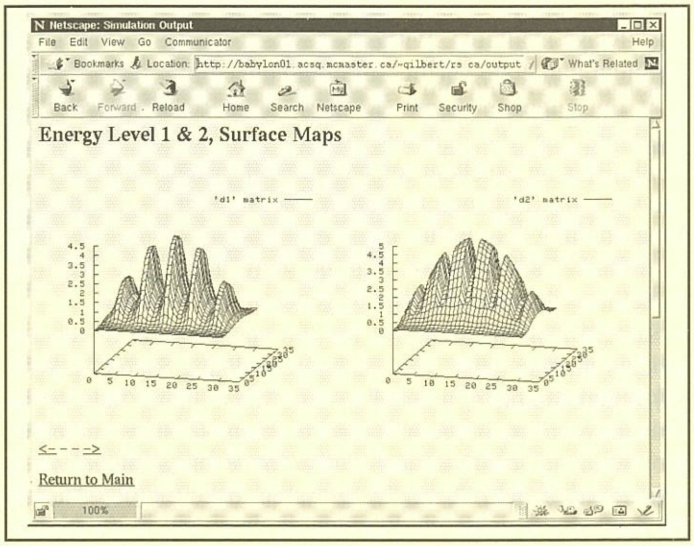

Figure 3: Netscape used to view output

Internally linked cell structures are represented as objects with uniform interfaces. Objects are always a collection of linked cells. Objects are merged one at a time by the model designer into hierarchical maps. Each group of objects communicates with its neighboring group by being placed close enough so that a cellular interface is made.

II. Design Overview

A simple text menu based cell and code editing tool is used to configure the simulation. The menu is designed to launch geometry and code editors, similar to the fashion of the classical Borland C editors which produced code for DOS computers. The text menu based implementation was chosen over a graphical implementation for two reasons: it runs easily over a telnet session, allowing scientists to work remotely, and it is easier to implement than a full graphical user input (GUI) system. If time permits an X based GUI may be designed to replace the text menus, which would also allow remote access, with the addition of a more sophisticated geometry input mechanism.

For the front end editor to produce an efficient executable model, it first writes a configuration file which is passed through the model generator (see Figure 2). The model generator reads information about the constants, geometry and physics of the model as specified by the configuration file and checks that the model's design is internally consistent. The information in the configuration file is translated into a collection of C++ classes specifically tailored for the current simulation. The model specific C++ classes inherit general features from the base modeling class and the final code is passed to gcc for compilation.

While the simulator is running, it generates periodic data snapshots of some area of interest. Snapshots are automatically rendered by gnuplot, a batch driven scientific data plotting program, and the rendered output files are copied to the users web directory so they can be remotely viewed (see Figure 3). The data snapshots will be stored in an online database, so that a user may interactively view the simulator's history.

III. Cartesian Embedded Maps

All maps are rectangular grids belonging to one of two types. A map is either a map of simple cells, where each cell computes physical properties based on its constants and the constants and properties of its neighbors as defined by its partial differential equation, or a map has other maps as its cells, effectively sub-maps as shown in Figure 4.

Cell maps solve for variable properties (flux, temperature etc.) as defined by the modeler. Maps may be grouped with adjacent maps which use a different formula basis, and which solve for a different set of variables. Maps may have any dimension, and may be nested at any level. All maps

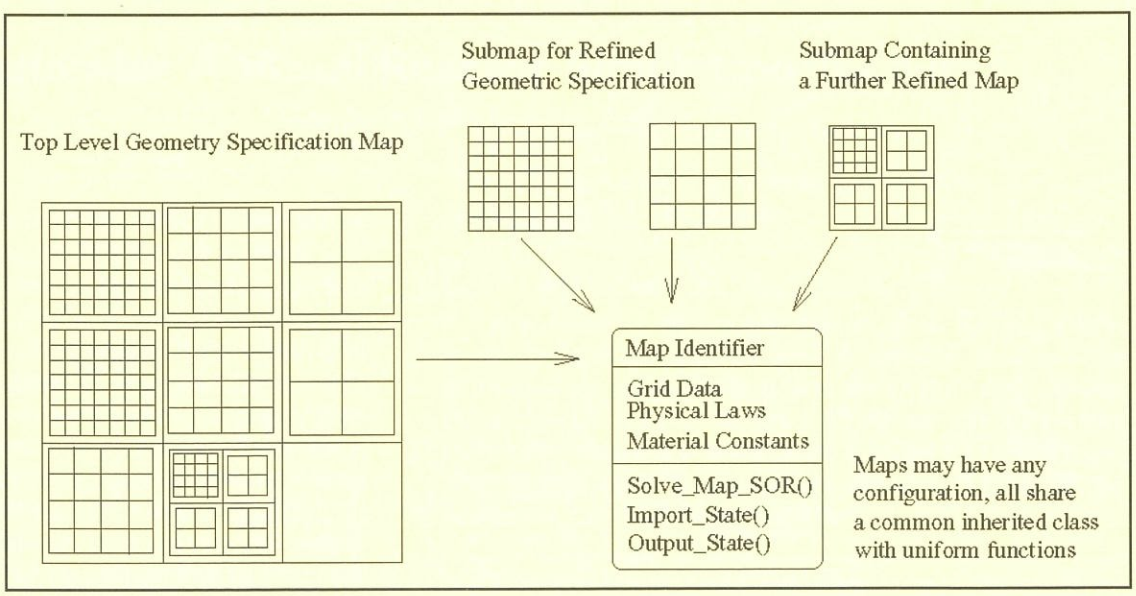

Figure 4: Map layout

use identical interface functions, like Read_Element(), Output_State(), Import_State(), and Solve_Map_SOR().

By default when maps share their values with bordering maps, if a variable is not defined by both adjacent maps, then the numerical value is mirrored at the edge. This way a quantity of interest (poison buildup for example) may be defined for only a small region of the geometry if it does not apply to the entire model. Memory is conserved, and the modeler need not be concerned with the details of the implementation.

Inheritance in C++ is used to merge the map specific data structures and formulas with generic functions so that each map may have a uniform interface. If a map has submaps, then the top level Solve_Map_SOR() function calls the Solve_Map_SOR() function of its children, each in turn, until the entire grid has reached a new equilibrium.

IV. An Equation Translator

One of the fundamental problems in allowing a model's physics to be fully configurable is that it means the model must be able to handle any imaginable equation, that fits in with its general structures. One option is to allow the model designer to compile their own object codes, written in the native language of the model. The trouble with this approach is the modeler is forced to think more about programming than physics. Another approach would be to have the modeler select precompiled physics equations from an exhaustive menu. This constrains the configuration to whatever physics the system designer is aware of, as no menu is ever fully exhaustive.

This project follows a compromise between these two alternatives. An equation translator along with an easy to edit library of equations is supplied. The equation translator takes formulas expressed in a mathematically natural way and converts these equations into a form that a C compiler can understand.

The equation translator runs in three modes (configurable for each cell):

1. A strict mode which only accepts linear equations following a tightly defined syntax.
2. A mixed C mode where recognized simulator symbols can be intermingled with raw C code.
3. A literal mode, where C code is passed directly to the C compiler, and no translation is done.

The basic element of any simulation is a cell. Each cell has a set of equations associated with it that define the physics of that cell as well as a set of constants that define the material properties of the cell (see Figure 5). Since not all maps are required to support the same set of variable properties, all cells need not support the same set of physical laws. A cell is described in the model configuration file as:

```
rs_cell <const_id> <prop_id> {
     <prop_1>=<finite_diff_1>;
     <prop_2>=<finite_diff_2>;
     ...
     <prop_n>=<finite_diff_n>;
}
```

An equation may have three sorts of identifiers, either constants, variable properties, or external identifiers. The equation translator must have a way to recognize these, and so constant and property structures are mentioned in the cell definition. Constant types and property types must also be defined. A property type declaration is a list of property names, followed by an identifier, and is handled exactly like a struct declaration in C, except that the model generator makes note of the form that the structure takes.

```
rs_prop struct {
     <prop_1>;
     <prop_2>;
     ...
     <prop_n>;
} <prop_id>;
```

Constant types are described in an analogous fashion. Constants have fixed values, and are defined by a pointer to the materials library.

The general steady state finite-differenced multi-group diffusion equation [8] is written as:

$$\left[\Sigma_{R_i}^{g} + \Sigma_j^J \frac{D_{ij}^g}{\Delta_{ij}^2}\right]\phi_{ig} - \Sigma_j^J \frac{D_{ij}^g}{\Delta_{ij}^2}\phi_{ig} - \tag{1}$$

$$\Sigma_{g'=1}^{g-1}\Sigma_{S_i}^{g'\rightarrow g}\phi_{ig'} = \frac{\chi^g}{k}\Sigma_{g'=1}^{G} \upsilon_{g'}\Sigma_{f_i}^{g'}\phi_{ig'}$$

Equations recorded for each cell are used as part of an iterative solution to solve for the flux of the map, all % where i represents the index value of the local position, and g represents the energy group level. This equation is reorganized to solve for % and can in principle be written in standard C notation and then be merged at compile time with the iterative solver. This strategy may be used with any finite differenced equation, although the flux equation is used in the following examples.

In order to support hierarchical maps the model must declare and array of pointers for each map object. In standard C notation each cell has a field pointing to its update function, a pointer to the constants library (materials cross sections for example), a pointer to a structure of variables to solve for (flux or temperature). Variables in C notation are identified as:

```
grid[x * this->X_MAX + y]
     ->property->phi[g]
```

Constants are identified as:

```
grid[x * this->X_MAX + y + 1]
     ->constant->Sigma_R[g]
```

The first job of the equation translator is to find properties or constant definitions in a users equation and automatically insert the pointers. The position in the grid array is computed based on the current objects dimensions. Finite difference methods work with neighboring cells, so the sub index [E], [W], [N] and [S] are automatically translated into the correct relative position formula, if the reference is to the current cell, the position pointer is dropped. Using these conventions variables can be referred to in the configuration file more simply as:

```
phi[g]     and    Sigma[S][g]
```

The first and last terms from equation (1) are:

$$\left[\Sigma^{g}_{R_i} + \Sigma^{J}_{j} \frac{D^{g}_{ij}}{\Delta^{2}_{ij}}\right] \phi_{ig} \tag{2}$$

$$\frac{\chi^{g}}{k} \sum^{G}_{g'=1} \upsilon_{g'} \Sigma^{g'}_{f_i} \phi_{ig'} \tag{3}$$

Since summation is a common operation the equation translator uses a short form to express it. In the model configuration file term (3) can be written as:

```
(Chi[g]/k) * Sum(g'=1..G,                    (4)
nu[g'] * Sigma_f[g'] * phi[g'])
```

For the summation operator to work correctly the bounds must be known at compilation time. Summation with more subtly expressed bounds must be coded in C either using the mixed or literal cell equation mode as a for() or while() loop. In strict mode the summation operator is handled by unrolling the summation and listing each element explicitly. This allows for very efficient execution, and no chance of a non-terminating loop.

Subscripted variables are commonly marked with a prime symbol ('). The equation translator allows the prime symbol to be used as part of a local variable to help distinguish it from other variables.

Term (2) can be written as:

```
(Sigma_R[g] +                                (5)
      (D[E]+D[W]+D[N]+D[S])
            /delta^2)*phi[g]
```

The [N], [S], [E], and [W] tags are converted by the equation translator into their correct relative position, and the neighboring values of D are returned in each case. Caret (^) is allowed to represent exponentiation as it does in Pascal, even though this is not normally present in C. Since term (5) has assumed that delta is uniform, and since this may not always be the case, it is convenient to have a special form of summation which more closely matches the original equation.

Term (2) could also be written as:

```
(Sigma_R[g] + Sum(j=[N]..[W],                (6)
   D[j]/delta[j]^2)*phi[g]
```

In term (6) the mathematics expressed is the same as the first term in the original equation. Instead of the limits of the sum being integers, [N], and [W], are used to suggest a clockwise tour of the four directions.

V. Project Status

The described simulation toolkit is still in the early stages of its development. Currently the model generator can handle two dimensional geometrical grids, and plans are in place to extend the solver to three dimensions. The equation translator allows for expressing the relative position of variable properties, or constants, in neighboring cells, with the use of the [N], [S], [E] and [W] tags, and automatically inserts the correct pointer information. The summation, and exponentiation operators have not yet be implemented.

A method for integrating the existing codes into the proposed simulator has not yet been thoroughly investigated. It is anticipated that C++ class wrappers can be used to encapsulate the input and output of external executable programs, and merge their output with the new structures.

Output generation of data files over the web has been tested, and a basic version of the simulation generator, and equation translator have also been tested. Most of the base layers of the menu input system are ready.

It is hoped that when the model generator is ready it will be used to assist with routine analysis jobs by providing a quick and ready estimate of the reactors status. An early well integrated prototype capable of running a sophisticated simulation should be ready in fall 2001.

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Investigation of Tritium in Groundwater at Pickering NGS

by J. DeWilde, Lawrence Yu[1], D. Belanger, R. Wootton, K. Hansen, E. McGurk,[2] A. Teare,[3]

Ed Note: *This paper was originally presented at the 22nd CNS Annual Conference in Toronto, June 2001under the title "Tritium in Groundwater Investigation at the Pickering Nuclear Generating Station".*

Abstract

Ontario Power Generation Inc. (OPG) investigated tritium in groundwater at the Pickering Nuclear Generating Station (PNGS). The objectives of the study were to evaluate and define the extent of radio-nuclides, primarily tritium, in groundwater, investigate the causes or sources of contami-nation, determine impacts on the natural environment, and provide recommendations to prevent future discharges.

This paper provides an overview of the investigations conducted in 1999 and 2000 to identify the extent of the tritium beneath the site and the potential sources of tritium released to the groundwater. The investiga-tion and findings are summarized with a focus on unique aspects of the investigation, on lessons learned and benefits. Some of the investigative techniques discussed include process assessments, video inspections, hydrostatic and tracer tests, Helium 3 analysis for tritium age dating, deuterium and tritium in soil analysis. The investigative techniques have widespread applications to other nuclear generating stations.

Introduction

Ontario Power Generation Inc. (OPG) investigated tritium in groundwater at the Pickering Nuclear Generating Station (PNGS) as part of an Ontario Ministry of the Environment (MOE) Director's Order[1]. Tritium had been identified in the groundwater at several locations under the station, most notably seeping into a break in a sewage line near the Unit 1 Reactor Building. This paper provides an overview of the investiga-tions conducted in 1999 and 2000 to identify the extent of the tritium in groundwater beneath the site and the potential sources of tritium released to the groundwater. The setting of the site, the investigation and findings are summarized. The paper focuses on the specific investigations: on the unique aspects of the investigations, on lessons learned and benefits. The investigation techniques have widespread applications to other nuclear generating stations.

Site Setting

The PNGS site is located in the Regional Municipality of Durham, on the north shore of Lake Ontario. The 270 ha site was developed for use as a nuclear power station using CANDU reactors beginning in 1964. The bulk of the generating station property is located within 50 ha [Figure 1].

The site ranges in elevation from about 113 metres above sea level (masl) (370 feet above sea level (fasl)) at the crest of an eastern landfill to about 77 masl (253 fasl) in the vicinity of the power generation facilities. The geologic overburden overlying the bedrock in the vicinity of PNGS ranges from about 14 m to 23 m (45 to 75 ft) thick. During the construction of the site, there was a significant amount of "cut and fill" that has altered the stratigraphy of the shallow subsurface.

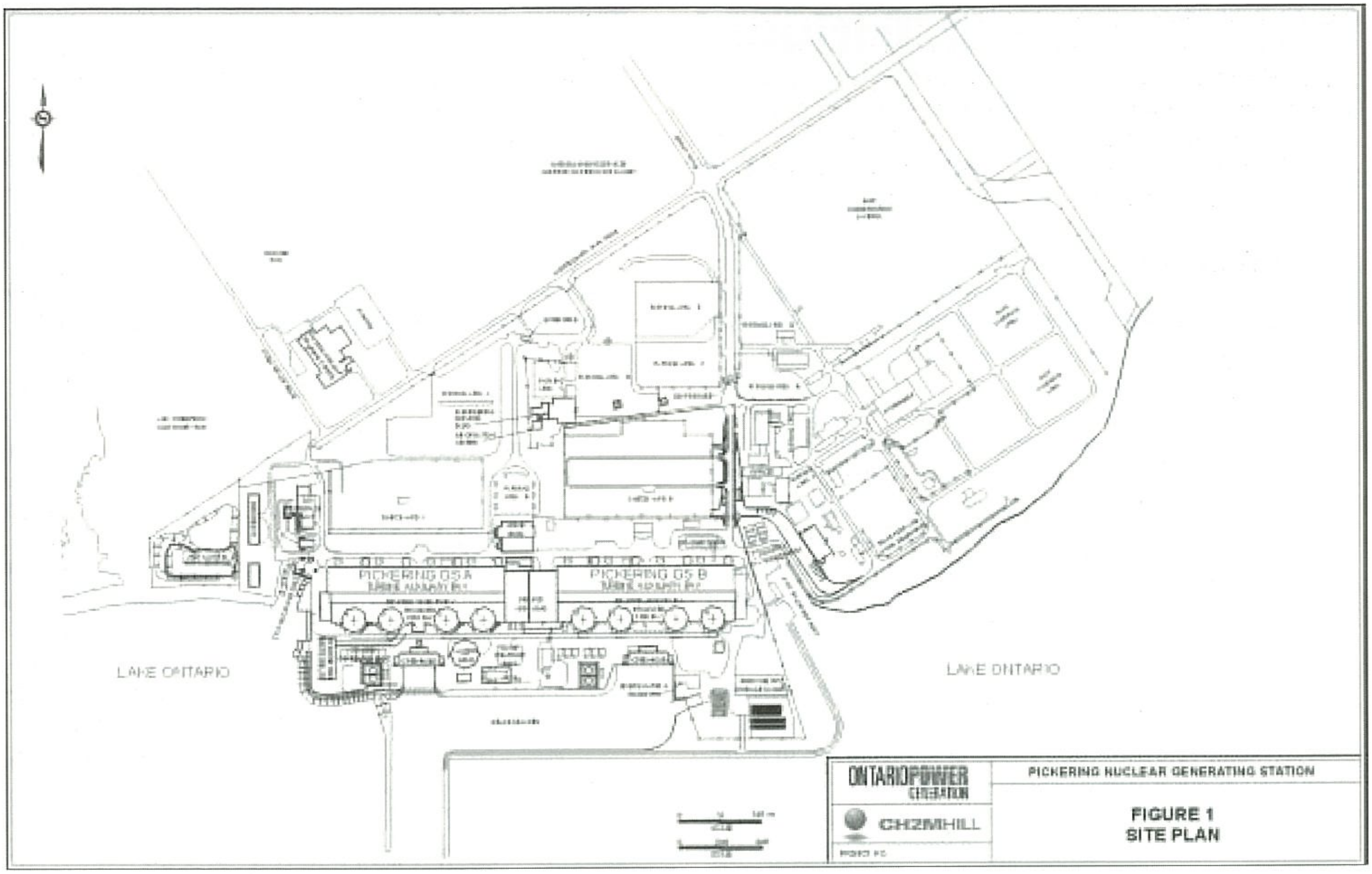
Horizontal groundwater flow in the area of PNGS is generally from the north to the south with discharge into Lake Ontario. The station has changed the flow regime in the immediate area of the site. Groundwater flowing from the north is intercepted by permeable backfill surrounding large cooling water ducts on the north side of the station and is directed to the west and east. Founda-tion drains in deep basements intercept and collect groundwater and discharge it to the lake. Backfill materials, structures and an additional sump collecting groundwater (vacuum building sump) also influence the groundwater flow on the south side of the station.

More information on the PNGS site hydrogeology can be found in the Pickering Nuclear Site Wide Groundwater Monitoring System[2] presented elsewhere in these proceedings.

1 Ontario Power Generation Inc., Pickering NGS

2 CH2M HILL Canada Limited, Waterloo, Ontario

3 CH2M HILL Canada Limited, North York, Ontario



Overview of Investigation

In June 1998, elevated tritium was identi-fied in sewage leaving the PNGS site. Through sample analysis and a video inspec-tion, the source of the tritium was identified as groundwater entering a broken sewer line. The sewer line was cut and capped and the Tritium in Groundwater Study (TIGS) initiated. The objectives of the study were to:

1. Evaluate the groundwater for radio-nuclide impacts
2. Define the extent of contamination
3. Investigate the cause(s) or source(s) of contamination
4. Determine the impact on the natural environment
5. Provide recommendations to prevent future discharges that may result in adverse impacts
6. Prepare recommendations for additional works required to satisfy the Director's Order
7. Document the results in an environmen-tal site assessment report

The investigative approach used for the TIGS was iterative. A phased approach began with general studies such as the Radiological Source Term Assessment and the Site-Wide Groundwater Monitoring System Study to identify general systems/pro-cesses or areas of concern with respect to potential impacts to groundwater. Detailed, specific investigations, such as tracer and leak detection tests were then conducted by a team of investigators to investigate systems or areas of concern that were identified during the earlier studies. The various investigations are listed below and expanded upon in later sections:

- Process assessments of Unit 1 risks
- Video inspections
- Hydrostatic/tracer tests of sumps
- Assessment of tritium migration through concrete
- Helium gas sampling for tritium age dating
- Monitoring well installation with soil and groundwater analysis

Other investigations conducted but not discussed in this paper include:

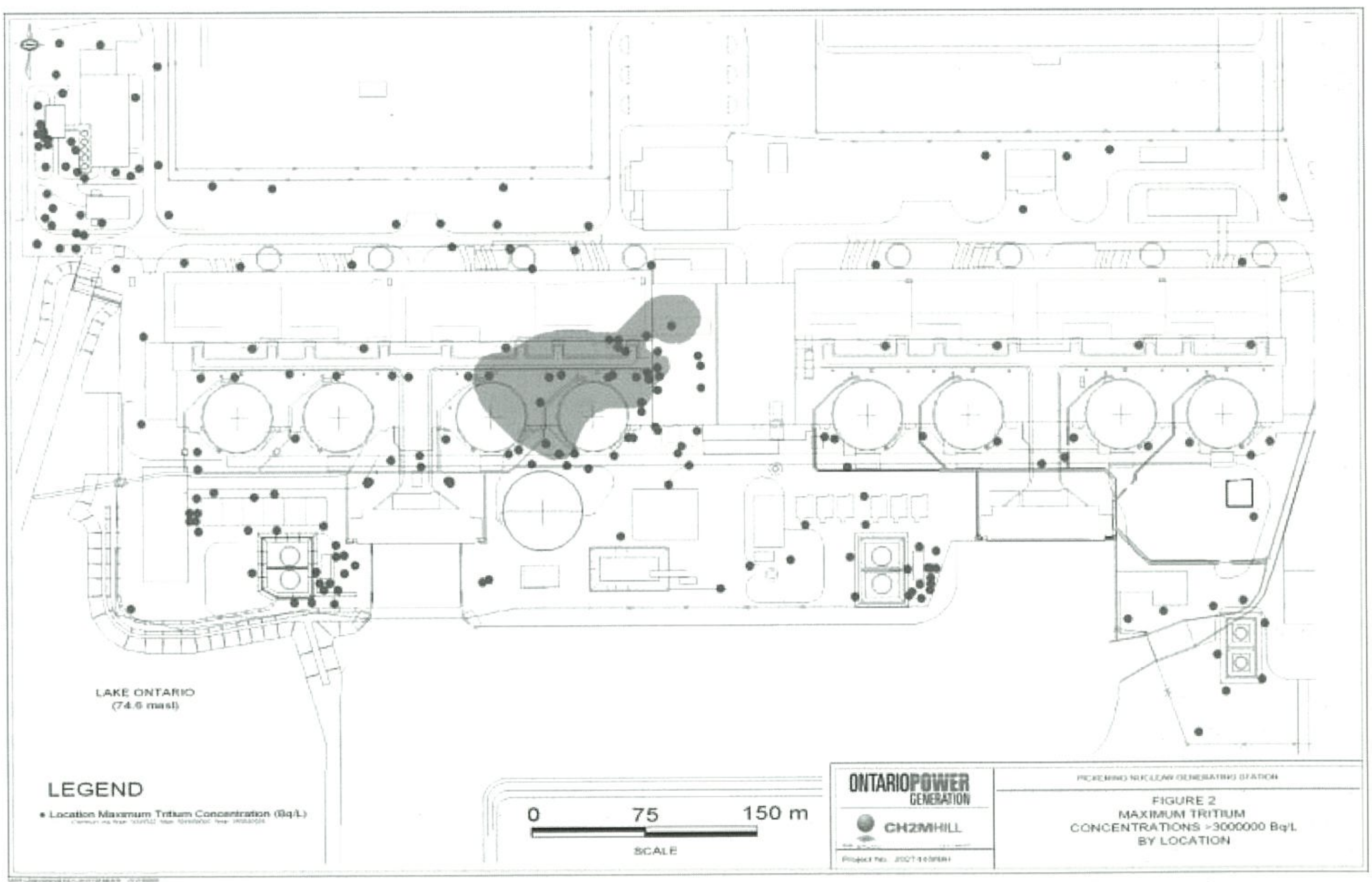
- Assessing risks of contamination from all station system, structures and equipment (Radiological Source-Term Assessment)
- Modeling atmospheric deposition of tritium
- Leak tests on pipes and pipe penetrations
- Sump/catchbasin sampling program
- Background information collection
- Detailed drawing review

A screening criterion for groundwater not used as drinking water is not available for Ontario or any other jurisdiction. To accom-modate PNGS's situation, OPG developed a risked-based tritium criterion. The study used a human health and ecological risk assess-ment approach to derive a proposed criterion of 3E6 Bq/L (81 µCi/kg) representing the level above which there is a potential for an environmental impact. For the purposes of the investigation and this paper "contaminated groundwater" is defined as groundwater containing tritium above the proposed criterion.

Conclusions of the Investigation

Based on the TIGS work, a number of conclusions were made. These are sum-marized below.

- The tritium contamination in groundwater has been delineated in the Unit 1 area based on the results of an extensive groundwater monitoring well network [Figure 2]. The highest concentration of tritium in groundwater was found in an area to the northeast of the Unit 1 Reactor Building where concentrations were up to 2.7E8 Bq/L (7E3 µCi/kg).
- The tritium contamination was also delineated vertically and was typically limited to the upper 3 to 4.6 m (10 to 15 ft) of the water table.
- Tritium is the only radionuclide of con-cern identified at significant concentra-tions in the groundwater. For the most part, other radionuclides were not detected in the groundwater or were less than environmental quality guidelines required for the site.
- Based on the tritium activity contours and depth of tritium, the inventory was esti-mated to range from 1.6E13 to 1.6E14 Bq (4E2 to 4E3 Ci).
- The results of the atmospheric deposition modeling were consistent with the tritium concentrations identified across the site.
- For the Unit 1 area, the groundwater is generally collected and contained by site sumps and discharged to the lake through monitored pathways. As a result, ground-water with high tritium is contained onsite and does not discharge directly to the lake. The total loading from the ground-water discharges is estimated to be 3.7 percent of the total annual tritium dis-charges from the PNGS site.
- The Spent Resin Storage Tank (SRST) vault sumps received slurry water from the SRST as well as drainage from the vault. The Unit 1 SRST sump was con-sidered to be the source of the tritium in groundwater in the area to the northeast of Unit 1 for three reasons. It was found to be leaking at the joint between the RAB floor and the sump wall. The sump is located close to the centre of the tritium plume. Finally, average concentrations of tritium in the sump (8.0E9 Bq/L; 2E4 µCi/kg) are consistent with the tritium concentrations found in the groundwater.



- The equivalent sump at Unit 2 was also found to be leaking at the same location and this sump is considered to be the source of tritium in groundwater found to the west of Unit 1.
- A sump in the Unit 1 reactor building is also considered to be a probably source of tritium contamination in groundwater. Testing of the Moderator Purification Room sump indicates that the sump leaks at a rate of about 150 L/day. At the time of the test, the sump contained about 1E10 Bq/L (2.7E5 µCi/kg) of tritium.

Investigative Techniques

As discussed above, the TIGS comprises a number of individual investigations. The purpose of this paper is to share with industry the investigations techniques, in particular, the methodology, the findings, and lessons learned. These techniques have applications at other sites. Further details of these items can be found in the TIGS report[3]. Several investigations are described in greater detail in other papers and are not discussed here. These investigations include the groundwater monitoring system[4], the radiological source-term assessment[5] and the atmospheric deposition modeling[6].

Process Assessments

Based on the Radiological Source Term Assessment[7], a number of systems were identified as potential sources for contamina-tion of groundwater. These systems were investigated in detail using document reviews, staff interviews, system inspections and walk-downs. The documents reviewed included Design Manuals, Operating Manuals, In-Service Reports, System Flow Sheets, Plans, Significant Event Reports, and previous investigative reports. Information was also obtained from Operating Experience (OPEX) databases and discussions with other sites.

The assessments were used to identify contamination risks and areas requiring further testing. They were also used as a reference base for other TIGS investigations. The process assessments were considered a necessary first step of the TIGS to focus the investigations and to ensure that no risks were left unidentified and unassessed.

Video Inspections

Video camera inspections were conducted on a number of sumps, foundation drains, a sewage pipe, vaults and catch basins. They were used to identify the sewage line break, to evaluate the condition of sumps and to clarify inconsistencies within drawings. To conduct the inspections, pipe cameras and push rods were used.

Of particular interest was a Reactor Building (RB) foundation drain that was investigated through the use of video inspections. Drawings showed this perforated pipe to discharge in the plant but the outlet could not be physically located. The risk existed that plant spills could enter this drain and enter the groundwater through the perforated pipe. Through the use of a push rod video camera and a tracer dye, the discharge point was found to be outside the plant in a sump that had no inputs.

Assessment of Tritium Migration through Concrete

Tritium migration through structural concrete was considered a possible cause of subsurface contamination. To assess this risk, a contaminant transport calculation was performed to assess tritium migration by diffusion and hydraulic flow in the Reactor Buildings.

The study concentrated on developing a preliminary estimate of the amount of tritium-contaminated water or vapour that could migrate through cracks and joints on the reactor building walls and dome, through the sumps and pits located in the floor slab, and during abnormal events (i.e. during retube or pressure tests). Potential pathways such as intact concrete, concrete with through-wall micro cracks, and construction joints and water stops were evaluated. OPG supplied information on the building configuration, construction methods, probable defects and source terms. Mathematical models were then used to estimate the possible migration through the concrete[8].

OPG evaluated the case where tritium diffused to the outer building surfaces. This diffusion was considered a risk as precipita-tion could then leach the tritium from the concrete which would raise the tritium level in the runoff water and result in infiltration to the groundwater.

The average tritium concentration in the air, expressed as water activity inside the Reactor Building, was calculated to be 1.61E8 Bq/L (4.4E3 µCi/kg). Migration from diffusion of tritiated moist air could occur through cracks and joints as well as through the concrete itself. The length of cracks and joints in the structural components were estimated by considering the effective pathways, taking into account the effects of aging on PVC joints and cracks. The transport flux calculations through the Reactor Building walls and dome were 3,278 and 9,819 Bq/s, respectively. When the flux was diluted with possible precipitation, the resulting concentra-tion was 2.5E5 Bq/L (6.8 mCi/kg).

Various sumps and pits in the Reactor Building often contain water and the risk existed that tritiated water would migrate from these locations. The hydrostatic head created from water in the sumps would allow tritiated water to permeate into the concrete as well as migrate through cracks and joints by hydraulic flow.

To evaluate this risk a model was developed to estimate the water flow rate and the tritium flow rate from the Reactor Building sumps. The model assumed a typical crack width of 0.1 mm, which, from a structural point of view, is not considered to be a significant crack for concrete water-retaining structures. The findings from the model indicated that the greatest potential for tritium leakage through concrete was at the Moderator Purification Room Sump. At an assumed crack width of 0.1 mm, a tritium flow rate of 1.3E9 Bq/day (0.035 Ci/day) was calculated. This sump however, only received water on a periodic basis. The East Fuelling Machine Room sump was also considered to be a significant historical risk with a calculated flux of 5.9E10 Bq/day (1.6 Ci/day). However, this sump was retrofitted with a steel liner in the mid 1980s.

Hydrostatic Tracer Tests

Sumps in the Active Drainage System were considered to be a significant risk of groundwater contamination as they often contain liquids for extended periods of time and leaks could go undetected. Tracer tests and hydrostatic pressure tests were conducted on several Reactor Auxiliary Bay (RAB) and Reactor Building sumps to evaluate the potential for leakage to the environment.

Tests essentially consisted of filling the sumps to floor level or above with tracer water (a fluorescein or bromide solution) and monitoring the change in water level over time. Sampling was also conducted on adjacent monitoring wells and foundation drains to identify the tracer in groundwater. Two challenges existed in conducting the tracer tests: the selection of an environmen-tally safe and detectable tracer for use in the Reactor Building; and the design of a hydrostatic pressure test to measure small leakage rates.

Tracer tests were conducted at two locations within the reactor building. Fluorescein was an initial choice due to its conservative nature and small particle size. This tracer was used in other studies onsite and therefore other options were assessed. Tritium, Bromide, and Oxygen-17 were likely candidates but, after evaluation, none of these were able to replace Fluorescein. Tritium, a common and effective tracer, could not be used as the groundwater was contaminated with this radionuclide. Bromide was also considered but discounted as it had the potential to create corrosive halides. An isotope of oxygen (Oxygen-17) was con-sidered but was found to be too costly considering the quantities required to increase concentrations significantly above background.

A novel method of conducting hydrostatic pressure tests was developed because possible sources could not be ruled out without a rigorous test. A detection limit of <0.3 L/day was required to discount a potential source of contamination. Due to the surface area of the sump a leak at that rate would cause a head drop of 1cm in 28 days. This was considered too slow and open to error from measurement or evaporation. To increase measurement sensitivity, a 10 cm (4") manometer and a vent were fitted to the sump manhole cover. The sump was filled with tracer solution, the manhole sealed to the sump and the mano-meter filled above the floor level. This configuration allowed for a detection limit of leakage better than 0.3 L/day and proved successful in measuring very low leakage rates.

Tritium/Helium-3 Residence Times and Tritium Age Dating

Tritium undergoes beta decay with a half-life ($t_{1/2}$) of 12.43 years to produce helium-3, which converts to helium-4. In recent years, it has been demonstrated that combined measure-ments of the groundwater concentrations of tritium, helium-3, helium-4, and neon can, under appropriate conditions, provide reliable values of the groundwater residence time[9,10,11]. Tritium and helium analyses were used to determine the relative age of the groundwater to assess sources and to aid in understanding the groundwater flow system.

Samples were collected for tritium/ helium-3 analysis from 12 wells in the area of Unit 1. Samples were collected using diffu-sion samplers, suspended in the wells below the water table. After about one week, the samples were retrieved and the gas analyzed. Samples were also collected from the same wells for analysis of tritium and deuterium.

The samples from the wells with the highest tritium concentrations could be analyzed for helium-3 due to the high levels of helium-3. Also the values obtained could not be considered absolute residence times due to the high concentrations, the possibility of helium-3 migration, the possible effects of more than one source and possible changes in groundwater flow conditions.

Tritium/helium-3 residence times were calculated to be between 0.1 and 14 years for six of the samples. Groundwater with the lowest tritium concentrations and having deuterium concentrations similar to natural background levels (~144 ppm) had the shortest calculated tritium/helium-3 residence times of 0.9 years and less. The results were generally consistent with the interpretation of groundwater flow in the area of the samples.

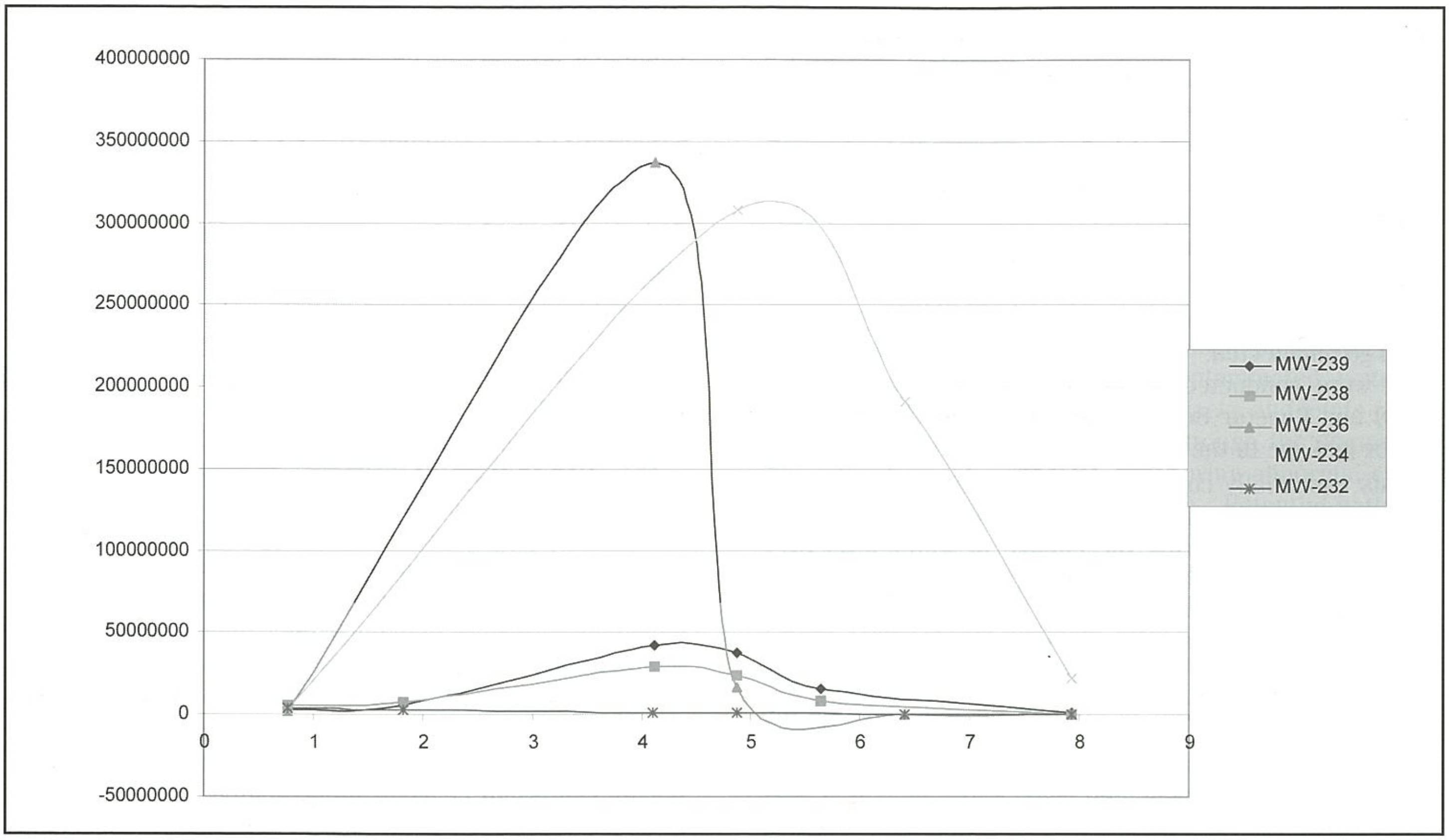
The analysis was useful in confirming existing groundwater flow information but was less useful in identifying the source of contamination or delineating the extent of contamination. As development in this area continues, helium-3 analysis could provide a valuable tool in groundwater investigations of this nature.

Deuterium Analysis

Deuterium and tritium analyses were used to calculate tritium concentrations at 100% deuterium concentration. This was done to determine if the tritium could be related to process water. The Moderator system typically contains 3.7E11 to 7.4E11 Bq/L (10 to 20 Ci/kg) of tritium at 100% deuterium while the Primary Heat Transport system contains less than 3.7E10 Bq/L (<1 Ci/kg) of tritium at 100% deuterium.

The background deuterium concentration was assumed to be the concentration found in the least tritium contaminated samples. For samples for which the tritium concentration is less than 2E4 Bq/L (0.54 μCi/kg), the deuterium concentrations averaged 143.1 ppm with a standard deviation of 2.5 ppm for 13 measurements. The deuterium background concentration onsite was therefore, assumed to lie within the range of 140.6 and 145.6 ppm.

Assuming the deuterium found in the samples resulted from a two-component mixture of heavy water and "uncon-



taminated water" with deuterium concentrations of 140.6, 143.1, and 145.6 ppm, the resulting tritium concentrations at 100% deuterium were calculated. For example, a well with tritium activity of 1.5E11 Bq/L and a deuterium concentration of 464.2 ppm was calculated to have a tritium activity at 100% deuterium of 4.7E11 to 4.6E11 Bq/L (12.7 to 12.4 Ci/kg). The results clearly showed the source of this tritium in groundwater to be from the Moderator system rather than the primary heat transport system. This example also shows that, at high tritium and deuterium levels, the calculation is not sensitive to the background deuterium assumed.

The calculation is sensitive to the assumed background deuterium concentration at lower levels of deuterium. For example, one sample contained 2.3E5 Bq/L (6.2 µCi/kg) tritium and 144.3 ppm deuterium. The tritium at 100% deuterium was calculated to range from 1.9E11 to -1.8E11 Bq/L (5.2 to -4.8 Ci/kg). Although the calculations were sensitive at low levels of deuterium, the analysis met its objectives and served to conclude the source of the contamination.

Tritium in Soil

The vertical extent of tritium in ground-water was assessed through the use of wells at various depths and by the analysis of tritium in soil. In particular, the tritium in soil provided valuable and detailed data on the vertical tritium profiles. This information was used to delineate contamination and assess sources of contamination.

The tritium in soil analysis was conducted either by centrifugal extraction of the water in the soil and analysis of the water or by adding a known mass of soil into a known volume of water and analyzing the tritium in the resulting mixture. In addition, the moisture content of the soil was analyzed where possible. The results were reported as tritium per kg of soil and since tritium is contained only in a liquid phase and not in the soil, the moisture content was used to convert the soil concentrations to a tritium in soil water concentration. For example: tritium in soil at 2.6E5 Bq/L (6.9 µCi/kg) of soil at a moisture content of 4.3 percent by weight equals 6.0E6 Bq/L (160 µCi/kg) in water. For some of the samples, soil moisture was not analyzed and therefore this value was assumed based on data in the surrounding wells. It was found that the calculation is relatively insensitive to changes in moisture content.

Tritium versus depth profiles were plotted and in most of the profiles, the tritium concentrations dropped to less than about 20 percent of the peak concentration by a depth of about 6.1 m to 7.6 m (20 to 25 ft) below surface [Figure 3]. From the tritium profiles, the thickness of the tritium plume was found to be on the order of about 3.0 to 4.6 m (10 to 15 ft). In most cases, the tritium found in the soil pore water was at low tritium concentra-tion at depths of about 4.6 m (25 ft) below surface.

The tritium in soil pore water was found to correlate well with the tritium in ground-water data from monitoring wells. The data indicated that the source of the contamination was near the surface, providing additional evidence to support the conclusions derived from leak testing.

Acknowledgements

This TIGS was conducted by a number of departments and staff at OPG and by various external contractors. The members of the team and their primary roles are:

- Pickering Nuclear Design Projects, Environmental Projects: team leader and project management
- Pickering Nuclear Field Engineering: contract coordinator, contractor safety
- Pickering Nuclear A Days Operations: sampling and implementation of field work at Pickering Nuclear A
- Pickering Nuclear Drafting: detailed drawing review
- Pickering Nuclear Environment Safety and Health: oversight and regulatory liaison
- Pickering Nuclear Chemistry Lab: sample analysis and collection
- Kinectrics (formerly Ontario Power Technologies): sample analysis and tritium migration through concrete
- CG&S: installation of wells, data interpretation, reporting, and various tests and sampling programs
- Atomic Energy of Canada Limited (AECL): video inspections, Helium 3 analysis, and technical support
- Jacques Whitford Environment Limited (JWEL): atmospheric deposition modelling

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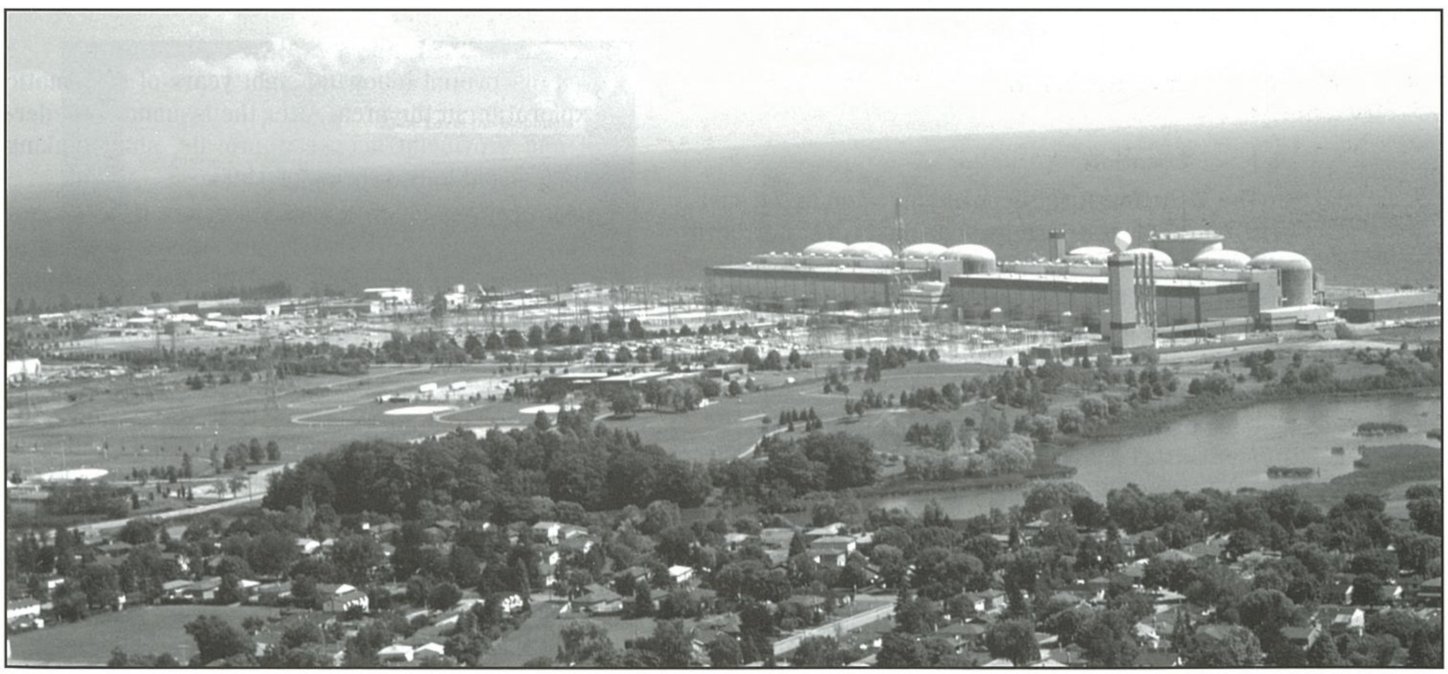


A view of the Pickering nuclear generating stations ("A", four units at right, "B" left) from north looking toward Lake Ontario.

McArthur River Uranium Mine
- world's largest and highest grade uranium deposit has required innovative mining techniques

by Martin Quick[1]

Ed Note: *The following paper was presented at the 22nd CNS Annual Conference held in Toronto, Ontario, June 2001.*

Abstract

Discovered in 1988, the McArthur River mine contains the world's largest, highest grade uranium deposit. As of December 31, 2000, proven ore reserves contain 355.5 million lbs. at a grade of 21.0% U_3O_8, and probable ore reserves of 39 million lbs. at a grade of 23.04% U_3O_8. In addition the mine has resources of 145.4 million lbs. averaging 10.74% U3O8. Production in 2000, the first year of operation, was just under 11.0 million lbs. U_3O_8, and the mine is now forecast to produce its planned annual capacity of 18 million lbs. U_3O_8 in 2001.

Mining this high-grade ore body presents serious challenges in controlling radiation and in dealing with water pressures in excess of 5000 kPa. Experience after 1 year of operation has shown conclusively that the non-entry mining method is working well, but modifications to the original extraction method were necessary to overcome occasional sloughing of the hanging-wall. Raise boring is the only mining method used to date to extract the ore, and all underground development is in waste rock to provide radiation shielding. High-pressure ground water is controlled primarily by perimeter freezing, supplemented by grouting. The ore cuttings from the raise boring are currently removed continuously from the excavation by scooptram and fed to the underground grinding circuit. The ground, slurried ore is then pumped to surface storage pachucas, where it is then loaded into specially designed transportation tanks and road-hauled to the mill located 80 km away at Key Lake.

The paper focuses on operational activities that have taken place during the first year of production, as well as mining obstacles that have occurred and their remedies. Radiation protection, worker health and safety issues are discussed, and future probable modifications and innovations to the extraction methods will be summarized, including the use of jet boring, box-hole raise boring, and expandable reamer heads.

1. Introduction

1.1. Location

The McArthur River deposit is located in the eastern part of the Athabasca Basin in northern Saskatchewan, Canada ***(see Figure 1)***, and is located 80 kilometres northeast of Key Lake and 40 kilometres southwest of the Cigar Lake deposit. The site is approximately 620 kilometres north of Saskatoon, a city with a population of 220,000, and the location of Cameco's corporate office.

1.2. History

Cameco, through one of its predecessor companies, Saskatchewan Mining Development Corporation, began the McArthur River exploration joint venture in 1980. The project is now owned by Cameco Corporation (69.805%), and Cogema Resources Inc. (30.195%). In 1988 the ore body was discovered following eight years of systematic exploration in the area. After the issuance of federal and provincial license approvals, shaft sinking commenced in the spring of 1993.

An Environmental Impact Statement (EIS) to proceed to underground production was submitted in late 1995, and the public hearings were conducted in the fall of 1996. A favourable Panel report was issued in February, 1997. Both provincial and federal government approvals were received in May, 1997.

In August 1997 all licenses and permits had been received by both federal and provincial agencies to allow the two-year construction of the project to proceed. Construction was completed within the feasibility cost estimate and on schedule.

Operating licenses were received in October, 1999 for McArthur River, and in November, 1999

1 Martin Quick is Vice-President, Mining at Cameco Corporation

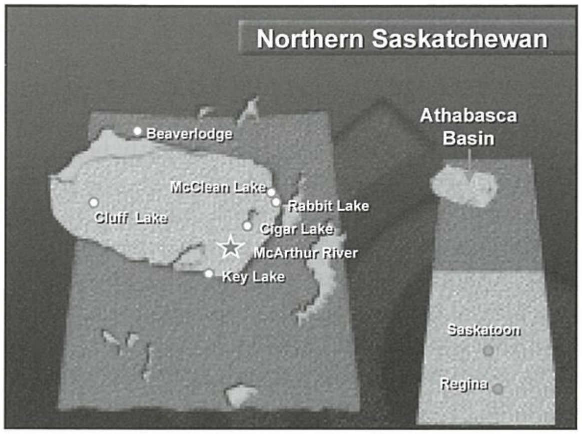


Figure 1: Location Map

for Key Lake to receive and process the high grade McArthur River ore. Production commenced, as scheduled, in early December.

2. Geology

The large and high grade Saskatchewan uranium deposits occur at or close to the unconformity which separates the generally flat lying, unmetamorphosed middle Proterozoic sandstones of the Athabasca Group from folded and metamorphosed lower Proterozoic and Archean rocks beneath. At McArthur River this unconformity is at a depth of 500 to 600 metres. The mineralization at McArthur River is associated with a northeast trending, southeast dipping zone of reverse faulting along which the unconformity is displaced vertically 60 to 80 metres. This is referred to as the P2 fault. Locally the basement rocks include pelitic gneisses and significant quartzite units.

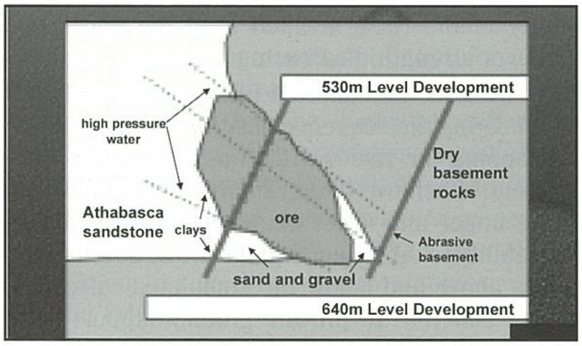


Figure 2: Challenging Ground Conditions

Alteration is characterized by intense silicification of the sandstone with less intense clay alteration compared to other Athabasca deposits. The mineralization, which has been traced over a 1700 metre strike length is largely pitchblende, without the associated cobalt-nickel-arsenic minerals which are present at Key Lake and Cigar Lake

Shaft sinking and diamond drilling from underground revealed the presence of ground water associated with the sandstone and the conglomerate. The quantity of ground water depends locally on the nature of flow pathways, hydrostatic pressure and pathway impedance. Mine development in sandstone and conglomerate requires extensive water control measures.

Four distinct ore zones, and one mineralized (or resource) zone, have been delineated by surface and underground drilling, but only Zones 1 and 2 have been fully defined. Mining has so far been confined to Zone 2

Large ground water flows associated with unconsolidated sand, clay and brecciated rock have been intercepted along the footwall of the Zone 2 orebody. These areas have not responded well to pressure grouting techniques due to the difficulty in penetrating the fine grained clays and sands in these areas. Ground freezing was necessary to consolidate this zone prior to mining. Drilling has also revealed ground water and brecciated sandstone above the ore zone. Acceptable locations for mine development for Zone 2 are therefore limited to the hanging wall basement rock and the quartzite below the mineralization.

The latest ore reserves and resources are shown in the table below.

	TONNES (Thouands)	AVERAGE GRADE $\%U_3O_8$	TOTAL (Million Lbs. U_3O_8)
Proven Reserves	768	21.00%	355.5
Probable Reserves	77	23.04	39.0
Total	845	21.19%	394.5
Indicated Resources	**614**	**10.74**	**145.4**

Table 1. McArthur River Project - Reserves and Resources as of December 31, 2000

3. Mining Method

All active mine planning to date has utilized the raise boring mining method. The high grade Zone 2 orebody is the first zone being mined. Freezing has been introduced to control ground water and occasional unconsolidated ground conditions in this area, and was implemented approximately nine months prior to mining in order to provide a frozen barrier sufficient to permit the safe extraction of the ore.

A surface freeze plant of 800 tonne capacity provides a chilled brine (-38 degrees Celsius) which circulates through a heat exchanger located on the 530 metre level. A lower pressure brine at -32 degrees Celsius is then used to circulate through freeze pipes surrounding the ore zones. Freeze holes are at two metre centres and drilled to approximately 100 metres in depth. In the Zone 2 orebody

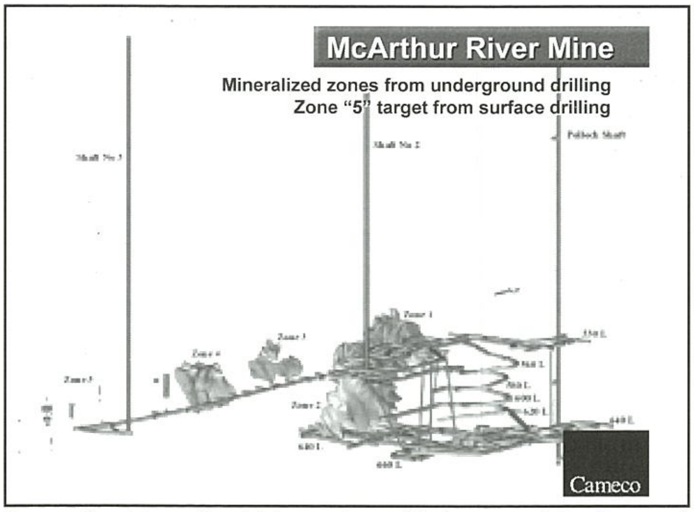


Figure 3: Mineralized Zones from Underground Drilling and "Zone 5" Target from Surface Drilling.

there are 78 holes in use for the freezing of the first two mining panels, and 59 holes for the third panel.

The raise bore mining method as applied at McArthur River requires the establishment of mine openings of adequate size in surrounding non-radioactive rock both above and below the ore zone. Conventional drill and blast tunnelling methods are used to develop these openings. Standard rock bolting, screening and a 75 millimetre application of shotcrete (a cement product sprayed onto the walls and roof of underground openings) are utilized to provide long term ground support. The raise boring mining method is a four step process ***(see Figure 4).***

Firstly, the raise bore machine is set up in the production chamber above the ore zone. The raise bore machine then drills a 300 millimetre pilot hole from the upper chamber, through the waste rock, the ore zone and the waste rock below the ore zone and into the lower extraction chamber. These pilot holes are up to 125 metres in length.

Secondly, after breakthrough of the pilot hole into the extraction chamber, the pilot hole drill bit is removed and replaced with a reaming head.

The reaming head was initially 2.4 metres in diameter, but as geotechnical conditions have been positive, raises with a diameter of 3.0 metres are currently being utilized. By applying upward thrust and rotation, the raise bore machine then reams the waste rock immediately above the extraction chamber in order to sink the reamer head into the rock. Reaming is then stopped, and an ore handling chute is placed beneath the raise opening. Once the installation of this ore collection chute is complete the reaming can then continue. Reamed cuttings are removed with a conventional remote control front-end loader (scooptram) and radiometrically scanned. Waste rock and low grade mineralized material is hoisted to surface for appropriate disposal. High grade ore is delivered directly to the underground processing plant (for details see below).

The raise bore reaming typically produces a fine material with few large pieces. Typically, 80 % of the reamed product is less than 19 millimetres in size. Larger pieces can be produced either due to blocky ground or the jointed nature of the ore zone, and are likely to originate within the raise during reaming of these areas, or as sloughage after the reamer head has passed.

Reaming continues upward until the top of the ore zone has been reached. At this point the reaming head is lowered to the extraction chamber and removed. The raise bore machine then raises the pilot drill rods and removes them within the upper chamber.

In the third step of the process, the bottom of the raise is then covered, and the empty raise is filled with a 5 metre thick, rapid cure, high strength concrete plug introduced from below into the lower part of the raise. This concrete plug is designed to support the placement of the next, and much larger, concrete pour.

Finally, once this first concrete application has cured, the remainder of the raise is filled from the upper chamber with a lower strength, fast curing concrete.

After curing of the concrete fill, extraction of adjacent ore by repeating the sequence described above, is possible. By overlapping the raises a high percentage extraction of the ore zone is achieved. After mining and filling a series of rows, the upper and lower chambers are widened to provide the ability to mine sequential rows of bored raises. The chambers above and below the completed raises are then filled with concrete to provide ground support as mining progresses with the completion of each row of bore holes.

To the end of March, 2001, thirty-nine stope raises have been completed which have produced an average of 372,000 pounds of U_3O_8 per raise from within initial Zone 2 mining area, with this zone providing most of the production planned during the first years of mining. Due to the high-grade nature of the ore, an average of only 120 tonnes is required to be mined each day. A total of 3 raise bore machines are necessary to achieve the designed production rate of 18.7 million lbs. of U_3O_8 per year.

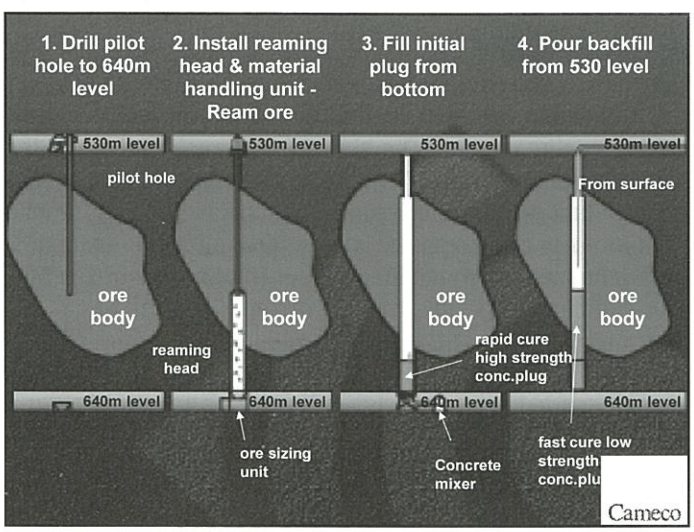


Figure 4: Raise Bore Mining and Backfilling Sequence

4. Initial Mining Challenges

The mining of the initial raise bore holes proved to be quite interesting. The design concept relied upon the raise bore machine providing control of the rate of mining. This was accomplished by limiting, if necessary, the rotation and pull force on the reamer to produce at approximately 25 tonnes per hour which matched the designed material flow of the Transportable Mining Unit (TMU) located immediately at the bottom of the raise. The design of the TMU permitted the containment of the mined material and the wet screening of the ore. Once screened, the undersize was immediately pumped to the ore surge bins. Oversize (+25mm) from screening was placed in a steel box for direct transfer to the grinding circuit. It was reasoned that this system design would limit exposures to employees from radon progeny, gamma and long lived radioactive dust (LLRD) due to its containment, shielding and exhaust ventilation characteristics.

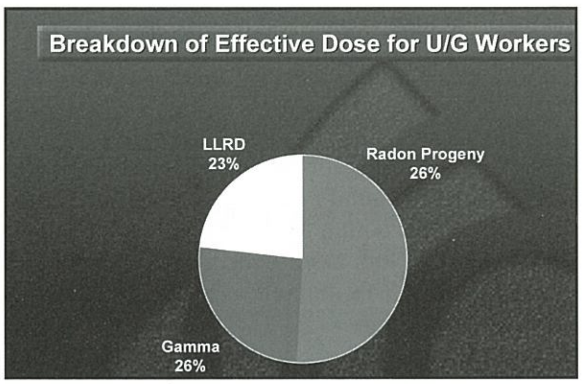


Figure 5: Breakdown of Effective Dose for U/G Workers

Mining in the ore body had not been conducted prior to this time due to licensing constraints; therefore, this was the first experience with raise bore mining in ore. What was experienced proved to be somewhat different than expected. Mining produced an excessive amount of oversize material that often would choke off the feed to the vibrating screen. As well, some unconsolidated clays encountered while mining occasionally blocked the raise itself. These conditions resulted in excessive employee intervention with the TMU in order to facilitate material flow. It was apparent that the system which was originally designed to protect employees from radiation was, in practice, exposing them to potentially higher radiation exposures and, as well, to unanticipated occupational safety hazards by working to clear obstructions.

On one occasion, the material flow within the raise exceeded the processing capacity of the TMU, and the raise gradually filled with clay and rock. A minor water flow into the raise (from residual water trapped within the perimeter freeze wall) was contained by the material in the raise creating the potential for an uncontrolled run of material. This danger was recognized and precautions were taken to remove all employees from the area. A run of material did occur shortly thereafter with damaging consequences to the TMU. A subsequent review of the handling of mined material followed resulting in a new safer, and simpler design. The new design is referred to as the Ore Collection Chute (OCC) and is basically a conical chute covering the bore hole with a 1.5 metre bottom opening supported on four steel legs. This design eliminated the need for employee interaction altogether as remote controlled vehicles were utilized to receive the ore cuttings and transport them to the grinding circuit.

Having improved this key part of the mining cycle, a modified fixed screening unit (FSU) has been located close to the underground processing section. This permits the use of the two ore surge bins, which are designed to add a buffer between mining and ore processing operations.

5. Ore Processing

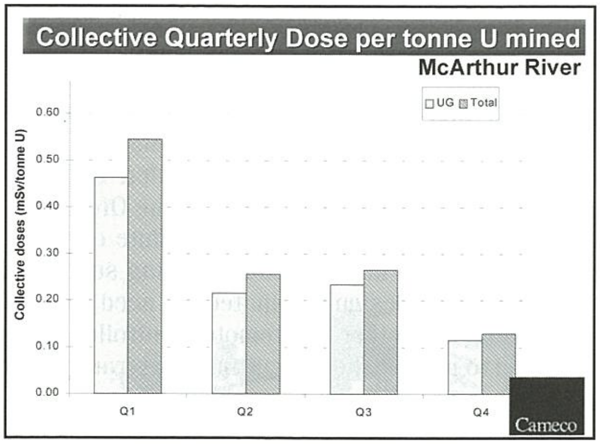
Once mined, the ore is transferred to a grinding circuit located underground. It was decided to process the ore to a slurry suitable to be pumped directly to surface. This eliminates the need to hoist the high grade ore within the shaft used to move men and material and to supply fresh air.

The grinding circuit is fairly conventional and includes a semi-autogenous grinding (SAG) mill fed directly from the mining area, or from one of two ore surge tanks. The mill has been sized to grind ore that has a Bond work index of 17 kWh/t to 90% passing 300 microns. A classifying screen is operated in closed circuit with the ball mill. The classifier screen underflow, the final ground slurry, is pumped to the two underground ore thickeners. Overflows are recycled back to the SAG mill.

Thickener underflow slurry (controlled at 50% solids by weight), is pumped from the underground ore thickeners to a thickener underflow tank. This feeds the ore slurry to one of two positive displacement hoisting pumps, each of which is connected to a dedicated pipeline to convey the ore slurry directly to surface.

On surface the ore slurry is pumped through a U_3O_8 on-stream analyser. Depending on the indicated ore grade, the slurry can be placed into one of four ore storage tanks to allow for subsequent blending. When container loading begins, the ore is then re-slurried, blended, thickened to >50% solids by weight, and placed into purpose-designed containers. Once all four containers are filled, washed and scanned, the truck departs for Key Lake. Each truck is designed to carry four containers and results in the transportation of 15 tonnes (21.2 m3 of slurry) of ore per trip (see Figure 6). Approximately eight trips per day are required to transport ore to the Key Lake mill at average grades.

At the Key Lake operation the ore is diluted to 4 % U3O8 by the blending of special waste material prior to milling.



McArthur River: Collective Quarterly Dose per Tonne U Mined

6. Radiation Control

The control of radiation has been the primary factor in the designs for mine and plant layout, equipment selection and the processing of the ore at McArthur River. In order to minimize exposures the following criteria were applied:

(a) Radon gas is controlled by a dual ventilation system. A primary fresh air flow is always maintained in all active work areas, with a secondary exhaust system to remove contaminated air from particular sources.

(b) Radon is also controlled by the freezing and grouting techniques used to control ground water.

(c) During all mining and processing stages the ore is fully contained where practical.

(d) Gamma radiation is controlled by utilizing the principles of shielding, distance and time. The use of heavy wall steel pipes, thick vessel walls, concrete and sometimes lead sheeting is standard practice.

(e) Mining and ore handling and processing is accomplished remotely with computer control.

(f) Due to the low tonnages required to be mined there is a long period between scheduled maintenance work.

A total of three shafts are utilized to provide 455 m3/s of air to the mine. Two shafts supply fresh air (the main service shaft #1 called the Pollock shaft, and shaft #3), while a third shaft is used for exhaust air (shaft #2).

Every job has been analysed for exposure and time, and distance and shielding calculations have been done to ensure that radiation doses are acceptable. The radiation exposure calculations included estimates of exposures arising from equipment maintenance and spill clean-up. As a result of these design criteria, it was anticipated that the workers would be well within the regulatory dose limit. Actual exposure results for the first year of operation has verified that the radiation control techniques used are in line with predictions and provide very minimal exposures. A summary of radiation results are shown in **Table 2.**

JOB GROUP	MEAN INDIVIDUAL EFFECTIVE DOSE (mSv)	MAX. INDIVIDUAL EFFECTIVE DOSE (mSv)
Surface Workers	0.5	3.1
Underground Workers	1.4	9.3
Overall	1.2	9.3

Table 2. Individual Effective Doses

7. Future Mining Innovations

Although 100% of the current stoping (ore extraction process) is carried out by conventional raise boring, other methods are being developed to extract the ore where it is not practicable to develop openings above and below the stoping block, and to reduce the amount of waste rock being mined. In some cases alternative methods of "blind" boring will have to be implemented, and include:

7.1 Jet Boring

The jet boring method has been pioneered at Cigar Lake, where due to poor ground conditions, it will be the primary method of ore extraction when production commences in 2005. The method has been successfully tested at Cigar Lake in excavating 3 m diameter cavities, utilizing water pressures up to 100Mpa.

This method which requires only the lower chamber, will have limited applicability at McArthur and will be restricted to those areas where raise boring is precluded due to the presence of incompetent ground conditions (water bearing sandstone and excessive faulting).

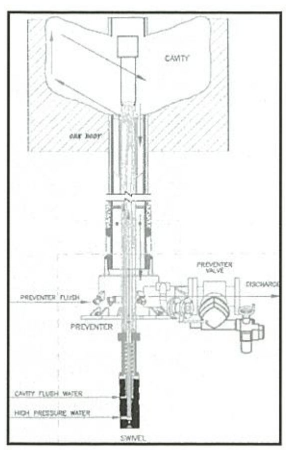


Figure 7: Jet Boring System

7.2 Boxhole Boring/Stoping

The boxhole boring/stoping method only requires the lower mining chamber. The machine pushes the reamer upwards through the ore, with stabilizers being added to the drill rods as mining progresses. The ore falls down the raise to a chute above the box-hole machine, where it is diverted to a loader or container. The method utilizes an expandable reamer head to improve productivity. For box-hole stoping, once the raise is reamed blast holes are drilled from the security of production drill drifts placed lateral to the raise and above the mining chamber. These blast holes intersect the raise, and are loaded with explosives and blasted, as required, to provide broken ore. The ore falls to the drift below and is picked-up with a remotely operated scooptram.

7.3 Expandable Raise Reamer Boring

This type of boring has applicability in both conventional raise boring as well as box-hole boring, and investigations and test-work are now at an advanced stage. The prime advantages of this method are to dramatically reduce the amount of raise borer waste and low-grade cuttings that are currently produced, and to speed-up the cycle time per raise.

After the pilot hole has been completed, the collapsed expandable reamer is attached to the bottom of the drill string and reams a 1.14m diameter hole until the ore zone is reached. The reamer wings are then extended to 3.0m diameter and the ore extracted. After completion of the mining of the ore the fully expanded reamer, with zero rotation, is lowered to the bottom of the enlarged raise until the lower portion of the reamer enters the raise. The wings are then collapsed and the reamer is lowered and retrieved through the pilot reamed hole.

It is anticipated that the first production prototype collapsible reamer will be in service sometime in 2002.

8. Conclusion

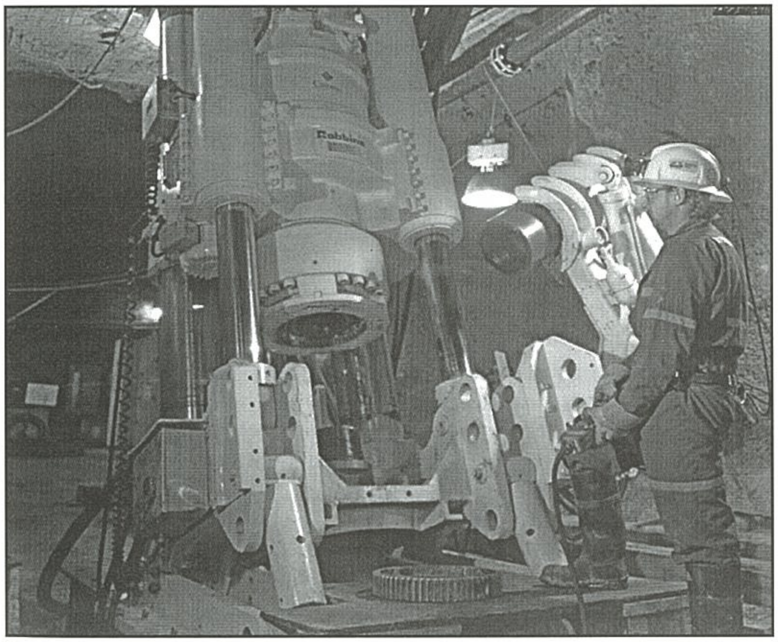
The McArthur River mine is now the largest uranium producer in the world. As a world class ore body, this deposit has secured Cameco's position as a world leader in uranium production for decades to come.

The McArthur River Joint Venture has spent approximately C$450 million during the eleven years from discovery to production. While this may seem a long project lead time, it is in reality representative of the normal time investment required to bring a uranium mine into production within Canada.

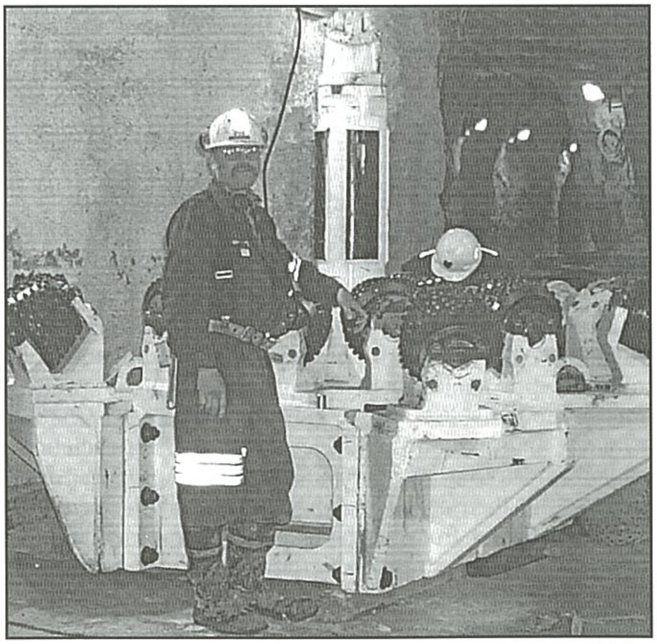
Through well-focused engineered design and extensive project review, it has been shown that this deposit can be mined by non-entry methods, such as raise boring, to achieve the goal of high grade ore extraction in a safe and well-engineered manner.

Radiation exposures can be effectively managed while mining high grade uranium ores. During the first year of production, radiation doses have remained relatively constant while production has increased considerably. As a result, the collective dose per unit production is now between 0.1 and 0.2 mSv per tonne of uranium.

Mining rates are increasing as productivity improvements are being made with the three raise bore machines presently in operation. The production rate of 18 million pounds of U3O8 per annum should be achieved this year.



Two views of specialized mining machinery used at McArthur River.



A Canadian at UNSCEAR

Just before the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) held its 50th session in April this year it officially obtained a new Secretary, **Dr. Norman Gentner,** formerly with Atomic Energy of Canada Limited at its Chalk River Laboratory.

Norman actually had been with the UNSCEAR secretariat for a few weeks previous to his official appointment on April 15, 2001 by the Secretary General of the United Nations, Kofi Annan. As Secretary he is director of the UNSCEAR secretariat.

He brings strong credentials to the challenging post. Born in Saskatchewan he obtained a B.Sc. in biochemistry from the University of Saskatchewan in 1963, winning the Copeland Prize. Then he went to the University of California at Davis where he earned his Ph.D. in 1967. He spent a further year at that university as a National Research Council Postdoctoral Fellow and then moved to Stanford University School of Medicine for two years working with Nobel Prize winner, Professor Paul Berg.

In 1971 he returned to Canada and joined the Radiation Biology Branch at AECL's Chalk River Laboratory. One of his areas of research was investigating whether there exists significant numbers of people with untoward susceptibility to adverse health effects from exposure to ionizing radiation. He became manger of the Branch in 1989 and then Senior Science Advisor in 1993. In this last role he provided advice to many groups and organizations, such as the Canadian Space Agency, the Department of National Defence, Atomic energy control Board, Ontario Hydro, World Health Organization. He was a Canadian representative to UNSCEAR from 1989 to 2000. In 1990 he was a member of the International Atomic Energy Agency Expert Group that set up the Chernobyl Centre for International Research.

The role of UNSCEAR Secretary has two dimensions, external and internal. As Secretary Dr. Gentner is responsible for carrying out the mandate of the Committee during the 51 weeks of the year UNSCEAR does not meet. He is also director of the secretariat, overseeing the organization of meetings, the selection of consultants, representing UNSCEAR at international meetings, and generally ensuring that the work of the Committee proceeds efficiently and effectively.

UNSCEAR was created by the United Nations in 1955 in response to widespread concerns regarding the effects of radiation on human health and the environment. At that time, nuclear weapons were being tested in the atmosphere, and radioactive debris was dispersing throughout the environment, reaching the human body through intake of air, water and foods. The Committee was requested to collect, assemble and evaluate information on the levels of ionizing radiation and radionuclides from all sources (natural and produced by man) and to study their possible effects on man and the environment. Although fallout from weapons testing has essentially disappeared UNSCEAR continues to fulfill that broad mandate.

The Committee is comprised of scientists from 21 member states: Argentina, Australia, Belgium, Brazil, Canada, China, Egypt, France, Germany, India, Indonesia, Japan, Mexico, Peru, Poland, Russia, Slovak Republic, Sudan, Sweden, United Kingdom, and the United States of America. The UNSCEAR Secretariat is located in Vienna.

The Committee produces periodic reports to the UN General Assembly. These reports have become regarded by the scientific community as authoritative and balanced reviews. They are increasingly used by organizations and individual scientists as source of valuable information. The reports review exposures from all radiation sources, natural and man made. They include detailed studies on radiation induced cancer, on the body's repair systems, on the risks of hereditary diseases from radiation exposure, and on the combined effects of radiation and other agents. Assessments are also made of the radiological consequences of accidents, such as Chernobyl.

The latest publication of the Committee is the UNSCEAR 2000 Report, titled "SOURCES AND EFFECTS OF IONIZING RADIATION" published in two volumes comprising 1300 pages. The UNSCEAR 2000 Report includes extensive scientific reviews and assessments in ten annexes:

Annex A: Dose assessment methodologies (64 pages)
Annex B: Exposures from natural radiation sources (74 pages)
Annex C: Exposures from man-made sources of radiation (136 pages)
Annex D: Medical radiation exposures (204 pages)
Annex E: Occupational radiation exposures (157 pages)
Annex F: DNA repair and mutagenesis (72 pages)
Annex G: Biological effects at low radiation doses (102 pages)
Annex H: Combined effects of radiation and other agents (118 pages)
Annex I: Epidemiological evaluation of radiation-induced cancer (153 pages)
Annex J: Exposures and effects of the Chernobyl accident (115 pages)

The impetus for the formation of UNSCEAR related to concern about hereditary effects of radiation. At its meeting in April 2001 the Committee set these concerns in perspective with its latest comprehensive review of the risks to offspring (hereditary risks) following parental exposure to radiation. These risks are relatively small: The major finding is that the total risk of inducing hereditary effects is 0.3-0.5% per gray to the first generation following exposure. This is less than one-tenth the risk of fatal carcinogenesis following irradiation, and constitutes only 0.4-0.6% of the baseline frequency of such disorders in the human population. The scientific findings will be published this fall as the UNSCEAR 2001 Report, entitled "HEREDITARY EFFECTS OF RADIATION".

Further information on UNSCEAR and its reports can be obtained at its Web site: www.unscear.org

GENERAL news

Education Initiatives

In response to many observations that the state of nuclear engineering programs in Canadian universities had been declining over the past several years, three different initiatives have been announced recently.

McMaster University

Atomic Energy of Canada Limited has entered into an agreement with McMaster University to provide $10,000 per year for the next five years for a scholarship program. Four scholarships of $2,500 will be awarded each year for engineering students in their second undergraduate year. Requirements include: outstanding academic standing; demonstrated leadership qualities; an interest in advanced engineering projects. Winners will be offered summer employment or work terms in the year following the award.

Ecole Polytechnique

Atomic Energy of Canada Limited, Babcock & Wilcox Canada and the Natural Science and Engineering Research Council have established an Industrial Research Chair of Fluid Structure Interaction at the Ecole Polytechnique in Montreal. The primary area of research will be the investigation of how the flow of fluids through industrial machinery causes vibration and damage. Direct funding for the five-year project is $1.5 million, with NSERC providing half and AECL and B & W sharing the other half. Ecole Polytechnique will provide laboratory space and services valued at $375,000.

University of Toronto

The University of Toronto has established a Centre for Nuclear Engineering within its Department of Applied Science and Engineering and appointed Dr. James Smith as its director. Among the objectives of the new Centre are: stimulation of research in nuclear engineering; strengthening of nuclear engineering at the undergraduate level; provision of professional development opportunities. The Centre, which will begin programs in January 2002, will offer a Masters program in nuclear engineering.

Network of Excellence

Earlier in the year Ontario Power Generation announced that it was committing $5 million over five years towards the creation of a Universities' Network of Excellence in Nuclear Engineering. This is a partnership with five Ontario universities that have strong engineering programs - Queen's, Toronto, McMaster, Waterloo and Western. The programis to foster collaborative research and education for the development of nuclear technology. OPG is encouraging the universities to seek matching funding from the federal Natural Sciences and Engineering Research Council (NSERC). OPG has also committed $750,000 to establish an NSERC chair in Nuclear Fuel Waste chemistry at the University of Western Ontario, and, $105,000 for scholarships for masters students in nuclear engineering at McMaster University.

W. B. Lewis Lecture

Dr. Robin Jeffrey, CEO of British Energy plc., will give the *W. B. Lewis Lecture* for 2001. The lecture will be given Wednesday, October 17, 2001 in the Laurentian Room of the Chateau Laurier Hotel in Ottawa, beginning at 7:30 p.m. There will be a reception preceding the lecture.

Dr. Jeffrey became executive chairman of British Energy earlier this year. For the past four years he was deputy chairman and Board member responsible for North America, which included the establishment of Bruce Power. He has a B.Sc. in chemical engineering from Glasgow University and a Ph.D. in fluid mechanics from Cambridge University. Following several years with Babcock International he joined the south of Scotland Electricity Board in 1979, eventually becoming chief executive of Scottish Power, one of the privatized companies that merged into British Energy.

The W. B. Lewis lectures were initiated by Atomic Energy of Canada Limited in 1988 to honour the memory of Dr. W. B. Lewis who the scientific work of AECL for three decades and is considered the "father" of CANDU. AECL financially support s the lectures, while Carleton University and University of Ottawa provide the venue. There is no admission charge.

The title of Dr. Jeffrey's lecture will be "Replacing Nuclear with Nuclear - A UK Perspective".

IMPELA Technology Sold

Atomic Energy of Canada Limited has sold its IMPELA electron accelerator technology to Iotron Industries Canada Inc. of Port Coquitlam, B.C.

IMPELA is a commercial scale electron beam accelerator that uses high-energy electrons to sterilize medical equipment and supplies, and for food irradiation. Lloyd Scott, president of Iotron, commented that his company had been using an IMELA machine since 1994. They expect to put two more units into service in the near future.

IAEA Reappoints ElBaredi

Delegates of the member states of the International Atomic Energy Agency to its Annual Conference in Vienna, approved by acclamation the reappointment of Dr. Mohamed ElBaredi to a second four-year term as Director General.

During his first term in that office Dr. ElBaradei initiated programs to strengthen the IAEA's work in nuclear safety, verification and technology. He joined the IAEA secretariat in 1984 as a legal adviser. Subsequently he headed the Division of External Relations and in 1993 was appointed Deputy Director General for External Relations. Born in 1942, he obtained a Doctorate in International Law from the New York University School of Law in 1974.

AECL Appointment

At the end of August, Atomic Energy of Canada Limited announced the appointment of **Doug Christensen** as General Manager, External Relations. There are four components in the External Relations portfolio: Shareholder Relations; Environment; International Agencies; and Stakeholder Relations.

Betty Rozendaal is Director, Environment; David Tregunno, Senior Manger for international relations; and Danielle Laurier is Manager, stakeholder relations.

New French Company

In early September, a new French nuclear company was born, called **Areva.** It combines Cogema, Framatome and CEA-Industrie but remains as a primarily state-owned entity, with the Commissariat d' Energie Atomique holding 79%.

Areva will be organized in two main divisions: Energy and Advanced Technology, with provision for a third division. The Energy division comprises Framatome ANP and Cogema plus some smaller firms such as Technicatome. The Advanced Technology division has Framatome Connectors International and part of STMicroelectronics. The new holding company is valued at 80 billion French francs.

An advertising campaign is being launched to sell the name "Areva", with a slogan "living better through advanced technology".

Nuclear at Chemistry Conference

Through the efforts of Prof. Derek Lister of the University of New Brunswick, there will be a full session on nuclear technology at the 51st Canadian Chemical Engineering Conference being held in Halifax, 14 - 17 October 2001. Among the nuclear papers being presented are:

- Nuclear Education and Training at UNB by R. A. Chaplin
- Heavy Water Process Simulator by A. E. Everatt and D.K. Ryland
- Operational Experience and Demonstration of High Detritiation Factors with Pilot Scale CECE Facility by W. R> Graham, J. M. Miller, A. E. Everatt, J. R. R> Tremblay and D. A. Spagnolo
- Nuclear Technology for Detection of Ordnance by E.M.A. Hussein and E. J. Waller
- The Chemistry Control Program for Point Lepreau Nuclear Steam Generators by C. MacNeil, A Dykerman, G, Brown
- Prototype CIRCE Plant - Industrial Demonstration of Heavy Water Production from Reformed Hydrogen Source by J. Blouin, D. A. Spagnolo, H. B. Boniface, R. R. Sadhanker, A. J. Miller
- Numerical Analysis of the Flow in CANDU Outlet Feeder Pipes Showing Flow-Assisted Corrosion by S. Supa-Amornkul, F. R. Steward, D. H. Lister

Bruce Power Begins Work on Bruce A

In July Bruce Power announced that it had engaged contractors to assist in the initial work towards the restart of the Bruce 3 and 4 units. The plan is to have the two units on line by summer 2003.

The main contractor and project manager will be by a joint venture of Acres-Sargent and Lundy, an alliance of Acres International and Sargent & Lundy, two large engineering companies, and E.S. Fox Ltd..

RCM Technologies Canada Co. is the main contractor for the engineering, procurement and construction work needed to complete the environmental qualification of the equipment in the two units.

National Nuclear Corp. of the UK together with Atomic Energy of Canada Limited and Candesco will do the safety analysis.

Golder Associates will do the environmental assessment as required by the Canadian Nuclear Safety commission.

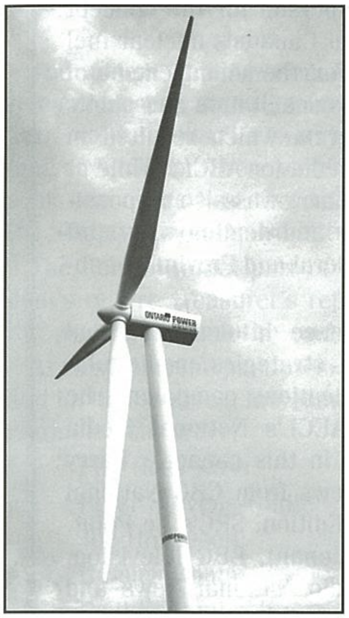
The budgeted cost of the restart project is $340 million.

CNA Appointment

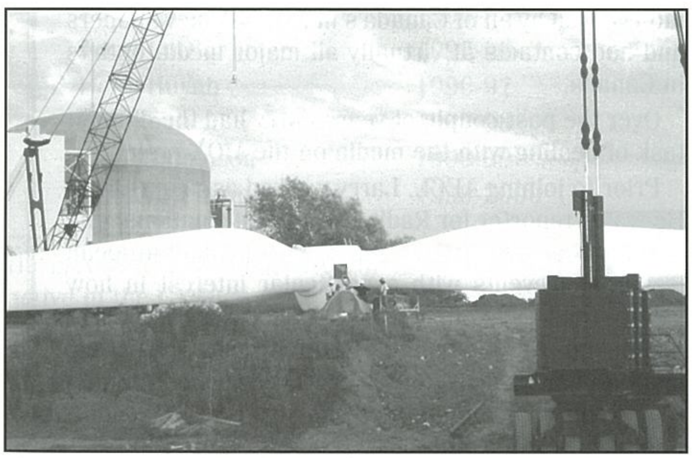
The Canadian Nuclear Association has appointed **Al Shpyth** as Director, Regulatory and Environmental Affairs, a new position at the Association. He is now located at the CNA's Ottawa offices.

Al will also continue as Director, Government Relations for Cameco Corporation. A graduate of University of Saskatchewan and York University in economics He worked from 1991 to 1996 in various roles with the Government of Saskatchewan, including executive assistant and special adviser to Premier Roy Romanow.

Windmill at Pickering



With great fanfare, Ontario Power Generation launched a 30 storey high windmill located on the grounds of the Pickering NGS in late August, 2001. The blades of the propeller have a span of 39 metres. *(See photos)* The wind turbine will produce 1.8 megawatts. At its maximum rating it would take over 250 such machines to match the output of one Pickering NGS, when the wind is blowing. It is estimated that its maximum capacity factor will be about 25%.



British Energy recommends nuclear

In is official submission to the "Review of UK Energy Policy" being conducted by the British government, British Energy urged for a policy that would support new nuclear power plants. Stating that nuclear power should continue to supply 25% of UK electricity, British Energy argued for a policy of "replace nuclear with nuclear".

Nuclear power is the only large scale generation option that does not contribute to global warming whilst delivering security of energy supply, BE stated. The market on its own will not achieve security, environment and economic objectives, BE asserted Therefore, government needs to set the framework. If government addresses a number of key issues, new nuclear could be delivered in the UK by the private sector, the BE said in its submission, and it was prepared to do so.

The submission stated, "British Energy's view is that the Westinghouse AP 1000 and CANDU NG 600 designs, amongst others, could be delivered in time to form the basis of the 'Replace Nuclear with Nuclear' new build programme."

The full submission by British Energy can be found on its Web site.

CNSC Hearings

The Canadian Nuclear Safety Commission has scheduled the following hearings.

October 3

Day two (of the CNSC two-day procedure) on the application from Ontario Power Generation for the restart of the Pickering "A" nuclear generating station. Day one was held in two parts in June and August. Seven oral submissions are scheduled and 37 written submissions will be tabled.

October 4

Five licensing items will be held on October 4:

- day two of consideration of renewal of the Operating Licence for Cameco's Rabbit Lake, McArthur River, and Key Lake mines, and
- day one for the renewal of the Operating Licence for Cogema's Cluff Lake mine and for an application from Cameco for approval of evaluation of mining methods at Cigar Lake.

November 15

A special one-day hearing will be held on the application for an Operating Licence for the Canadian Light Source accelerator at the University of Saskatchewan.

Day one hearings will be held on renewal of Operating Licences for the following facilities:

- Zircatec's Port Hope fuel manufacturing facility
- Cameco's Blind river and Port Hope uranium processing facilities.

Day two will be held January 17, 2002.

OBITUARIES

Douglas G. Andrews

Professor Douglas G. Andrews, a pioneer nuclear engineering professor, died September 20, 2001, in Oakville at the age of 83, from complications of a severe stroke.

Doug Andrews received his M.A. from King's College, Cambridge in Mechanical Engineering. He was working on his D.Sc. when the Second World War erupted and he moved to serve with British Intelligence. After the war he spent a few years with the British Atomic Energy Research Establishment. Upon coming to Canada, he worked for the aviation company A.V. Rowe Co. for a short period.

In 1957 he joined the Department of Chemical Engineering and Applied Chemistry of the University of Toronto as the first Professor of Nuclear Engineering. Some years later he was instrumental in the installation of the SLOWPOKE 1 sub-critical reactor in the Wallberg Building at U of T, the first of its kind in a Canadian university. He retired in 1983. In 1992 he was honoured by his alma mater with a D.Sc. in recognition of his lifetime career achievements and also the fact that his postgraduate studies were suspended because of the war.

Doug Andrews was one of the founders of the Canadian Nuclear Association and later was one of the charter members of the Canadian Nuclear Society. Over the years he chaired several CNA committees including those on Nuclear Education and Nuclear Safety. During the 1960's, when there was much concern about the impacts on the Canadian public of Russian atmospheric atomic bomb tests he arranged training for many Toronto engineers, police and firefighters on public health and emergency measures aspects of radiation. Many nuclear engineering specialists who now work in the Canadian nuclear industry did their postgraduate studies under Professor Andrews.

A funeral service was held September 24 at the Oakville Funeral Home in Oakville, Ontario.

Larry Shewchuk

The Canadian nuclear industry has lost one of its finest spokespersons. Larry Sewchuck, manager of public affairs at Atomic Energy of Canada Limited, died July 26, 2001, after a long and valiant battle with cancer.

Larry was continually quoted in the press and often heard on radio and seen on television, replying to questions or correcting misleading statements by anti-nuclear activists.

Larry Shewchuk joined AECL in 1991 at the Whiteshell Laboratories. He soon became the company's primary media spokesperson for the concept for deep geological disposal of Canada's nuclear fuel waste. He was responsible for the management of media relations for the public consultation and public hearings phase of that program which resulted in mostly balanced to positive media for AECL. While at the Whiteshell Laboratories, Larry was also responsible for Government Relations and dealing with staff from the offices of various Federal and Provincial cabinet ministers.

With his extensive experience in designing and implementing communications strategies, media relations and proactive communications campaigns, he assumed responsibility for AECL's National Media Relations program in 1997. In this capacity, Larry worked with documentary crews from CBC National News, CTV's W5 and Sunday Edition, SRC's Le Point, Global Television, ABC T.V. (Japan), BBC Television, Moscow One, CNN, CBC Radio National News and National Public Radio among many others. He was interviewed by all of Canada's major daily newspapers and had contacts at virtually all major media outlets in Canada.

Over the past couple of years Larry had the difficult task of dealing with the media on the MOX project.

Prior to joining AECL, Larry worked as a journalist. He was a reporter for Radio Canada International and covered North American, Asian, African and European issues and events with a particular interest in how science and technology would impact on the environment and the economy of developing countries. Earlier he was a foreign correspondent for the Christian Science Monitor (radio service) and a producer with CBC Newsworld.

Donna Roach, Manager, Public Affairs at AECL's Chalk River Laboratories, was a close friend of Larry. She commented that his quick wit and his ability to always find the positive in every situation will be greatly missed. "You would have thought that his work was his biggest passion but work never held a candle to the passion he felt for his family and for life in general. We have truly lost a gentleman and a role model", she added.

CNS news

Annual General Meeting

The fourth Annual General Meeting of the Canadian Nuclear Society since its incorporation was held June 11, 2001, at the Delta Chelsea Hotel in Toronto, Ontario, beginning at 5:15 p.m. There were 59 members and 3 guests present, one of the best turnouts for an AGM in the history of the Society. Among those attending were 11 past presidents.

The normal initial part of the agenda of minutes, president's report, treasurer's report and appointment of auditor, proceeded smoothly and expeditiously.

At this point the past presidents present were introduced and invited to give a few remarks. Those attending were, in chronological order:

Phil Ross-Ross	1981-82 and 1982-83
Peter Stevens-Guille	1985-86
Joe Howieson	1986-87
Hugues Bonin	1990-91
Paul Fehrenbach	1993-94
Ed Price	1994-95
Jerry Cuttler	1995-96
Hong Huynh	1996-97
Ben Rouben	1997-98
Paul Thompson	1998-99
Krish Krishnan	1999-2000

(It may be noted that several are still very active in the CNS.)

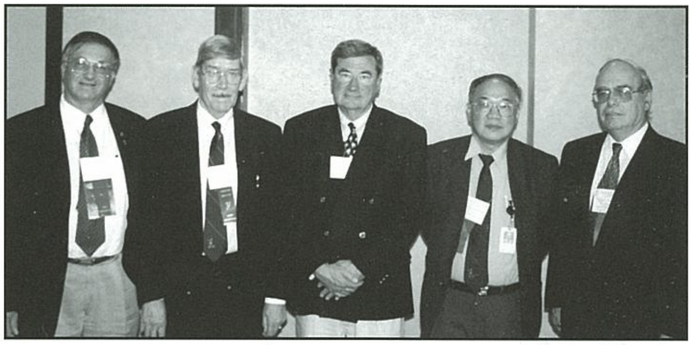
Short reports were presented on most of the CNS committees.

Then a motion was presented to increase the maximum number of elected (voting) members of the governing CNS Council from 22 to 25. Outgoing president Ken Smith explained that the many tasks faced by the Council required more volunteers. This motion was quickly passed.

With that in hand, past president Krish Krishnan presented a proposed slate of candidates for officers and members of Council. On a call for further nominations Jerry Cuttler offered to serve again as a member-at-large and his name was added to the list. With no further nominations the slate was elected by acclamation. (See list of officers and Council members elsewhere in this issue.)

At this point, outgoing president Ken Smith presented the symbolic gavel to Dave Jackson, president for 2001 - 2002. Krish Krishnan then presented a plaque to Ken Smith in recognition of his leadership over the past year.

Following a short address by the new president the meeting was adjourned at 6:50 p.m.



CNS Executive for 2001-2002 at the Annual General Meeting 11 June 2001. Left to right: Ben Rouben, secretary; Ian Wilson, 1st vice-president; David Jackson, president; Andrew Lee, treasurer; Ken Smith, past-president. Missing: Jeremy Whitlock, 2nd vice-president.

Eleven past presidents of the CNS attended the Annual General Meeting held in Toronto, 11 June 2001. Left to right: Hong Huynh, 1996-97, Ben Rouben, 1997-98, Jerry Cuttler, 1995-96, Krish Krishnan, 1999-2000, Paul Thompson, 1998-99, Joe Howieson, 1986-87, Peter Stevens-Guille, 1985-86, Paul Fehrenbach, 1993-94, Hugues Bonin, 1990-91, Ken Smith, 2000-2001 (outgoing president), Phil Ross-Ross, 1981-82, 1982-83, Ed Price, 1994-95.

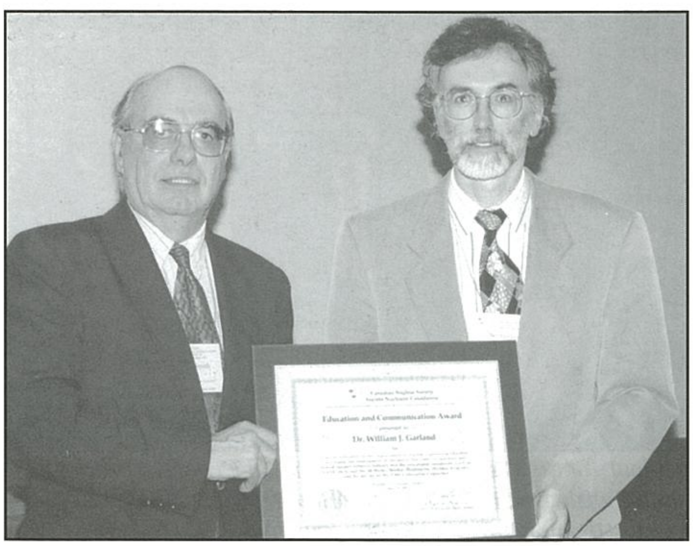
CNS awards three members

At the special awards luncheon during the Annual Conference held in Toronto in June 2001, the Canadian Nuclear Society recognized three of its members for their contributions.

Two members were given the **Education and Communication Award.** This award, which was established in 1997, recognizes recipients for significant achievements in improving the understanding of nuclear science and technology among educators, students and the public.

Dr. Reza Moridi, who is with the Radiation Safety Institute of Canada, was presented with the Education and Communication Award for his work in educating the public on matters related to nuclear materials, radiation and radiation safety, using educational software developed at the Institute. He has conducted numerous interviews with journalists from the press, radio and television. When the Institute conducted tests for radon contamination of 3,500 classrooms in the Toronto area Dr. Moridi took advantage of these tests to do presentations to dissipate concerns about radon. He has also been involved in the training of personnel (including military) on the safe use of radiation sources. In his unavoidable absence, Dr. Moridi's wife and son accepted the award on his behalf.

Ken Smith presents Paul Thompson with a certificate confirming his appointment as a Fellow of the Canadian Nuclear Society (FCNS).



Ken Smith presents Bill Garland with the CNS Education and Communication Award during the CNS Annual Conference, June 2001.

Dr. William J. Garland, a professor in the Department of Engineering Physics, McMaster University, and a long-time scholar, has taught and supervised numerous undergraduate and graduate students. He has demonstrated relentless search for novel methods of teaching CANDU reactor physics, thermalhydraulics and man-machine information management. Professor Garland has pioneered the use of Internet and distance teaching methods, sustained efforts in enhancing industry-academia relationships, resulting in programs such as CANTEACH and the McMaster University's Nuclear Technology Diploma program. He has given sustained service to the CNS especially through his involvement in the Universities' Committee and Student Conferences.

Paul Thompson was named a **Fellow of the Canadian Nuclear Society.** The designation denotes outstanding merit through major and sustained contributions that relate to the advancement of nuclear technology in Canada, demonstrated maturity of judgement, breadth of experience and service to the Society.

In his various roles at the Point Lepreau nuclear generating station Paul has contributed in many areas such as: reactor physics, safety analysis, licensing, and management. He was involved in the recovery, clean up and re-commissioning of the primary heat transport system and has conducted studies into the safety aspects of plant ageing. Paul has also been a major contributor to the Society, both at the branch and national levels. He was the 18th president of the CNS in 1998 -1999.

26th CNS / CNA Student Conference

An innovation was tried for the **26th Student Conference** sponsored by the Canadian Nuclear Society and the Canadian Nuclear Association and proved successful. For the first time, the CNS / CNA Student Conference was associated with the Society's Annual Conference.

The format saw the Student Conference run on the Sunday, June 10, 2001, prior to the official opening of the 22nd CNS Annual Conference. This resulted in more students participating and a far larger audience.

There were thirteen papers presented, in two sessions, morning and afternoon. A point of distinction was the use of both official languages, in some cases within a single paper.

For judging purposes the papers were divided into three categories based on the scholastic level of the authors: undergraduate, masters and doctorate. The winners were:

Undergraduate

The Design of an Irradiation Facility for the Destruction of Spent Nitrocellulose Plastic Explosives. by Julian O. A. Kim, Mathieu L'Italien, Phillippe Nault and Chris Prechotko of the Royal Military College.

Masters

SLOWPOKE Integrated Reactor Control and Instrumentation System (SIRCIS) by Lloyd R. Cosby, Royal Military College.

Doctorate

Foundation for a Visual Reactor Simulation Toolkit by David Gilbert, McMaster University

The 26th CNS / CAN Student Conference was organized and chaired by Professors Hugues Bonin of the Royal Military College and William Garland of McMaster University.

The three winning papers are reprinted as a Supplement to this issue of the *CNS Bulletin.*

Flanked by professors Hugues Bonin (L) and Bill Garland (R) are the participants in session 1 of the 26 CNS/CNA Student Conference, 10 June 2001. Left to right: Simon Turbide, David Gilbert, Benoît Villien, Frédéric Grenier, Dany Thériault, Ha Tae Sung, Lloyd Cosby.

Participants in Session 2 of the 26th CNS/CNA Student Conferrence, 10 June, 2001 pose with conference coordinators, Prof. Hugues Bonin (L) and Bill Garland (R). Left to right: Kathleen Heppell-Masys, Charlene Fawcell, Julian Kim, Phillipe Nault, Ian Miedema, Ellen Meadd, Bernard Ellaschuk.

Another successful Teachers' Workshop

Twelve high school science teachers from New Brunswick attended a four-day professional development workshop on *"Science of Nuclear Energy and Radiation"* held in July at the University of New Brunswick in Fredericton. The workshop was organized by Clair Ripley of Atomic Energy of Canada Limited and Mark McIntyre, Atlantic Nuclear Services Ltd, and chairman of the New Brunswick Branch of the Canadian Nuclear Society.

The first day was devoted to lectures on nuclear energy, nuclear reactors, climate change, and fuel storage. On day two the group toured the Point Lepreau nuclear generating station and the cancer centre at the Saint John Regional Hospital. Day three combined demonstrations and experiments on radiation, a tour of the Centre for Nuclear Energy research at UNB and a talk by Ed Waller on his experience in the exclusion of Chernobyl. That evening there was a dinner with Dr. Doug Boreham of AECL-CRL speaking about low level radiation with a talk entitled *"Radiation vs. Viagra - What's Up?"*. The last day was devoted to lectures on risk assessment and the medical use of radioisotopes, followed by a final discussion period.

The assessments of the course were all very positive, with comments of "highly recommended", "thought provoking", "well organized", and, "overall a 'national class institute".

Participants in the July 2001 teachers' workshop on "Science of Nuclear Energy and Radiation" pose in front of the Point Lepreau NGS with Clair Ripley, workshop organizer (far left.) and Sue Moore of NB Power (far right).

Young Generation Network at Annual Conference

Paul Lefreniere

A special noon-hour session was held during the 22nd CNS Annual Conference by the North American Young Generation Network (NA-YGN) focussed at the "under 35" professionals in the nuclear industry.

Organized by Mark McIntyre, chair of the CNS New Brunswick Branch, the event drew an overflowing crowd to the assigned room. *(See photo)*.

Mark outlined the origins of the Young Generation Network in Europe and recounted some of their efforts at the CoP meetings related to the Kyoto protocol for limits on CO2 emissions. A parallel North American group has been formed with the support of the American Nuclear Society and the Canadian Nuclear Society. He encouraged those in the room to become involved.

Then he introduced his two invited speakers, Fred Boyd, and Paul Lafreniere. Fred gave a "20 minute history" of the Canadian nuclear industry, reminding or informing the audience that the nuclear program in Canada was now close to 60 years old, having begun with the Montreal Laboratory during the Second World War.

Paul provided a number of personal vignettes from his own career at Hydro Quebec and Atomic Energy of Canada Limited to give a human touch to the science and technology.

Those interested in learning more of the NA-YGN should contact Mark McIntyre, e-mail: mmcintyre@nbpower.com

Mark McIntyre addresses the over-flowing audience at the special Young Generation Network event he organized which was held during the CNS Annaul Conference, June 2001.

BOOK REVIEW

Unlocking the Atom

By Hans Tammemagi and David Jackson

This book is sub-titled "The Canadian Book on Nuclear Technology. It is the first book to deal with nuclear science and technology for the "educated general public" from a Canadian perspective. In doing so it describes the many Canadian achievements in developing the CANDU reactor, in production and application of radioisotopes, in uranium mining and related areas.

It gives an introduction to radiation, and covers a wide range of topics related to the application of nuclear energy, including; power reactors, nuclear safety, nuclear waste, uranium fusion and industrial and research applications. The text is augmented with 80 figures or photographs along with profiles of a dozen Canadian nuclear pioneers.

The authors have extensive background in the nuclear filed combined with experience as writers and educators. **Hans Tammemagi** is an author and columnist who spent many years in the Canadian nuclear waste program. His third book, *The Waste Crisis: Landfills, Incinerators and the search for a Sustainable Future* won the 2000 Niagara Book Prize. **David Jackson** spent a number of years as a research scientist, was director of Canada's National Fusion Program and chairman of the International Fusion Research Council of the IAEA. He is a professor (adjunct) at McMaster University and 2001 - 2002 president of the Canadian Nuclear Society.

This book is easy to read yet technically accurate. Beyond its general audience it would serve as a good reference at the senior high school or undergraduate university level. *(At the time of writing it had not yet gone on sale. Look for it this fall.)*

Publications available

AECL Annual Report

Atomic Energy of Canada Limited's **Annual Report** for fiscal year 2000-2001, entitled, *The Renaissance of the Nuclear Industry,* was tabled in Parliament on 2001 September 18 and is now being distributed. It is published in English and French. The annual report will be available on AECL's website <www.aecl.ca >. Hard copies can be obtained from AECL's Public Affairs department.

Maintenance Programs for Nuclear Power Plants

This draft Regulatory Standard number C-210 has recently been issued by the Canadian Nuclear Safety Commission for comment. The deadline for submitting comments is November 30, 2001. The proposed standard describes the maintenance program for structures, systems and components of a nuclear power plant that licensees must develop as a condition of a licence to operate. Copies can viewed on the Commission's Website < www.nuclearsafety.gc.ca > or ordered from its offices in Ottawa through e-mail: reg@cnsc-ccsn.gc.ca.

Emergency Planning at Class I Nuclear Facilities and Uranium Mines and Mills

This is a Regulatory Guide from the Canadian Nuclear Safety Commission, numbered G-225. It provides guidance for licence applicants on the development of emergency measures to satisfy the requirements of the *Nuclear Safety and Control Act* and its regulations. It has taken into account comments on a draft version issued in 1999. The Guide can be seen on the CNSC Website < www.cnsc-ccsn.gc.ca > or obtained from the CNSC offices in Ottawa through e-mail: publications@cnsc-ccsn.gc.ca.

A Critical Review of the System of Radiation Protection

Those unhappy with the existing rules and limits for radiation protection should find this report interesting. It was prepared by the Committee on Radiation Protection and Public Health (CRPPH) of the OECD Nuclear Energy Agency. To quote the Foreword, "this material should be considered as a contribution to the evolving debate over the future direction of the international system of radiation protection."

Copies can be obtained from OECD Publications, 2 rue Andre-Pascal, 75775 Paris Cedex 16, France.

Videos

The World Nuclear Association (formerly the Uranium Institute) has produced a 12 minute video that gives the major arguments for the use of nuclear power. It can be viewed at its Website < www.world-nuclear.org >. Although currently just in English, WNA will be producing it in 10 languages.

The Impotence of Being Earnest

by Jeremy Whitlock

The politics of Environmentalism - sometimes amusing, always self-contradictory - reached a new low in Bonn this summer. The machinations at the COP-6 Kyoto negotiations brought new meaning to the phrase "ulterior motive", and read like the plot of a bad Mafia movie:

© Lorne Whitlock, 2001

Fade in...

The exit of kingpin America leaves a void exploited mercilessly by the Euro Greens. These are the power brokers of the new millennium. They have negligible popular support but control the European agenda through cunning and hard-won coalitions.

Now, with the Yanks gone, they control the Kyoto agenda as well. This is their time. Wiseguys at last, without the birthright.

The Euro Greens despise nuclear power. They don't understand it, but understanding is overrated. It's clean ... too clean. It works ... too well. It cannot be allowed to thrive.

The Canadians and the Japanese want nuclear power, and the Canadians and Japanese are carbon pigs, so they matter. But the Canadians and Japanese are not untouchable. They can be lured into the Fool's Paradigm, where a forest is not a temporary stop on the Carbon Cycle, but a permanent reservoir, a sink. It is not their fault - this stupid idea comes from elsewhere, from people with Degrees.

The EU Wannabees who favour nuclear power - the Slovaks, Bulgarians, Lithuanians, Czechs, Lithuanians, and Hungarians - are told to sit down and shut up. This is not their fight. They bring nothing to the table. If you want to be made, sit in the shade.

The oil sheiks in the G77 Group give their full support to a no-nukes clause. Their motive, at least, is clear and rational.

The meeting of the Dons ensues, presided over by COP-6 President and all-round Goodfella, Jan Pronk (of the anti-nuclear Netherlands Labour Party). The Canadians and Japanese play hard. The Euro Greens tell them to stick it. Don't even show us your stinkin' alternative proposal. We wipe our behinds with more meaningful paper.

The Canadians and Japanese fold. The Euro Greens grin. The EU Wannabees mop their brows. Russia looks confused.

Fade out...

Or perhaps that's according too much chic to this chicanery. What happened in Bonn was little more than lynch-mob mentality and Lilliputian delusion. Nuclear power is hardly down for the count. No puppet politician can stifle the fact that a tennis-ball-sized lump of uranium can power a home for three years with nary an ounce of air pollution.

Increasingly, decision-makers are shirking ideology and giving nuclear power top marks for sustainable development. The petty string-pullers at Bonn are not only behind the times; they're behind their own bureaucracies: the European Commission has itself endorsed numerous statements of late on the importance of nuclear technology.

More to the point, COP-6 does nothing to deserve the accolades heaped upon it by those who would dance on the nuclear grave. It does not, in fact, discourage the use of nuclear power to meet Kyoto targets, nor the continuing use of nuclear power. All that it does is hinder the developed world from helping the developing world (via the Clean Development Mechanism), or other less-viable developed economies (via the Joint Implementation mechanism).

This peculiar hypocrisy, where a country like France can hobble the proven technology from which it derives 80% of its electrical energy, is informative. Can we not, finally, let go of the notion that the public will be won over by rational argument and clean living? These are, no doubt, the main column and the supply train - but the vanguard of this noble crusade is surely something else, as subtle as the force which opposes it.

Anti-nuclearism, as put forth some time ago in this very humble space, is a meme. And memes are best fought with memes. This is the time to harness the main audio-visual pathways that inform the masses. Not aggressively. Not pedagogically. Not with any immediate expectations.

This is not the time to back down, as the industry has unfortunately just done, on ambitious plans to speak directly to the public. The tide is turning. Canadians deserve to learn about the world-leading, home-grown technology that can sustainably power economies at almost any level of sophistication.

COP-6 shows us, if nothing else, that "earned media" is a pipe dream where memes are concerned. The media mirrors society, and we have ample evidence that society does not turn easily from a meme (also by definition). It is a "trickle" process, demanding craftsmanship and patience.

That anti-nuclearism is unbeatable by traditional channels, and indeed, that nuclear power is a singularly peculiar beast in the first place, would - understandably - not be appreciated by somebody new to our scene. Part of the problem, therefore, has been the oft-changing hands in the front offices and PR departments of our leading organizations.

The sooner we shake this handicap, the better.

CALENDAR

2001

Sept. 24 - 27

7th International Conference on CANDU Fuel
Kingston, Ontario
Contact: Prof. Brent Lewis
Royal Military College
Tel: 613-541-6611
e-mail: lewis-b@rmc.ca

Sept. 30 - Oct. 4

ICEM'01 - 8th International Conference on Radioactive Waste Managment and Environmental Remediation
Bruges, Belgium
Contact: Donna McComb
Laser Options Inc.
Tucson, Arizona
Tel. 520-292-5652
e-mail: dmccomb@laser-options.com
web: www.icemconf.com

Oct. 3 - 5

Climate Change: Canadian Technologies Development
Toronto, Ontario
Contact: Duane Pendergast
Comutare
Tel; 403-328-1804
e-mail:
duane.pendergast@computare.org
or CNS office

Oct. 8 - 9

Power Generation and Sustainable Development
Liege, Belgium
Contact: A.I.M.
e-mail: ch.lacrosse@aim.skynet.be
web: www.conf_aim.skynet.be

Oct. 14 - 17

51st Canadian Chemical Engineering Conference
Halifax, Nova Scotia
See Website:
www.chemeng.ca/halifax2001

Oct. 15 - 16

CERI 2001 Electricity Conference
Calgary, Alberta
See Website:
www.ceri.ca
e-mail: conference@ceri.ca

Nov. 7 - 8

CANDU Fuel Technology Course
Mississauga (Sheridan Park), Ontario
Contact: CNS Office
Tel: 416-977-7620
e-mail: cns-snc@on.aibn.com

Nov. 9 - 10

Conference on Women in Engineering
Kingston, Ontario
Contact: CWIE Committee
Queen's University
Tel: 613-533-6008
Fax: 613-533-6678

Nov. 11 - 15

ANS Winter Meeting
Reno, Nevada
Contact: ANS
LaGrange Park, Illinois
Tel. 708-352-6611
e-mail: meetings@ans.org

Nov. 11 - 16

6th International Conference on Tritium Science and Technology
Tsukuba-shi, Ibaraki-ken, Japan
Contact: Dr. M. Nishi
Japan Atomic Energy Research Institute
Tel. +81-29-282-6390
e-mail: nishi@tpl.tokai.jaeri.go.jp

2002

January ??

Health Physics Society (mid year meeting)
Orlando, Florida
See Website:
www.hps.org

February 18,19

CNA Nuclear Industry Winter Seminar
Ottawa, Ontario
Contact: Lise Marshall
CNA Office
Tel: 613-237-4262
e-mail: marshalll@cna.ca

March 10 - 14

4th International Conference on Isotopes
Cape Town, South Africa
Contact: 4ICI Conference Secretariat
Claremont, South Africa
Tel. +27-21-762-8600
e-mail: 4ici@globalconf.co.za
Web: www.globalconf.co.za

April 14 - 18

ICONE-10 10th International Conference on Nuclear Engineering
Arlington, Virginia
Contact: Dr. Jovica Riznic
CNSC
e-mail: riznicj@cnsc-ccsn.gc.ca
web: www.asme.org/icone10

April 16 - 20 — **International Youth Nuclear Congress**
Taejon, Korea
Contact: Han Seong Son
KAERI
e-mail: hsson@nanum.kaeri.re.kr
web: www.iync.org

May 5 - 8 — **4th CNS International Steam Generator Conference**
Toronto, Ontario
Contact: Robert Tapping
Tel: 613-584-8811 ext 3219
e-mail: tappingr@aecl.ca

June 17 - 21 — **ANS Annual Meeting**
Hollywood, Florida
Contact: ANS
LaGrange Park, Illinois
Tel. 708-352-6611
e-mail: meetings@ans.org

June 2 - 5 — **23rd CNS Annual Conference**
Toronto, Ontario
Contact: CNS office
Toronto, Ontario
Tel. 416-977-7620
e-mail: cns-snc@on.aibn.com

July ?? — **Symposium on the Isolation of Radioactive Waste**
Toronto, Ontario
Contact: Judy Tamm
AECL - SP
Tel. 905-823-9060 ext. 4197
e-mail: tammj@aecl.ca

Aug. 4 - 8 — **Spectrum 2002**
Reno, Nevada
See Website:
www.ans.org/spectrum

Aug. 11 - 16 — **INAC 2002 International Nuclear Atlantic Conference and Exhibition**
Rio de Janiero, Brazil
e-mail: tdn@ten.com.br

Oct. 6 - 10 — **ANS International Topical Meeting on Probabilistic Safety Assessment**
Detroit, Michigan
See Website:
www.ners.engin.umich.edu/PSAConf

Oct. 7 - 10 — **PHYSOR-2002: International Conference on the New Frontiers of Nuclear Technology - Reactor Physics, Safety and High-Performance Computing**
Seoul, Korea
Contact: Prof. Nam Zin Cho
KAIST
Taejon, Korea
Tel. +82-42-869-3819
e-mail: tpc@physor2002.kaist.ac.kr

Oct. 21 - 25 — **PBNC 2002 - 13th Pacific Basin Nuclear Conference**
Shenzhen, China
Contact: PBNC 2002 Secretariat
Fax: +86-10-6852-7188
e-mail: cns@cnnc.com.cn

?? (Fall) — **Corrosion of Nuclear Reactor Core Components**
Toronto, Ontario
Contact: CNS Office
Tel. 416-979-7620
e-mail: cns-snc@on.aibn.com

Conference draw winners

Two "CNS Inukshuit" statuettes were awarded by a draw from the returned badges at the close of the 22nd CNS Annual Conference in June. The winners were: Randall McArthur of AECL and Cristian Stoica from Cernavoda in Romania.

CANDU Fuel Course

The CNS is holding a two-day introductory course on CANDUJ fuel design on November 7 and 8, 2001. For information or to register contact the CNS office: tel. 416-977-7620; e-mail: cns-snc@on.aibn.com

Correction

In the comment "Review too soft" in the last issue of the CNS Bulletin (Vol. 22, No. 2) the URL for Archie Robertson' website was incorrect. It should read < www.magma.ca/~jalrober >

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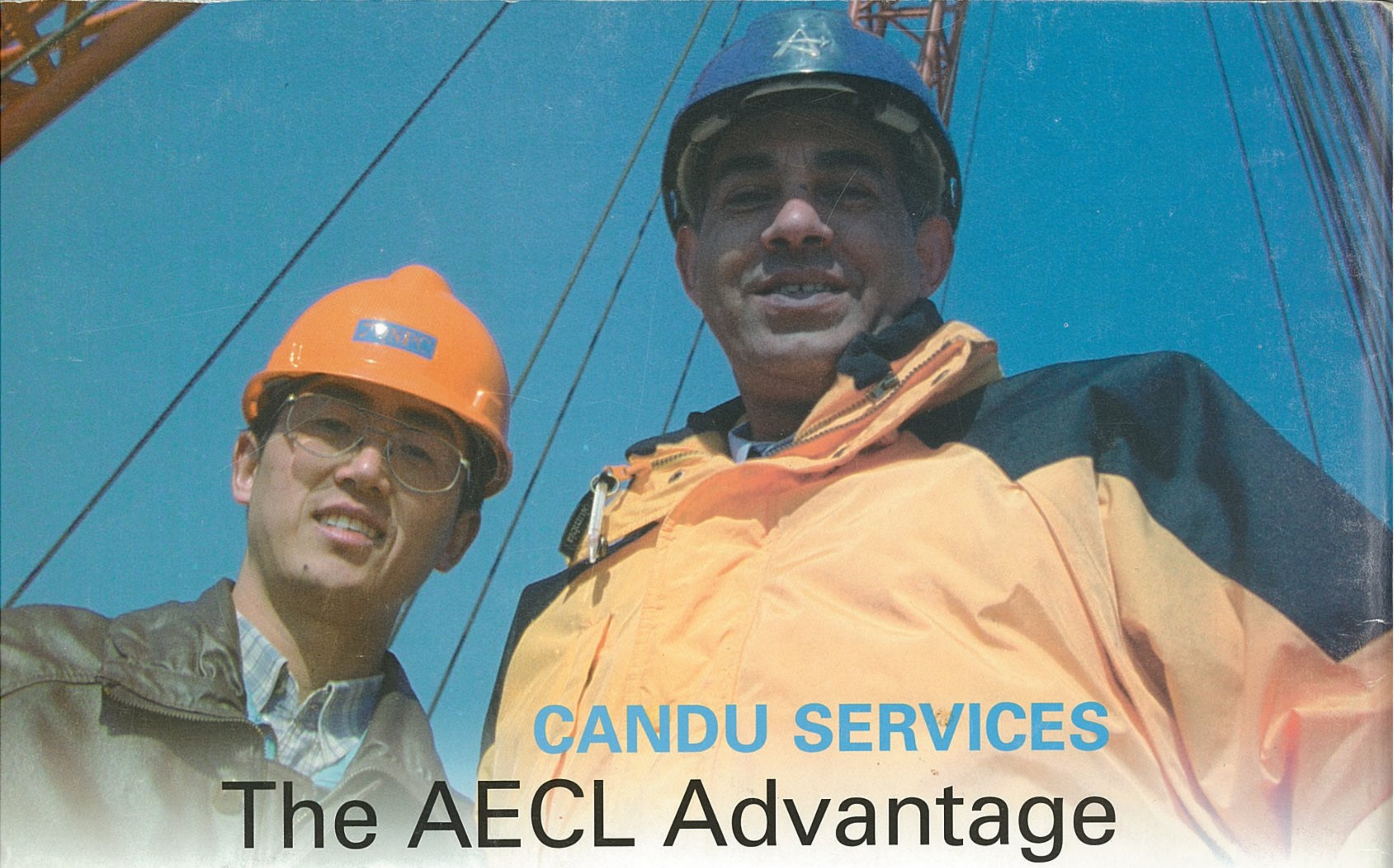
CNS WEB Page

For information on CNS activities and other links

http://www.cns-snc.ca



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